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"This document has been prepared by MSL Engineering Limited for the Participants of the Joint Industry Project on Development of Grouted Tubular Joint Technology for Offshore Strengthening and Repair. This document is confidential to the Participants in the Joint Industry Project, under the terms of their contract for participation in the project."

**JOINT INDUSTRY PROJECT**

# DEVELOPMENT OF GROUTED TUBULAR JOINT TECHNOLOGY FOR OFFSHORE STRENGTHENING AND REPAIR

**Final Report**

**DOC REF C14100R020 Rev 2 JUNE 1997**

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## FOREWORD

This document has been prepared by MSL Engineering Limited for seven sponsoring organisations:

British Gas plc
Chevron U.K. Limited
Exxon Production Research Company
Health and Safety Executive (HSE)
Mineral Management Service (MMS)
Mobil North Sea Limited
Shell U.K. Exploration and Production

This document addresses the development of grouted tubular joint technology for offshore strengthening and repair. A project steering committee including representatives of the sponsoring organisations oversaw the work and contributed to the development of this document. During the life of the project, the following individuals served on the committee:

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The Project Manager at MSL Engineering was Mr D J Morahan who carried out the work with guidance and support from Mr M Lalani and Dr A F Dier and technical assistance from a number of MSL Engineering staff. The Manager at TNO, where all the testing was conducted, was R J van Foeken and he was assisted by a number of technicians.

No responsibility of any kind for injury, death, loss, damaged or delay however caused, resulting from the use of the recommendations can be accepted by MSL Engineering or others with its preparation.

JOINT INDUSTRY PROJECT

# DEVELOPMENT OF GROUTED TUBULAR JOINT TECHNOLOGY FOR OFFSHORE STRENGTHENING AND REPAIR

**Final Report**

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NOMENCLATURE

| | |
|---|---|
| D | Outside diameter of chord |
| T | Wall thickness of chord |
| $T_p$ | Wall thickness of pile |
| $T_e$ | Effective thickness |
| d | Outside diameter of brace |
| t | Wall thickness of brace |
| $\gamma$ | Gamma ratio = D/2T |
| $\beta$ | Beta ratio = d/D |
| $\tau$ | Tau ratio = t/T |
| $\alpha$ | 2L/D |
| SCF | Stress concentration factor |
| SNCF | Strain concentration factor |
| cs | Chord saddle |
| bs | Brace saddle |
| cc | Chord crown |
| bc | Brace crown |
| $F_y$ | Yield stress |
| $F_u$ | Ultimate stress |
| $\varepsilon$ | Permanent elongation |
| ipb | In-plane bending |
| opb | Out-of-plane bending |
| ax-c | Axial compression |
| ax-t | Axial tension |
| $\theta$ | Brace/joint intersect angle |
| LJF | Local Joint Flexibility |

## TECHNICAL SUMMARY

The Joint Industry Project (JIP) entitled 'Development of Grouted Tubular Joint Technology for Offshore Strengthening and Repair' was concluded by MSL Engineering in 1997. The JIP was carried out on behalf of seven sponsoring organisations.

Background

Chord grout-filling has been recognised as offering a technically-efficient and cost-effective method for the strengthening and repair of tubular joints. From a fatigue standpoint, the grout constrains chord wall bending local to the intersection. This has the effect of reducing Stress Concentration Factors (SCFs) and, therefore, decrease local fatigue loading. As the grout also confines global chord ovalisation, the static strength of grouted tubular joints also increase. Apart from strengthening and repair applications, 'grouted' joints are often the by-product of jacket designs when main or skirt piles are used and the annulus between the leg or sleeve and pile is grouted. In these cases, the joints are often referred to as double-skin grouted joints. Whilst design codes permit their use, guidance on grouted joints is limited. The JIP was, therefore, initiated to establish a design practice to permit the routine application of grouted joints for strengthening/repair.

Objectives

The primary objectives were two-fold:

- To generate specific local stress and ultimate strength data on grouted joints to develop design practice in terms of formulations for stress concentration factors and ultimate strength.

- Prepare an offshore grouting procedure for strengthening/repair of existing tubular joints.

Scope of Work

The detailed scope of work of the project is summarised below:

(a) Twelve tubular joints - five T joints and seven DT joints - were designed and fabricated using standard offshore practice. The joints were of large scale construction (chord diameters of 406mm). Brace-to-chord diameter ratios ($\beta$) ranged between 0.4 and 1.0, and chord radius-to-thickness ratios ($\gamma$) ranged between 12 and 26. The brace-to-chord thickness ratio ($\tau$) was nominally 1.0 in all cases. Likewise, the brace-chord angle ($\theta$) was nominally 90° in all cases.

(b) The specimens were instrumented using load cells to measure global applied loads, and strain gauges around the brace-chord intersection to permit measurement of local strains. Transducers (LVDT) were used to measure relative displacements between the chord and brace in the region of the joint to obtain local joint flexibilities (LJF). The layout of gauges and transducers followed standard industry practice.

(c) A purpose-built test rig capable of accommodating T and DT joint configurations and applying in-plane and out-of-plane load was fabricated.

(d) Each virgin joint was first subjected to elastic tests to measure SCFs under axial compression, axial tension, in-plane bending (IPB) and out-of-plane bending (OPB).

(e) The chords of the specimens were subsequently grouted using standard offshore practice, and the elastic tests repeated. Since local stress behaviour in grouted joints is known to depend on the load history of the joint, the first grouted specimen was subjected to a wide range of axial preload investigations. The findings from these preload investigations were used to select the preload condition for the remainder of the specimens.

(f) On conclusion of the SCF tests, each specimen was subjected to an ultimate load test. The loading condition chosen was either IPB or OPB.

(g) In parallel to the above experimental programme, a separate offshore installation study was carried out to develop recommended offshore grouting procedures.

Results

**As-welded SCFs**

In general, the chord side SCFs were higher than brace side SCFs, as expected. SCF predictions using the well-known and ISO-recommended Efthymiou parametric equations were compared with the measured SCFs. Typically, the Efthymiou predictions were within 15% of the measured SCFs. The discrepancies can be assigned to the presence of the welds, the variations in local wall thicknesses and experimental scatter.

**Effect of Load History**

A grouted T joint having relatively small $\beta$ (0.4) and large $\gamma$ (26) ratios was used to investigate axial preload effects. This geometry was chosen since it was the most flexible and expected to have the most pronounced effect due to preload. A total of 44 sets of grouted strain measurements at different load levels were carried out on this specimen as part of the investigations. The results revealed that, generally, the SCFs remain essentially constant following the application of an axial preload beyond 50-60% of the as-welded tension strength of the joint, as predicted using ISO recommendations without safety factor. Therefore, for the remaining grouted specimens, SCF tests were conducted for no preload and repeated after the application of 50% preload. For the sake of completeness, in all but one specimen, SCF tests were also carried out after the application of 100% pre-load.

**Grouted SCFs**

The salient observations about grouted SCF tests are:

(i) For axial loading, the SCFs at the saddle locations reduced due to the presence of grout which reduces ovalization. Further, unlike as-welded joints, grouted SCFs differed between compression and tension loading due to the different load transfer mechanisms that exist for these two load cases for grouted joints. In many

instances, SCFs at the crown locations increased or remained the same as the as-welded SCFs. This is partly because a more even stress distribution exists for grouted joints vis-à-vis as-welded joints.

(ii) For moment loads, an SCF variation was observed between the tension and compression sides, as expected. This variation was dependant on joint configuration, location (brace v/s chord) and geometric parameters. The chord saddle SCFs reduced for OPB by up to 70% and the chord crown SCFs for IPB reduced by up to 50%.

**SCF Reduction Factors**

The Reduction Factor (RF) is defined as the ratio of grouted SCF to as-welded SCF. An RF can therefore be applied to an as-welded SCF to obtain a grouted SCF. The term RF implies that the as-welded SCF reduces when the tubular joint is grouted. The term RF is therefore generic as the grouted SCF may indeed be larger than the as-welded SCF ie. the RF may be larger than unity, depending on location.

One of the objectives was to develop parametric equations which derive an RF. The RF would then be applied to an as-welded SCF to obtain a grouted SCF. Formulations were developed using the grouted strain measurements over the as-weld strain measurements, however, the resultant RF formulations can only be used in conjunction with measured as-welded strains. Given the observed discrepancies between the Efthymiou derived as-welded SCF and the measured as-welded SCF, RF formulations were also developed using grouted strain measurements over Efthymiou derived as-welded SCFs. These formulations are for use with SCFs derived using Efthymiou parametric equations.

**Ultimate Capacities**

The ultimate strength tests were limited to either IPB or OPB loading. It is well known that for brace compression loading, the capacity for a grouted joint may normally be limited by the squash or local buckling capacity of the brace. Similarly, for brace tension loading, the strength of a grouted joint may be limited by the shear pull-out capacity of the chord plug.

In this project, failure of grouted joints subjected to IPB was generally through local buckling of the crown brace wall, local to the compression side of the intersection, accompanied by tensile tearing initiating from the crown location on the tension side. Similar failure mechanisms were observed for OPB loading, with failure concentrated at the saddle locations. In both cases of IPB and OPB, a shift in the brace neutral axis at the intersection was observed, compared with as-welded failure observations. In all cases, the measured capacities were substantially greater than those corresponding to the as-welded predictions. A capacity formulation previously postulated by MSL was verified by the test data and is proposed for design purposes.

**Recommendations**

Based on the SCF and ultimate strength data collected in this project, the following recommendations for the fatigue and strength evaluation of grouted joints are made.

Fatigue

(a) Calculate as-welded SCFs using the Efthymiou equations.

(b) Calculate RFs for chord side and brace side using the parametric equations in the tables below.

(c) Multiply calculated as-welded SCFs from (a) with calculated RFs from (b) to give predicted SCFs for grouted joints.

(d) The configuration and geometric ranges of validity for the RFs are noted in the tables below. For joints whose $\gamma$ ratios are greater than 26, the RF formulations may be used to give an initial estimate of the likely effect of grout-filling on SCFs. For joints with brace angle $\theta$ less than 90° or brace-to-chord thickness ratio $\tau < 1.0$, a similar approach may be adopted. However, it is expected from the standpoint of engineering mechanics that, at low $\theta$ values, the joint becomes stiffer and the formulations below may be unconservative. Note that a programme of work is underway at MSL to investigate $\tau$ effects as a Phase 2 to this project. This effort is funded by four of the seven sponsoring organisations. This Phase 2 is scheduled for completion by year end 1997.

(e) For joints of configurations other than T/Y or DT/X, it is recommended that the RF formulations for only T joints are used, in conjunction with (d) above.

(f) Existing, appropriate, S-N curves for as-welded tubular joints may be used to estimate fatigue lives of grouted joints.

Strength

Use the ISO TC67/WG3 tubular joint provisions, but substitute Qu as follows:

| Brace Load | Qu |
|---|---|
| Axial tension | $2.5\,\beta\,\gamma\,Ka$ |
| In-plane bending | $1.5\,\beta\,\gamma$ |
| Out-of-plane bending for Y and K joints | |
| Out-of-plane bending for X joints | $1.5\,\beta\,\gamma\,/\,\sqrt{Q_\beta}$ |

$Ka = (1 + 1/\sin\theta)/2$ $\quad Q_\beta = 0.3/(\beta(1-0.833\beta))$ for $\beta > 0.6$, else $Q_\beta = 1.0$

**Recommended formulations for reduction factors on CHORD side**

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2$ but $RF \geq 0.10$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Joint Type** | **Load (Position)** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
| **DT** | COMP (Saddle) | 0.57 | -2.08 | 0.001 | -0.003 | 2.55 | 0 |
| | COMP (Crown) | 4.9 | -1.7 | -0.32 | 0.15 | -1.15 | 0.005 |
| | TENS (Saddle) | 0.25 | -1.28 | 0.03 | -0.047 | 2.2 | 0 |
| | TENS (Crown) | 3.9 | -2.9 | -0.2 | 0.04 | 1.01 | 0.004 |
| | IPB (Crown) | 1.8 | -0.08 | -0.08 | 0.07 | -1 | 0 |
| | OPB (Saddle) | 2.35 | -5.15 | -0.03 | 0.03 | 4 | 0 |
| **T** | COMP (Saddle) | 1.07 | -0.68 | -0.043 | 0.06 | -0.53 | 0 |
| | COMP (Crown) | -0.55 | 6.9 | -0.03 | 0.01 | -4.8 | 0 |
| | TENS (Saddle) | 0.87 | -1.49 | 0.001 | 0.01 | 0.65 | 0 |
| | TENS (Crown) | -1.37 | 7.4 | 0.02 | -0.05 | -4.3 | 0 |
| | IPB (Crown) | 0.45 | 1.5 | -0.01 | -0.01 | -0.7 | 0 |
| | OPB (Saddle) | 1.56 | -2.62 | -0.012 | 0.015 | 1.3 | 0 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | | |

**Recommended formulations for reduction factors on BRACE side**

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2 + a_6\beta^3\gamma^3$ but $RF \geq 0.10$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Joint Type** | **Load Position** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ |
| DT | COMP (Saddle) | -0.01 | -1.3 | 0.04 | -0.08 | 3.15 | 0 | 0 |
| | COMP (Crown) | 1.1 | 0.56 | -0.056 | 0.09 | -1.78 | 0.001 | 0 |
| | TENS (Saddle) | 1.92 | -4.4 | -0.08 | 0.1 | 3.4 | 0.001 | -0.001 |
| | TENS (Crown) | 1.37 | -3.09 | 0.002 | 0.07 | 1.39 | -0.001 | 0 |
| | IPB (Crown) | 2.45 | -3.5 | -0.03 | 0.03 | 2.03 | 0 | 0 |
| | OPB (Saddle) | -0.43 | -0.64 | 0.096 | -0.17 | 3.8 | 0 | 0 |
| T | COMP (Saddle) | 1.25 | -1.64 | -0.036 | 0.04 | 0.8 | 0 | 0 |
| | COMP (Crown) | -1.26 | 5.0 | 0.002 | 0.03 | -3.3 | 0 | 0 |
| | TENS (Saddle) | 0.72 | -0.7 | -0.008 | 0.004 | 0.5 | 0 | 0 |
| | TENS (Crown) | 2.86 | -2.9 | -0.09 | 0.1 | 0.7 | 0 | 0 |
| | IPB (Crown) | 0.31 | 0.91 | -0.007 | 0.015 | -0.7 | 0 | 0 |
| | OPB (Saddle) | 0.88 | -0.84 | 0.001 | -0.016 | 0.6 | 0 | 0 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | | | |

(ii) Note that no Qu term is provided for axial compression since most grouted joints cannot fail under compression; compression capacity is limited by that of the brace.

(iii) Note that tension and moment capacities should not exceed the brace capacity (either local or global buckling).

**Local Joint Flexibility**

Although not targeted as a prime objective, the opportunity was taken to catalogue the local joint flexibilities in the linear elastic sense. From a non-linear standpoint, the load-deformation curves established for the ultimate load tests and reported in the main document give a full trace of the loading, peak and unloading path for each joint tested. It is clear from an examination of the LJFs in the linear elastic region that the presence of grout substantially stiffens the joint.

The effects of grouted joints should be considered in the structural model used to determine the applied loads on the joint. Presence of grout clearly stiffens the joint, such that the most appropriate model is likely to be one in which a rigid offset from the chord centreline to the chord wall at each incoming brace is provided. If the structure is modelled with rigid joints located at the chord centreline, an assessment should be made of whether or not use of the load from the model will produce conservative results. If joint flexibility has been introduced at the chord surface, while using a rigid offset to that point, only the flexibility need be altered. It is generally conservative to assume grouted joints have no local flexibility, i.e. they are rigid up to failure.

**Offshore Installation Study**

Detailed offshore grouting procedures for horizontal and inclined members, including fatigue details and construction details such as grout inlets/outlets and grout bags have been developed and reported. Further, recommendations on grout materials, mixes and QA are cited, to permit the routine offshore implementation of grouting of tubular members. To assist with cost estimations, offshore equipment requirements and estimated durations are also catalogued.

**Closure**

The grouted joints JIP has been successfully executed, leading to a design practice for strengthening/repair of joints using chord grout-filling. Procedures for offshore grouting have been developed, benchmarked against previous experience and actual trials. It is expected that the technology developed in this JIP will lead to a routine application of chord grout-filling provided it satisfies target fatigue and/or strength requirements.

# 1. INTRODUCTION

The modification, strengthening and repair of existing offshore installations has received significant attention and forms an important and integral part of offshore engineering. The need for strengthening/repair stems from increased load by placement of additional equipment, increase in operational safety, increase in operational service life, damage and/or regulatory requirements. It has increasingly been recognised that chord grout filling offers an extremely technically-efficient and cost-effective method to meet these strengthening/repair requirements for tubular joints. However, there is little or no guidance available in codes, guidance documents or the technical literature. This is not surprising, as the available pertinent data relate to a single K joint, two T joints and one DT joint. The DNV research in this area in the early 1980s related to double-skin tubular joints only, subjected to axial loads only, and is therefore not applicable to the strengthening/repair of tubular joints, which requires the chord of the joint to be completely grout filled over a characteristic length. One project conducted in the late 1970s/early 1980s remains confidential. However, the dominant data generated in that project relate to double-skin joints or joints with $\gamma$ ratios well in excess of ratios which cover current practice and, therefore, the data which fall in these two categories are equally inapplicable. An examination of the few available data and field experience in this area revealed the following:

- The presence of the grout increases the radial stiffness of the chord member. The grout restricts local chord wall deformations, which leads to a reduction of deformation-induced bending stresses and associated SCFs.

- Any reduction in SCF implies an enhancement in fatigue life.

- The chord member bending stiffness is increased, resulting in a reduction of stress at crown locations which are driven by the $\alpha$ ratio. The increased chord bending stiffness also implies that the capacity of large $\beta$ ratio, grouted T/Y joints, subjected to axial loads, may not be limited by chord failure in the beam-bending sense.

- The grout severely restricts ovalisation of the chord cross-section, which indicated an increase in the capacity of grouted joints when compared with the ungrouted case.

- The data available indicated that fatigue lives of grouted joints may be increased by over 10-fold when compared with equivalent ungrouted joints. These data also indicated substantial enhancements in joint strength and joint impact resistance, to the extent that, in perhaps the majority of cases, the capacity of the joint is greater than the capacity of the in-coming braces.

- Grouting technology is well proven and offshore grouting works can be executed with confidence.

- The deployment of this technique offshore has low equipment and resource requirements compared with other techniques and, hence, significant cost savings can be accrued.

- This technique is amenable to deployment using ROV technology with no diver intervention, resulting in substantial safety and costs benefits.

- A study of offshore installation times indicate that this technique can be implemented offshore within a time frame which is less than half the time required to implement other comparable techniques. The cost benefits in this respect are self-evident.

In response to the above observations, the identified need and the identified substantial economic, safety and technical benefits, MSL Engineering (MSL) launched a joint industry initiative to develop grouted joint technology as a repair/strengthening measure. The primary objectives of this project were, firstly, to generate specific data and information on grouted joint behaviour to develop a detailed design practice for the practical range of applications and parameters and, secondly, to develop and prepare a deployment procedure to ensure safe, cost-effective and technically-compliant applications.

## 1.1 Description of Test Programme

Experimental work has been conducted to determine the effects of grout filling of chord members on the stress concentrations at brace-chord intersections and on the ultimate bending strength. The experimental programme consisted of a series of as-welded SNCF measurements, grouted SNCF measurements and ultimate strength tests on T and DT joints. The specimen test matrices are summarised in Tables 1-1 and 1-2. The test series consisted of five T-joints and seven DT-joints, with nominal values of the following geometrical parameters: $\beta$ = 0.41, 0.67 and 1.0, $\gamma$ = 12.7, 20.3 and 25.7 and $\tau$ = 1.0.

| Test series for **T** joints $\tau$=1.0 | | | |
|---|---|---|---|
| $\gamma$ | $\beta$ = 0.41 | $\beta$ = 0.67 | $\beta$ = 1.0 |
| 12.7 | T1 | | T3 |
| 20.3 | | T5 | |
| 25.7 | T7 | | T9 |

**Table 1-1: Test matrix for T-joints - Specimen Designation**

| Test series for **DT** joints $\tau = 1.0$ | | | |
|---|---|---|---|
| $\gamma$ | $\beta = 0.41$ | $\beta = 0.67$ | $\beta = 1.0$ |
| 12.7 | | DT2 | DT3 |
| 20.3 | DT4 | DT5 | DT6 |
| 25.7 | | DT8 | DT9 |

**Table 1-2: Test matrix for DT-joints - Specimen Designation**

The configuration and dimensions of the specimens are presented in Figure 1-1 for the T-joints and in Figure 1-2 for the DT-joints. The chord length was equal to 6 times the chord diameter. The brace length was 5 times the brace diameter. The specific selection of the joint parameters was dictated to a degree by the availability of pipe sizes and material strengths. The resultant joint parameters were optimised, where possible, to facilitate joint failure rather than brace failure during the ultimate strength tests. Generally, the brace tubulars were of a higher yield strength than the chord tubulars. This increased the likelihood of a joint failure without affecting the measured SNCFs. The chosen size of tubulars resulted in large scale specimens which minimised potential scale effects. The resultant test rig was substantial due to the size of specimens and to satisfy the requirement of having the ability to test in all four loading modes with the specimens remaining in-situ.

## 1.2 Background

### 1.2.1 Existing Guidance

The provisions of major design codes on any aspect of grouted joints are limited. API RP2A[1], HSE Guidance Notes[2], NPD[3] and DNV[4] all state that the capacity of grouted joints may be established by testing and/or analytical methods.

With the exception of Lloyds[5], no specific guidance on the determination of stresses is given. Lloyds provides guidance to cover double-skin joints only. Lloyds recommend the determination of an effective thickness which gives the same moment of inertia as that calculated from treating the chord shell and pile as a composite section, but neglecting grout. Lloyds recommend that the effective thickness calculated on this basis should be limited to 1.75T. The resultant effective thickness is then used in parametric SCF equations developed for as-welded joints.

### 1.2.2 Previous Research

A number of research and development programmes have been carried out to investigate the behaviour of grouted joints. The research has typically been conducted on double-skin 'pile sleeve' type joints or ad hoc tests on individual grouted joints commissioned by Operators with geometries specific to offshore platform joints requiring strengthening.

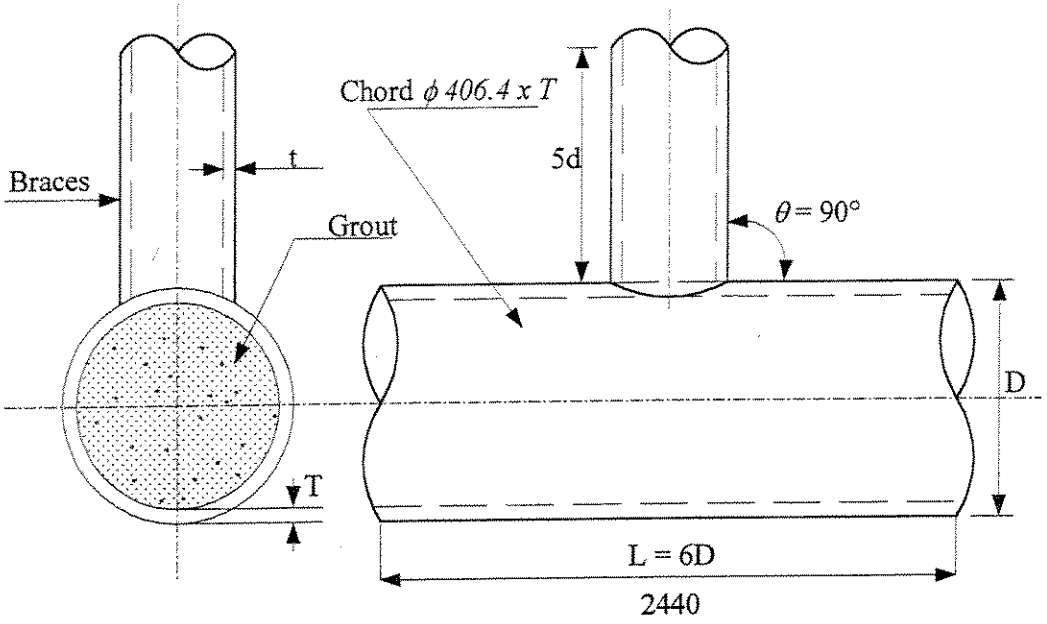



**Figure 1-1: T-joint configuration and dimensions**

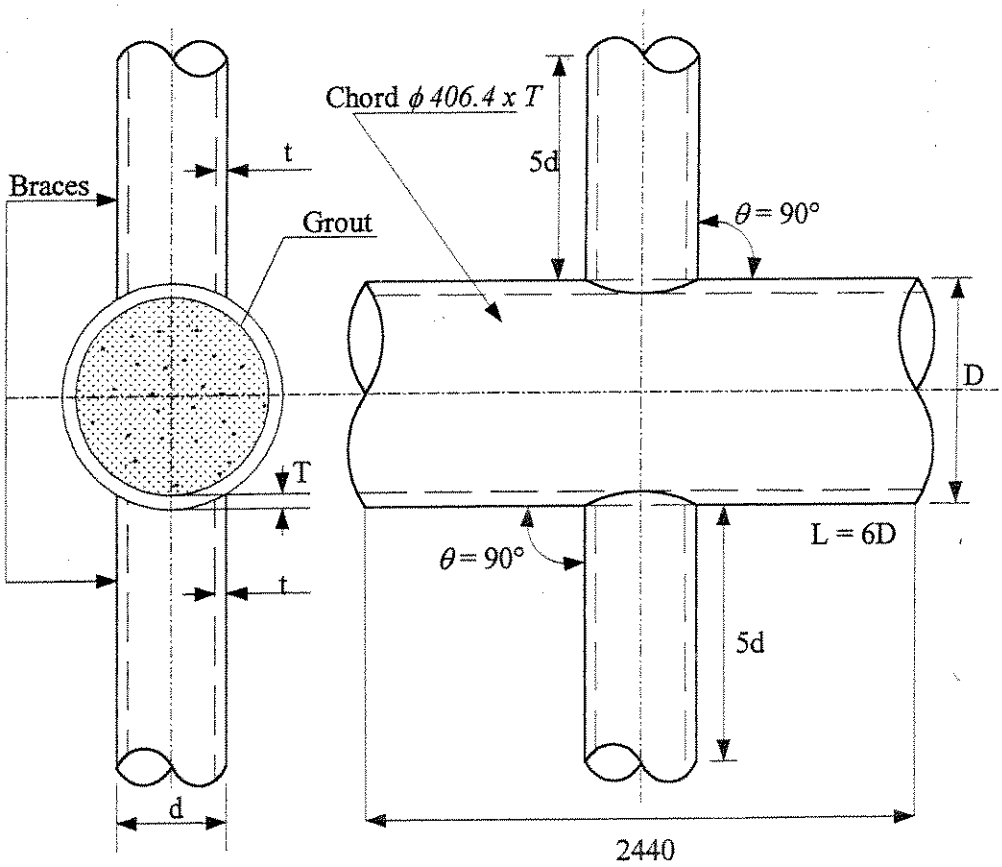



**Figure 1-2: DT-joint configuration and dimensions**

Results from the EEC Composite Jacket Project[6] are confidential, although general trends noted from the findings are described. A series of elastic, ultimate strength and fatigue tests on either double-skin or fully grouted joints were carried out. It is understood, however, that a portion of the experimental programme concentrated on thin chord sections, giving $\gamma$ ratios in excess of the ratios for joints in existing offshore installations.

A Veritec joint industry project addressed the elastic, ultimate strength and fatigue response of double-skin grouted joints through both experimental and numerical means.

Tebbett et al[7] summarise the results of ten T joint tests, in which the chords of five specimens were reinforced with a grouted pile, i.e. grout was placed in the annulus and in the pile. Unfortunately, no thickness values for the joints are given in the paper.

Lalani et al[8] report on a series of elastic tests (axial and bending) and an ultimate balanced axial load test on a non-overlapping grouted K-joint.

References 9 and 10 report on a series of elastic tests (axial and bending) on a grouted T joint.

Marshall[11] reviews SCF formulations for simple steel reinforced and double-skin/grouted joints. Marshall proposed that the $\gamma$ value in SCF equations can be modified to take account of the additional stiffness for grouted joints. The effective thickness is defined as:

$$T_e = ((T^3 + T_p^3)/T)^{0.5}$$

The effective thickness is limited to 2T, compared with the Lloyds' limitation of 1.75T.

Brown et al[12] report on a series of elastic tests (axial and bending) and fatigue tests on two grouted T joints.

Review of the available literature indicates that much of the testing reported is of an ad hoc nature and addresses technology specific to an identified problem. In particular, the number of tests carried out on fully grouted specimens with varying geometric parameters are limited.

## 2. TEST SPECIMENS

### 2.1 T-Joints

The configuration and nominal dimensions of the T-joints are shown in Figure 1-1 and Table 2-1. The chord length is equal to 6 times the chord diameter, i.e. $\alpha = 12$. The brace length is equal to 5 times the brace diameter.

| Test series and nominal dimensions for **T**-joints - Dimensions in (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chord | | $\beta = 0.41$ | | $\beta = 0.67$ | | $\beta = 1.0$ | |
| | $\gamma$ | Braces | Specimen | Braces | Specimen | Braces | Specimen |
| 406.4x16 | 12.7 | 168.3x16. | T1 | | | 406.4x16. | T3 |
| 406.4x10 | 20.3 | | | 273x10. | T5 | | |
| 406.4x7.9 | 25.7 | 168.3x8. | T7 | | | 406.4x7.9 | T9 |

**Table 2-1: Nominal dimensions for T-joints**

### 2.2 DT-Joints

The configuration and nominal dimensions for the DT-joints are shown in Figure 1-2 and Table 2-2. The chord length is equal to 6 times the chord diameter, i.e. $\alpha = 12$. The brace length is equal to 5 times the brace diameter.

| Test series and nominal dimensions for **DT**-joints - Dimensions in (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chord | | $\beta = 0.41$ | | $\beta = 0.67$ | | $\beta = 1.0$ | |
| | $\gamma$ | Braces | Specimen | Braces | Specimen | Braces | Specimen |
| 406.4x16 | 12.7 | | | 273x16. | DT2 | 406.4x16. | DT3 |
| 406.4x10 | 20.3 | 168.3x10. | DT4 | 273x10 | DT5 | 406.4x9.5 | DT6 |
| 406.4x7.9 | 25.7 | | | 273x7.8 | DT8 | 406.4x7.9 | DT9 |

**Table 2-2: Nominal dimensions for DT-joints**

### 2.3 Welding of Test Specimens

The weld design is based on full brace capacity, which is dependent upon the brace dimensions and material strength. All welding was carried out using shielded metal arc welding (SMAW), in welding position 2G (axis of the weld horizontal) in accordance with section 5.8 of ANSI/AWS D1.1-90 Structural Welding Code for Steel[13]. The welding sequence for the tubular connection is shown in Figure 2-1, and the weld details for the T-joints and DT-joints are shown in Figure 2-2. The welding procedures and weld profiles are presented in Appendix A. The weld profiles contained in Appendix A relate to the locations presented in Figure 2-3.

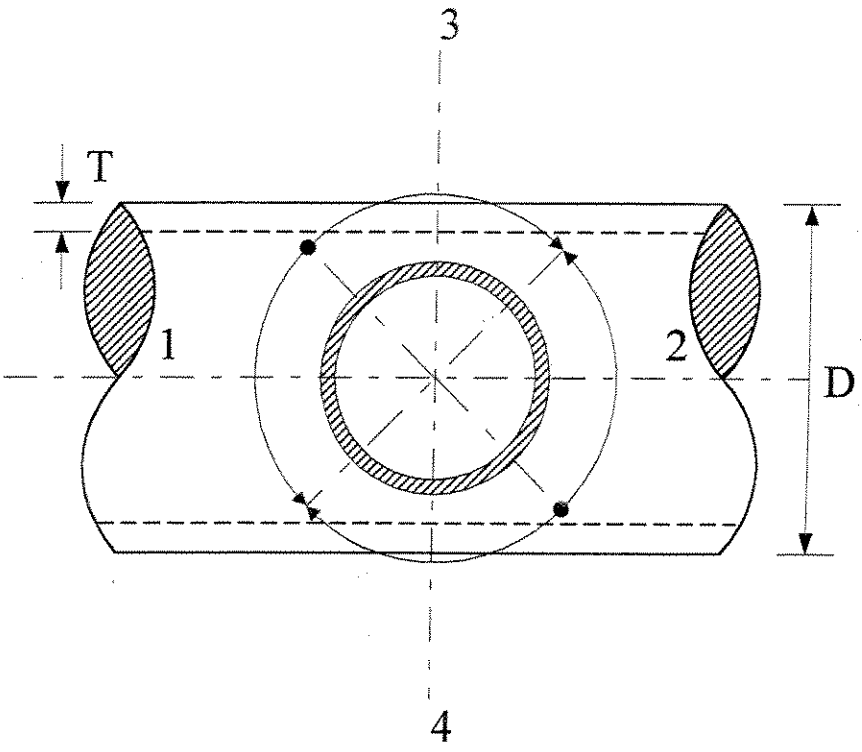



**Figure 2-1: Welding sequence**

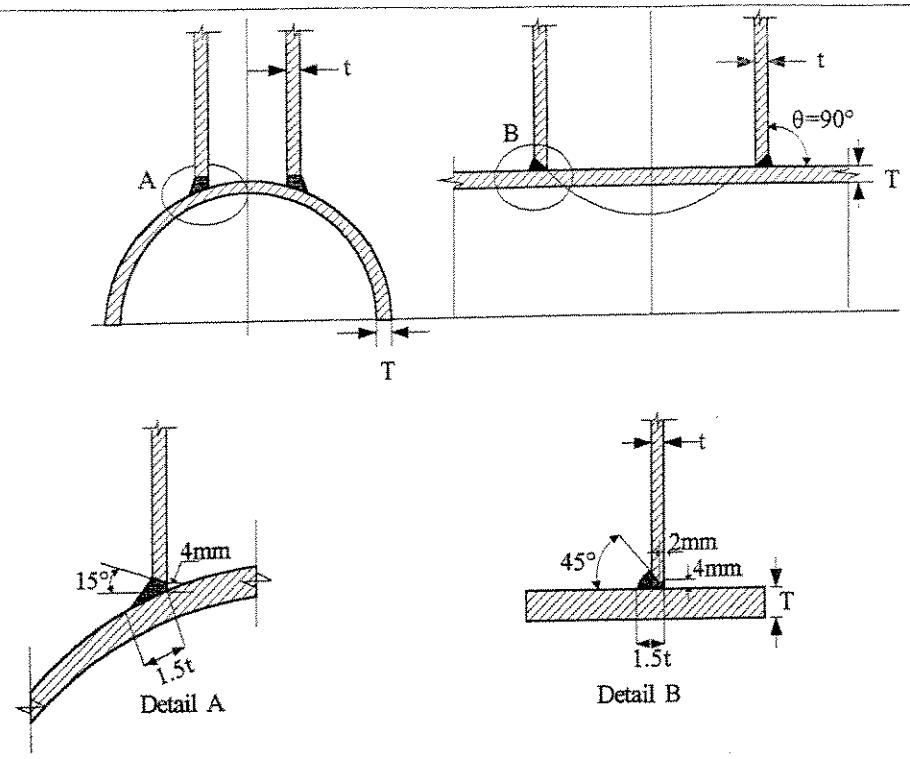
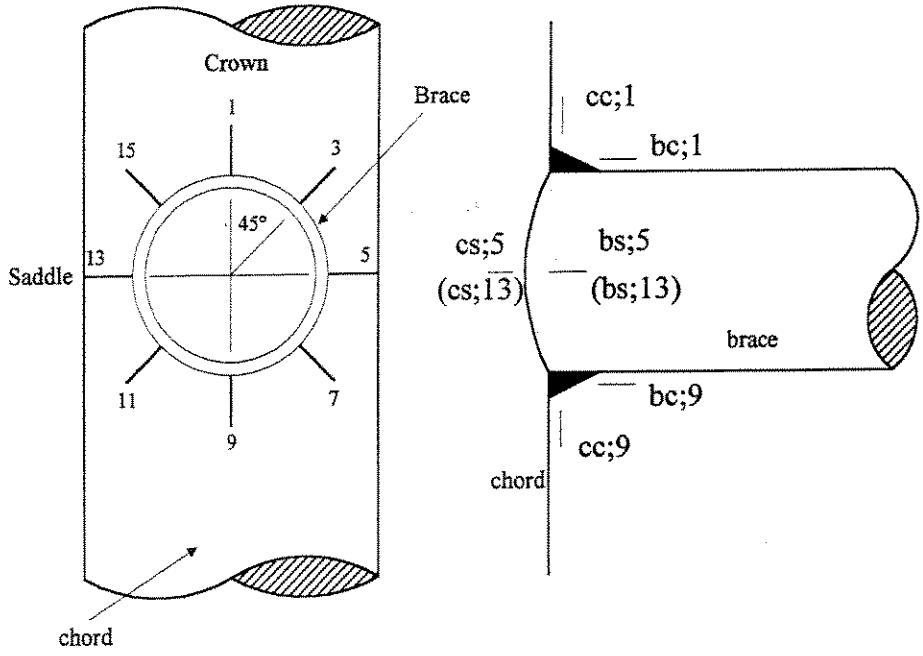



**Figure 2-2: Welding details of T-joints and DT-joints**




Note: Weld shapes measured at 45° intervals around joint intersect

**Figure 2-3: Location of weld profiles**

## 2.4 Grouting of Test Specimens

A detailed description of the grouting procedure for the chord grout-filling of the tubular joints is given in Appendix A. The grouting of the 5 T-joints and 7 DT-joints was done on November 1st 1995 at the TNO laboratory by Halliburton. The grouting spread is illustrated in Figure 2-4. The duration of grouting the twelve test specimens was approximately two hours. Four cubes were taken from each batch mixed and eight cubes from each test specimen. The majority of batches completely filled two chords. The grout was taken from the outlet in order to determine the compressive strength.

All chord tubulars were grouted in the upright position with grout injection at the base. The chords were filled with potable water prior to grouting. The water was displaced through outlets at the top of the chords as the grout was injected. During the grouting procedure, two additional tubulars (D = 350mm) were grouted. Approximately six months after grouting, one tube was sliced open. Figures of the sliced sections are presented in Appendix A. No crack was observed in the grout core but an extremely fine gap between the grout core and inside wall of the tubular was found.

The chosen grout was Oilwell G cement with a specific gravity of $2.02 \pm 0.02$. The specific gravity was measured during the grouting of the test specimens, in accordance with the grouting procedures, using a pressurised mud-balance. The measured specific gravity for each batch is presented in Table 2-3.

| Batch | Specific gravity at pump | Specimen | Specific gravity at outlet |
|---|---|---|---|
| **1** | 2.03 | 350∅ tubular 1<br>350∅ tubular 2 | 1.99<br>2.0 |
| **2** | 2.02 | T5 | 2.0 |
| **3** | 2.02 | T3<br>DT4 | 2.0<br>2.0 |
| **4** | 2.03 | T9<br>DT8 | 2.0<br>2.0 |
| **5** | 2.02 | DT2<br>DT5 | 2.01<br>2.01 |
| **6** | 2.02 | T7<br>T1 | 2.0<br>2.01 |
| **7** | 2.02 | DT9<br>DT6 | 2.0<br>2.0 |
| **8** | 2.02 | DT3 | 2.0 |

**Table 2-3: Specific gravity of the grout**

During the first few days of curing, external temperature measurements were taken on one of the dummy steel tubes. These are presented in Table 2-4.

| Hours after grouting | Average External Temperature [°C] on pipe |
|---|---|
| 0 | 17 |
| 2 | 21 |
| 3 | 23 |
| 7 | 46 |
| 16 | 55 |
| 21 | 48 |
| 25 | 45 |
| 45 | 25 |
| 74 | 20 |

**Table 2-4: Temperature measurements during curing of the grout**

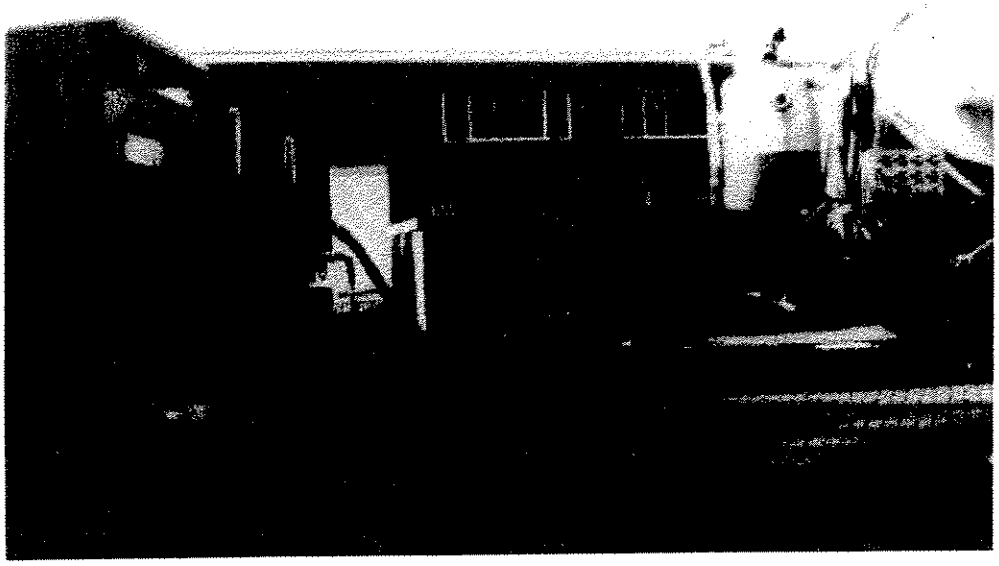


**Figure 2-4: Equipment used for grouting**



MSL

## 2.5 Material Properties

### 2.5.1 Circular Hollow Sections

The circular hollow sections used for the specimens were hot-finished seamless steel tubes in accordance with API-5L Gr. X52N or steel grade Fe 510 D in accordance with Euronorm EN 10025 (or prEN 10210 draft). The actual mechanical properties $F_y$ (yield stress), $F_u$ (ultimate stress), permanent elongation $\varepsilon$ and necking of the different circular hollow sections was determined by tensile tests and carried out in accordance with Euronorm EN 10.002 "Tensile tests for steel". The tubular sections were provided with mill certificates. The nominal and the actual material properties of the different tubulars are tabulated in Appendix A.

The coupon test results are summarised in the following Table 2-5.

| Specimen | Yield str. (Fy) Brace | Yield str. (Fy) Chord | Ult. str. (Fu) Brace | Ult. str. (Fu) Chord |
|---|---|---|---|---|
| T1 | 347.8 | 358.5 | 520.3 | 507.1 |
| T3 | 383.3 | 358.5 | 581.6 | 507.1 |
| T5 | 283.6 | 334.5 | 408.0 | 427.0 |
| T7 | 245.6 | 331.6 | 405.1 | 499.5 |
| T9 | 331.6 | 331.6 | 499.5 | 499.5 |
| DT2 | 495.5 | 358.5 | 585.2 | 507.1 |
| DT3 | 383.3 | 358.5 | 581.6 | 507.1 |
| DT4 | 339.4 | 334.5 | 550.0 | 427.0 |
| DT5 | 283.6 | 334.5 | 408.0 | 427.0 |
| DT6 | 363.4 | 334.5 | 508.2 | 427.0 |
| DT8 | 328.5 | 331.6 | 509.9 | 499.5 |
| DT9 | 331.6 | 331.6 | 499.5 | 499.5 |

**Table 2-5: Tensile coupon tests referenced by test specimen (MPa)**

### 2.5.2 Grout

The results of the cube tests are presented in Appendix A. The cube test results are summarised in the following Tables 2-6 and 2-7.

| Batch | Age | Specimen | Average |
|---|---|---|---|
| DRUM | 7 day | - | 23.95 |
| | 14 day | - | 33.80 |
| | 21 day | - | 40.00 |
| | 28 day | - | 35.00 |
| 1 | 28 day | S-D1/D2 | 45.77 |
| 2 | 28 day | T5 | 33.60 |
| 3 | 28 day | T3 DT4 | 35.50 |
| 4 | 28 day | T9 DT8 | 37.07 |
| 5 | 28 day | DT2 DT5 | 39.10 |
| 6 | 28 day | T7 T1 | 37.50 |
| 7 | 28 day | DT9 DT6 | 35.00 |
| 8 | 28 day | DT3 | 38.57 |

**Table 2-6: Compressive strength per batch (Mpa)**

| Specimen | Average |
|---|---|
| T1 | 39.05 |
| T3 | 37.15 |
| T5 | 43.25 |
| T7 | 43.58 |
| T9 | 41.50 |
| DT2 | 45.48 |
| DT3 | 51.23 |
| DT4 | 39.08 |
| DT5 | 49.43 |
| DT6 | 44.95 |
| DT8 | 46.93 |
| DT9 | 49.05 |

**Table 2-7: Compressive strength at time of ultimate test (MPa)**

Table 2-6 presents the average compressive strengths using cubes taken from batch mixes. With the exception of specimens T5 and DT3 all batches were sufficient for the filling of two specimens. The results for the specimen cubes were obtained 28 days after filling of the chords. Table 2-7 presents the average compressive strengths obtained by testing the relevant grout cubes at the time of the specimen ultimate strength test. The age of the cubes range from 3 months to 7 months.

### 2.5.3 Welds

All specimens were welded by SMAW process. Test specimens T1, T3, T5, DT2, DT3, DT4, DT5 and DT6 were welded with a KRYO 1 electrode and specimens T7, T9, DT8 and DT9 were welded with a Safdry 58 electrode.

The welding procedures are presented in Appendix A

## 2.6 Measured Dimensions

### 2.6.1 Circular Hollow Sections for the Specimens

The actual dimensions for the T-joints and DT-joints were determined by measuring the wall thickness and diameter at several locations on the test specimens and on separate pieces of left-over pipe material, from which the specimens were fabricated. The separate pieces were used for the determination of material properties. For the fabrication of test specimens, eleven different tubulars were used. Wall thickness measurements were taken using a micrometer for the DT-joint chords at 90° intervals at one chord end. These were combined with micrometer measurements taken at 90° intervals at each end of the associated tubulars used in specimen fabrication to provide an averaged wall thickness. In addition, the chord and brace wall thicknesses were measured using ultra-sonic methods. The measurements were taken at 90° intervals near to the fabricated specimen joint. The results are presented in Appendix A.

The following Table 2-8 presents a summary of diameter and wall thickness measurements.

| Specimen | Chord | | Brace | |
|---|---|---|---|---|
| | D | T | d | t |
| T1 | 406.78 | 16.39 | 167.81 | 16.32 |
| T3 | 406.78 | 16.39 | 407.02 | 16.10 |
| T5 | 407.05 | 10.19 | 237.34 | 9.82 |
| T7 | 406.96 | 7.86 | 168.41 | 8.31 |
| T9 | 406.96 | 7.86 | 406.96 | 7.86 |
| DT2 | 406.78 | 16.39 | 273.09 | 15.76 |
| DT3 | 406.78 | 16.39 | 407.02 | 16.10 |
| DT4 | 407.05 | 10.19 | 168.57 | 9.95 |
| DT5 | 407.05 | 10.19 | 273.34 | 9.82 |
| DT6 | 407.05 | 10.19 | 407.60 | 9.61 |
| DT8 | 406.96 | 7.86 | 273.21 | 7.88 |
| DT9 | 406.96 | 7.86 | 406.96 | 7.86 |

**Table 2-8: Summary of the average actual dimensions**

### 2.6.2 Welds

The actual weld shapes at the crown and saddle location, and also between these locations for the $\beta=1.0$ specimens, are presented in Appendix A for each test specimen.

# 3 INSTRUMENTATION

## 3.1 Strain Gauges

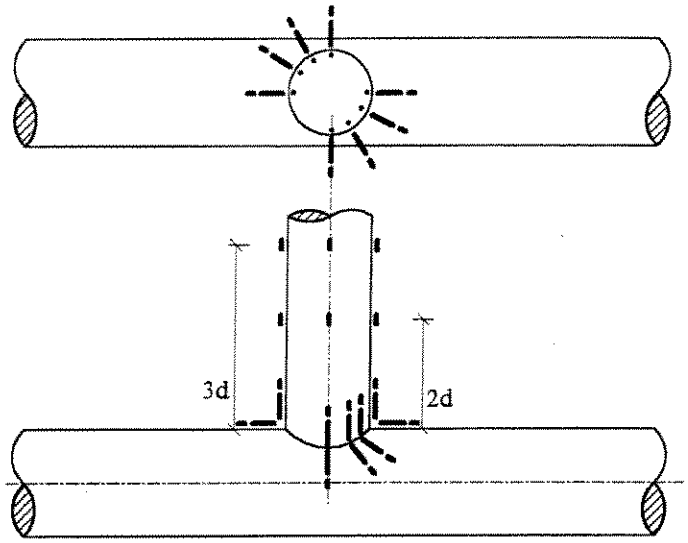
Little test data exists for SNCF measurements on grouted tubular joints. The guidance available for as-welded joints[2 and 4] states that the nearest gauge should be located at a minimum of 4mm from the weld toe in order to avoid the concentrating effect of the weld. The available guidance also gives recommendation for gauge positioning in the region of stress variation, between the region effected by the weld and where the stress becomes equal to the nominal stress. Puthli et al[14] go one step further by giving guidance for the location of gauges to enable non-linear extrapolation, i.e. quadratic extrapolation. Strain gauge positions were chosen to bound the possibility of either linear or non-linear extrapolation.

All specimens were instrumented with strip gauges and single element gauges. The strip gauges contained five individual single element strain gauges at 2mm spacings, two of which were unused. At each measurement location (e.g. chord crown) a strip gauge and a single element gauge were placed on a line orthogonal to the weld. The first gauge of the strip was placed at 0.4 x (T or t) but not less than 4mm from the weld toe. The single element gauge was placed at the HSE[2] recommended last gauge position. Appendix A contains the specification used for the strain gauging of specimens.

The T-joint specimens were instrumented at all saddle and crown locations on both the chord and brace, as shown in Figure 3-1. In addition, the $\beta = 1.0$ T-joint specimens were gauged with two sets of gauges at 30° intervals in two diagonally opposite quadrants on both the chord and brace. The DT-joint specimens were instrumented at one saddle and crown location for each brace on both the chord and brace, as shown in Figure 3-2. In addition, the $\beta = 1.0$ DT-joint specimens were gauged with a set of gauges at 30° intervals in one quadrant on one brace and the opposite quadrant on the other brace. The strain gauge locations are presented in Appendix A.

As-welded SCF/SNCF ratios have been well documented, however, it was necessary to establish the SCF/SNCF ratio for specimens in the grouted condition and whether or not it differed to that of the as-welded condition. Therefore, in addition to the single element strain gauges, Specimen T7 was instrumented with 2mm rosette gauges to enable the determination of SCF/SNCF ratios in the grouted condition. Each rosette gauge consisted of three single element gauges set at 0°, 45° and 90° directions. The rosette gauges were placed on a line orthogonal to the weld at one crown and one saddle location on both the chord and brace. Section 7.2 presents the results of the SCF/SNCF ratio measurements. The SCF/SNCF ratios measured for specimen T7 in the grouted condition were similar to the as-welded condition.

Strain gauges were also used at two brace cross section locations away from the weld to measure the nominal axial and/or bending strain and to verify the loads measured by the dynamometers, see Figure 3-3.




Note: Intermediate gauges @ 30° & 60° positions on both braces are for β = 1.0 joints.

Key:

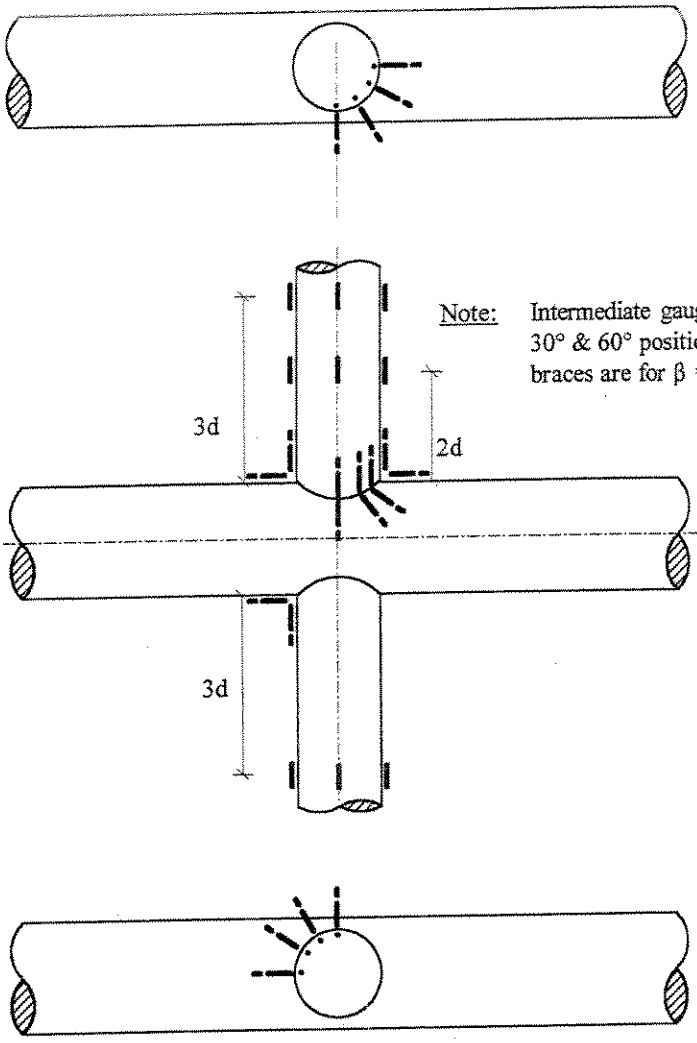
- Strip gauge, consisting of 5 strain gauges, 3 of which are used
- Single strain gauge

№: of gauges per specimen

| Location | β = 0.41 & 0.67 | | β = 1.0 | |
|---|---|---|---|---|
| | Strip gauges | Single gauges | Strip gauges | Single gauges |
| **Brace** | 4 | 12 | (+4) 8 | (+4) 16 |
| **Chord** | 4 | 4 | (+4) 8 | (+4) 8 |
| **Total** | 8 | 16 | (+8) 16 | (+8) 24 |

Note: The first β = 1.0 joint tested was gauged with a full compliment of gauges, by providing additional intermediate gauges.( )

**Figure 3-1: Strain gauging of T-joint specimens**




Note: Intermediate gauges @ 30° & 60° positions on both braces are for β = 1.0 joints.

Key:

- Strip gauge, consisting of 5 strain gauges, 3 of which are used
- Single strain gauge

Nº: of gauges per specimen

| Location | β = 0.41 & 0.67 | | β = 1.0 | |
|---|---|---|---|---|
| | Strip gauges | Single gauges | Strip gauges | Single gauges |
| **Braces** | 4 | 16 | (+6) 8 | (+6) 20 |
| **Chord** | 4 | 4 | (+6) 8 | (+6) 8 |
| **Total** | 8 | 20 | (+12) 16 | (+12) 28 |

Note: The first β = 1.0 joint tested was gauged around the full compressive side of brace & gauged around the full tensile side of the other brace for I.P.B.

**Figure 3-2: Strain gauging of DT-joint specimens**

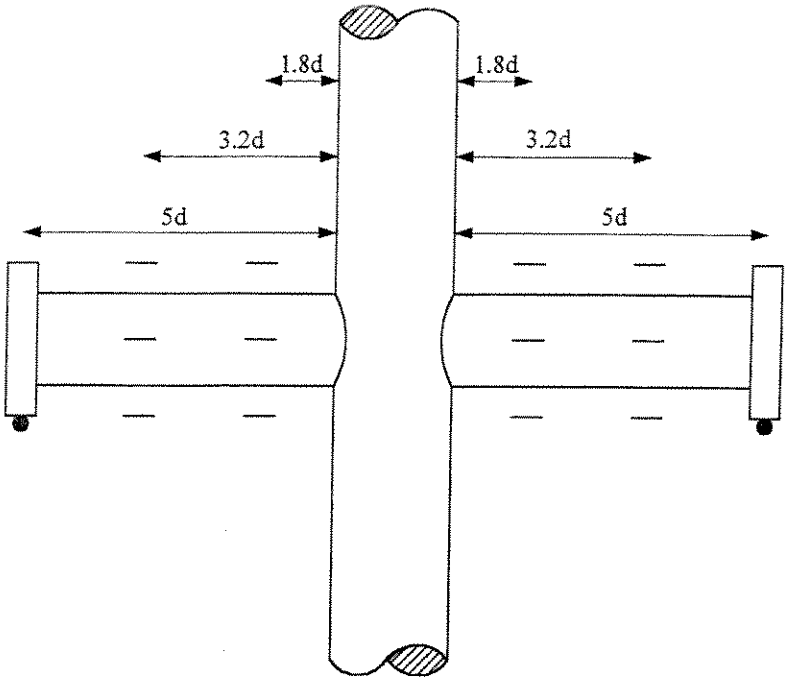



**Figure 3-3: Location of the strain gauges for nominal strains on brace**

## 3.2 Electrical Transducers

Electrical displacement transducers were used to measure (1) the local deformation of the joint under axial load or bending moment, see Figures 3-4 and 3-5, and (2) the deflection of the braces under bending, to determine overall deformation of the test specimen by measurement at two points along each brace, see Figures 3-6 and 3-7. Appendix A contains the transducer measurements.

For axial load and out-of-plane bending load, the local joint deformation was determined for the DT-joints by the measurement of distances between two points, each positioned 100mm along each brace from the saddle position. Measurement data on either side of the joints were averaged for the axial conditions; the difference between the data were used to calculate rotation for the out-of-plane bending case, see Figure 3-4. The T-joint specimens were similar with the exception that one brace point was replaced by an attachment to the chord on the opposite side of the joint to the brace, see Figure 3-5. The transducer mounting locations were chosen to minimise the effect any local deformation of tubular walls may have on the measurement of joint deformation. For in-plane bending load, the local joint deformation was determined in a similar manner to that discussed above. The transducer mounting points were located 130mm along the brace from the crown positions. Again, the locations were chosen to minimise the effects of local tubular wall deformations.

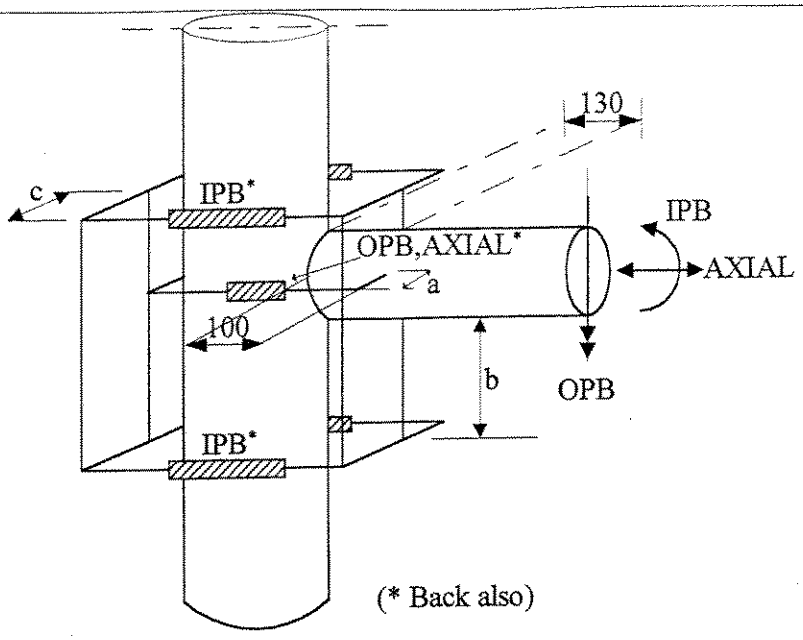



**Figure 3-4: Measurement of T-joint local deformations.**

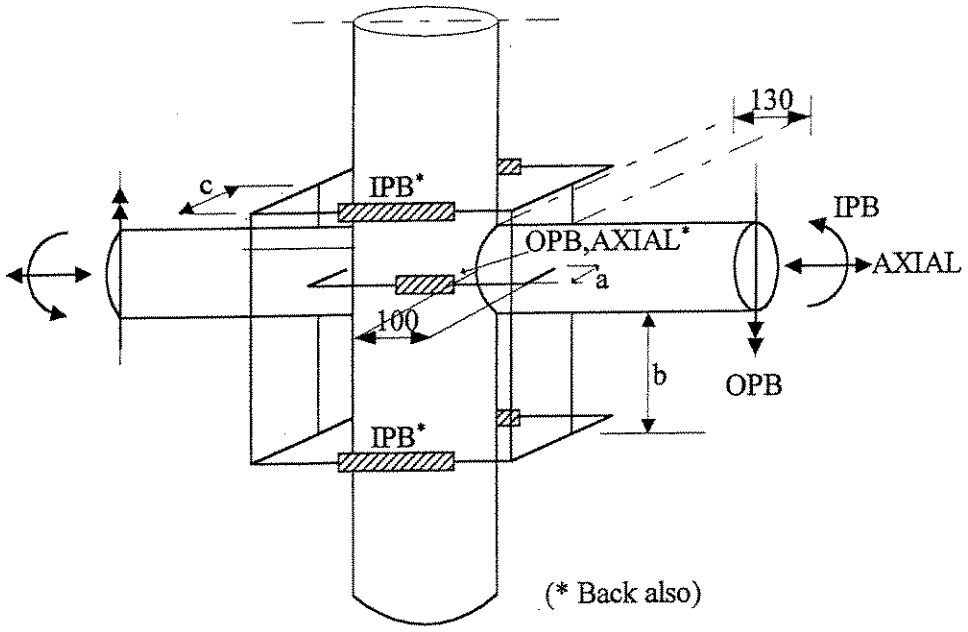



**Figure 3-5: Measurement of DT-joint local deformations**

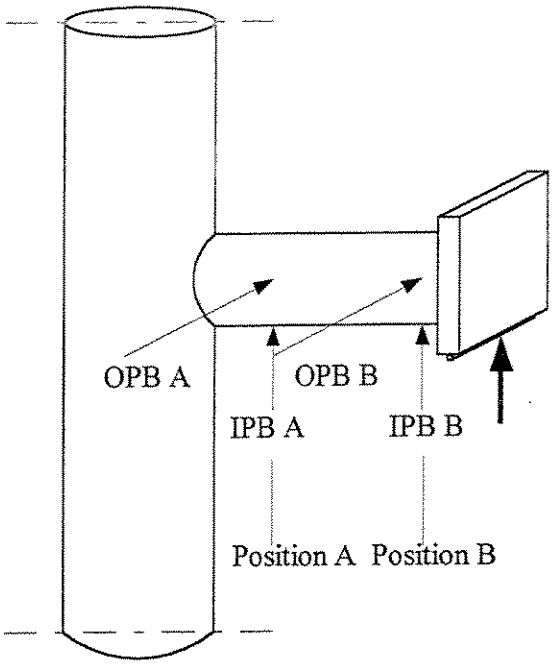



**Figure 3-6: Measurement of T-joint global bending deformation**

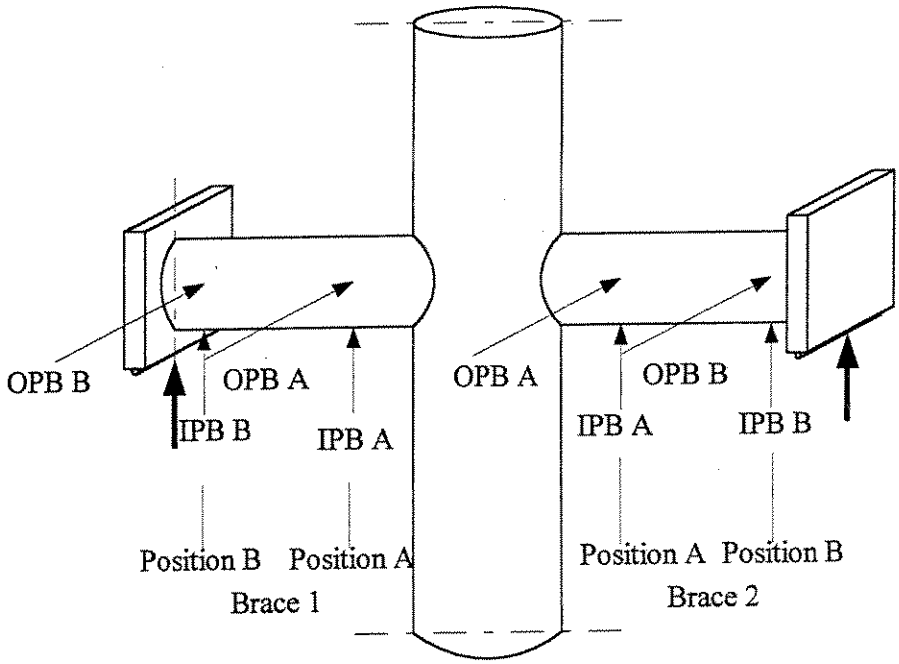



**Figure 3-7: Measurement of DT-joint global bending deformation**

# 4 TEST RIG AND TESTING PROCEDURE

## 4.1 General

Before the test specimens were placed into the test rig, their actual geometries were measured, strain gauges were attached, and preparations for attachment of displacement transducers were made. Appendix A contains the loading conditions considered and the overall dimensions of the specimens. The test rig configuration for the T-joints and DT-joints was essentially the same, with a modification of columns and beams to accommodate the two joint types.

## 4.2 Test Rig and Loading System for T-joints

The test rig configuration for T-joints is presented in Figure 4-1. The chord ends are connected to the test rig by hinges for all loading conditions. The axial load in the braces was applied by a hydraulic jack at the brace end. In the axial tension loading condition, the axial load was applied to the test specimen by means of four or six bars, equally loaded and distributed around the brace end. During axial loading of the DT-joint, the compression load was recorded by a 500 kN or a 4000 kN dynamometer, depending on specimen size and required load level. The axial tension loading was recorded by strain gauges on the loading bars. The maximum capacity of the six bars was 2000 kN. The nominal strain gauges on the braces were used to verify the applied load.

For the in-plane bending loading condition, the moment was applied by pulling the brace ends with bars attached to jacks. The load was measured with a dynamometer. The load was measured by a 200 kN or 800 kN dynamometer. The strain gauges on the braces were used to verify the applied bending moment. Similarly, the out-of-plane bending moment was applied by a tensile bar at the end of the braces. The chord was restricted from torsion by mounting plates attached to the chord ends. The applied loads were again measured at each end by a 200 kN or 800 kN dynamometer. The strain gauges on the braces were again used to verify the applied bending moment.

## 4.3 Test Rig and Loading System for DT-joints

The test rig for DT-joints is presented in Figure 4-2. The axial load in the braces was applied by a hydraulic jack at one brace end. The other brace end was axially restrained. For the axial compression loading, a spherical bearing was used to assure the required end conditions. For the axial tension loading condition, the tensile loading was applied to one brace end by means of four or six bars, which were equally loaded. The chord ends were restrained against out-of-plane movement by the attachment of mounting plates on the chord ends to the test frame. During axial loading of the DT-joint, the compression load was recorded by a 500 kN or

4000 kN dynamometer. The dynamometer used depended on specimen size and therefore the required load level. The axial tension loading was recorded by four or six bars instrumented with strain gauges. The strain gauges on the braces were used to verify the applied load.

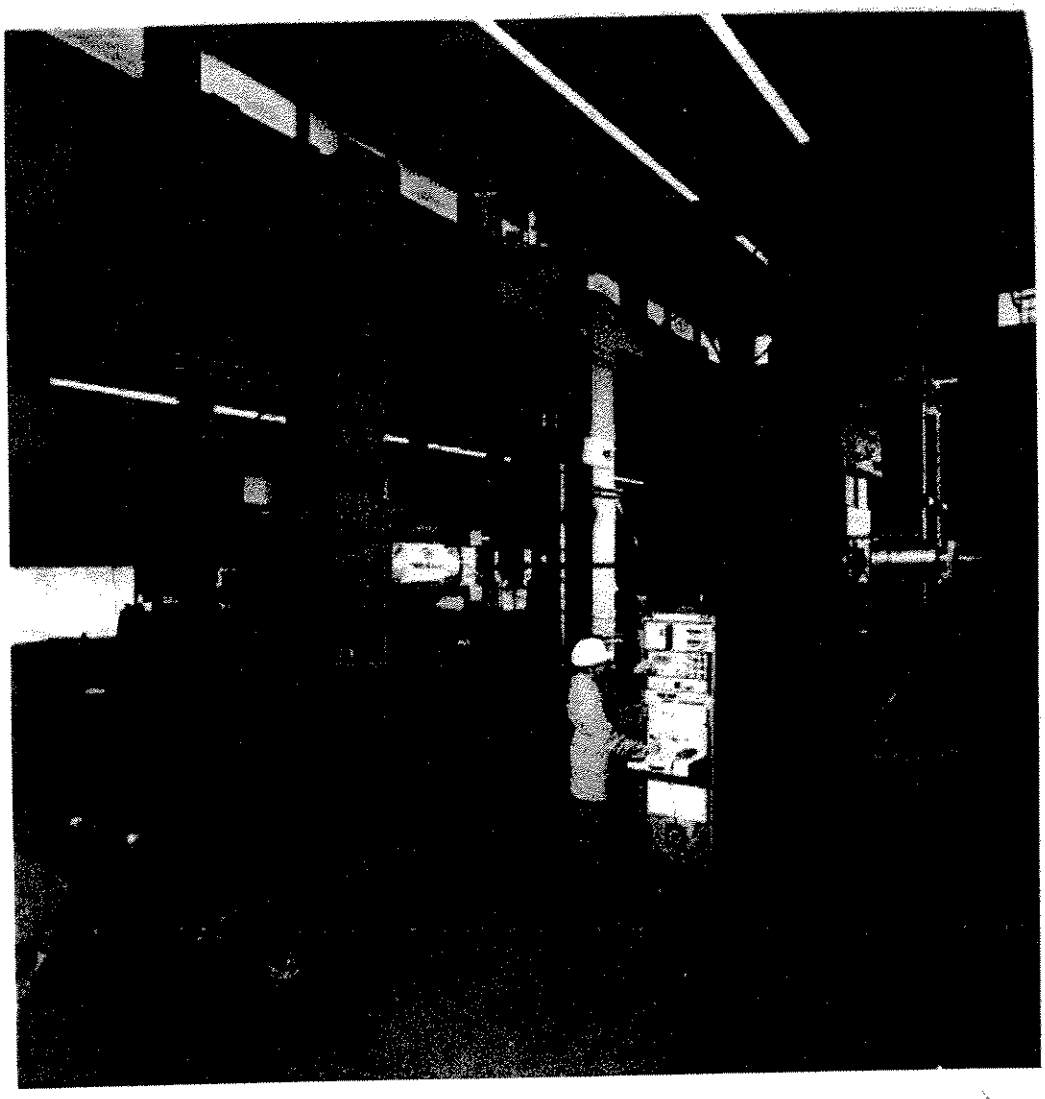


**Figure 4-1: Test rig for T-joints**



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**Figure 4-2: Test rig for DT-joints**



MSL

For the in-plane-bending load, one chord end was pushed with a hydraulic jack while the brace ends were restrained against movement in the direction of the chord axis. Movement of the brace end in the axial direction of the brace and rotation of the brace end were, however, allowed. The chord was supported orthogonally to the braces. The load was measured with a dynamometer aligned with the chord axis. The load was measured by a 500 kN or 2000 kN dynamometer. The strain gauges on the braces were used to verify the applied bending moment.

The out-of-plane bending moment was applied by a tensile bar at the end of the braces. The load was applied at each brace end using jacks. The jack loads were kept similar by use of a system which monitors the loads applied and adjusts as necessary. The applied load was measured at each end by a 200 kN or 800 kN dynamometer. The strain gauges on the braces were used to verify the applied bending moment.

## 4.4 Data Recording

During testing, discrete measurements were taken of:

- relative displacement between chord and brace from which local joint flexibility was obtained;
- displacement at two points along brace from which rotation was calculated;
- strains:
  - for the axial compression load case: (load cell and strain gauges on brace);
  - for the axial tension load case: (tensile bar strain gauges and strain gauges on brace);
  - for the in-plane bending moment case: (load cell for applied load and strain gauges on brace);
  - for the out-of-plane bending moment case: (load cell of applied load and strain gauges on brace);

The measurement of displacements, strains and loads were performed by means of HP dataloggers and a micro-computer.

## 4.5 Testing Sequence

The DT-joint test specimens were first tested in the as-welded condition in the following sequence: DT4, DT8, DT5, DT2, DT9, DT6 and DT3. After testing of the DT-joints, the test rig was modified to accommodate the T-joints which were then tested in the as-welded condition in the following order: T9, T3, T5, T7 and T1. After grouting of the specimen chords, the specimens were tested in the following order T7, T1, T5, T9, T3, DT4, DT2, DT5, DT8, DT9, DT6 and DT3.

The following loading sequence was used to generate strain gauge data for the as-welded (ungrouted) specimens:

1. Application of ten cycles of in-plane bending load on the brace at 15-20% of the (ISO) predicted ultimate load of the ungrouted joint subjected to in-plane bending.

2. Application of in-plane bending load to the brace in three equal increments, up to the applied load reached in step 1. After each load increment, strain gauge measurements, displacements and applied load were taken. Subsequently, the load was reduced in three equal stages back to zero, taking measurements at each load level.

3. Repetition of steps 1 and 2 for out-of-plane bending, axial compression and axial tension.

Prior to testing of the specimens in the grouted condition, an investigation on the effects of preload on local strain measurement was carried out in order to establish an appropriate preload history to be applied to the grouted joint specimens. This investigation is discussed in Section 7.

With the exception of specimen T7, which was utilised for the conduct of the above mentioned preload investigations, the loading sequence for the majority of grouted specimens was as follows:

1. Application of ten cycles of in-plane bending load on the brace at 15-20% of the (ISO) predicted ultimate load of the ungrouted joint subjected to in-plane bending.

2. Application of in-plane bending load to the brace in three equal increments, up to the applied load reached in step 1. After each load increment, measurements of strain, displacement and applied load were taken. The load was then reduced in three equal stages, taking measurements at each load level.

3. Repetition of steps 1 and 2 for out-of-plane bending, axial compression and axial tension.

4. Application of an axial compression and tension load at 50% of predicted ultimate load of the ungrouted joint subjected to axial tension.

5. Repetition of steps 1,2 and 3.

6. Application of an axial compression and tension load at 100% of predicted ultimate load of the ungrouted joint subjected to axial tension.

7. Repetition of steps 1,2 and 3.

8. Conduct ultimate bending capacity test (ipb or opb).

# 5 DETERMINATION OF STRAIN CONCENTRATION FACTORS

## 5.1 Nominal Strains

The nominal strain is defined as the maximum elastic strain on the OD of the tubular assuming that the brace behaves as a beam (M/Z) or axial (P/A) member. For the bending load cases, the moment was determined as the load applied at the brace end times the distance to the intersection of the chord and the brace.

## 5.2 Hot Spot Strain and SNCF

The procedure for the determination of the hot spot strain was an extrapolation of strains from a defined region adjacent to the weld, defined as the extrapolation region, see Figure 5-1. The extrapolation region was defined by a specified minimum and maximum distance from the weld toe of the joint, in such a way that the effects of the global geometry of the weld (flat, concave, convex) and the condition at the weld toe (angle, undercut) were not included in the hot spot strain.

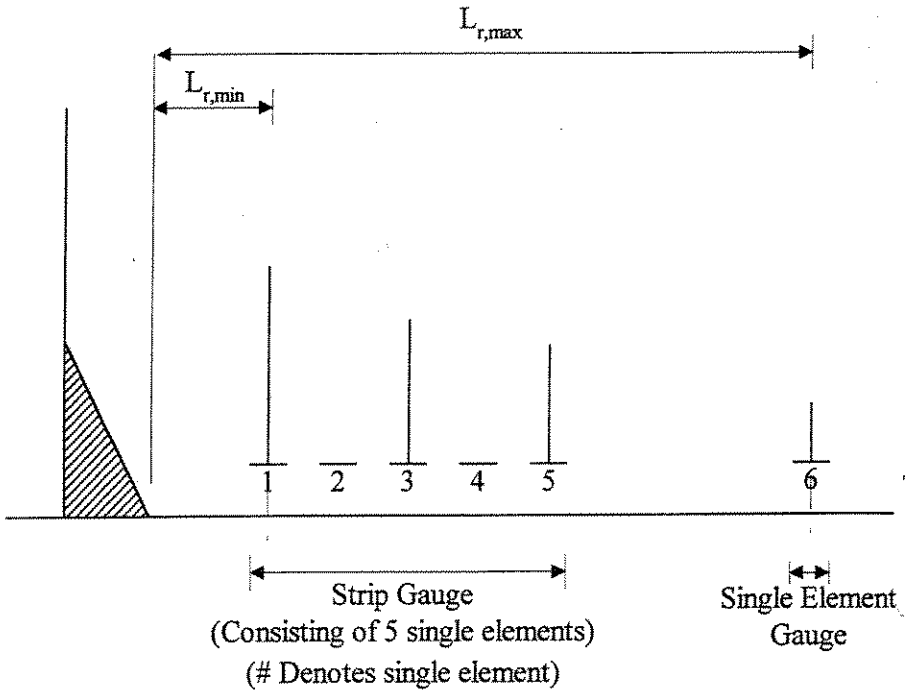



**Figure 5-1: Extrapolation region**

The adopted extrapolation region is defined by the following minimum distance ($l_{r,min}$) and maximum distance ($l_{r,max}$) from the weld toe as a function of the chord and brace dimensions,

Chord Side

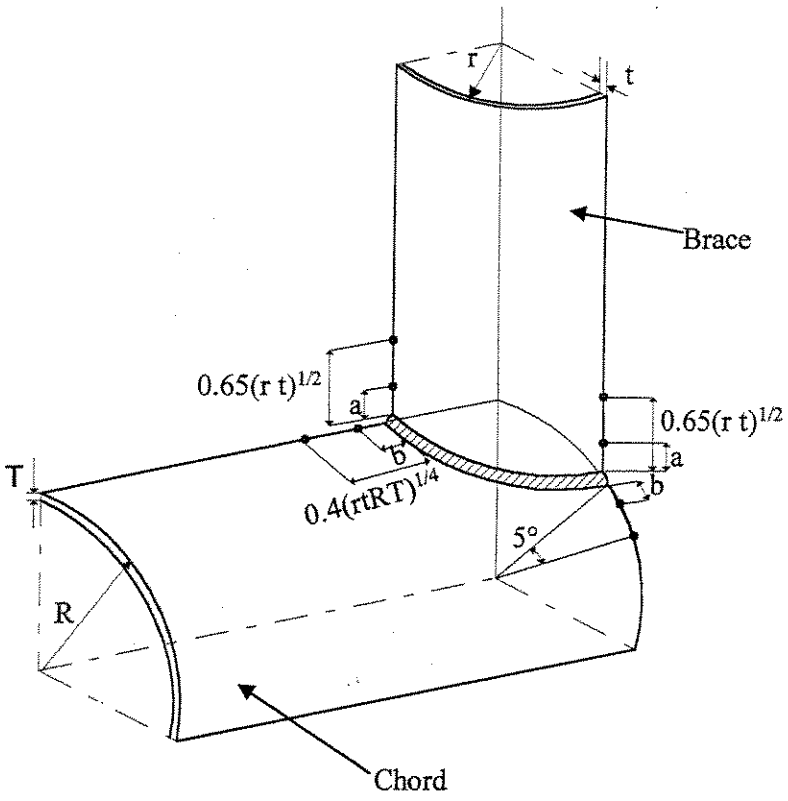
- $l_{r,min} = 0.4T$ but not less than 4mm — for crown and saddle
- $l_{r,max} = 0.4\ (rtRT)^{1/4}$ — for crown
- $l_{r,max} = R\pi\ 5/180$ — for saddle

Brace Side

- $l_{r,min} = 0.4t$, but not less than 4mm — for crown and saddle
- $l_{r,max} = 0.65\ (rt)^{½}$ — for crown and saddle

The hot spot strain was determined by use of a parabolic curve fitted through data points and parabolic extrapolation to the weld toe. The extrapolation was based on the strain component perpendicular to the weld.

The SNCF value was calculated by the ratio of the hot spot strain divided by the nominal strain.




a = 0.4t but not less than 4mm
b = 0.4T but not less than 4mm

**Figure 5-2: Minimum and maximum distance from the weld toe**

# 6 OVERVIEW OF GROUTED TUBULAR JOINT BEHAVIOUR

## 6.1 General

The following sections present a technical appraisal of the behaviour of grouted tubular 'T' and 'DT' joints. Section 6.2 discusses in general terms the reduction in SCFs (Stress Concentration Factors) for the various load cases.

Stress Concentration Factors (SCFs) are to some extent dependent on the previous loading history for grouted tubular joints. Under tensile loading or on the tension side of in-plane or out-of-plane bending, some level of local separation and yielding occurs giving rise to the notion of SCF dependency on preload. This aspect is discussed further in Section 6.3.

## 6.2 Load Case Effects

The presence of grout significantly stiffens the chord member in the beam bending sense, restricts ovalisation of the chord and restricts chord wall deformations. The presence of grout has the effect of providing a more even distribution of stresses around the joint intersection. For the majority of specimens tested this resulted in an increase in SCF for the grouted condition at the crown location.

The effect of grout on SCFs for the various load cases are discussed in more detail below.

### 6.2.1 Axial Loading

Reduced grouted SCFs, compared to as-welded SCFs, exist at the saddle location. Resistance to axial loading at this location is predominantly by chord wall bending for small $\beta$ ratio joints, and membrane action for high $\beta$ ratio joints. The presence of grout restricts chord wall deformations and ovality and therefore results in a reduction in SCFs. Behaviour is similar for the chord side and brace side.

An increase in SCFs, over as-welded SCFs, particularly for compressive loading is present at the crown location due to the increased stiffness afforded by the grout, which attracts additional load. Behaviour is similar for the chord side and brace side.

### 6.2.2 In-plane Bending

The reduction in SCFs for in-plane bending loads is low on the chord side, given the greater relative stiffness at crown locations vis-à-vis saddle locations. The presence of grout causes the neutral axis to shift towards the compressive side of the crown. Therefore, the reduction in SCFs differs between the tension side and the compressive side of the brace as indicated in the test results.

### 6.2.3 Out-of-Plane Bending

The reduction in SCFs is similar to that for in-plane bending loading. Again, the reduction in SCFs differ between the tension side and compressive side of the brace.

## 6.3 Preload Effects

Preload is defined here as the load history a particular joint has been subjected to. Preload and its magnitude and load sign have been seen to affect SCFs for a grouted joint.

Preload investigations carried out by Veritec indicated that a threshold SCF value existed for double skin grouted joints. The SCF threshold value is defined as being the highest SCF measured for any preload. The SCF threshold value was obtained by steadily increasing tensile preload prior to SCF measurements at lower loads, until a drop in the measured SCF was observed. It was observed that substantial yielding occurred at the hot spot location for that preload which gave the SCF threshold value.

It was found that measured SCFs in specimens which had received reversed pre-loads, i.e. tension and compression, were larger than in those which had experienced uni-directional preload.

The Veritec work also measured residual strains as the specimens went through the first SCF measurement cycle. These residual strains increased as the preload levels increased. Subsequent shake-down procedures were adopted. A number of cycles, at a load corresponding to a maximum stress less than the yield stress at the hot spot location, were applied until the measured residual strain was less than 1%.

For the joint types tested in this JIP test programme, the behaviour for the fully grouted test specimens has shown that the grouted SCF remains constant at increasing preload levels, for tension loading. This is the case for the tension side of bending load cases and at all gauge positions for the axial tension case. Conversely, the grouted SCF begins to increase above 50% preload (predicted as-welded ultimate tensile capacity) on the compressive side for the bending load cases and for the majority of gauge positions for the axial compression case. In this instance, the SCF increases to a greater extent at the chord saddle location. Section 7 presents the results in more detail.

# 7 TEST RESULTS

## 7.1 Preload Investigation Results on Specimen T7

Specimen T7 was subjected to preload under compression/tension levels from 20% to 130% of ISO predicted as-welded joint tensile capacity in steps of 10% to 20%. Figure 7-1 summarises the SNCF measurement and preloading sequence. Appendix B contains a detailed description of the test sequence for the preload investigation.

SNCFs were determined for T7 at several preload levels. Figures 7-2 to 7-5 present a summary of the results contained in Appendix B, which contains further details of the SNCF measurements taken.

Figure 7-2 presents the in-plane bending SNCFs for brace and chord crown positions as a function of the axial preload level expressed as a percentage of the mean ultimate strength of the joint as given by ISO code. After 60 % preload, the SNCFs at the compression loaded side of the chord crown position increase marginally. At all other measurement locations the SNCFs remain constant.

Figure 7-3 presents the out-of-plane bending SNCFs for brace and chord saddle as a function of the axial preload level. After 60 % preload, the SNCFs at the compression side of the chord saddle positions increase. At all other measurement locations the SNCFs remain constant.

Figure 7-4 presents the average SNCFs for axial compression loading and are shown for the saddle and crown positions on the brace and chord. After 60 % preload, a significant increase in the SNCFs is indicated for the saddle positions on the chord side. Increases in SNCFs are also found at the chord crown and brace saddle positions. The SNCF at the brace crown location remains constant.

Figure 7-5 presents the average SNCFs for axial tension loading and are shown for the saddle and crown positions on the brace and chord. The SNCFs remain constant for all preload levels.

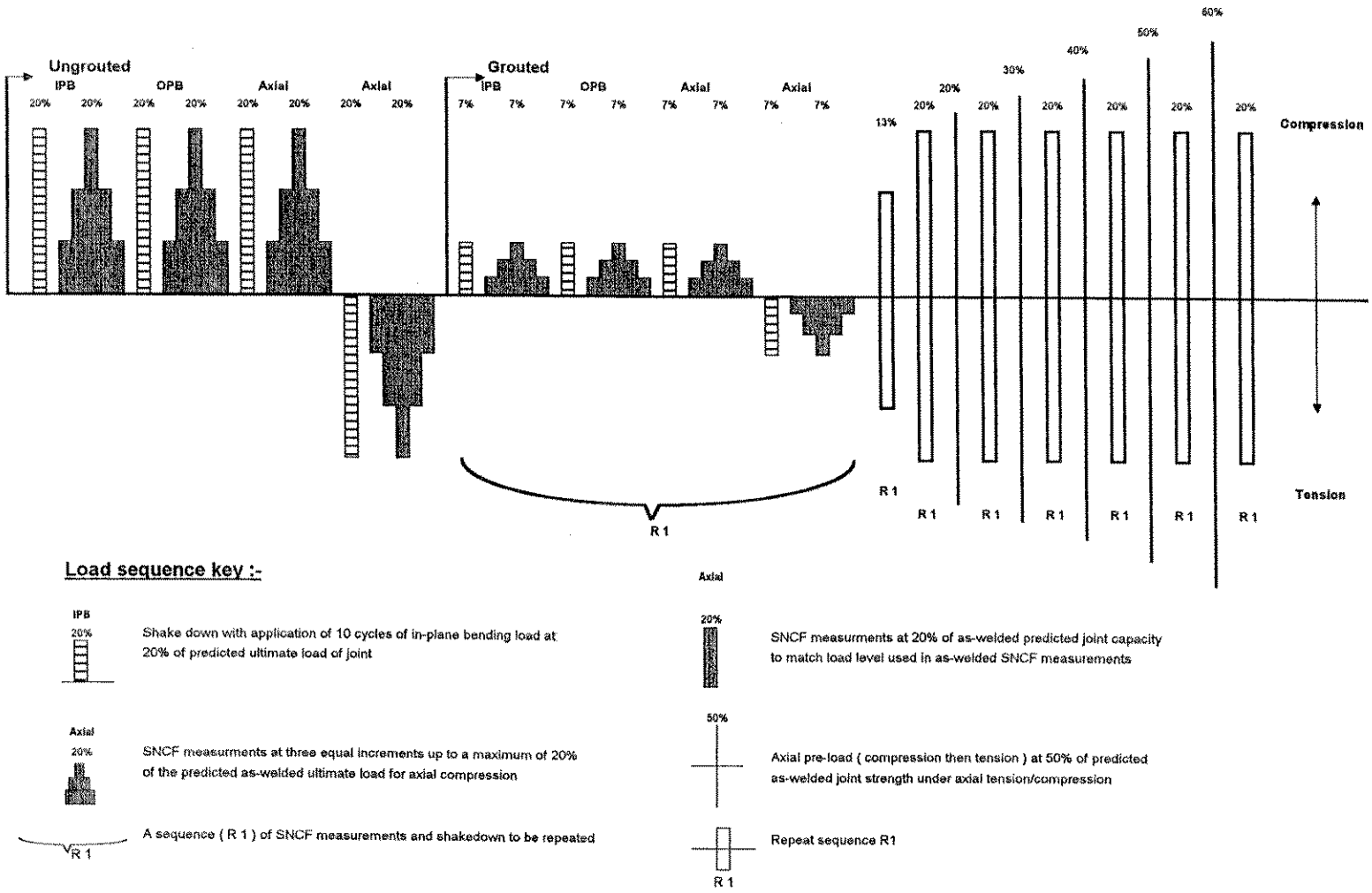



**Figure 7-1: SNCF measurement and preload sequence for specimen T7**

The results presented for the preload investigations on Specimen T7, indicate the SNCFs remain constant, for all loading conditions, at preload levels between 15% and 60% of the as-welded predicted mean ultimate joint tensile strength as given by the ISO code. The results also indicate that the SNCFs for the tension side of bending cases and the axial compression case, even at the high preload levels, do not increase beyond the SNCF measured at 60% preload. The SNCFs remain constant, to a large extent, for the axial tension case. The SNCFs increase beyond preload levels of 60% for the axial compression case, and only marginally exceed the SNCFs measured for the axial tension case at 130% preload. Below the 130% preload level, the SNCFs measured for the axial tension case are higher than those measured for the axial compression case.

Based on the results obtained from the preload investigation on Specimen T7, the majority of specimens were preloaded in increments of 0%, 50% and 100%. SNCF measurements were taken, after each preload increment.

## 7.2 SCF/SNCF ratio

With additional strain gauge rosettes mounted on Specimen T7, at one crown and one saddle position on the chord and brace, the actual stresses were determined. Using single strain gauges, only a strain concentration can be determined at the hot spot location. However, using rosette gauges, the stress concentration can be determined at the hot spot location. Appendix B contains summary tables of SCF/SNCF ratios for Specimen T7. The SCF/SNCF ratios for the preload levels applied are presented in Figure 7-6, 7-7 and 7-8 for the loading conditions considered.

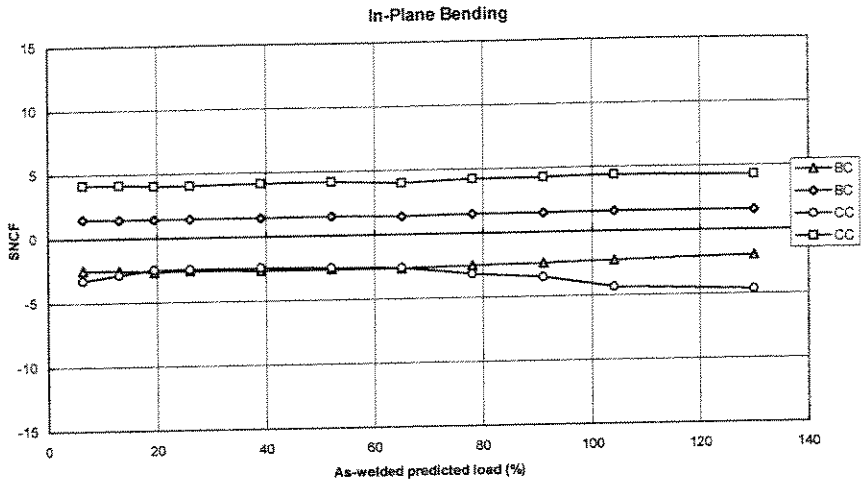



**Figure 7-2: SNCFs as function of the axial preload for in-plane bending**

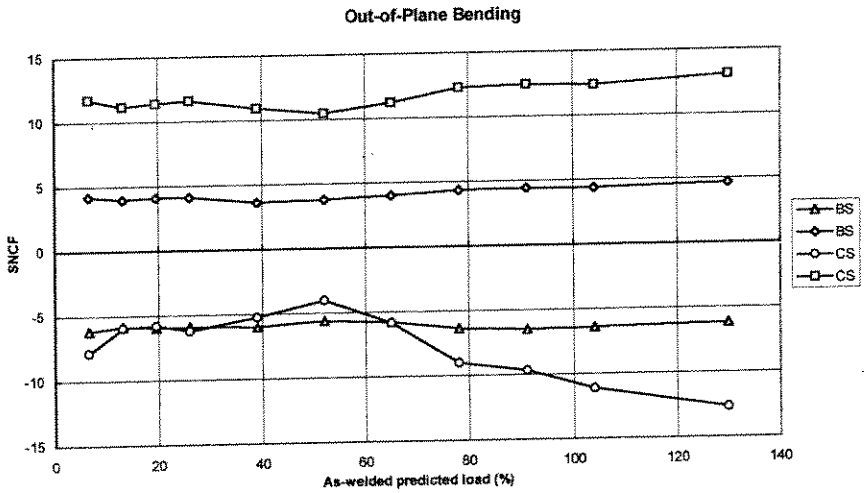



**Figure 7-3: SNCFs as function of the axial preload for out-of-plane bending**

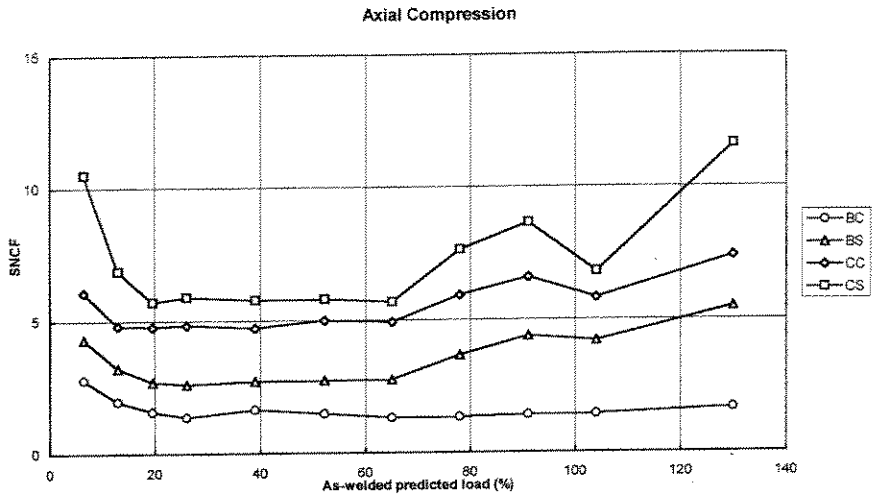



**Figure 7-4: SNCFs as function of the axial preload for axial compression**

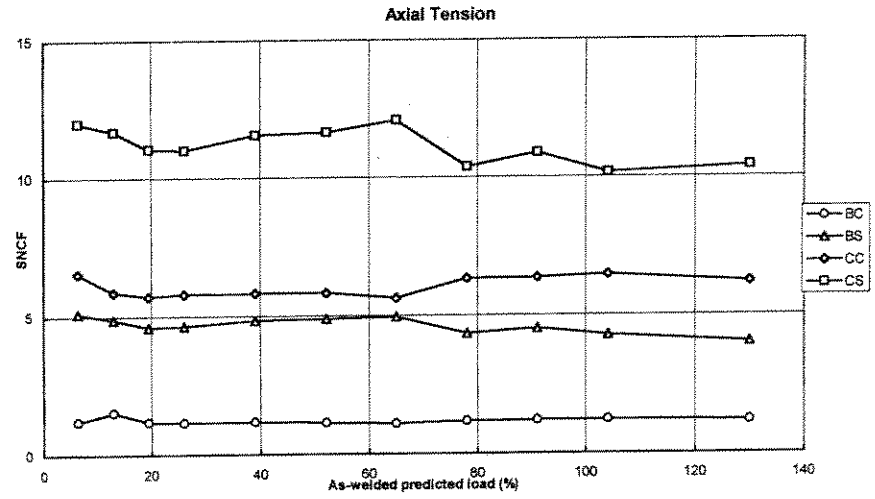



**Figure 7-5: SNCFs as function of the axial preload for axial tension**

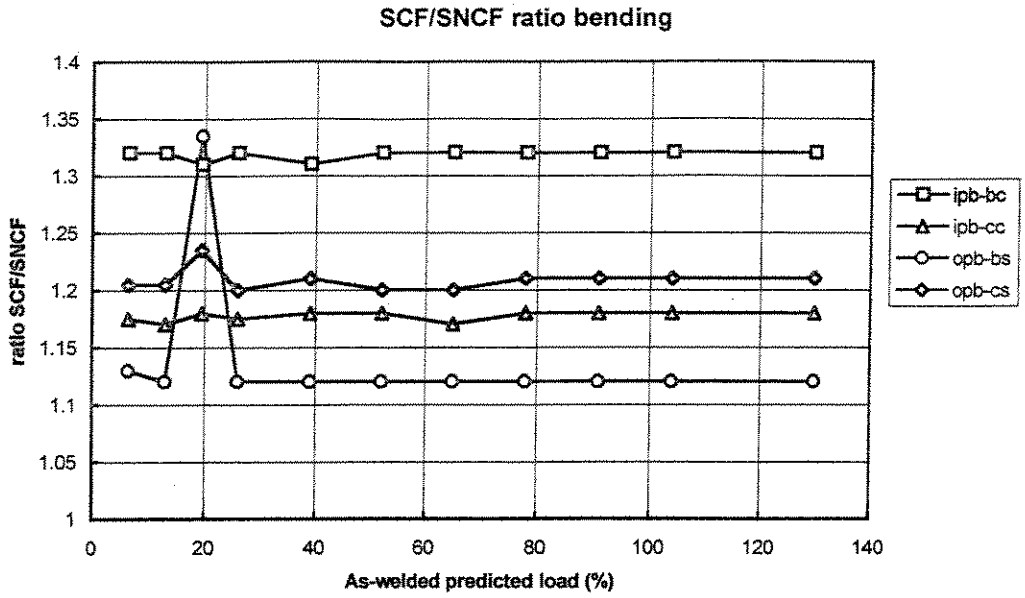



**Figure 7-6: SCF/SNCF ratios for in-plane and out-of-plane bending as function of the applied preload level.**

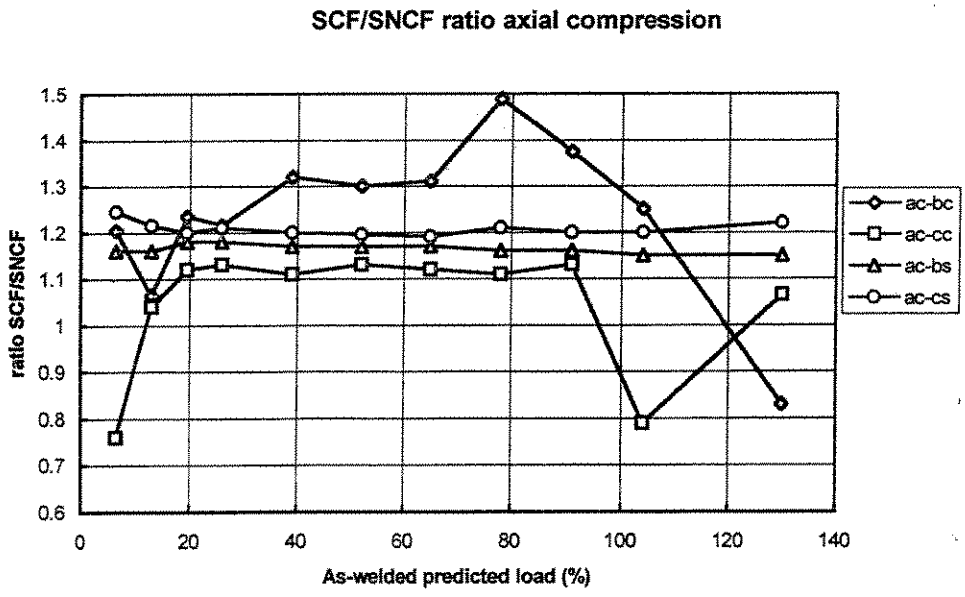



**Figure 7-7: SCF/SNCF ratios for axial compression as function of the applied preload level.**

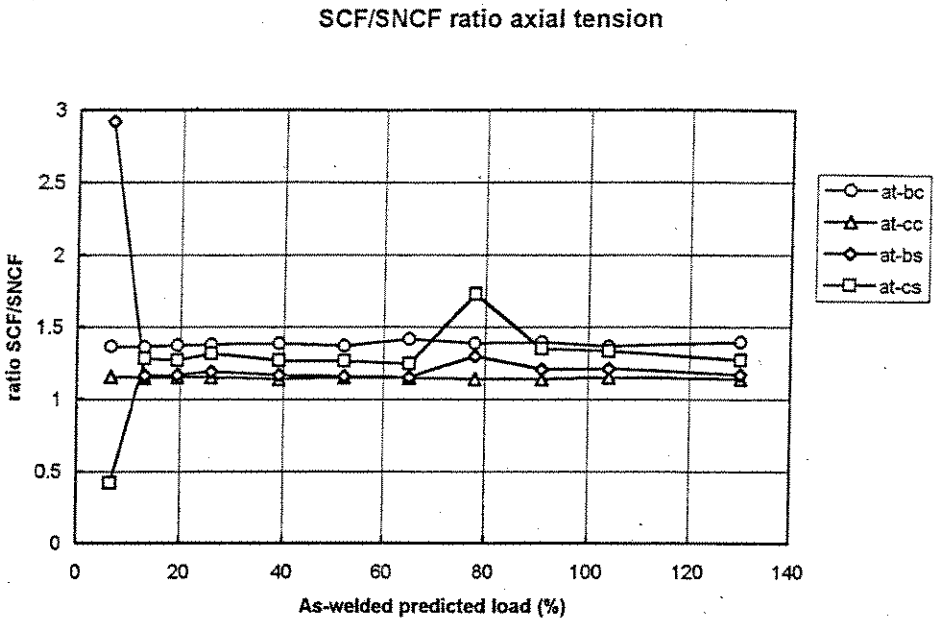



**Figure 7-8: SCF/SNCF ratios for axial tension as function of the applied preload level.**

From the results presented in Figure 7-6, it would appear that the SCF/SNCF ratio should remain constant at all measurement locations through the range of applied preload levels for axial tension and axial compression loading conditions. Figure 7-7 and Figure 7-8 also demonstrate this to a degree. It is therefore concluded that the variations seen in Figure 7-7 and Figure 7-8 can be attributed to malfunctioning gauges and/or mis-readings.

Figure 7-6 demonstrates stability in the SCF/SNCF ratio for both the tension side and compression side of bending load through the full range of applied preload levels. The visible peak experienced by the brace saddle located gauges, for out-of-plane bending, can be attributable to a mis-read gauge.

The results indicate that the grouted SCF/SNCF ratios range between 1.10 and 1.37 at the 50% preload level for all loading modes. The average grouted SCF/SNCF ratio was approximately 1.2 which was subsequently used for the conversion of grouted SNCFs to grouted SCFs for all specimens. The 1.2 ratio was also utilised as the factor for converting the as-welded SNCFs to as-welded SCFs.

## 7.3 As-welded SNCF Results and Measurements

As-welded SNCF measurements were taken for all specimens for in-plane bending, out-of-plane bending, axial compression and axial tension load cases, in turn. SNCFs were measured in the above noted sequence, since in-plane bending typically results in the lowest SNCFs and axial tension typically gives rise to the highest SNCFs, i.e. the sequence was chosen so that load cases would have minimal effect on the next load case SNCF measurement. Prior to each SNCF measurement load case, a minimum of ten cycles of that load were applied to 'shake' out any residual strains. SNCF measurements were taken in three equal increments up to approximately 20% of the ISO predicted as-welded ultimate joint capacity for that load case. SNCF measurements were also taken in three equal increments as the load was reduced back to zero. The SNCF measurements were repeated for each load case considered.

SNCFs are presented for the tension side and compression side of the bending load cases to enable comparison to the corresponding grouted SNCFs contained in Section 7.4.

Appendix C contains the full set of SNCF measurements taken for each of the test specimens.

### 7.3.1 T-Joints

A summary of the SNCF results for the T-joints are presented in Table 7-1 for in-plane bending, Table 7-2 for out-of-plane bending, Table 7-3 for axial compression and Table 7-4 for axial tension load cases.

Specimen T9 was investigated twice. It was placed in the test rig and loaded in all four loading modes twice in order to determine any possible influence of assembly/disassembly of the test specimen into the test rig on the load and strain measurements. The second investigation is marked by '(s) second'. The full results of this exercise are presented in Appendix C. However, little influence of assembly/disassembly was found as can be inferred from inspection of Tables 7-1 to 7-4.

| Specimen | β | γ | Brace Crown | | Chord Crown | |
|---|---|---|---|---|---|---|
| | | | Tension Side | Compression Side | Tension Side | Compression Side |
| T1 | 0.41 | 12.4 | 1.37 | 1.32 | 2.42 | 2.45 |
| T3 | 1.0 | 12.4 | 1.16 | 1.14 | 3.09 | 2.51 |
| T5 | 0.67 | 20.0 | 1.59 | 1.43 | 3.96 | 3.23 |
| T7 | 0.41 | 25.9 | 1.66 | 1.67 | 5.00 | 4.50 |
| T9 | 1.0 | 25.9 | 1.37 | 1.45 | 2.89 | 2.51 |
| T9(s) | 1.0 | 25.9 | 1.36 | 1.45 | 2.87 | 2.51 |

**Table 7-1: Summary of SNCF results for in-plane bending**

| Specimen | β | γ | Brace Saddle | | Chord Saddle | |
|---|---|---|---|---|---|---|
| | | | Tension Side | Compression Side | Tension Side | Compression Side |
| T1 | 0.41 | 12.4 | 2.97 | 3.18 | 6.14 | 6.0 |
| T3 | 1.0 | 12.4 | 4.97 | 4.64 | 6.66 | 7.35 |
| T5 | 0.67 | 20.0 | 7.71 | 7.78 | 13.84 | 14.35 |
| T7 | 0.41 | 25.9 | 6.24 | 7.07 | 18.43 | 17.01 |
| T9 | 1.0 | 25.9 | 6.57 | 7.53 | 15.44 | 16.99 |
| T9(s) | 1.0 | 25.9 | 6.43 | 7.45 | 15.12 | 16.76 |

**Table 7-2: Summary of SNCF results for out-of-plane bending**

| Specimen | β | γ | Averaged Values | | | |
|---|---|---|---|---|---|---|
| | | | Brace Crown | Brace Saddle | Chord Crown | Chord Saddle |
| T1 | 0.41 | 12.4 | 0.25 | 5.39 | 5.79 | 9.36 |
| T3 | 1.0 | 12.4 | 2.07 | 4.29 | 8.56 | 2.95 |
| T5 | 0.67 | 20.0 | 1.10 | 10.97 | 8.58 | 17.79 |
| T7 | 0.41 | 25.9 | 1.37 | 10.46 | 8.50 | 27.76 |
| T9 | 1.0 | 25.9 | 2.18 | 7.11 | 7.73 | 12.13 |
| T9(s) | 1.0 | 25.9 | 2.21 | 7.00 | 7.84 | 11.93 |

**Table 7-3: Summary of SNCF results for axial compression loading**

| Specimen | β | γ | Averaged Values | | | |
|---|---|---|---|---|---|---|
| | | | Brace Crown | Brace Saddle | Chord Crown | Chord Saddle |
| T1 | 0.41 | 12.4 | 0.24 | 4.96 | 5.35 | 8.69 |
| T3 | 1.0 | 12.4 | 2.08 | 4.34 | 8.51 | 2.72 |
| T5 | 0.67 | 20.0 | 1.01 | 10.83 | 8.02 | 17.63 |
| T7 | 0.41 | 25.9 | 0.71 | 10.37 | 7.99 | 25.91 |
| T9 | 1.0 | 25.9 | 2.15 | 6.88 | 7.49 | 11.62 |
| T9(s) | 1.0 | 25.9 | 2.21 | 6.77 | 7.72 | 11.41 |

**Table 7-4: Summary of SNCF results for axial tension loading**

7.3.2 DT-Joints

Summaries of the SNCF results for the DT-joints are presented in Table 7-5 for in-plane bending, Table 7-6 for out-of-plane bending, Table 7-7 for axial compression and Table 7-8 for axial tension load cases.

Appendix C contains the full set of SNCF measurements taken for each of the test specimens.

| Specimen | β | γ | Brace Crown | | Chord Crown | |
|---|---|---|---|---|---|---|
| | | | Tension Side | Compression Side | Tension Side | Compression Side |
| DT2 | 0.67 | 12.4 | 1.45 | 1.54 | 3.12 | 3.43 |
| DT3 | 1.0 | 12.4 | 1.33 | 1.03 | 2.59 | 2.19 |
| DT4 | 0.41 | 20.0 | 2.36 | 2.56 | 4.08 | 4.38 |
| DT5 | 0.67 | 20.0 | 1.45 | 1.78 | 5.88 | 4.09 |
| DT6 | 1.0 | 20.0 | 1.46 | 1.23 | 2.51 | 2.62 |
| DT8 | 0.67 | 25.9 | 1.57 | 1.57 | 4.03 | 3.84 |
| DT9 | 1.0 | 25.9 | 1.47 | 1.26 | 2.79 | 2.96 |

**Table 7-5: Summary of SNCF results for in-plane bending**

| Specimen | β | γ | Brace Saddle | | Chord Saddle | |
|---|---|---|---|---|---|---|
| | | | Tension Side | Compression Side | Tension Side | Compression Side |
| DT2 | 0.67 | 12.4 | 4.76 | 4.22 | 5.71 | 7.65 |
| DT3 | 1.0 | 12.4 | 2.28 | 1.95 | 2.49 | 2.65 |
| DT4 | 0.41 | 20.0 | 3.47 | 4.06 | 9.65 | 8.91 |
| DT5 | 0.67 | 20.0 | 7.64 | 7.47 | 18.16 | 12.08 |
| DT6 | 1.0 | 20.0 | 2.58 | 2.25 | 5.62 | 3.04 |
| DT8 | 0.67 | 25.9 | 8.39 | 9.14 | 18.85 | 17.32 |
| DT9 | 1.0 | 25.9 | 2.26 | 2.27 | 4.50 | 7.06 |

**Table 7-6: Summary of SNCF results for out-of-plane bending**

| Specimen | β | γ | Averaged Values | | | |
|---|---|---|---|---|---|---|
| | | | Brace Crown | Brace Saddle | Chord Crown | Chord Saddle |
| DT2 | 0.67 | 12.4 | 0.05 | 9.13 | 1.73 | 13.11 |
| DT3 | 1.0 | 12.4 | 0.72 | 3.59 | 0.65 | 3.39 |
| DT4 | 0.41 | 20.0 | 0.71 | 11.06 | 3.65 | 26.27 |
| DT5 | 0.67 | 20.0 | 0.07 | 15.84 | 3.43 | 29.93 |
| DT6 | 1.0 | 20.0 | 0.93 | 4.37 | 0.51 | 7.11 |
| DT8 | 0.67 | 25.9 | 0.42 | 17.94 | 1.42 | 36.60 |
| DT9 | 1.0 | 25.9 | 1.04 | 3.71 | 0.60 | 8.47 |

**Table 7-7: Summary of SNCF results for axial compression loading**

| Specimen | β | γ | Averaged Values | | | |
|---|---|---|---|---|---|---|
| | | | Brace Crown | Brace Saddle | Chord Crown | Chord Saddle |
| DT2 | 0.67 | 12.4 | 0.07 | 9.26 | 1.76 | 13.27 |
| DT3 | 1.0 | 12.4 | 0.72 | 3.53 | 0.66 | 3.38 |
| DT4 | 0.41 | 20.0 | 0.00 | 11.25 | 3.70 | 26.14 |
| DT5 | 0.67 | 20.0 | 0.05 | 15.50 | 3.78 | 29.77 |
| DT6 | 1.0 | 20.0 | 0.98 | 4.17 | 0.52 | 6.62 |
| DT8 | 0.67 | 25.9 | 0.43 | 18.08 | 1.32 | 36.99 |
| DT9 | 1.0 | 25.9 | 1.05 | 3.54 | 0.62 | 8.32 |

**Table 7-8: Summary of SNCF results for axial tension loading**

### 7.3.3 Summary As-welded SCFs

The stress/strain ratio of 1.2 has been applied to the as-welded SNCF measurements to obtain as-welded SCFs which are presented in matrix format in the following tables. The SCFs presented are the averaged measured values for the four load cases.

The SCFs presented in the tables correspond to the following load case and gauge position key:-

| | |
|---|---|
| IPB | OPB |
| Ax-Tc | Ax-Ts |
| Ax-Cc | Ax-Cs |

where;

IPB = Averaged IPB results at crown position

OPB = Averaged OPB results at saddle position

Ax-Tc = Averaged axial tension results at crown position

Ax-Ts = Averaged axial tension results at saddle position

Ax-Cc = Averaged axial compression results at crown position

Ax-Cs = Averaged axial compression results at saddle position.

Tables 7-9 and 7-10 present as-welded SCFs on the chord side for the T and DT specimens. Tables 7-11 and 7-12 present as-welded SCFs on the brace side for the T and DT specimens.

| | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| γ | 12.7 | 2.93<br>6.42<br>6.95 | T1 | 7.30<br>10.43<br>11.23 | | | | 3.37<br>10.21<br>10.27 | T3 | 8.41<br>3.26<br>3.54 |
| γ | 20.3 | | | | 4.36<br>9.62<br>10.30 | T5 | 16.86<br>21.16<br>21.35 | | | |
| γ | 25.7 | 5.69<br>9.59<br>10.20 | T7 | 21.17<br>31.09<br>33.31 | IPB<br>Ax-Tc<br>Ax-Cc | | OPB<br>Ax-Ts<br>Ax-Cs | 3.22<br>8.99<br>9.30 | T9 | 19.38<br>13.94<br>14.53 |

**Table 7-9: T-joints - Chord side As-Welded SCFs**

| | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12.7 | | | | 3.98 | | 8.08 | 2.99 | | 3.10 |
| | | | | | 2.11 | DT2 | 15.92 | 0.79 | DT3 | 4.06 |
| | | | | | 2.08 | | 15.73 | 0.78 | | 4.07 |
| γ | 20.3 | 5.14 | | 11.81 | 6.06 | | 18.20 | 3.10 | | 5.18 |
| | | 4.44 | DT4 | 31.37 | 4.54 | DT5 | 35.72 | 0.62 | DT6 | 7.94 |
| | | 4.38 | | 31.52 | 4.12 | | 35.92 | 0.61 | | 8.53 |
| | 25.7 | | | | 4.79 | | 21.59 | 3.47 | | 6.90 |
| | | | | | 1.58 | DT8 | 44.39 | 0.74 | DT9 | 9.98 |
| | | | | | 1.70 | | 43.92 | 0.72 | | 10.16 |

**Table 7-10: DT joints - Chord side As-Welded SCFs**

| | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12.7 | 1.61 | | 3.70 | | | | 1.38 | | 5.77 |
| | | 0.29 | T1 | 5.95 | | | | 2.50 | T3 | 5.21 |
| | | 0.30 | | 6.47 | | | | 2.48 | | 5.15 |
| γ | 20.3 | | | | 1.82 | | 9.26 | | | |
| | | | | | 1.21 | T5 | 13.00 | | | |
| | | | | | 1.32 | | 13.16 | | | |
| | 25.7 | 1.99 | | 7.96 | IPB | | OPB | 1.68 | | 8.44 |
| | | 1.16 | T7 | 12.44 | Ax-Tc | | Ax-Ts | 2.58 | T9 | 8.26 |
| | | 1.14 | | 12.55 | Ax-Cc | | Ax-Cs | 2.62 | | 8.53 |

**Table 7-11: T joints - Brace side As-Welded SCFs**

| | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12.7 | | | | 1.81 | | 5.44 | 1.43 | | 2.53 |
| | | | | | 0.08 | DT2 | 11.11 | 0.86 | DT3 | 4.24 |
| | | | | | 0.06 | | 10.96 | 0.86 | | 4.31 |
| γ | 20.3 | 2.64 | | 4.74 | 1.97 | | 9.07 | 1.62 | | 2.89 |
| | | 1.23 | DT4 | 13.50 | 0.06 | DT5 | 18.60 | 1.18 | DT6 | 5.00 |
| | | 1.07 | | 13.27 | 0.08 | | 19.01 | 1.12 | | 5.24 |
| | 25.7 | | | | 1.92 | | 10.46 | 1.64 | | 2.71 |
| | | | | | 0.52 | DT8 | 21.70 | 1.26 | DT9 | 4.25 |
| | | | | | 0.50 | | 21.53 | 1.25 | | 4.45 |

**Table 7-12: DT joints - Brace side As-Welded SCFs**



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## 7.4 Grouted SNCF Results and Measurements

SNCF measurements were taken for in-plane bending, out-of-plane bending, axial compression and axial tension load cases, in turn. Based on the findings from the preload investigation on Specimen T7, in general 0%, 50% and 100% preload levels were applied to the remaining specimens. As with the as-welded SNCF measurements, the grouted SNCF measurements were taken in three equal load increments corresponding to those used in the as-welded condition for each of the specimens. The SNCFs were measured for each of the load cases. The SNCFs were calculated from an average of two values. One value relates to the SNCF obtained during the loading path (between zero load and peak load), and the other to the unloading path (between peak and zero load).

The following sections summarise the measured SNCFs at the crown and saddle positions for each specimen for the load cases considered. Appendix C contains the data generated during testing from which the data in the following sections have been extracted.

### 7.4.1 T-Joints

A summary of the SNCF results for the grouted T-joint specimens are presented in the following tables. Each table contains the results of the SNCF at the brace crown, brace saddle, chord crown and chord saddle positions for each of the preload levels.

The two values given in the tables for in-plane bending and out-of-plane bending represent tension side SNCFs and compression side SNCFs in that order. The format for the tables presenting results for specimen T7 differ to those of the other specimens due to the number of preload levels tested. For specimen T7, separate tables have been generated for each of the loading conditions.

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 1.35/1.49 | | 2.22/2.02 |
| | OPB | 2.38/2.81 | | 4.5/3.5 | |
| | COMPRESSION | 2.07 | 1.42 | 3.47 | 4.65 |
| | TENSION | 3.71 | 0.94 | 4.98 | 4.84 |
| | | | | | |
| 45% | IPB | | 1.38/1.33 | | 2.43/2.29 |
| | OPB | 2.46/3.0 | | 4.68/4.07 | |
| | COMPRESSION | 3.35 | 1.02 | 5.72 | 5.90 |
| | TENSION | 3.07 | 0.93 | 4.70 | 4.89 |
| | | | | | |
| 90% | IPB | | 1.39/1.32 | | 2.22/2.34 |
| | OPB | 2.34/2.90 | | 4.32/4.04 | |
| | COMPRESSION | 3.12 | 1.00 | 4.74 | 5.34 |
| | TENSION | 2.45 | 1.12 | 3.55 | 4.77 |
| | | | | | |
| 130% | IPB | | 1.40/1.31 | | 2.26/2.34 |
| | OPB | 2.33/2.84 | | 4.46/4.15 | |
| | COMPRESSION | 2.92 | 0.96 | 4.50 | 5.21 |
| | TENSION | 2.42 | 1.02 | 3.65 | 4.87 |

**Table 7-13: Summary of grouted SNCFs for specimen T1, $\gamma$ = 12.4, $\beta$ = 0.41, after four levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 1.29/1.53 | | 2.78/2.0 |
| | OPB | 1.32/2.11 | | 2.31/2.19 | |
| | COMPRESSION | 1.72 | 2.77 | 0.42 | 8.13 |
| | TENSION | 1.75 | 2.33 | 0.52 | 9.05 |
| | | | | | |
| 50% | IPB | | 1.27/1.27 | | 2.84/2.32 |
| | OPB | 1.28/1.86 | | 1.82/1.94 | |
| | COMPRESSION | 1.30 | 2.41 | 0.28 | 8.90 |
| | TENSION | 1.33 | 2.24 | 0.67 | 9.45 |

**Table 7-14: Summary of grouted SNCFs for specimen T3, $\gamma$ = 12.4, $\beta$ = 1.0, after two levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 1.74/2.18 | | 3.59/2.76 |
| | OPB | 2.88/3.97 | | 3.38/6.58 | |
| | COMPRESSION | 2.76 | 2.41 | 4.47 | 7.00 |
| | TENSION | 3.66 | 1.49 | 5.31 | 6.35 |
| | | | | | |
| 50% | IPB | | 1.74/2.02 | | 3.62/2.90 |
| | OPB | 2.96/4.06 | | 3.64/6.66 | |
| | COMPRESSION | 3.75 | 2.28 | 5.94 | 8.43 |
| | TENSION | 3.63 | 1.69 | 5.08 | 7.61 |
| | | | | | |
| 100% | IPB | | 1.84/1.75 | | 3.46/3.27 |
| | OPB | 3.83/3.95 | | 5.13/6.40 | |
| | COMPRESSION | 4.33 | 2.13 | 5.91 | 8.77 |
| | TENSION | 2.73 | 1.86 | 3.73 | 7.42 |

**Table 7-15: Summary of grouted SNCFs for specimen T5, $\gamma$ = 20.0, $\beta$ = 0.67, after three levels of compression and tension preload**

| Preload Level % | Brace Crown | | Chord Crown | |
|---|---|---|---|---|
| | Tension Side | Compression Side | Tension Side | Compression Side |
| 7 | 1.50 | 2.45 | 4.16 | 3.26 |
| 13 | 1.49 | 2.51 | 4.17 | 2.84 |
| 20 | 1.48 | 2.62 | 4.07 | 2.45 |
| 26 | 1.47 | 2.57 | 4.05 | 2.43 |
| 40 | 1.48 | 2.62 | 4.14 | 2.40 |
| 52 | 1.50 | 2.60 | 4.20 | 2.51 |
| 65 | 1.41 | 2.63 | 4.00 | 2.57 |
| 78 | 1.52 | 2.50 | 4.22 | 3.18 |
| 90 | 1.51 | 2.41 | 4.28 | 3.47 |
| 105 | 1.57 | 2.29 | 4.36 | 4.35 |
| 130 | 1.56 | 1.98 | 4.31 | 4.65 |

**Table 7-16: Summary of grouted SNCFs for specimen T7 for in-plane bending, $\gamma$ = 25.9, $\beta$ = 0.41, measured during preload investigations**

| Preload Level % | Brace Saddle | | Chord Saddle | |
|---|---|---|---|---|
| | Tension Side | Compression Side | Tension Side | Compression Side |
| **7** | 4.20 | 6.15 | 11.71 | 7.85 |
| **13** | 4.00 | 5.84 | 11.16 | 5.96 |
| **20** | 4.10 | 5.92 | 11.42 | 5.81 |
| **26** | 4.11 | 5.91 | 11.59 | 6.20 |
| **40** | 3.65 | 5.98 | 10.95 | 5.22 |
| **52** | 3.78 | 5.63 | 10.48 | 4.01 |
| **65** | 4.01 | 5.79 | 11.21 | 5.82 |
| **78** | 4.35 | 6.35 | 12.30 | 9.03 |
| **90** | 4.43 | 6.52 | 12.49 | 9.69 |
| **105** | 4.41 | 6.41 | 12.41 | 11.14 |
| **130** | 4.66 | 6.19 | 13.07 | 12.68 |

**Table 7-17: Summary of grouted SNCFs for specimen T7 for out-of-plane bending, $\gamma$ = 25.9, $\beta$ = 0.41, measured during preload investigations**

| Preload Level % | Brace Crown | Chord Crown | Brace Saddle | Chord Saddle |
|---|---|---|---|---|
| **7** | 2.87 | 6.07 | 4.31 | 1.051 |
| **13** | 1.96 | 4.82 | 3.22 | 6.87 |
| **20** | 1.57 | 4.76 | 2.69 | 5.72 |
| **26** | 1.37 | 4.83 | 2.60 | 5.89 |
| **40** | 1.65 | 4.73 | 2.73 | 5.77 |
| **52** | 1.48 | 5.00 | 2.73 | 5.80 |
| **65** | 1.32 | 4.94 | 2.77 | 5.70 |
| **78** | 1.36 | 5.93 | 3.67 | 7.64 |
| **90** | 1.41 | 6.61 | 4.38 | 8.66 |
| **105** | 1.43 | 5.82 | 4.20 | 6.81 |
| **130** | 1.66 | 7.39 | 5.49 | 11.60 |

**Table 7-18: Summary of grouted SNCFs for specimen T7 for axial compression, $\gamma$ = 25.9, $\beta$ = 0.41, measured during preload investigations**

| Preload Level % | Brace Crown | Chord Crown | Brace Saddle | Chord Saddle |
|---|---|---|---|---|
| **7** | 1.20 | 6.54 | 5.10 | 11.99 |
| **13** | 1.54 | 5.87 | 4.88 | 11.69 |
| **20** | 1.17 | 5.71 | 4.59 | 11.07 |
| **26** | 1.17 | 5.81 | 4.63 | 11.02 |
| **40** | 1.19 | 5.83 | 4.84 | 11.57 |
| **52** | 1.14 | 5.82 | 4.88 | 11.65 |
| **65** | 1.09 | 5.64 | 4.94 | 12.08 |
| **78** | 1.19 | 6.34 | 4.33 | 10.38 |
| **90** | 1.21 | 6.36 | 4.51 | 10.89 |
| **105** | 1.23 | 6.47 | 4.27 | 10.16 |
| **130** | 1.19 | 6.20 | 4.02 | 9.85 |

**Table 7-19: Summary of grouted SNCFs for specimen T7 for axial tension, $\gamma = 25.9$, $\beta = 0.41$, measured during preload investigations**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| **0%** | IPB | | 1.43/2.06 | | 2.63/2.31 |
| | OPB | 1.59/3.21 | | 4.19/4.82 | |
| | COMPRESSION | 2.51 | 2.54 | 6.63 | 3.05 |
| | TENSION | 1.98 | 1.85 | 6.77 | 2.64 |
| | | | | | |
| **50%** | IPB | | 1.42/2.06 | | 2.65/2.43 |
| | OBP | 1.56/2.06 | | 4.28/4.59 | |
| | COMPRESSION | 2.70 | 2.53 | 2.72 | 8.00 |
| | TENSION | 2.03 | 1.99 | 2.79 | 7.34 |
| | | | | | |
| **100%** | IPB | | 1.45/1.92 | | 2.63/2.15 |
| | OPB | 0.77/1.52 | | 1.99/3.58 | |
| | COMPRESSION | 2.62 | 1.66 | 7.74 | 1.86 |
| | TENSION | 2.19 | 1.62 | 7.86 | 2.03 |

**Table 7-20: Summary of grouted SNCFs for specimen T9, $\gamma = 25.9$, $\beta = 1.0$, after three levels of compression and tension preload**

### 7.4.2 DT-Joints

A summary of the SNCF results of the grouted DT-joint specimens are presented in the following tables. Each table contains the results of the SNCF at the brace crown, brace saddle, chord crown and chord saddle position for the preload levels considered.

The two values given in the tables for in-plane bending and out-of-plane bending represent tension side SNCFs and compression side SNCFs in that order.

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 2.43/1.59 | | 2.18/2.76 |
| | OPB | 2.96/3.57 | | 4.30/4.25 | |
| | COMPRESSION | 2.93 | 1.54 | 4.70 | 2.47 |
| | TENSION | 3.74 | 0.79 | 5.11 | 1.77 |
| | | | | | |
| 50% | IPB | | 2.53/1.63 | | 2.38/2.89 |
| | OPB | 3.07/3.65 | | 4.50/4.36 | |
| | COMPRESSION | 3.12 | 1.67 | 5.07 | 2.72 |
| | TENSION | 3.76 | 0.73 | 5.17 | 1.68 |
| | | | | | |
| 100% | IPB | | 2.38/1.64 | | 2.56/2.88 |
| | OPB | 3.33/3.60 | | 5.10/4.26 | |
| | COMPRESSION | 4.18 | 1.43 | 6.41 | 3.11 |
| | TENSION | 3.40 | 0.78 | 4.60 | 1.59 |

**Table 7-21: Summary of grouted SNCFs for specimen DT2, $\gamma$ = 12.4, $\beta$ = 0.67, after three levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 2.51/1.19 | | 1.52/1.75 |
| | OPB | 1.79/2.06 | | 2.60/2.39 | |
| | COMPRESSION | 3.36 | 0.79 | 3.27 | 1.03 |
| | TENSION | 2.11 | 0.84 | 3.09 | 0.93 |
| | | | | | |
| 50% | IPB | | 2.62/1.21 | | 1.44/1.77 |
| | OPB | 1.89/2.18 | | 2.61/2.41 | |
| | COMPRESSION | 3.24 | 0.89 | 3.22 | 1.21 |
| | TENSION | 2.78 | 0.80 | 3.45 | 0.85 |
| | | | | | |
| 100% | IPB | | 2.71/1.24 | | 1.53/1.77 |
| | OPB | 1.97/2.22 | | 2.76/2.48 | |
| | COMPRESSION | 3.30 | 1.21 | 3.33 | 1.20 |
| | TENSION | 3.11 | 0.81 | 3.53 | 0.86 |

**Table 7-22: Summary of grouted SNCFs for specimen DT3, $\gamma$ = 12.4, $\beta$ = 1.0, after three levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 3.58/2.24 | | 1.62/3.19 |
| | OPB | 3.57/2.68 | | 3.89/6.39 | |
| | COMPRESSION | 1.69 | 2.05 | 3.51 | 2.37 |
| | TENSION | 3.32 | 1.11 | 6.91 | 2.19 |
| | | | | | |
| 50% | IPB | | 3.70/2.27 | | 1.67/3.24 |
| | OPB | 3.89/2.82 | | 4.23/6.70 | |
| | COMPRESSION | 1.76 | 1.99 | 3.26 | 2.60 |
| | TENSION | 3.44 | 1.03 | 6.94 | 2.10 |
| | | | | | |
| 100% | IPB | | 3.69/2.23 | | 1.60/3.18 |
| | OPB | 3.92/2.85 | | 4.26/6.70 | |
| | COMPRESSION | 1.77 | 1.89 | 3.60 | 2.85 |
| | TENSION | 4.11 | 1.29 | 8.35 | 2.59 |

**Table 7-23: Summary of grouted SNCFs for specimen DT4, $\gamma$ = 20.0, $\beta$ = 0.41, after three levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 2.77/1.82 | | 2.30/3.19 |
| | OPB | 3.47/4.31 | | 3.68/9.91 | |
| | COMPRESSION | 3.55 | 1.76 | 7.01 | 2.74 |
| | TENSION | 4.61 | 0.87 | 8.38 | 1.14 |
| | | | | | |
| 50% | IPB | | 2.77/1.82 | | 2.28/3.22 |
| | OPB | 4.20/4.92 | | 4.94/11.49 | |
| | COMPRESSION | 3.61 | 1.93 | 7.47 | 1.65 |
| | TENSION | 5.30 | 0.80 | 9.66 | 0.62 |
| | | | | | |
| 100% | IPB | | 2.84/1.85 | | 2.45/3.26 |
| | OPB | 4.54/4.93 | | 4.88/11.37 | |
| | COMPRESSION | 4.08 | 1.98 | 7.44 | 2.97 |
| | TENSION | 5.42 | 0.74 | 9.82 | 0.42 |

**Table 7-24: Summary of grouted SNCFs for specimen DT5, $\gamma$ = 20.0, $\beta$ = 0.67, after three levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 3.05/1.44 | | 1.30/2.32 |
| | OPB | 2.55/2.09 | | 3.44/4.77 | |
| | COMPRESSION | 3.74 | 1.41 | 5.91 | 1.57 |
| | TENSION | 2.59 | 1.08 | 4.75 | 1.21 |
| | | | | | |
| 50% | IPB | | 3.31/1.43 | | 0.95/2.27 |
| | OPB | 2.60/2.28 | | 3.53/4.86 | |
| | COMPRESSION | 4.00 | 1.32 | 6.34 | 1.49 |
| | TENSION | 3.29 | 1.07 | 5.38 | 1.09 |
| | | | | | |
| 100% | IPB | | 3.10/1.42 | | 1.29/2.27 |
| | OPB | 2.52/2.33 | | 3.45/5.10 | |
| | COMPRESSION | 3.98 | 1.49 | 6.41 | 1.45 |
| | TENSION | 3.19 | 1.06 | 5.24 | 1.07 |

**Table 7-25: Summary of grouted SNCFs for specimen DT6, $\gamma$ =20.0, $\beta$ = 1.0, after three levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 2.96/1.53 | | 1.07/2.74 |
| | OPB | 3.71/4.34 | | 4.11/9.41 | |
| | COMPRESSION | 2.44 | 1.99 | 4.67 | 1.54 |
| | TENSION | 4.04 | 0.59 | 6.90 | 1.80 |
| | | | | | |
| 50% | IPB | | 3.07/1.53 | | 1.15/2.77 |
| | OPB | 3.95/4.55 | | 5.23/9.77 | |
| | COMPRESSION | 3.23 | 1.61 | 7.27 | 2.38 |
| | TENSION | 5.36 | 0.60 | 10.50 | 1.93 |
| | | | | | |
| 100% | IPB | | 3.10/1.51 | | 1.21/2.73 |
| | OPB | 4.15/4.80 | | 5.82/10.29 | |
| | COMPRESSION | 2.62 | 1.60 | 4.19 | 1.19 |
| | TENSION | 5.75 | 0.60 | 11.05 | 2.00 |

**Table 7-26: Summary of grouted SNCFs for specimen DT8, $\gamma$ = 25.9, $\beta$ = 0.67, after three levels of compression and tension preload**

| Preload | Loadcase | Brace | | Chord | |
|---|---|---|---|---|---|
| | | Saddle | Crown | Saddle | Crown |
| | | | | | |
| 0% | IPB | | 2.77/1.51 | | 0.51/2.51 |
| | OPB | 2.33/1.47 | | 6.97/3.59 | |
| | COMPRESSION | 3.37 | 1.56 | 8.05 | 2.06 |
| | TENSION | 1.64 | 1.03 | 5.57 | 1.15 |
| | | | | | |
| 50% | IPB | | 2.78/1.51 | | 0.52/2.52 |
| | OPB | 2.27/1.55 | | 6.88/3.82 | |
| | COMPRESSION | 3.50 | 1.82 | 8.46 | 2.12 |
| | TENSION | 1.65 | 1.03 | 5.70 | 1.12 |
| | | | | | |
| 100% | IPB | | 2.89/1.52 | | 0.69/2.57 |
| | OPB | 2.23/1.76 | | 6.73/4.29 | |
| | COMPRESSION | 3.44 | 1.98 | 8.19 | 1.98 |
| | TENSION | 2.25 | 1.01 | 7.62 | 1.08 |

**Table 7-27: Summary of grouted SNCFs for specimen DT9, $\gamma$ = 25.9, $\beta$ = 1.0, after three levels of compression and tension preload**

### 7.4.3 Summary Grouted SCFs

As with the as-welded SCFs, the grouted SCFs were obtained by the application of a stress/strain ratio of 1.2 to the grouted SNCFs. The following tables present the grouted SCFs in matrix format, following the key identified in Section 7.3.3.

Tables 7-28 and 7-29 present grouted SCFs on the chord side for the T and DT specimens. Tables 7-30 and 7-31 present grouted SCFs on the brace side for the T and DT specimens.

| | | β = 0.41 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | γ = 4 | | | | | | | | |
| | 12.7 | 2.83<br>5.87<br>7.00 | T1 | 5.26<br>5.64<br>6.20 | | | | 3.10<br>11.34<br>10.68 | T3 | 2.26<br>0.80<br>0.34 |
| γ | 20.3 | | | | 3.91<br>9.13<br>9.56 | T5 | 6.18<br>6.10<br>6.32 | | | |
| | 25.7 | 3.95<br>6.77<br>5.93 | T7 | 10.21<br>14.50<br>6.84 | IPB<br>Ax-Tc<br>Ax-Cc | | OPB<br>Ax-Ts<br>Ax-Cs | 3.05<br>8.81<br>9.60 | T9 | 5.32<br>3.35<br>3.26 |

**Table 7-28: T-joints - Chord side Grouted SCFs**

| | | β = 0.41 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | γ = 4 | | | | | | | | |
| | 12.7 | | | | 3.16<br>2.02<br>3.26 | DT2 | 5.32<br>6.20<br>6.08 | 1.93<br>1.02<br>1.45 | DT3 | 3.01<br>4.14<br>3.86 |
| γ | 20.3 | 2.94<br>2.52<br>3.12 | DT4 | 6.55<br>8.33<br>3.91 | 3.30<br>0.74<br>1.98 | DT5 | 8.59<br>11.59<br>8.96 | 1.93<br>1.31<br>1.79 | DT6 | 5.04<br>6.46<br>7.61 |
| | 25.7 | | | | 2.35<br>2.32<br>2.86 | DT8 | 9.00<br>12.60<br>8.72 | 1.82<br>1.34<br>2.54 | DT9 | 6.42<br>6.84<br>10.15 |

**Table 7-29: DT joints - Chord side Grouted SCFs**

| γ | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12.7 | 1.62 | | 3.28 | | | | 1.52 | | 1.88 |
| | | 1.12 | T1 | 3.68 | | | | 2.69 | T3 | 1.60 |
| | | 1.33 | | 3.60 | | | | 2.89 | | 1.56 |
| | 20.3 | | | | 2.26 | | 4.21 | | | |
| | | | | | 2.03 | T5 | 4.36 | | | |
| | | | | | 2.74 | | 3.95 | | | |
| | 25.7 | 2.42 | | 5.88 | IPB | | OPB | 2.09 | | 2.17 |
| | | 1.31 | T7 | 5.93 | Ax-Tc | | Ax-Ts | 2.43 | T9 | 2.39 |
| | | 1.58 | | 3.32 | Ax-Cc | | Ax-Cs | 3.24 | | 3.03 |

**Table 7-30: T joints - Brace side Grouted SCFs**

| γ | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12.7 | | | | 2.50 | | 4.03 | 2.29 | | 2.44 |
| | | | | | 0.88 | DT2 | 4.51 | 0.96 | DT3 | 3.34 |
| | | | | | 2.00 | | 3.74 | 1.07 | | 3.89 |
| | 20.3 | 3.58 | | 4.02 | 2.76 | | 4.90 | 2.84 | | 2.89 |
| | | 1.24 | DT4 | 4.13 | 0.96 | DT5 | 6.36 | 1.28 | DT6 | 3.95 |
| | | 2.39 | | 2.11 | 2.32 | | 4.33 | 1.58 | | 4.80 |
| | 25.7 | | | | 2.76 | | 5.10 | 2.57 | | 2.29 |
| | | | | | 0.72 | DT8 | 6.43 | 1.24 | DT9 | 1.98 |
| | | | | | 1.93 | | 3.88 | 2.18 | | 4.20 |

**Table 7-31: DT joints - Brace side Grouted SCFs**

## 7.5 Discussion of Test Results

A summary of the results are presented by the Figures contained in Appendix C which compare the grouted SNCFs with the as-welded SNCFs at the crown and saddle positions for the chord and brace. The results are presented as functions of β for constant γ. The SNCFs presented for the grouted joints were taken following the 50% preloading level.

Table 7-32 presents a summary of SNCF results for in-plane bending and out-of-plane bending for specimens in the as-welded condition and grouted condition. In the as-welded condition the SNCFs are comparable between the tension side and compression side for the bending load cases, as presented. However, in the grouted condition the SNCFs deviate between the tension side and compression side for the bending load cases. Although deviation between tension side and compression side SNCFs exists, the average SNCF values were used for subsequent data reduction.

## In-Plane Bending SNCF Results

**As-welded IPB SNCF**

| Specimen | Brace Crown | | Chord Crown | |
|---|---|---|---|---|
| | Tens | Comp | Tens | Comp |
| T1 | 1.37 | 1.32 | 2.42 | 2.45 |
| T3 | 1.16 | 1.14 | 3.09 | 2.51 |
| T5 | 1.59 | 1.43 | 3.96 | 3.23 |
| T7 | 1.66 | 1.67 | 5.00 | 4.50 |
| T9 | 1.37 | 1.45 | 2.89 | 2.51 |
| DT2 | 1.45 | 1.54 | 3.12 | 3.43 |
| DT3 | 1.33 | 1.03 | 2.59 | 2.19 |
| DT4 | 2.36 | 2.56 | 4.08 | 4.38 |
| DT5 | 1.45 | 1.78 | 5.88 | 4.09 |
| DT6 | 1.46 | 1.23 | 2.51 | 2.62 |
| DT8 | 1.57 | 1.57 | 4.03 | 3.84 |
| DT9 | 1.47 | 1.26 | 2.79 | 2.96 |

**Grouted IPB (50% preload) SNCF**

| Specimen | Brace Crown | | Chord Crown | |
|---|---|---|---|---|
| | Tens | Comp | Tens | Comp |
| T1 | 1.38 | 1.33 | 2.43 | 2.29 |
| T3 | 1.27 | 1.27 | 2.84 | 2.32 |
| T5 | 1.74 | 2.02 | 3.62 | 2.90 |
| T7 | 1.50 | 2.60 | 4.20 | 2.51 |
| T9 | 1.42 | 2.06 | 2.65 | 2.43 |
| DT2 | 2.53 | 1.63 | 2.38 | 2.89 |
| DT3 | 2.62 | 1.21 | 1.44 | 1.77 |
| DT4 | 3.70 | 2.27 | 1.67 | 3.24 |
| DT5 | 2.77 | 1.82 | 2.28 | 3.22 |
| DT6 | 3.31 | 1.43 | 0.95 | 2.27 |
| DT8 | 3.07 | 1.53 | 1.15 | 2.77 |
| DT9 | 2.78 | 1.51 | 0.52 | 2.52 |

**Av. Grout/Av. As-weld**

| Brace Crown | Chord Crown |
|---|---|
| 1.01 | 0.97 |
| 1.10 | 0.92 |
| 1.25 | 0.91 |
| 1.23 | 0.71 |
| 1.23 | 0.94 |
| 1.39 | 0.80 |
| 1.62 | 0.67 |
| 1.21 | 0.58 |
| 1.42 | 0.55 |
| 1.76 | 0.63 |
| 1.46 | 0.50 |
| 1.57 | 0.53 |

**R.F. In-plane bending**

| Specimen | Brace Crown | | | Chord Crown | | |
|---|---|---|---|---|---|---|
| | Tens | Comp | Average | Tens | Comp | Average |
| T1 | 1.01 | 1.01 | 1.01 | 1.00 | 0.93 | 0.97 |
| T3 | 1.09 | 1.11 | 1.10 | 0.92 | 0.92 | 0.92 |
| T5 | 1.09 | 1.41 | 1.25 | 0.91 | 0.90 | 0.91 |
| T7 | 0.90 | 1.56 | 1.23 | 0.84 | 0.56 | 0.70 |
| T9 | 1.04 | 1.42 | 1.23 | 0.92 | 0.97 | 0.94 |
| DT2 | 1.74 | 1.06 | 1.40 | 0.76 | 0.84 | 0.80 |
| DT3 | 1.97 | 1.17 | 1.57 | 0.56 | 0.81 | 0.68 |
| DT4 | 1.57 | 0.89 | 1.23 | 0.41 | 0.74 | 0.57 |
| DT5 | 1.91 | 1.02 | 1.47 | 0.39 | 0.79 | 0.59 |
| DT6 | 2.27 | 1.16 | 1.71 | 0.38 | 0.87 | 0.62 |
| DT8 | 1.96 | 0.97 | 1.46 | 0.29 | 0.72 | 0.50 |
| DT9 | 1.89 | 1.20 | 1.54 | 0.19 | 0.85 | 0.52 |

## Out-of-Plane Bending SNCF Results

**As-welded OPB SNCF**

| Specimen | Brace Saddle | | Chord Saddle | |
|---|---|---|---|---|
| | Tens | Comp | Tens | Comp |
| T1 | 2.97 | 3.18 | 6.14 | 6.00 |
| T3 | 4.97 | 4.64 | 6.66 | 7.35 |
| T5 | 7.71 | 7.78 | 13.84 | 14.35 |
| T7 | 6.24 | 7.07 | 18.43 | 17.01 |
| T9 | 6.57 | 7.53 | 15.44 | 16.99 |
| DT2 | 4.76 | 4.22 | 5.71 | 7.65 |
| DT3 | 2.28 | 1.95 | 2.49 | 2.65 |
| DT4 | 3.47 | 4.06 | 9.65 | 8.91 |
| DT5 | 7.64 | 7.47 | 18.16 | 12.08 |
| DT6 | 2.58 | 2.25 | 5.62 | 3.04 |
| DT8 | 8.39 | 9.14 | 18.85 | 17.32 |
| DT9 | 2.26 | 2.27 | 4.50 | 7.06 |

**Grouted OPB (50% preload) SNCF**

| Specimen | Brace Saddle | | Chord Saddle | |
|---|---|---|---|---|
| | Tens | Comp | Tens | Comp |
| T1 | 2.46 | 3.00 | 4.68 | 4.07 |
| T3 | 1.28 | 1.86 | 1.82 | 1.94 |
| T5 | 2.96 | 4.06 | 3.64 | 6.66 |
| T7 | 3.78 | 5.63 | 10.48 | 4.01 |
| T9 | 1.56 | 2.06 | 4.28 | 4.59 |
| DT2 | 3.07 | 3.65 | 4.50 | 4.36 |
| DT3 | 1.89 | 2.18 | 2.61 | 2.41 |
| DT4 | 3.89 | 2.82 | 4.23 | 6.70 |
| DT5 | 4.20 | 4.92 | 4.94 | 11.49 |
| DT6 | 2.60 | 2.28 | 3.53 | 4.86 |
| DT8 | 3.95 | 4.55 | 5.23 | 9.77 |
| DT9 | 2.27 | 1.55 | 6.88 | 3.82 |

**Av. Grout/Av. As-weld**

| Brace Saddle | Chord Saddle |
|---|---|
| 0.89 | 0.72 |
| 0.33 | 0.27 |
| 0.45 | 0.37 |
| 0.71 | 0.41 |
| 0.26 | 0.27 |
| 0.75 | 0.66 |
| 0.96 | 0.98 |
| 0.89 | 0.59 |
| 0.60 | 0.54 |
| 1.01 | 0.97 |
| 0.48 | 0.41 |
| 0.84 | 0.93 |

**R.F. Out-of-plane bending**

| Specimen | Brace Saddle | | | Chord Saddle | | |
|---|---|---|---|---|---|---|
| | Tens | Comp | Average | Tens | Comp | Average |
| T1 | 0.83 | 0.94 | 0.89 | 0.76 | 0.68 | 0.72 |
| T3 | 0.26 | 0.40 | 0.33 | 0.27 | 0.26 | 0.27 |
| T5 | 0.38 | 0.52 | 0.45 | 0.26 | 0.46 | 0.36 |
| T7 | 0.61 | 0.80 | 0.70 | 0.57 | 0.24 | 0.40 |
| T9 | 0.24 | 0.27 | 0.26 | 0.28 | 0.27 | 0.27 |
| DT2 | 0.64 | 0.86 | 0.75 | 0.79 | 0.57 | 0.68 |
| DT3 | 0.83 | 1.12 | 0.97 | 1.05 | 0.91 | 0.98 |
| DT4 | 1.12 | 0.69 | 0.91 | 0.44 | 0.75 | 0.60 |
| DT5 | 0.55 | 0.66 | 0.60 | 0.27 | 0.95 | 0.61 |
| DT6 | 1.01 | 1.01 | 1.01 | 0.63 | 1.60 | 1.11 |
| DT8 | 0.47 | 0.50 | 0.48 | 0.28 | 0.56 | 0.42 |
| DT9 | 1.00 | 0.68 | 0.84 | 1.53 | 0.54 | 1.03 |

**Table 7-32: Summary of tension side and compression side bending SNCFs**

The averaging of tension side and compression side SNCF is based on the recognition that a joint in-situ on a platform could well be subjected to cyclic loading which causes alternating tension and compression loading at a hot spot location. The hot spot stress range is more accurately calculated using the average SNCF (SCF) value rather than either the tension side value alone or the compression side value alone.

Table 7-33 presents the Reduction Factors derived using the measured grouted SNCFs over the measured as-welded SNCFs. In the grouted condition there is a reduction in SNCF at the saddle location for out-of-plane bending and axial tension, on the chord side and brace side. There is also a reduction in SNCF at the crown location for in-plane bending on the chord side. The brace side SNCF however, increases for in-plane bending. Also, the SNCF at the crown location generally increases for axial tension and axial compression on both the chord side and brace side. For some joints the SNCFs for the grouted condition are significantly higher than SNCFs for the as-welded condition, i.e. the RF is above unity, at brace crown locations for all pertinent load cases. The largest RF recorded at the brace crown location is 4.43, despite excluding four factors in excess of 10 due to the near zero values of the as-welded SNCF. In the grouted condition the SNCFs increased, but do not represent the critical SNCF for the grouted condition. For the chord side crown, the absolute highest recorded factor is 3.53.

Tables 7-34 to 7-37 present the RFs in matrix format, following the key identified in Section 7.3.3. Tables 7-34 and 7-35 present RFs on the chord side for the T and DT specimens. Tables 7-36 and 7-37 present RFs on the brace side for the T and DT specimens.

| Specimen Ident. | D (mm) | d (mm) | T (mm) | $T_e$ (mm) | t (mm) | L (mm) | θ (°) | β | γ | $\gamma_e$ Ax & OPB | $\gamma_e$ IPB | τ | α | Condition | Chord SCFs IPB | Chord SCFs OPB | Chord SCFs Comp. Ax-s | Chord SCFs Comp. Ax-c | Chord SCFs Tens. Ax-s | Chord SCFs Tens. Ax-c | Brace SCFs IPB | Brace SCFs OPB | Brace SCFs Comp. Ax-s | Brace SCFs Comp. Ax-c | Brace SCFs Tens. Ax-s | Brace SCFs Tens. Ax-c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 406.78 | 167.81 | 16.39 | 29.4 | 16.32 | 2440 | 90.0 | 0.413 | 12.409 | 6.92 | 11.71 | 0.996 | 12.00 | Measured | 0.97 | 0.72 | 0.55 | 1.01 | 0.54 | 0.91 | 1.01 | 0.89 | 0.56 | 4.43 | 0.62 | 3.89 |
| T3 | 406.78 | 407.02 | 16.39 | 29.4 | 16.10 | 2440 | 90.0 | 1.000 | 12.409 | 6.92 | 11.71 | 0.982 | 12.00 | Measured | 0.92 | 0.27 | 0.09 | 1.04 | 0.25 | 1.11 | 1.10 | 0.33 | 0.30 | 1.16 | 0.31 | 1.08 |
| T5 | 407.05 | 273.34 | 10.19 | 23.6 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 8.62 | 18.36 | 0.964 | 11.99 | Measured | 0.90 | 0.37 | 0.30 | 0.93 | 0.29 | 0.95 | 1.24 | 0.45 | 0.30 | 2.07 | 0.34 | 1.67 |
| T7 | 406.96 | 168.41 | 7.86 | 21.4 | 8.31 | 2440 | 90.0 | 0.414 | 25.888 | 9.49 | 23.42 | 1.057 | 11.99 | Measured | 0.69 | 0.48 | 0.21 | 0.58 | 0.47 | 0.71 | 1.22 | 0.74 | 0.26 | 1.39 | 0.48 | 1.13 |
| T9 | 406.96 | 406.96 | 7.86 | 21.4 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 9.49 | 23.42 | 1.000 | 11.99 | Measured | 0.95 | 0.27 | 0.22 | 1.03 | 0.24 | 0.98 | 1.24 | 0.26 | 0.36 | 1.24 | 0.29 | 0.94 |
| DT2 | 406.78 | 273.09 | 16.39 | 29.4 | 15.76 | 2440 | 90.0 | 0.671 | 12.409 | 6.92 | 11.71 | 0.962 | 12.00 | Measured | 0.79 | 0.66 | 0.39 | 1.57 | 0.39 | 0.95 | 1.38 | 0.74 | 0.34 | 33.40 | 0.41 | 10.43 |
| DT3 | 406.78 | 407.02 | 16.39 | 29.4 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 6.92 | 11.71 | 0.982 | 12.00 | Measured | 0.67 | 0.97 | 0.95 | 1.86 | 1.02 | 1.29 | 1.61 | 0.96 | 0.90 | 1.24 | 0.79 | 1.11 |
| DT4 | 407.05 | 168.57 | 10.19 | 23.6 | 9.95 | 2440 | 90.0 | 0.414 | 19.973 | 8.62 | 18.36 | 0.976 | 11.99 | Measured | 0.57 | 0.55 | 0.12 | 0.71 | 0.27 | 0.57 | 1.35 | 0.85 | 0.16 | 2.23 | 0.31 | 1.00 |
| DT5 | 407.05 | 273.34 | 10.19 | 23.6 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 8.62 | 18.36 | 0.964 | 11.99 | Measured | 0.54 | 0.47 | 0.25 | 0.48 | 0.32 | 0.16 | 1.40 | 0.54 | 0.23 | 27.57 | 0.34 | 16.00 |
| DT6 | 407.05 | 407.60 | 10.19 | 23.6 | 9.61 | 2440 | 90.0 | 1.001 | 19.973 | 8.62 | 18.36 | 0.943 | 11.99 | Measured | 0.62 | 0.97 | 0.89 | 2.92 | 0.81 | 2.10 | 1.76 | 1.00 | 0.92 | 1.42 | 0.79 | 1.09 |
| DT8 | 406.96 | 273.21 | 7.86 | 21.4 | 7.88 | 2440 | 90.0 | 0.671 | 25.888 | 9.49 | 23.42 | 1.003 | 11.99 | Measured | 0.49 | 0.42 | 0.20 | 1.68 | 0.28 | 1.46 | 1.44 | 0.49 | 0.18 | 3.83 | 0.30 | 1.40 |
| DT9 | 406.96 | 406.96 | 7.86 | 21.4 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 9.49 | 23.42 | 1.000 | 11.99 | Measured | 0.53 | 0.93 | 1.00 | 3.53 | 0.69 | 1.81 | 1.56 | 0.85 | 0.94 | 1.75 | 0.47 | 0.98 |

Note :- Assumed Stress/Strain relationship = 1.2

**Table 7-33: Summary of measured Reduction Factors**

| γ | β = 0.414 | β = 0.67 | β = 1 |
|---|---|---|---|
| 12.7 | 0.97 0.72<br>0.91 T1 0.54<br>1.01 0.55 | | 0.92 0.27<br>1.11 T3 0.25<br>1.04 0.09 |
| 20.3 | | 0.90 0.37<br>0.95 T5 0.29<br>0.93 0.30 | |
| 25.7 | 0.69 0.48<br>0.71 T7 0.47<br>0.58 0.21 | IPB OPB<br>Ax-Tc Ax-Ts<br>Ax-Cc Ax-Cs | 0.95 0.27<br>0.98 T9 0.24<br>1.03 0.22 |

**Table 7-34: T joints - Chord side Measured RFs**

| γ | β = 0.414 | β = 0.67 | β = 1 |
|---|---|---|---|
| 12.7 | | 0.79 0.66<br>0.95 DT2 0.39<br>1.57 0.39 | 0.67 0.97<br>1.29 DT3 1.02<br>1.86 0.95 |
| 20.3 | 0.57 0.55<br>0.57 DT4 0.27<br>0.71 0.12 | 0.54 0.47<br>0.16 DT5 0.32<br>0.48 0.25 | 0.62 0.97<br>2.10 DT6 0.81<br>2.92 0.89 |
| 25.7 | | 0.49 0.42<br>1.46 DT8 0.28<br>1.68 0.20 | 0.53 0.93<br>1.81 DT9 0.69<br>3.53 1.00 |

**Table 7-35: DT joints - Chord side Measured RFs**

| γ | β = 0.414 | β = 0.67 | β = 1 |
|---|---|---|---|
| 12.7 | 1.01 0.89<br>3.89 T1 0.62<br>4.43 0.56 | | 1.10 0.33<br>1.08 T3 0.31<br>1.16 0.30 |
| 20.3 | | 1.24 0.45<br>1.67 T5 0.34<br>2.07 0.30 | |
| 25.7 | 1.22 0.74<br>1.13 T7 0.48<br>1.39 0.26 | IPB OPB<br>Ax-Tc Ax-Ts<br>Ax-Cc Ax-Cs | 1.24 0.26<br>0.94 T9 0.29<br>1.24 0.36 |

**Table 7-36: T joints - Brace side Measured RFs**

| γ | | β = 0.414 | | | β = 0.67 | | | β = 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12.7 | | | | 1.38 | | 0.74 | 1.61 | | 0.96 |
| | | | | | 10.43 | DT2 | 0.41 | 1.11 | DT3 | 0.79 |
| | | | | | 33.40 | | 0.34 | 1.24 | | 0.90 |
| | 20.3 | 1.35 | | 0.85 | 1.40 | | 0.54 | 1.76 | | 1.00 |
| | | 1.00 | DT4 | 0.31 | 16.00 | DT5 | 0.34 | 1.09 | DT6 | 0.79 |
| | | 2.23 | | 0.16 | 27.57 | | 0.23 | 1.42 | | 0.92 |
| | 25.7 | | | | 1.44 | | 0.49 | 1.56 | | 0.85 |
| | | | | | 1.40 | DT8 | 0.30 | 0.98 | DT9 | 0.47 |
| | | | | | 3.83 | | 0.18 | 1.75 | | 0.94 |

**Table 7-37: DT joints - Brace side Measured RFs**

## 7.6 Ultimate Strength Test Results and Measurements

The specimens were loaded up to failure under in-plane or out-of-plane bending, see Table 7-38. The load-rotation plots for the ultimate load tests are presented in Appendix D. Pictures of the failure modes are also presented in Appendix D.

| Joint | Maximum moment [kNm] | | Loading type | Failure mode |
|---|---|---|---|---|
| | At Chord C.L. | At Chord Face | | |
| **T1** | 152 | 122 | opb | shear failure in chord at saddle |
| **T3** | 923 | 839 | opb | near to failure but limited by test rig capacity |
| **T5** | 249 | 217 | opb | shear failure in chord saddle |
| **T7** | 63 | 51 | opb | shear failure in chord saddle |
| **T9** | 512 | 465 | opb | brace buckling |
| **DT2** | 425 | 370 | opb | shear failure in chord saddle |
| **DT3** | 813 | 739 | opb | near to failure but limited by testing capacity |
| **DT4** | 97 | 78 | ipb | brace buckling |
| **DT5** | 267 | 232 | ipb | brace buckling |
| **DT6** | 613 | 557 | ipb | brace buckling |
| **DT8** | 216 | 188 | opb | shear failure in chord saddle |
| **DT9** | 402 | 365 | ipb | brace buckling |

**Table 7-38: Summary of Ultimate Load Tests**

## 7.7 Local Joint Flexibility

Local joint flexibility was calculated from data obtained with displacement transducers. These measurements were taken across the joint and give bending and axial rotations and displacements respectively. Appendix A presents the layouts of transducers utilised in measuring displacements for the T and DT specimens. Flexibilities were measured in the as-welded and grouted conditions for in-plane bending, out-of-plane bending, axial compression and axial tension load cases. Appendix C contains local bending and local axial deformation plots for all specimens. Figures 7-9 and 7-10 present typical local bending and local axial deformation plots respectively.

For all specimens, the grout significantly increases the rotational stiffness at the joint for in-plane bending. The relative stiffness increases as $\gamma$ increases. As expected, the grout has little or no effect on the rotational stiffness of the $\beta = 1.0$ DT joints for out-of-plane bending. There is also little or no effect on the axial stiffness for this joint type under axial tension and compression. The presence of grout significantly increases the stiffness of the T joint specimens for all loading modes.

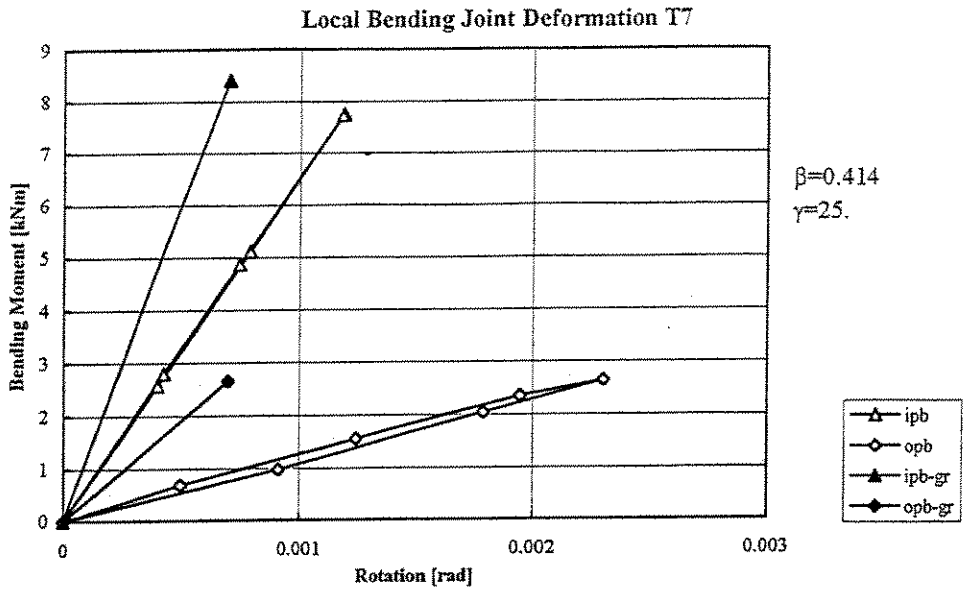


**Figure 7-9: Typical local bending joint flexibility plot**

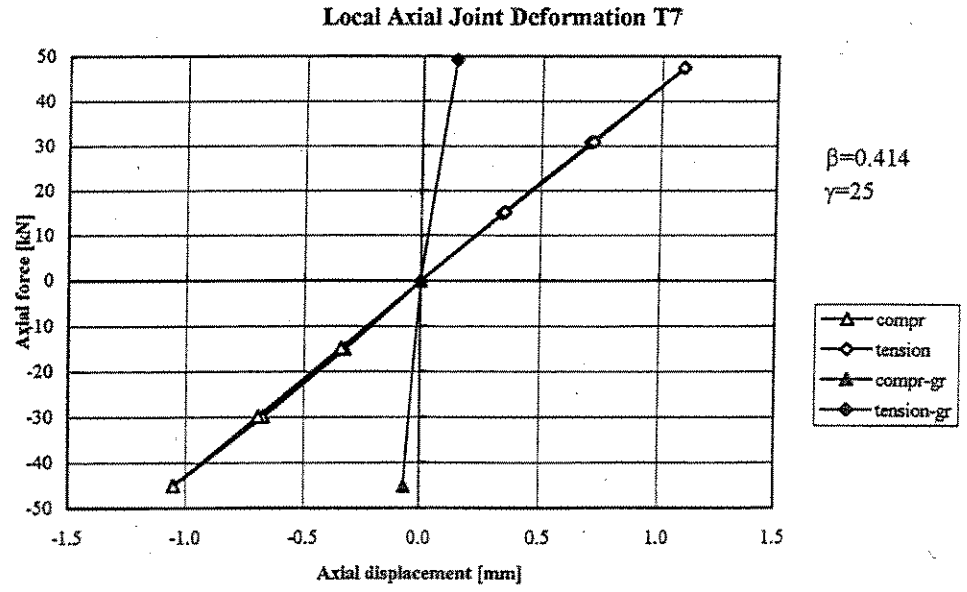


**Figure 7-10: Typical local axial joint flexibility plot**

# 8. ANALYSIS OF TEST RESULTS

## 8.1 General

This section presents comparisons between measured as-welded SCFs and predicted as-welded SCFs and the findings of studies conducted on the development of formulations to predict SCF Reduction Factors (RFs), i.e. the ratio of grouted SCF to as-welded SCF. The as-welded predicted SCFs were derived using Efthymiou[15] and Lloyds[5] parametric equations. Appendix E contains the development of formulations, using the measured as-welded and measured grouted SNCs (inferred from measured SNCFs), to predict the RF for each joint and load type for both the chord and brace side of the weld. Appendix E also contains the development of formulations using Efthymiou predicted as-welded and measured grouted SNCs, to predict the RF for each joint and load type.

## 8.2 As-welded SCFs

Results presented in Section 7.3 indicate comparable values between the tension side and compression side SNCFs under in-plane bending and out-of-plane bending load. This is observed for the chord side and brace side SNCFs and is consistent for both the T-joint specimens and DT-joint specimens.

The results presented in Table 8-1 generally demonstrate good correlation between the measured and predicted as-welded SCFs. The predicted as-welded SCFs were derived using the Efthymiou parametric equations and Lloyd's parametric equations, which were typically to within 15% of the measured as-welded SCFs.

A detailed examination of the results presented in Table 8-1 reveals that the SCF predictions perform better for the chord side locations. The SCF predictions perform equally well for the DT-joint and T-joint specimens. Generally, the chord side as-welded SCF is higher than the brace side as-welded SCF and therefore, the accuracy of predicted as-welded SCFs is more critical for the chord side. Table 8-2 presents the ratios between measured as-welded SCFs and predicted SCFs.

The variation between measured and predicted as-welded SCFs can be attributed to a number of factors. The most likely cause for variation can be assigned to the size and profile of the weld. This is particularly true at the saddle location for the axial and out-of-plane bending loading conditions as may be inferred from the results.

The Efthymiou equations used for the derivation of as-welded SCFs perform well and recognising that these equations represent the most popular and preferred set by the offshore industry, it is recommended that the Efthymiou equations are adopted.

| Specimen Ident. | D (mm) | d (mm) | T (mm) | t (mm) | L (mm) | θ (°) | β | β (Modified) | γ | τ | α | Source | Chord SCFs | | | | | | Brace SCFs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | IPB Crown | OPB Saddle | Comp. Ax-s | Comp. Ax-c | Tens. Ax-s | Tens. Ax-c | IPB Crown | OPB Saddle | Comp. Ax-s | Comp. Ax-c | Tens. Ax-s | Tens. Ax-c |
| T1 | 406.78 | 167.81 | 16.39 | 16.32 | 2440 | 90.0 | 0.413 | 0.413 | 12.409 | 0.996 | 12.00 | Efthymiou | 3.65 | 8.29 | 13.28 | 6.06 | 13.28 | 6.06 | 2.87 | 5.85 | 8.37 | 3.08 | 8.37 | 3.08 |
| | | | | | | | | | | | | Lloyds | 3.07 | 7.08 | 10.92 | 6.61 | 10.92 | 6.61 | 1.89 | 3.91 | 6.12 | 1.85 | 6.12 | 1.85 |
| | | | | | | | | | | | | Measured | 2.93 | 7.30 | 11.23 | 6.95 | 10.43 | 6.42 | 1.61 | 3.70 | 6.47 | 0.30 | 5.95 | 0.29 |
| T3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.000 | 0.961 | 12.409 | 0.982 | 12.00 | Efthymiou | 3.20 | 7.92 | 5.10 | 8.25 | 5.10 | 8.25 | 2.44 | 4.23 | 3.46 | 3.53 | 3.46 | 3.53 |
| | | | | | | | | | | | | Lloyds | 2.69 | 6.82 | 3.85 | 7.42 | 3.85 | 7.42 | 1.62 | 3.67 | 3.20 | 1.57 | 3.20 | 1.57 |
| | | | | | | | | | | | | Measured | 3.37 | 8.41 | 3.54 | 10.27 | 3.26 | 10.21 | 1.38 | 5.77 | 5.15 | 2.48 | 5.21 | 2.50 |
| T5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 0.672 | 19.973 | 0.964 | 11.99 | Efthymiou | 4.80 | 17.86 | 19.97 | 6.59 | 19.97 | 6.59 | 3.39 | 10.84 | 11.84 | 2.62 | 11.84 | 2.62 |
| | | | | | | | | | | | | Lloyds | 4.05 | 16.33 | 18.28 | 7.08 | 18.28 | 7.08 | 2.58 | 8.82 | 10.34 | 1.80 | 10.34 | 1.80 |
| | | | | | | | | | | | | Measured | 4.36 | 16.86 | 21.35 | 10.30 | 21.16 | 9.62 | 1.82 | 9.26 | 13.16 | 1.32 | 13.00 | 1.21 |
| T7 | 406.96 | 168.41 | 7.86 | 8.31 | 2440 | 90.0 | 0.414 | 0.414 | 25.888 | 1.057 | 11.99 | Efthymiou | 6.52 | 18.41 | 29.62 | 7.25 | 29.62 | 7.25 | 4.38 | 12.11 | 16.53 | 2.52 | 16.53 | 2.52 |
| | | | | | | | | | | | | Lloyds | 5.47 | 15.72 | 28.06 | 7.67 | 28.06 | 7.67 | 2.88 | 8.87 | 14.83 | 1.98 | 14.83 | 1.98 |
| | | | | | | | | | | | | Measured | 5.69 | 21.17 | 33.31 | 10.20 | 31.09 | 9.59 | 1.99 | 7.96 | 12.55 | 1.14 | 12.44 | 1.16 |
| T9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 0.981 | 25.888 | 1.000 | 11.99 | Efthymiou | 4.11 | 16.83 | 10.84 | 9.25 | 10.84 | 9.25 | 2.84 | 8.58 | 5.85 | 2.62 | 5.85 | 2.62 |
| | | | | | | | | | | | | Lloyds | 3.46 | 12.51 | 7.71 | 7.57 | 7.71 | 7.57 | 2.29 | 6.96 | 5.95 | 1.36 | 5.95 | 1.36 |
| | | | | | | | | | | | | Measured | 3.22 | 19.38 | 14.53 | 9.30 | 13.94 | 8.99 | 1.68 | 8.44 | 8.53 | 2.62 | 8.26 | 2.58 |
| DT2 | 406.78 | 273.09 | 16.39 | 15.76 | 2440 | 90.0 | 0.671 | 0.671 | 12.409 | 0.962 | 12.00 | Efthymiou | 3.70 | 10.32 | 18.97 | 2.28 | 18.97 | 2.28 | 2.82 | 6.42 | 10.40 | 2.35 | 10.40 | 2.35 |
| | | | | | | | | | | | | Lloyds | 2.89 | 7.65 | 14.14 | 1.29 | 14.14 | 1.29 | 2.23 | 4.78 | 9.48 | 1.45 | 9.48 | 1.45 |
| | | | | | | | | | | | | Measured | 3.98 | 8.08 | 15.73 | 2.08 | 15.92 | 2.11 | 1.81 | 5.44 | 10.96 | 0.06 | 11.11 | 0.08 |
| DT3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.001 | 0.961 | 12.409 | 0.982 | 12.00 | Efthymiou | 3.20 | 2.64 | 4.67 | 2.36 | 4.67 | 2.36 | 2.44 | 1.41 | 3.08 | 2.35 | 3.08 | 2.35 |
| | | | | | | | | | | | | Lloyds | 2.36 | 2.45 | 4.19 | 0.55 | 4.19 | 0.55 | 1.86 | 2.07 | 3.52 | 1.32 | 3.52 | 1.32 |
| | | | | | | | | | | | | Measured | 2.88 | 3.10 | 4.07 | 0.78 | 4.06 | 0.79 | 1.43 | 2.53 | 4.31 | 0.86 | 4.24 | 0.86 |
| DT4 | 407.05 | 168.57 | 10.19 | 9.95 | 2440 | 90.0 | 0.414 | 0.414 | 19.973 | 0.976 | 11.99 | Efthymiou | 5.06 | 12.28 | 27.99 | 3.99 | 27.99 | 3.99 | 3.68 | 8.54 | 15.70 | 2.27 | 15.70 | 2.27 |
| | | | | | | | | | | | | Lloyds | 4.15 | 11.65 | 24.19 | 2.88 | 24.19 | 2.88 | 2.76 | 7.38 | 15.52 | 1.84 | 15.52 | 1.84 |
| | | | | | | | | | | | | Measured | 5.14 | 11.81 | 31.52 | 4.38 | 31.37 | 4.44 | 2.64 | 4.74 | 13.27 | 1.07 | 13.50 | 1.23 |
| DT5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 0.672 | 19.973 | 0.964 | 11.99 | Efthymiou | 4.80 | 16.64 | 30.60 | 2.71 | 30.60 | 2.71 | 3.39 | 10.09 | 16.15 | 1.84 | 16.15 | 1.84 |
| | | | | | | | | | | | | Lloyds | 3.88 | 14.23 | 26.30 | 1.06 | 26.30 | 1.06 | 2.98 | 8.74 | 16.78 | 1.45 | 16.78 | 1.45 |
| | | | | | | | | | | | | Measured | 6.06 | 18.20 | 35.92 | 4.12 | 35.72 | 4.54 | 1.97 | 9.07 | 19.01 | 0.08 | 18.60 | 0.06 |
| DT6 | 407.05 | 407.60 | 10.19 | 9.61 | 2440 | 90.0 | 1.001 | 0.976 | 19.973 | 0.943 | 11.99 | Efthymiou | 3.59 | 4.01 | 7.12 | 2.78 | 7.12 | 2.78 | 2.65 | 2.14 | 4.24 | 1.84 | 4.24 | 1.84 |
| | | | | | | | | | | | | Lloyds | 2.89 | 3.22 | 5.65 | 0.45 | 5.65 | 0.45 | 2.33 | 2.46 | 4.39 | 1.31 | 4.39 | 1.31 |
| | | | | | | | | | | | | Measured | 3.10 | 5.18 | 8.53 | 0.61 | 7.94 | 0.62 | 1.62 | 2.89 | 5.24 | 1.12 | 5.00 | 1.18 |
| DT8 | 406.96 | 273.21 | 7.86 | 7.88 | 2440 | 90.0 | 0.671 | 0.671 | 25.888 | 1.003 | 11.99 | Efthymiou | 5.72 | 22.44 | 41.26 | 3.08 | 41.26 | 3.08 | 3.82 | 13.15 | 21.03 | 1.42 | 21.03 | 1.42 |
| | | | | | | | | | | | | Lloyds | 4.69 | 20.74 | 38.34 | 0.95 | 38.34 | 0.95 | 3.65 | 12.88 | 24.00 | 1.46 | 24.00 | 1.46 |
| | | | | | | | | | | | | Measured | 4.79 | 21.59 | 43.92 | 1.70 | 44.39 | 1.58 | 1.92 | 10.46 | 21.53 | 0.50 | 21.70 | 0.52 |
| DT9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 0.981 | 25.888 | 1.000 | 11.99 | Efthymiou | 4.11 | 5.70 | 10.02 | 3.25 | 10.02 | 3.25 | 2.84 | 2.90 | 5.43 | 1.42 | 5.43 | 1.42 |
| | | | | | | | | | | | | Lloyds | 3.46 | 4.31 | 7.64 | 0.42 | 7.64 | 0.42 | 2.81 | 3.00 | 5.58 | 1.31 | 5.58 | 1.31 |
| | | | | | | | | | | | | Measured | 3.47 | 6.90 | 10.16 | 0.72 | 9.98 | 0.74 | 1.64 | 2.71 | 4.45 | 1.25 | 4.25 | 1.26 |

Note :- Assumed Stress/Strain relationship = 1.2

**Table 8-1: Summary of as-welded SCFs**

| Specimen Ident. | D (mm) | d (mm) | T (mm) | t (mm) | L (mm) | θ (°) | β | β (Modified) | γ | τ | α | Source | Chord SCFs | | | | | | Brace SCFs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | IPB Crown | OPB Saddle | Comp. Ax-s | Comp. Ax-c | Tens. Ax-s | Tens. Ax-c | IPB Crown | OPB Saddle | Comp. Ax-s | Comp. Ax-c | Tens. Ax-s | Tens. Ax-c |
| T1 | 406.78 | 167.81 | 16.39 | 16.32 | 2440 | 90.0 | 0.413 | 0.413 | 12.409 | 0.996 | 12.00 | Efthy/Meas | 1.25 | 1.14 | 1.18 | 0.87 | 1.27 | 0.94 | 1.79 | 1.58 | 1.29 | 10.27 | 1.41 | 10.70 |
| | | | | | | | | | | | | Lloyds/Meas | 1.05 | 0.97 | 0.97 | 0.95 | 1.05 | 1.03 | 1.17 | 1.06 | 0.95 | 6.17 | 1.03 | 6.43 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.19 | 1.17 | 1.22 | 0.92 | 1.22 | 0.92 | 1.52 | 1.50 | 1.37 | 1.66 | 1.37 | 1.66 |
| T3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.000 | 0.961 | 12.409 | 0.982 | 12.00 | Efthy/Meas | 0.95 | 0.94 | 1.44 | 0.80 | 1.56 | 0.81 | 1.77 | 0.73 | 0.67 | 1.42 | 0.66 | 1.41 |
| | | | | | | | | | | | | Lloyds/Meas | 0.80 | 0.81 | 1.09 | 0.72 | 1.18 | 0.73 | 1.17 | 0.64 | 0.62 | 0.63 | 0.61 | 0.63 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.19 | 1.16 | 1.32 | 1.11 | 1.32 | 1.11 | 1.51 | 1.15 | 1.08 | 2.24 | 1.08 | 2.24 |
| T5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 0.672 | 19.973 | 0.964 | 11.99 | Efthy/Meas | 1.10 | 1.06 | 0.94 | 0.64 | 0.94 | 0.68 | 1.86 | 1.17 | 0.90 | 1.98 | 0.91 | 2.16 |
| | | | | | | | | | | | | Lloyds/Meas | 0.93 | 0.97 | 0.86 | 0.69 | 0.86 | 0.74 | 1.42 | 0.95 | 0.79 | 1.37 | 0.80 | 1.49 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.19 | 1.09 | 1.09 | 0.93 | 1.09 | 0.93 | 1.31 | 1.23 | 1.15 | 1.45 | 1.15 | 1.45 |
| T7 | 406.96 | 168.41 | 7.86 | 8.31 | 2440 | 90.0 | 0.414 | 0.414 | 25.888 | 1.057 | 11.99 | Efthy/Meas | 1.15 | 0.87 | 0.89 | 0.71 | 0.95 | 0.76 | 2.20 | 1.52 | 1.32 | 2.21 | 1.33 | 2.17 |
| | | | | | | | | | | | | Lloyds/Meas | 0.96 | 0.74 | 0.84 | 0.75 | 0.90 | 0.80 | 1.44 | 1.11 | 1.18 | 1.74 | 1.19 | 1.71 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.19 | 1.17 | 1.06 | 0.95 | 1.06 | 0.95 | 1.52 | 1.37 | 1.11 | 1.27 | 1.11 | 1.27 |
| T9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 0.981 | 25.888 | 1.000 | 11.99 | Efthy/Meas | 1.28 | 0.87 | 0.75 | 0.99 | 0.78 | 1.03 | 1.69 | 1.02 | 0.69 | 1.00 | 0.71 | 1.02 |
| | | | | | | | | | | | | Lloyds/Meas | 1.07 | 0.65 | 0.53 | 0.81 | 0.55 | 0.84 | 1.37 | 0.83 | 0.70 | 0.52 | 0.72 | 0.53 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.19 | 1.35 | 1.41 | 1.22 | 1.41 | 1.22 | 1.24 | 1.23 | 0.98 | 1.93 | 0.98 | 1.93 |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| DT2 | 406.78 | 273.09 | 16.39 | 15.76 | 2440 | 90.0 | 0.671 | 0.671 | 12.409 | 0.962 | 12.00 | Efthy/Meas | 0.93 | 1.28 | 1.21 | 1.10 | 1.19 | 1.08 | 1.56 | 1.18 | 0.95 | 39.10 | 0.94 | 27.93 |
| | | | | | | | | | | | | Lloyds/Meas | 0.73 | 0.95 | 0.90 | 0.62 | 0.89 | 0.61 | 1.23 | 0.88 | 0.87 | 24.11 | 0.85 | 17.22 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.28 | 1.35 | 1.34 | 1.77 | 1.34 | 1.77 | 1.26 | 1.34 | 1.10 | 1.62 | 1.10 | 1.62 |
| DT3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.001 | 0.961 | 12.409 | 0.982 | 12.00 | Efthy/Meas | 1.11 | 0.85 | 1.15 | 3.02 | 1.15 | 2.98 | 1.71 | 0.56 | 0.72 | 2.72 | 0.73 | 2.72 |
| | | | | | | | | | | | | Lloyds/Meas | 0.82 | 0.79 | 1.03 | 0.71 | 1.03 | 0.70 | 1.30 | 0.82 | 0.82 | 1.53 | 0.83 | 1.53 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.35 | 1.08 | 1.11 | 4.26 | 1.11 | 4.26 | 1.32 | 0.68 | 0.88 | 1.78 | 0.88 | 1.78 |
| DT4 | 407.05 | 168.57 | 10.19 | 9.95 | 2440 | 90.0 | 0.414 | 0.414 | 19.973 | 0.976 | 11.99 | Efthy/Meas | 0.98 | 1.04 | 0.89 | 0.91 | 0.89 | 0.90 | 1.40 | 1.80 | 1.18 | 2.12 | 1.16 | 1.84 |
| | | | | | | | | | | | | Lloyds/Meas | 0.81 | 0.99 | 0.77 | 0.66 | 0.77 | 0.65 | 1.04 | 1.56 | 1.17 | 1.72 | 1.15 | 1.50 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.22 | 1.05 | 1.16 | 1.39 | 1.16 | 1.39 | 1.34 | 1.16 | 1.01 | 1.23 | 1.01 | 1.23 |
| DT5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 0.672 | 19.973 | 0.964 | 11.99 | Efthy/Meas | 0.79 | 0.91 | 0.85 | 0.66 | 0.86 | 0.60 | 1.72 | 1.11 | 0.85 | 21.93 | 0.87 | 30.70 |
| | | | | | | | | | | | | Lloyds/Meas | 0.64 | 0.78 | 0.73 | 0.26 | 0.74 | 0.23 | 1.51 | 0.96 | 0.88 | 17.31 | 0.90 | 24.23 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.24 | 1.17 | 1.16 | 2.56 | 1.16 | 2.56 | 1.14 | 1.16 | 0.96 | 1.27 | 0.96 | 1.27 |
| DT6 | 407.05 | 407.60 | 10.19 | 9.61 | 2440 | 90.0 | 1.001 | 0.976 | 19.973 | 0.943 | 11.99 | Efthy/Meas | 1.16 | 0.77 | 0.83 | 4.53 | 0.90 | 4.45 | 1.64 | 0.74 | 0.81 | 1.65 | 0.85 | 1.57 |
| | | | | | | | | | | | | Lloyds/Meas | 0.93 | 0.62 | 0.66 | 0.74 | 0.71 | 0.72 | 1.44 | 0.85 | 0.84 | 1.18 | 0.88 | 1.12 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.24 | 1.25 | 1.26 | 6.15 | 1.26 | 6.15 | 1.14 | 0.87 | 0.97 | 1.41 | 0.97 | 1.41 |
| DT8 | 406.96 | 273.21 | 7.86 | 7.88 | 2440 | 90.0 | 0.671 | 0.671 | 25.888 | 1.003 | 11.99 | Efthy/Meas | 1.19 | 1.04 | 0.94 | 1.81 | 0.93 | 1.94 | 1.99 | 1.26 | 0.98 | 2.82 | 0.97 | 2.75 |
| | | | | | | | | | | | | Lloyds/Meas | 0.98 | 0.96 | 0.87 | 0.56 | 0.86 | 0.60 | 1.90 | 1.23 | 1.11 | 2.89 | 1.11 | 2.82 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.22 | 1.08 | 1.08 | 3.24 | 1.08 | 3.24 | 1.05 | 1.02 | 0.88 | 0.97 | 0.88 | 0.97 |
| DT9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 0.981 | 25.888 | 1.000 | 11.99 | Efthy/Meas | 1.18 | 0.83 | 0.99 | 4.52 | 1.00 | 4.37 | 1.73 | 1.07 | 1.22 | 1.14 | 1.28 | 1.13 |
| | | | | | | | | | | | | Lloyds/Meas | 1.00 | 0.62 | 0.75 | 0.58 | 0.76 | 0.56 | 1.71 | 1.11 | 1.25 | 1.05 | 1.31 | 1.04 |
| | | | | | | | | | | | | Efthy/Lloyds | 1.19 | 1.32 | 1.31 | 7.75 | 1.31 | 7.75 | 1.01 | 0.97 | 0.97 | 1.09 | 0.97 | 1.09 |

Note :- Assumed Stress/Strain relationship = 1.2

**Table 8-2: Summary of as-welded SCF statistics**

## 8.3 Grouted SCFs

Results presented in Section 7.4 indicate a variation between the tension side and compression side grouted SNCF values under in-plane bending and out-of-plane bending load cases. The corresponding as-welded SNCF results show little difference between the tension side and compression side. The results indicate that the highest SNCF variation, i.e. between the tension side and compression side, is dependent on the specimen joint type, on which side is being considered (chord side or brace side) and on the geometric parameters $\beta$ and $\gamma$. For the majority of specimens the side which yields the highest SNCF on the chord is opposite to the side causing the highest SNCF on the brace, i.e. if the compression side SNCF is highest on the chord, then generally the tension side SNCF is highest on the brace. In addition, the trend remains constant, with the exception of Specimen T3, throughout the SNCF measurement/preload regime applied to each specimen, i.e. regardless of load history the dominant SNCF remains on the same side for in-plane and out-of-plane bending.

The results indicate that the presence of grout enhances the stiffness of the chord wall under compressive loading at the crown location. On the compression side of in-plane bending and under axial compression load the resultant chord side and brace side SCFs are higher than for the as-welded condition. The stiffness at the saddle location has less effect on SCFs due to the membrane action of the chord wall. Although the crown SCFs increase from the as-welded condition to the grouted condition, the saddle SCFs generally remain dominant for the DT-joint specimens. It is therefore concluded that the grouting of the DT-joint will reduce the dominant SCF and therefore increase fatigue resistance.

The grouted SCFs are similar to the as-welded SCFs at the crown location for the T-joint specimen. Given that the crown SCF is dominant in the grouted condition and in some instances greater than the dominant saddle SCF in the as-welded condition, it is concluded that grouting of the T-joint may reduce fatigue resistance. This observation is based on the test results obtained for Specimen T3.

Table 8-3 presents a summary of measured grouted SCF results. The table contains measured SCFs for both the chord and brace side in all four loading conditions. Table 8-3 also contains the derived grouted SCFs derived using the RF formulations discussed in Section 8.4.

## 8.4 RF Determination

The results presented in Table 8-4 demonstrate good correlation between the measured RFs and those derived using the developed formulations, as presented in Appendix E.

| Specimen Ident. | D (mm) | d (mm) | T (mm) | $T_c$ (mm) | t (mm) | L (mm) | θ (°) | β | γ | $\gamma_c$ Ax & OPB | $\gamma_c$ IPB | τ | α | Condition | Chord SCFs IPB | Chord SCFs OPB | Chord SCFs Comp. Ax-s | Chord SCFs Comp. Ax-c | Chord SCFs Tens. Ax-s | Chord SCFs Tens. Ax-c | Brace SCFs IPB | Brace SCFs OPB | Brace SCFs Comp. Ax-s | Brace SCFs Comp. Ax-c | Brace SCFs tens. Ax-s | Brace SCFs tens. Ax-c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 406.78 | 167.81 | 16.39 | 29.4 | 16.32 | 2440 | 90.0 | 0.413 | 12.409 | 6.92 | 11.71 | 0.996 | 12.00 | Measured formulations | 2.93 | 5.20 | 6.19 | 6.83 | 5.53 | 5.81 | 1.73 | 3.28 | 3.41 | 1.36 | 3.87 | 1.10 |
| | | | | | | | | | | | | | | Efthymiou based | 2.83 | 5.19 | 6.27 | 7.05 | 5.69 | 5.75 | 1.60 | 3.31 | 3.65 | 1.30 | 3.66 | 1.16 |
| | | | | | | | | | | | | | | Actual measured | 2.83 | 5.26 | 6.20 | 7.00 | 5.64 | 5.87 | 1.62 | 3.28 | 3.60 | 1.33 | 3.68 | 1.12 |
| T3 | 406.78 | 407.02 | 16.39 | 29.4 | 16.10 | 2440 | 90.0 | 1.000 | 12.409 | 6.92 | 11.71 | 0.982 | 12.00 | Measured formulations | 3.17 | 2.27 | 0.33 | 10.79 | 0.82 | 11.50 | 1.55 | 1.89 | 1.46 | 2.96 | 1.56 | 2.76 |
| | | | | | | | | | | | | | | Efthymiou based | 3.20 | 2.20 | 0.36 | 10.74 | 0.85 | 11.20 | 1.51 | 1.92 | 1.54 | 2.95 | 1.63 | 2.76 |
| | | | | | | | | | | | | | | Actual measured | 3.10 | 2.26 | 0.34 | 10.68 | 0.80 | 11.34 | 1.52 | 1.88 | 1.56 | 2.89 | 1.60 | 2.69 |
| T5 | 407.05 | 273.34 | 10.19 | 23.6 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 8.62 | 18.36 | 0.964 | 11.99 | Measured formulations | 3.81 | 6.19 | 6.45 | 9.59 | 5.94 | 9.17 | 2.29 | 4.18 | 4.44 | 2.74 | 4.59 | 2.01 |
| | | | | | | | | | | | | | | Efthymiou based | 3.88 | 6.22 | 6.39 | 9.58 | 6.32 | 9.16 | 2.26 | 4.24 | 3.97 | 2.75 | 4.37 | 2.03 |
| | | | | | | | | | | | | | | Actual measured | 3.91 | 6.18 | 6.32 | 9.56 | 6.10 | 9.13 | 2.26 | 4.21 | 3.95 | 2.74 | 4.36 | 2.03 |
| T7 | 406.96 | 168.41 | 7.86 | 21.4 | 8.31 | 2440 | 90.0 | 0.414 | 25.888 | 9.49 | 23.42 | 1.057 | 11.99 | Measured formulations | 3.90 | 10.07 | 7.06 | 6.00 | 14.05 | 6.63 | 2.41 | 5.90 | 3.35 | 1.57 | 6.12 | 1.25 |
| | | | | | | | | | | | | | | Efthymiou based | 3.81 | 10.09 | 6.74 | 5.90 | 14.74 | 6.80 | 2.39 | 5.93 | 3.32 | 1.56 | 5.81 | 1.29 |
| | | | | | | | | | | | | | | Actual measured | 3.95 | 10.21 | 6.84 | 5.93 | 14.50 | 6.77 | 2.42 | 5.88 | 3.32 | 1.58 | 5.93 | 1.31 |
| T9 | 406.96 | 406.96 | 7.86 | 21.4 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 9.49 | 23.42 | 1.000 | 11.99 | Measured formulations | 3.02 | 5.32 | 3.33 | 9.77 | 3.49 | 8.91 | 2.11 | 2.20 | 3.57 | 3.11 | 2.48 | 2.51 |
| | | | | | | | | | | | | | | Efthymiou based | 3.01 | 5.35 | 3.25 | 9.55 | 3.41 | 8.82 | 2.07 | 2.16 | 3.07 | 3.32 | 2.43 | 2.41 |
| | | | | | | | | | | | | | | Actual measured | 3.05 | 5.32 | 3.26 | 9.60 | 3.35 | 8.81 | 2.09 | 2.17 | 3.03 | 3.24 | 2.39 | 2.43 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DT2 | 406.78 | 273.09 | 16.39 | 29.4 | 15.76 | 2440 | 90.0 | 0.671 | 12.409 | 6.92 | 11.71 | 0.962 | 12.00 | Measured formulations | 2.97 | 5.21 | 5.73 | 3.34 | 6.00 | 2.05 | 2.46 | 3.93 | 3.79 | 0.26 | 4.64 | 0.12 |
| | | | | | | | | | | | | | | Efthymiou based | 3.28 | 5.92 | 5.90 | 2.94 | 6.90 | 2.00 | 2.52 | 4.04 | 3.83 | 2.07 | 4.53 | 0.88 |
| | | | | | | | | | | | | | | Actual measured | 3.16 | 5.32 | 6.08 | 3.26 | 6.20 | 2.02 | 2.50 | 4.03 | 3.74 | 2.00 | 4.51 | 0.88 |
| DT3 | 406.78 | 407.02 | 16.39 | 29.4 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 6.92 | 11.71 | 0.982 | 12.00 | Measured formulations | 1.95 | 3.06 | 3.75 | 1.49 | 4.14 | 1.11 | 2.36 | 2.57 | 4.05 | 1.15 | 3.80 | 1.00 |
| | | | | | | | | | | | | | | Efthymiou based | 1.90 | 3.17 | 4.74 | 1.68 | 4.48 | 1.51 | 2.40 | 2.56 | 4.14 | 1.07 | 3.48 | 0.96 |
| | | | | | | | | | | | | | | Actual measured | 1.93 | 3.01 | 3.86 | 1.45 | 4.14 | 1.02 | 2.29 | 2.44 | 3.89 | 1.07 | 3.34 | 0.96 |
| DT4 | 407.05 | 168.57 | 10.19 | 23.6 | 9.95 | 2440 | 90.0 | 0.414 | 19.973 | 8.62 | 18.36 | 0.976 | 11.99 | Measured formulations | 2.91 | 6.55 | 3.77 | 3.26 | 8.84 | 2.49 | 3.53 | 3.93 | 2.05 | 2.56 | 4.13 | 1.31 |
| | | | | | | | | | | | | | | Efthymiou based | 2.92 | 6.78 | 3.95 | 3.36 | 8.61 | 3.21 | 3.68 | 4.00 | 2.03 | 2.38 | 3.96 | 1.24 |
| | | | | | | | | | | | | | | Actual measured | 2.94 | 6.55 | 3.91 | 3.12 | 8.33 | 2.52 | 3.58 | 4.02 | 2.11 | 2.39 | 4.13 | 1.24 |
| DT5 | 407.05 | 273.34 | 10.19 | 23.6 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 8.62 | 18.36 | 0.964 | 11.99 | Measured formulations | 3.60 | 9.26 | 9.99 | 6.89 | 11.15 | 5.55 | 2.77 | 5.20 | 4.68 | 0.36 | 6.32 | 0.07 |
| | | | | | | | | | | | | | | Efthymiou based | 3.06 | 8.30 | 9.29 | 2.32 | 10.76 | 1.48 | 2.77 | 4.96 | 4.26 | 2.14 | 6.46 | 0.92 |
| | | | | | | | | | | | | | | Actual measured | 3.30 | 8.59 | 8.96 | 1.98 | 11.59 | 0.74 | 2.76 | 4.90 | 4.33 | 2.32 | 6.36 | 0.96 |
| DT6 | 407.05 | 407.60 | 10.19 | 23.6 | 9.61 | 2440 | 90.0 | 1.001 | 19.973 | 8.62 | 18.36 | 0.943 | 11.99 | Measured formulations | 1.86 | 4.94 | 8.22 | 1.78 | 6.62 | 1.11 | 2.68 | 2.73 | 4.95 | 1.80 | 3.37 | 1.11 |
| | | | | | | | | | | | | | | Efthymiou based | 1.87 | 4.83 | 7.15 | 1.80 | 5.94 | 1.14 | 2.60 | 2.69 | 4.43 | 1.76 | 3.92 | 1.31 |
| | | | | | | | | | | | | | | Actual measured | 1.93 | 5.04 | 7.61 | 1.79 | 6.46 | 1.31 | 2.84 | 2.89 | 4.80 | 1.58 | 3.95 | 1.28 |
| DT8 | 406.96 | 273.21 | 7.86 | 21.4 | 7.88 | 2440 | 90.0 | 0.671 | 25.888 | 9.49 | 23.42 | 1.003 | 11.99 | Measured formulations | 2.28 | 8.67 | 9.25 | 2.94 | 11.59 | 2.25 | 2.78 | 4.77 | 3.63 | 2.10 | 6.04 | 0.64 |
| | | | | | | | | | | | | | | Efthymiou based | 2.52 | 9.89 | 12.27 | 2.82 | 14.12 | 1.87 | 2.90 | 5.05 | 3.84 | 2.07 | 6.54 | 0.74 |
| | | | | | | | | | | | | | | Actual measured | 2.35 | 9.00 | 8.72 | 2.86 | 12.60 | 2.32 | 2.76 | 5.10 | 3.88 | 1.93 | 6.43 | 0.72 |
| DT9 | 406.96 | 406.96 | 7.86 | 21.4 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 9.49 | 23.42 | 1.000 | 11.99 | Measured formulations | 1.88 | 6.35 | 10.06 | 2.64 | 6.82 | 1.54 | 2.71 | 2.39 | 4.18 | 2.34 | 2.10 | 1.30 |
| | | | | | | | | | | | | | | Efthymiou based | 1.89 | 6.83 | 9.90 | 3.25 | 7.31 | 1.79 | 2.78 | 2.36 | 4.37 | 2.03 | 2.02 | 1.23 |
| | | | | | | | | | | | | | | Actual measured | 1.82 | 6.42 | 10.15 | 2.54 | 6.84 | 1.34 | 2.57 | 2.29 | 4.20 | 2.18 | 1.98 | 1.24 |

Note :- Assumed Stress/Strain relationship = 1.2
Measured formulations based on RFs derived using measured grouted SNCF/measured as-welded SNCF
Efthymiou based formulations using measured grouted SCF/Efthymiou as-welded SCF

**Table 8-3: Summary of grouted SCFs**

| Specimen Ident. | D (mm) | d (mm) | T (mm) | $T_c$ (mm) | t (mm) | L (mm) | θ (°) | β | γ | $\gamma_c$ Ax & OPB | $\gamma_c$ IPB | τ | α | Condition | Chord SCFs IPB | Chord SCFs OPB | Chord SCFs Comp. Ax-s | Chord SCFs Comp. Ax-c | Chord SCFs Tens. Ax-s | Chord SCFs Tens. Ax-c | Brace SCFs IPB | Brace SCFs OPB | Brace SCFs Comp. Ax-s | Brace SCFs Comp. Ax-c | Brace SCFs Tens. Ax-s | Brace SCFs Tens. Ax-c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 406.78 | 167.81 | 16.39 | 29.4 | 16.32 | 2440 | 90.0 | 0.413 | 12.409 | 6.92 | 11.71 | 0.996 | 12.00 | Measured formulations | 1.00 | 0.71 | 0.55 | 0.98 | 0.53 | 0.91 | 1.07 | 0.89 | 0.53 | 4.53 | 0.65 | 3.82 |
| | | | | | | | | | | | | | | Efthymiou based | 0.78 | 0.63 | 0.47 | 1.16 | 0.43 | 0.95 | 0.56 | 0.57 | 0.44 | 0.42 | 0.44 | 0.38 |
| | | | | | | | | | | | | | | Actual measured | 0.97 | 0.72 | 0.55 | 1.01 | 0.54 | 0.91 | 1.01 | 0.89 | 0.56 | 4.43 | 0.62 | 3.89 |
| T3 | 406.78 | 407.02 | 16.39 | 29.4 | 16.10 | 2440 | 90.0 | 1.000 | 12.409 | 6.92 | 11.71 | 0.982 | 12.00 | Measured formulations | 0.94 | 0.27 | 0.09 | 1.05 | 0.25 | 1.13 | 1.12 | 0.33 | 0.28 | 1.19 | 0.30 | 1.11 |
| | | | | | | | | | | | | | | Efthymiou based | 1.00 | 0.28 | 0.07 | 1.30 | 0.17 | 1.36 | 0.62 | 0.45 | 0.44 | 0.84 | 0.47 | 0.78 |
| | | | | | | | | | | | | | | Actual measured | 0.92 | 0.27 | 0.09 | 1.04 | 0.25 | 1.11 | 1.10 | 0.33 | 0.30 | 1.16 | 0.31 | 1.08 |
| T5 | 407.05 | 273.34 | 10.19 | 23.6 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 8.62 | 18.36 | 0.964 | 11.99 | Measured formulations | 0.87 | 0.37 | 0.30 | 0.93 | 0.28 | 0.95 | 1.26 | 0.45 | 0.34 | 2.07 | 0.35 | 1.65 |
| | | | | | | | | | | | | | | Efthymiou based | 0.81 | 0.35 | 0.32 | 1.45 | 0.32 | 1.39 | 0.67 | 0.39 | 0.33 | 1.05 | 0.37 | 0.78 |
| | | | | | | | | | | | | | | Actual measured | 0.90 | 0.37 | 0.30 | 0.93 | 0.29 | 0.95 | 1.24 | 0.45 | 0.30 | 2.07 | 0.34 | 1.67 |
| T7 | 406.96 | 168.41 | 7.86 | 21.4 | 8.31 | 2440 | 90.0 | 0.414 | 25.888 | 9.49 | 23.42 | 1.057 | 11.99 | Measured formulations | 0.68 | 0.48 | 0.21 | 0.59 | 0.45 | 0.69 | 1.21 | 0.74 | 0.27 | 1.37 | 0.49 | 1.08 |
| | | | | | | | | | | | | | | Efthymiou based | 0.58 | 0.55 | 0.23 | 0.81 | 0.50 | 0.94 | 0.55 | 0.49 | 0.20 | 0.62 | 0.35 | 0.51 |
| | | | | | | | | | | | | | | Actual measured | 0.69 | 0.48 | 0.21 | 0.58 | 0.47 | 0.71 | 1.22 | 0.74 | 0.26 | 1.39 | 0.48 | 1.13 |
| T9 | 406.96 | 406.96 | 7.86 | 21.4 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 9.49 | 23.42 | 1.000 | 11.99 | Measured formulations | 0.94 | 0.27 | 0.23 | 1.05 | 0.25 | 0.99 | 1.26 | 0.26 | 0.42 | 1.19 | 0.30 | 0.97 |
| | | | | | | | | | | | | | | Efthymiou based | 0.73 | 0.32 | 0.30 | 1.03 | 0.31 | 0.95 | 0.73 | 0.25 | 0.53 | 1.27 | 0.42 | 0.92 |
| | | | | | | | | | | | | | | Actual measured | 0.95 | 0.27 | 0.22 | 1.03 | 0.24 | 0.98 | 1.24 | 0.26 | 0.36 | 1.24 | 0.29 | 0.94 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DT2 | 406.78 | 273.09 | 16.39 | 29.4 | 15.76 | 2440 | 90.0 | 0.671 | 12.409 | 6.92 | 11.71 | 0.962 | 12.00 | Measured formulations | 0.74 | 0.65 | 0.36 | 1.61 | 0.38 | 0.97 | 1.36 | 0.72 | 0.35 | 4.34 | 0.42 | 1.47 |
| | | | | | | | | | | | | | | Efthymiou based | 0.89 | 0.57 | 0.31 | 1.29 | 0.36 | 0.87 | 0.89 | 0.63 | 0.37 | 0.88 | 0.44 | 0.38 |
| | | | | | | | | | | | | | | Actual measured | 0.79 | 0.66 | 0.39 | 1.57 | 0.39 | 0.95 | 1.38 | 0.74 | 0.34 | 33.40 | 0.41 | 10.43 |
| DT3 | 406.78 | 407.02 | 16.39 | 29.4 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 6.92 | 11.71 | 0.982 | 12.00 | Measured formulations | 0.68 | 0.99 | 0.92 | 1.91 | 1.02 | 1.40 | 1.65 | 1.02 | 0.94 | 1.34 | 0.90 | 1.15 |
| | | | | | | | | | | | | | | Efthymiou based | 0.60 | 1.20 | 1.02 | 0.71 | 0.96 | 0.64 | 0.98 | 1.81 | 1.34 | 0.46 | 1.13 | 0.41 |
| | | | | | | | | | | | | | | Actual measured | 0.67 | 0.97 | 0.95 | 1.86 | 1.02 | 1.29 | 1.61 | 0.96 | 0.90 | 1.24 | 0.79 | 1.11 |
| DT4 | 407.05 | 168.57 | 10.19 | 23.6 | 9.95 | 2440 | 90.0 | 0.414 | 19.973 | 8.62 | 18.36 | 0.976 | 11.99 | Measured formulations | 0.57 | 0.55 | 0.12 | 0.74 | 0.28 | 0.56 | 1.34 | 0.83 | 0.15 | 2.39 | 0.31 | 1.06 |
| | | | | | | | | | | | | | | Efthymiou based | 0.58 | 0.55 | 0.14 | 0.84 | 0.31 | 0.80 | 1.00 | 0.47 | 0.13 | 1.05 | 0.25 | 0.55 |
| | | | | | | | | | | | | | | Actual measured | 0.57 | 0.55 | 0.12 | 0.71 | 0.27 | 0.57 | 1.35 | 0.85 | 0.16 | 2.23 | 0.31 | 1.00 |
| DT5 | 407.05 | 273.34 | 10.19 | 23.6 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 8.62 | 18.36 | 0.964 | 11.99 | Measured formulations | 0.59 | 0.51 | 0.28 | 1.67 | 0.31 | 1.22 | 1.41 | 0.57 | 0.25 | 4.24 | 0.34 | 1.20 |
| | | | | | | | | | | | | | | Efthymiou based | 0.64 | 0.50 | 0.30 | 0.85 | 0.35 | 0.55 | 0.82 | 0.49 | 0.26 | 1.16 | 0.40 | 0.50 |
| | | | | | | | | | | | | | | Actual measured | 0.54 | 0.47 | 0.25 | 0.48 | 0.32 | 0.16 | 1.40 | 0.54 | 0.23 | 27.57 | 0.34 | 16.00 |
| DT6 | 407.05 | 407.60 | 10.19 | 23.6 | 9.61 | 2440 | 90.0 | 1.001 | 19.973 | 8.62 | 18.36 | 0.943 | 11.99 | Measured formulations | 0.60 | 0.95 | 0.96 | 2.90 | 0.83 | 1.78 | 1.65 | 0.94 | 0.94 | 1.62 | 0.67 | 0.95 |
| | | | | | | | | | | | | | | Efthymiou based | 0.52 | 1.20 | 1.00 | 0.65 | 0.83 | 0.41 | 0.98 | 1.26 | 1.05 | 0.96 | 0.92 | 0.71 |
| | | | | | | | | | | | | | | Actual measured | 0.62 | 0.97 | 0.89 | 2.92 | 0.81 | 2.10 | 1.76 | 1.00 | 0.92 | 1.42 | 0.79 | 1.09 |
| DT8 | 406.96 | 273.21 | 7.86 | 21.4 | 7.88 | 2440 | 90.0 | 0.671 | 25.888 | 9.49 | 23.42 | 1.003 | 11.99 | Measured formulations | 0.48 | 0.40 | 0.21 | 1.73 | 0.26 | 1.42 | 1.45 | 0.46 | 0.17 | 4.17 | 0.28 | 1.23 |
| | | | | | | | | | | | | | | Efthymiou based | 0.44 | 0.44 | 0.30 | 0.91 | 0.34 | 0.61 | 0.76 | 0.38 | 0.18 | 1.46 | 0.31 | 0.52 |
| | | | | | | | | | | | | | | Actual measured | 0.49 | 0.42 | 0.20 | 1.68 | 0.28 | 1.46 | 1.44 | 0.49 | 0.18 | 3.83 | 0.30 | 1.40 |
| DT9 | 406.96 | 406.96 | 7.86 | 21.4 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 9.49 | 23.42 | 1.000 | 11.99 | Measured formulations | 0.54 | 0.92 | 0.99 | 3.67 | 0.68 | 2.07 | 1.65 | 0.88 | 0.94 | 1.88 | 0.49 | 1.03 |
| | | | | | | | | | | | | | | Efthymiou based | 0.46 | 1.20 | 0.99 | 1.00 | 0.73 | 0.55 | 0.98 | 0.81 | 0.80 | 1.43 | 0.37 | 0.86 |
| | | | | | | | | | | | | | | Actual measured | 0.53 | 0.93 | 1.00 | 3.53 | 0.69 | 1.81 | 1.56 | 0.85 | 0.94 | 1.75 | 0.47 | 0.98 |

Note :- Assumed Stress/Strain relationship = 1.2
Measured formulations based on RFs derived using measured grouted SNCF/measured as-welded SNCF
Efthymiou based formulations using measured grouted SCF/Efthymiou as-welded SCF

**Table 8-4: Summary of reduction factors**

The developed RF formulations are of general applicability, i.e. the SCF for a grouted joint can be estimated by the product of the predicted RF and an as-welded SCF value obtained from any one of a number of sources. The derivation of RFs using formulations developed using the measured as-welded SCFs may make use of as-welded SCFs obtained from one of the following sources.

- SCF calculated from a Finite Element analysis of the as-welded joint
- SCF measured from steel specimens
- SCF measured from photoelasticity specimens

The derivation of RFs using formulations developed using the Efthymiou derived as-welded SCFs may make use of as-welded SCFs obtained from the Efthymiou parametric equations.

8.4.1 RF for Application to As-Welded Measured SCFs

The form of the equations for the derivation of RFs to be utilised in determining grouted SCFs using measured as-welded SCFs are presented in Tables 8-5 and 8-6 for chord side and brace side respectively. The tables also contain ranges of validity.

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2$ but $RF \geq 0.10$ | | | | | | |
|---|---|---|---|---|---|---|
| **Joint Type** | **Load (Position)** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ |
| **DT** | COMP (Saddle) | 1.46 | -3.1 | -0.045 | 0.05 | 2.5 |
| | COMP (Crown)* | 4.10 | -4.0 | -0.240 | 0.37 | 0.2 |
| | TENS (Saddle) | 0.43 | -1.6 | 0.025 | -0.05 | 2.5 |
| | TENS (Crown)* | -0.92 | 3.2 | 0 | 0.05 | -1.5 |
| | IPB (Crown) | 1.28 | -0.33 | -0.040 | 0.03 | -0.15 |
| | OPB (Saddle) | 2.25 | -3.8 | -0.045 | 0.04 | 2.6 |
| **T** | COMP (Saddle) | 1.37 | -1.1 | -0.05 | 0.06 | -0.3 |
| | COMP (Crown) | 1.35 | 0.2 | -0.05 | 0.05 | -0.5 |
| | TENS (Saddle) | 1.35 | -2.3 | -0.01 | 0.01 | 1.2 |
| | TENS (Crown) | 0.75 | 1.1 | -0.02 | 0.01 | -0.6 |
| | IPB (Crown) | 1.54 | -0.6 | -0.04 | 0.04 | 0 |
| | OPB (Saddle) | 1.77 | -2.4 | -0.03 | 0.03 | 0.9 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | |

* Unduly conservative RF may be predicted at crown position for axially loaded DT joints.

**Table 8-5: Recommended formulations for reduction factors on chord side**



MSL

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2$ but $RF \geq 0.10$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Joint Type** | **Load (Position)** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
| **DT** | COMP (Saddle) | 1.64 | -3.7 | -0.04 | 0.04 | 3.0 | 0 |
| | COMP (Crown)* | -5.36 | 32.0 | -0.12 | 0.16 | -25.8 | 0 |
| | TENS (Saddle) | 0.07 | -0.30 | 0.03 | -0.06 | 1.5 | 0 |
| | TENS (Crown)* | 2.0 | 2.5 | -0.15 | 0.26 | -2.27 | 0.003 |
| | IPB (Crown) | 1.05 | -0.21 | 0.02 | -0.02 | 0.8 | 0 |
| | OPB (Saddle) | 3.04 | -5.5 | -0.04 | 0.03 | 3.6 | 0 |
| **T** | COMP (Saddle) | 1.36 | -1.6 | -0.04 | 0.05 | 0.4 | 0 |
| | COMP (Crown) | 11.84 | -10.6 | -0.40 | 0.04 | -0.05 | 0 |
| | TENS (Saddle) | 1.6 | -2.4 | -0.02 | 0.02 | 1.1 | 0 |
| | TENS (Crown) | 10.33 | -10.0 | -0.34 | 0.33 | 0.9 | 0 |
| | IPB (Crown) | 0.5 | 1.5 | 0.01 | 0 | -1.0 | 0 |
| | OPB (Saddle) | 2.09 | -3.2 | -0.015 | 0.01 | 1.5 | 0 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | | |

* Non-conservative RF may be predicted at crown position for axially loaded DT joints.

**Table 8-6: Recommended formulations for reduction factors on brace side**

8.4.2 RF for Application to As-Welded Efthymiou SCFs

The form of the equations for the derivation of RFs to be utilised in determining grouted SCFs are presented in Tables 8-7 and 8-8 for chord side and brace side respectively. The resultant RFs are applicable to grouted SCFs derived using Efthymiou parametric equations. The tables contain ranges of validity.

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2$ but $RF \geq 0.10$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Joint Type** | **Load (Position)** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
| **DT** | COMP (Saddle) | 0.57 | -2.08 | 0.001 | -0.003 | 2.55 | 0 |
| | COMP (Crown) | 4.9 | -1.7 | -0.32 | 0.15 | -1.15 | 0.005 |
| | TENS (Saddle) | 0.25 | -1.28 | 0.03 | -0.047 | 2.2 | 0 |
| | TENS (Crown) | 3.9 | -2.9 | -0.2 | 0.04 | 1.01 | 0.004 |
| | IPB (Crown) | 1.8 | -0.08 | -0.08 | 0.07 | -1 | 0 |
| | OPB (Saddle) | 2.35 | -5.15 | -0.03 | 0.03 | 4 | 0 |
| **T** | COMP (Saddle) | 1.07 | -0.68 | -0.043 | 0.06 | -0.53 | 0 |
| | COMP (Crown) | -0.55 | 6.9 | -0.03 | 0.01 | -4.8 | 0 |
| | TENS (Saddle) | 0.87 | -1.49 | 0.001 | 0.01 | 0.65 | 0 |
| | TENS (Crown) | -1.37 | 7.4 | 0.02 | -0.05 | -4.3 | 0 |
| | IPB (Crown) | 0.45 | 1.5 | -0.01 | -0.01 | -0.7 | 0 |
| | OPB (Saddle) | 1.56 | -2.62 | -0.012 | 0.015 | 1.3 | 0 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | | |

**Table 8-7: Recommended formulations for reduction factors on chord side**

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2 + a_6\beta^3\gamma^3$ but $RF \geq 0.10$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Joint Type** | **Load Position** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ |
| DT | COMP (Saddle) | -0.01 | -1.3 | 0.04 | -0.08 | 3.15 | 0 | 0 |
| | COMP (Crown) | 1.1 | 0.56 | -0.056 | 0.09 | -1.78 | 0.001 | 0 |
| | TENS (Saddle) | 1.92 | -4.4 | -0.08 | 0.1 | 3.4 | 0.001 | -0.001 |
| | TENS (Crown) | 1.37 | -3.09 | 0.002 | 0.07 | 1.39 | -0.001 | 0 |
| | IPB (Crown) | 2.45 | -3.5 | -0.03 | 0.03 | 2.03 | 0 | 0 |
| | OPB (Saddle) | -0.43 | -0.64 | 0.096 | -0.17 | 3.8 | 0 | 0 |
| T | COMP (Saddle) | 1.25 | -1.64 | -0.036 | 0.04 | 0.8 | 0 | 0 |
| | COMP (Crown) | -1.26 | 5.0 | 0.002 | 0.03 | -3.3 | 0 | 0 |
| | TENS (Saddle) | 0.72 | -0.7 | -0.008 | 0.004 | 0.5 | 0 | 0 |
| | TENS (Crown) | 2.86 | -2.9 | -0.09 | 0.1 | 0.7 | 0 | 0 |
| | IPB (Crown) | 0.31 | 0.91 | -0.007 | 0.015 | -0.7 | 0 | 0 |
| | OPB (Saddle) | 0.88 | -0.84 | 0.001 | -0.016 | 0.6 | 0 | 0 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | | | |

**Table 8-8: Recommended formulations for reduction factors on brace side**

## 8.5 Ultimate Strength Determination

The results presented in Table 8-9 demonstrate good correlation between the measured and predicted ultimate joint capacity.

It is noted that five of the specimens failed with a true joint failure. The remaining seven specimens experienced brace failure, with the exception of specimens T3 and DT3 which reached test rig capacity. These seven specimens were, however, extremely close to joint failure and are therefore of interest. The ratio of predicted to measured capacities, presented in Table 8-9, are therefore shown in italics for these seven specimens.

The following equation is essentially that derived in Design Recommendations[16]. A minimum grout strength of 41.4 $Nmm^2$ at 28 days must be achieved as the strength of grout affects the strength of a grouted joint. The following equation, which does not include any factors of safety, was used to derive the predicted joint capacities for comparison with the measured results as presented in Table 8-9.

$$M_i,\ M_o = Q_u\, Q_f \frac{F_y T^2 d}{\sin\theta} \qquad \ldots 9.3.1$$

$M_i$ = strength for brace in-plane moment load

$M_o$ = strength for brace out-of-plane moment load

$F_y$ = characteristic yield stress of the chord member at the joint (or 0.7 times the characteristic tensile strength if less). If characteristic values are not available specified minimum values may be substituted.

$T$ = chord wall thickness

$d$ = brace diameter.

$\theta$ = brace/joint intersect angle

$Q_f$ = factor to allow for the presence of axial and moment loads in the chord

= 1.0 (No Chord loading present in tests).

$Q_u$ is a strength factor which varies with the joint and load type. $Q_u$ is defined in Table 8-10 for the ultimate load tests conducted.

| Specimen | D (mm) | d (mm) | T (mm) | t (mm) | L (mm) | θ (°) | β | γ | τ | α | $z_p$ | Yield strength Chord | Yield strength Brace | PREDICTED Moment Capacity (kNm) Joint[1] IPB | PREDICTED Moment Capacity (kNm) Joint[1] OPB | PREDICTED Moment Capacity (kNm) Brace | MEASURED Max. Applied Moment (kNm) At chord C.L. | MEASURED Max. Applied Moment (kNm) At chord face | Loading Type | Failure Mode | Predicted Failure Mode | Test/Pred. Joint Capacity At chord C.L. | Test/Pred. Joint Capacity At chord face |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 406.78 | 167.81 | 16.39 | 16.32 | 2440 | 90.0 | 0.413 | 12.409 | 0.996 | 12.00 | 3.76E+05 | 359 | 348 | 149 | 149 | 131 | 152 | 122 | OPB | Shear chord saddle | Brace | **1.02** | **0.82** |
| T3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 0.982 | 12.00 | 2.46E+06 | 359 | 383 | 877 | 877 | 943 | 923 | 839 | OPB | Rig capacity | Joint | *1.05* | *0.96* |
| T5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 0.964 | 11.99 | 6.82E+05 | 335 | 284 | 230 | 230 | 194 | 249 | 217 | OPB | Shear chord saddle | Brace | **1.08** | **0.95** |
| T7 | 406.96 | 168.41 | 7.86 | 8.31 | 2440 | 90.0 | 0.414 | 25.888 | 1.057 | 11.99 | 2.13E+05 | 332 | 246 | 67 | 67 | 52 | 63 | 51 | OPB | Shear chord saddle | Brace | **0.95** | **0.77** |
| T9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 1.000 | 11.99 | 1.25E+06 | 332 | 332 | 389 | 389 | 416 | 512 | 465 | OPB | Brace buckle | Joint | *1.32* | *1.20* |
| DT2 | 406.78 | 273.09 | 16.39 | 15.76 | 2440 | 90.0 | 0.671 | 12.409 | 0.962 | 12.00 | 1.04E+06 | 359 | 496 | 395 | 392 | 518 | 425 | 370 | OPB | Shear chord saddle | Joint | **1.08** | **0.94** |
| DT3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 0.982 | 12.00 | 2.46E+06 | 359 | 383 | 877 | 654 | 943 | 813 | 739 | OPB | Rig capacity | Joint | *1.24* | *1.13* |
| DT4 | 407.05 | 168.57 | 10.19 | 9.95 | 2440 | 90.0 | 0.414 | 19.973 | 0.976 | 11.99 | 2.51E+05 | 335 | 339 | 87 | 87 | 85 | 97 | 78 | IPB | Brace buckle | Brace | *1.11* | *0.89* |
| DT5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 0.964 | 11.99 | 6.82E+05 | 335 | 284 | 230 | 228 | 194 | 267 | 232 | IPB | Brace buckle | Brace | *1.16* | *1.01* |
| DT6 | 407.05 | 407.60 | 10.19 | 9.61 | 2440 | 90.0 | 1.001 | 19.973 | 0.943 | 11.99 | 1.52E+06 | 335 | 363 | 510 | 380 | 553 | 613 | 557 | IPB | Brace buckle | Joint | *1.20* | *1.09* |
| DT8 | 406.96 | 273.21 | 7.86 | 7.88 | 2440 | 90.0 | 0.671 | 25.888 | 1.003 | 11.99 | 5.55E+05 | 332 | 329 | 175 | 174 | 183 | 216 | 188 | OPB | Shear chord saddle | Joint | **1.24** | **1.08** |
| DT9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 1.000 | 11.99 | 1.25E+06 | 332 | 332 | 389 | 290 | 416 | 402 | 365 | IPB | Brace buckle | Joint | *1.03* | *0.94* |

(1) Reference 1, Formulation from Design Recommendations, MSL Document Reference C11100R223 Rev 0, April 1993

*Italics represent those joints which experienced brace failure or reached rig capacity.*

$$M = Q_u.F_y.T^2.d$$

**For DT OPB ;** $Q_u = 1.8.\beta.\gamma/(Q_\beta)^{0.5}$ for $\beta > 0.6$ $Q\beta = 0.3/(\beta(1-0.833\beta))$

for $\beta <= 0.6$ $Q\beta = 1.0$

**Else ;** $Q_u = 1.8.\beta.\gamma$

**Table 8-9: Summary of ultimate strength tests**

| Load Direction | Joint Configuration | |
|---|---|---|
| | T | DT |
| In-plane bending | $1.5\ \beta\ \gamma$ | $1.5\ \beta\ \gamma$ |
| Out-of-plane bending | $1.5\ \beta\ \gamma$ | $1.5\ \beta\ \gamma\ /\ \sqrt{Q_\beta}$ |

Notes:

$Q_\beta = 1.0$ for $\beta \le 0.6$

$= 0.3/(\beta(1 - 0.833\beta))$ for $\beta > 0.6$

**Table 8-10: $Q_u$ factor for grouted joints**

## 9. OFFSHORE INSTALLATION STUDY

The Offshore Installation Study presents a collation of the experience gained and procedures used on a number of projects where member grouting has been used as a strengthening measure. The study covers detailed offshore grouting procedures for horizontal and inclined members. Reference is made to previous offshore projects to evaluate durations of offshore activities. Recommendations are given on grout materials, grout mixes and Quality Assurance. Details are also given on grout inlets/outlets and grout bags. Recommendations are given to permit the routine offshore implementation of the grouting of tubular members.

The offshore Installation Study is contained in Appendix F.

## REFERENCES


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[4] Det norske Veritas. 'Rules for Classification of Fixed Offshore Installations'. DNV Rules, Parts 1 to 5, July 1991.

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[12] Brown, G. M. et al. 'Improving Structural Integrity by Injection of grout into fatigue-critical nodes in offshore structures'. Paper OTC 5984 of Offshore Technology Conference, Texas, May 1989.

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[15] Efthymiou, M.. 'Development of SCF Formulae and Generalised Influence Functions for use in Fatigue Analysis'. OTJ '88, Surrey, October 1988, plus updates.

[16] Formulation from Design Recommendations, MSL Document Reference C11100R223, Rev 0, April 1993.

# APPENDIX A

## Details for Materials, Welding, Grouting,

## Instrumentation and Loading Conditions

# Welding Procedures and Weld Shapes

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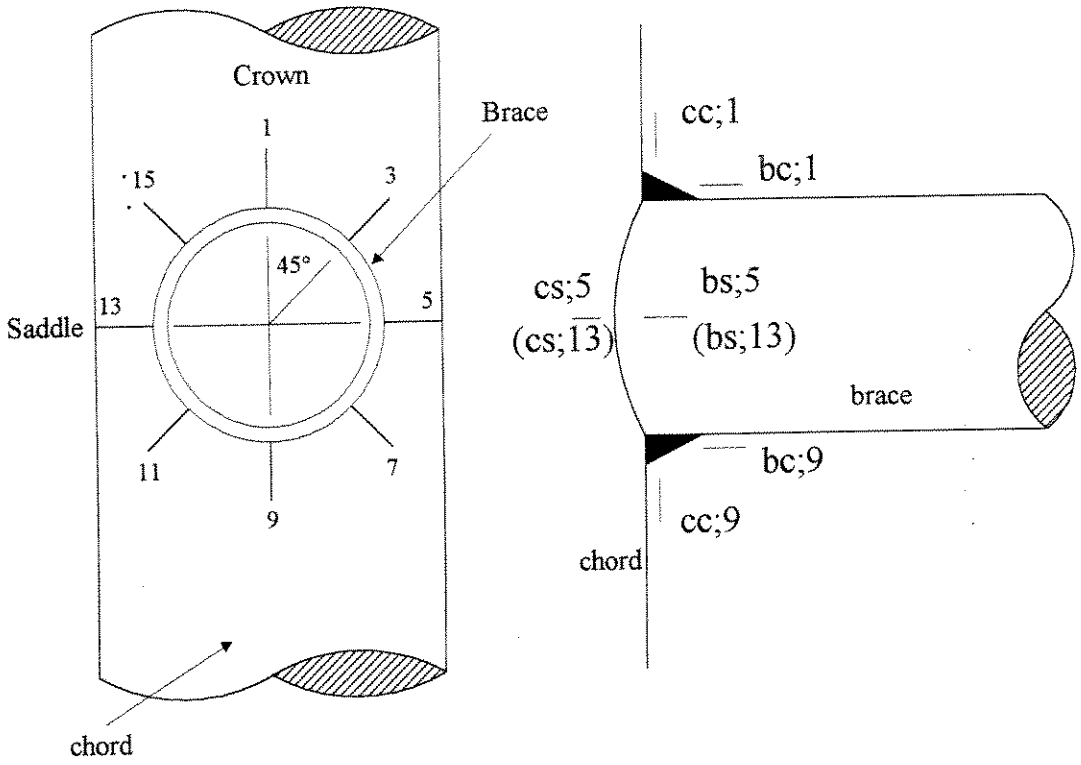
MSL

The weld shape locations are presented in the following Figure ,




Note: Weld shapes measured at 45° intervals around joint intersect

**Location of weld shapes**

# Lasmethode beschrijving
## welding procedure specification

| | | |
|---|---|---|
| | | wps nr.: 250 |
| | | rev nr.: 1 |
| | | geschr. (prep. by): C.W.R. Hoogenboom |
| klant (client): TNO BOUW DELFT | inspectie (insp. by): - | HSM ordernr.: 21227 |
| toepassing (scope): Welding of testpieces T7-T9/DT8-DT9 Grouted tubular joint technology for strengthening/repair | | tekening nr.: - |

| | | | | |
|---|---|---|---|---|
| basismateriaal (base material) | 1 Fe 360 or equal | | CE - | afm. (dim.): O.D. 406.4 / Wt 7.9-16 |
| | 2 Fe 360 or equal | | CE - | afm. (dim.): O.D. ≥ 168.3 / Wt 8 |

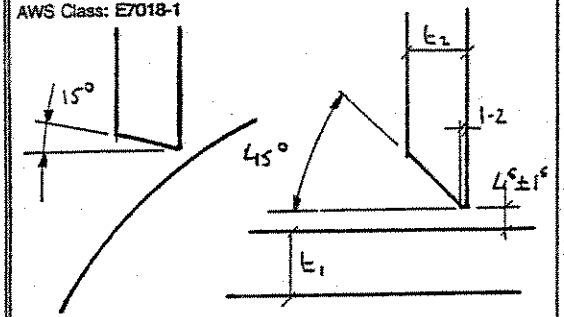
| lasproces (welding process) | grondlaag (root) | vullaag (filling pass) | tegenlas (backwelding) | oplassen (overlay welding) |
|---|---|---|---|---|
| | gl: SMAW | vl: SMAW | tl: NA | ol: NA |

| laspositie (welding position) | hechten (tackweld.): | proces (process) | min. temp. |
|---|---|---|---|
| 2G / TKY | As per tackweld procedure | hl: NA | T > 0°C |

| warmtebehandeling (heattreatment) | voorwarm temperatuur (pre-heating temp.): | temp. tijdens lassen (interp. temp): | nawarm temp. (soaking temp.): |
|---|---|---|---|
| | As per AWS D1.1; App. XI | 250°C | NA |
| | voorwarmdetails (pre-heating details): NA | isolatie (insulation): NO | nawarmtijd (soaking time): NA |

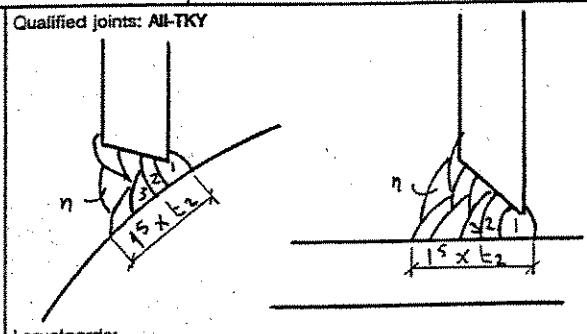
| gloeien (postweld heattr.) | | gloeiinstr. (heattr. instr.): |
|---|---|---|
| | NA | NA |

AWS Class: E7018-1




Lasnaadvorm:
(edge preperation) As per AWS D1.1; Section 10

Qualified joints: All-TKY




Lasvolgorde:
(bead sequence / welding sequence nrs.)

| lasvolgorde (bead- or welding seq.-nrs.) | betreft (appl. to) | lastoevoegmateriaal (filler-materials) | afm. (dim) | schutgas/poeder (shieldinggas/flux) | stroom (current) ~/⎓ (dc/ac) | +/- | ampérage | voltage | Gas l/min. | HI KJ/mm. | WTS mm/min. - ROL/mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Root | Safdry 58 | 3.15 | - | AC | | 85-100 | 24 | - | 1.8 / 2.8 | 80 - 80 |
| 2 | Fill | Safdry 58 | 3.15 | - | AC | | 90 - 110 | 24 | - | 1.2 / 2.0 | 85 - 120 |
| 3 - n | Fill/cap | Safdry 58 | 4.0 | - | AC | | 155 - 175 | 24 | - | 1.4 / 1.8 | 165 - 200 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

| bewerking laskanten (preped weldedges): | bewerking tegenlas (treatment of root): |
|---|---|
| Flame-cutting and grinding | NA |
| opmerking (remarks): Weld area shall be dry and free of scale, rust etc. | |

| lmk rapport nr. (pqr. nr.): NA | geldigheidsgebied lmk (validity range proc. qualification): | lasserskwalificaties volgens: (welder performance qual. acc.) |
|---|---|---|
| serial nr.: AWS D1.1 '94 | afm. (dim.): All | ASME IX and AWS D1.1 |
| volgens (acc.): | posities (pos.): All/TKY | |

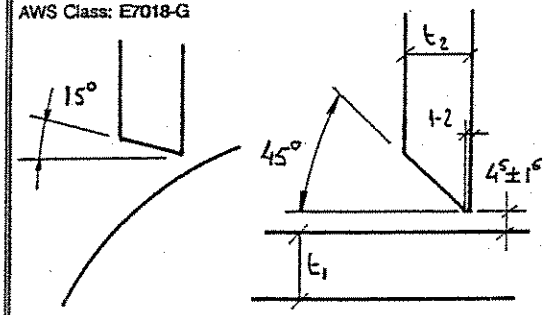
| inspectie: (inspection) | rt: - | mt/pt: 100% | others: Visual |
|---|---|---|---|
| datum: (date) | appr. QA dept. HSM: 27.02.95 | appr. customer: | appr. insp. auth.: |

QC 1

| | | |
|---|---|---|
| hsm | **Lasmethode beschrijving**<br>welding procedure specification | wps nr.: **150**<br>rev nr.: 1<br>geschr. (prep. by): **C.W.R. Hoogenboom** |
| klant (client): **TNO BOUW DELFT** | inspectie (insp. by): - | HSM ordernr.: **21227** |
| toepassing (scope): **Welding of testpieces T1-T3-T5/DT2-DT3-DT4-DT5-DT6<br>Grouted tubular joint technology for strengthening/repair** | | tekening nr.: - |

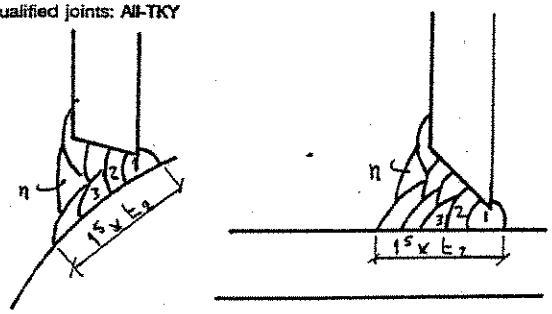
| | | | | |
|---|---|---|---|---|
| basismateriaal (base material) | 1 **Fe 360 or equal** | | **CE -** | afm. (dim.): **O.D. 406.4 / Wt 7.9-16** |
| | 2 **Fe 510 or equal** | | **CE ≤ 0.43** | afm. (dim.): **O.D. ≥ 168.3 / Wt 7.9-16** |
| lasproces (welding process) | grondlaag (root) | vullaag (filling pass) | tegenlas (backwelding) | oplassen (overlay welding) |
| | gl: **SMAW** | vl: **SMAW** | tl: **NA** | ol: **NA** |
| laspositie (welding position) | 2G / TKY | hechten (tackweld): **As per tackweld procedure** | proces (process) | min. temp. |
| | | | ht: **NA** | **T > 0°C** |
| warmtebehandeling (heattreatment) | voorwarm temperatuur (pre-heating temp.): **As per AWS D1.1; App. XI** | temp. tijdens lassen (interp. temp): **250°C** | nawarm temp. (soaking temp.): **NA** | |
| | voorwarmdetails (pre-heating details): **NA** | isolatie (insulation): **NO** | nawarmtijd (soaking time): **NA** | |
| gloeien (postweld heattr.) | **NA** | | gloeiinstr. (heattr. instr.): **NA** | |

AWS Class: E7018-G




Lasnaadvorm:
(edge preperation) As per AWS D1.1; Section 10

Qualified joints: All-TKY




Lasvolgorde:
(bead sequence / welding sequence nrs.)

| lasvolgorde (bead- or welding seq.-nrs.) | betreft (appl. to) | lastoevoeg-materiaal (filler-material) | afm. (dim) | schutgas/poeder (shieldinggas/flux) | stroom (current) –/~ (dc/ac) | stroom (current) +/- | stroom (current) ampérage | voltage | Gas l/min. | HI. KJ/mm. | WTS mm/min. - ROL/mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Root | KRYO 1 | 3.0 | - | AC | | 85-100 | 24 | - | 1.8 / 2.8 | 80 - 80 |
| 2 | Fill | KRYO 1 | 3.0 | - | AC | | 90 - 110 | 24 | - | 1.2 / 2.0 | 85 - 120 |
| 3 - n | Fill/cap | KRYO 1 | 4.0 | - | AC | | 155 - 175 | 24 | - | 1.4 / 1.8 | 165 - 200 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
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| | | | | | | | | | | | |

| | |
|---|---|
| bewerking laskanten (preped weldedges): **Flame-cutting and grinding** | bewerking tegenlas (treatment of root): **NA** |
| opmerking (remarks): **Weld area shall be dry and free of scale, rust etc.** | |

| | | |
|---|---|---|
| lmk rapport nr. (pqr. nr.): **NA**<br>serial nr.:<br>volgens (acc.): **AWS D1.1 '94** | geldigheidsgebied lmk (validity range proc. qualification):<br>afm. (dim.): **All**<br>posities (pos.): **All/TKY** | lasserskwalificaties volgens: (welder performance qual. acc.) **ASME IX and AWS D1.1** |

| | | | | |
|---|---|---|---|---|
| inspectie: (inspection) | rt: - | ut: QC 1 100% | mt/pt: 100% | others: Visual |
| datum: (date) | appr. QA dept. HSM: 27.02.95 | appr. customer: | appr. insp. auth.: | |

# Lasmethode beschrijving
welding procedure specification

| | |
|---|---|
| wps nr.: | 106 |
| rev nr.: | 0 |
| geschr. (prep. by): | C.W.R. Hoogenboom |
| klant (client): | TNO BOUW DELFT |
| inspectie (insp. by): | - |
| HSM ordernr.: | 21227 |
| toepassing (scope): | Testpieces; Welding of end-plates<br>Grouted tubular joint technology for strengthening/repair |
| tekening nr.: | - |

| | | | | |
|---|---|---|---|---|
| basismateriaal (base material) | 1 | Fe 360 / Fe 510 or equal | CE ≤ 0.43 | afm. (dim.): O.D. ≥ 168.3 / Wt 7.9-16 |
| | 2 | Fe 510 or equal | CE ≤ 0.43 | afm. (dim.): Wt 30 - 100 |

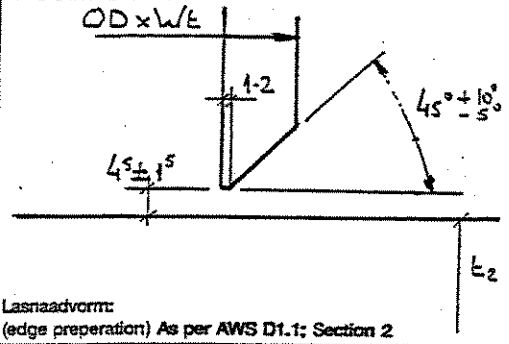
| lasproces (welding process) | grondlaag (root) | vullaag (filling pass) | tegenlas (backwelding) | oplassen (overlay welding) |
|---|---|---|---|---|
| | gl: SMAW | vl: SMAW | tl: NA | ol: NA |

| laspositie (welding position) | hechten (tackweld): | proces (process) | min. temp. |
|---|---|---|---|
| All | As per tackweld procedure | hl: NA | T > 0°C |

| warmtebehandeling (heattreatment) | voorwarm temperatuur (pre-heating temp.): | temp. tijdens lassen (interp. temp): | nawarm temp. (soaking temp.): |
|---|---|---|---|
| | As per AWS D1.1; App. XI | 250°C | NA |
| | voorwarmdetails (pre-heating details): NA | isolatie (insulation): NO | nawarmtijd (soaking time): NA |

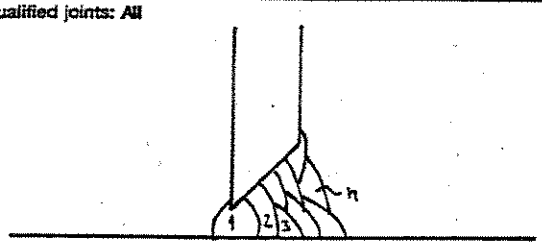
| gloeien (postweld heattr.) | | gloeiinstr. (heattr. instr.): |
|---|---|---|
| | NA | NA |

AWS Class: E7018-G




Lasnaadvorm:
(edge preperation) As per AWS D1.1; Section 2

Qualified joints: All




Lasvolgorde:
(bead sequence / welding sequence nrs.)

| lasvolgorde (bead- or welding seq.-nrs.) | betreft (appl. to) | lastoevoegmateriaal (filler-material) | afm. (dim) | schutgas/poeder (shielding gas/flux) | stroom (current) =/~ (dc/ac) | +/- | ampérage | voltage | Gas l/min. | HI. KJ/mm. | WTS mm/min. - ROL/mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Root | KRYO 1 | 3.0 | - | AC | | 85-100 | 24 | - | 1.8 / 2.8 | 60 - 80 |
| 2 | Fill | KRYO 1 | 3.0 | - | AC | | 90 - 110 | 24 | - | 1.2 / 2.0 | 85 - 120 |
| 3 - n | Fill/cap | KRYO 1 | 4.0 | - | AC | | 155 - 175 | 24 | - | 1.4 / 1.8 | 165 - 200 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

| bewerking laskanten (preped weldedges): | bewerking tegenlas (treatment of root): |
|---|---|
| Flame-cutting and grinding | NA |
| opmerking (remarks): Weld area shall be dry and free of scale, rust etc. | |

| lmk rapport nr. (ppr. nr.): | geldigheidsgebied lmk (validity range proc. qualification): | lasserskwalificaties volgens: (welder performance qual. acc.) |
|---|---|---|
| NA | afm. (dim.): All | ASME IX and AWS D1.1 |
| serial nr.: AWS D1.1 '94 | posities (pos.): All | |
| volgens (acc.): | | |

| inspectie: (inspection) | rt: - | ut: 100% | mt/pt: 100% | others: Visual |
|---|---|---|---|---|
| datum: (date) | appr. QA dept. HSM: 14.02.95 | appr. customer: | appr. insp. auth.: | |

QC 1

| | | |
|---|---|---|
| hsm | **Lasmethode beschrijving**<br>welding procedure specification | wps nr.: 060<br>rev nr.: 0<br>geschr. (prep. by): C.W.R. Hoogenboom |
| klant (client): TNO BOUW DELFT | inspectie (insp. by): - | HSM ordernr.: 21227 |
| toepassing (scope): **Welding of Testpieces; Tackwelding**<br>**Grouted tubular joint technology for strengthening/repair** | | tekening nr.: - |

| | | | | |
|---|---|---|---|---|
| basismateriaal (base material) | 1 Fe 360 / Fe 510 or equal | | CE ≤ 0.43 | afm. (dim.): All |
| | 2 Fe 360 / Fe 510 or equal | | CE ≤ 0.43 | afm. (dim.): All |

| lasproces (welding process) | grondlaag (root) | vullaag (filling pass) | tegenlas (backwelding) | oplassen (overlay welding) |
|---|---|---|---|---|
| | gl: All | vl: NA | tl: NA | ol: NA |

| laspositie (welding position) | | hechten (tackwelding): | | |
|---|---|---|---|---|
| | All | - | proces (process) | min. temp. |
| | | | hl: NA | NA |

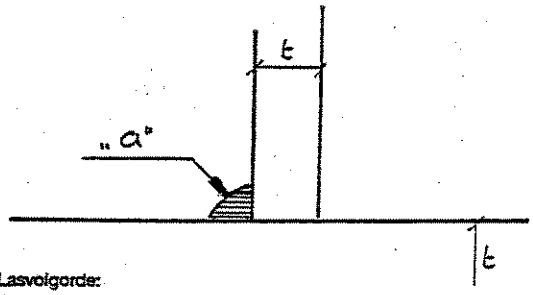
| warmtebehandeling (heattreatment) | voorwarm temperatuur (pre-heating temp.): | temp. tijdens lassen (interp.temp): | nawarm temp. (soaking temp.): |
|---|---|---|---|
| | T °C | | NA |
| | voorwarmdetails (pre-heating details): | isolatie (insulation): | nawarmtijd (soaking time): |
| | GASBURNER | - | NA |

| gloeien (postweld heattr.) | | gloeiinstr. (heattr. instr.): |
|---|---|---|
| | NA | NA |

AWS Class: NA

Lasnaadvorm:
(edge preperation) -

Qualified joints: -




Lasvolgorde:
(bead sequence / welding sequence nrs.)

| lasvolgorde (bead- or welding seq.-nrs.) | beltelt (appl. to) | lastoevoegmateriaal (filler material) | afm. (dim) | schutgas/poeder (shielding-gas/flux) | stroom (current) =/~ (dc/ac) | +/- | ampérage | voltage | Gas l/min. | Hl. KJ/mm. | WTS mm/min - FICL/mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Tack | LNM 28 | 1.0 | 85Ar-15$CO_2$ | DC | + | ± 220 | 22 - 24 | ± 16 | - | - |
| 2 | Tack | Stelrod 200 | 1.2 | 85Ar-15$CO_2$ | DC | + | 200 - 250 | ± 26 | ± 16 | - | - |
| 3 | Tack | DWA 55L | 1.2 | 85Ar-15$CO_2$ | DC | + | 200 - 250 | ± 26 | ± 16 | - | - |
| 4 | Tack | KRYO 1 | 4.0 | - | AC | | 140 - 180 | 24 - 26 | - | - | - |

- $T_o$ = preheat-temperature as per WPS.
- T = 50°C minimum or T = $T_o$ + 50°C.
- Minimum tack-weld length; l = 50mm.
- Minimum weld-size; a = 4mm.

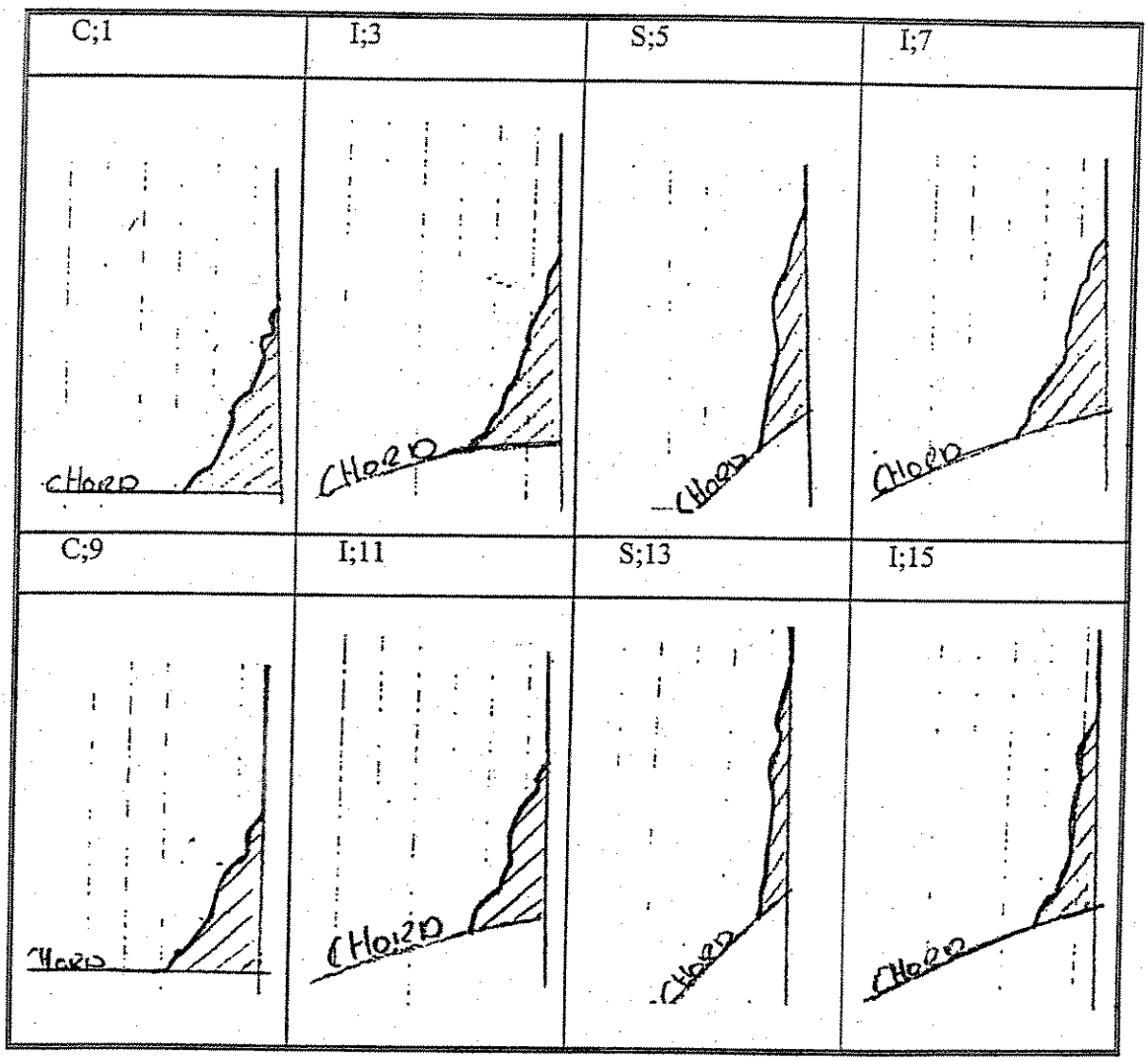
opmerking (remarks): Weld area shall be dry and free of scale, rust etc.

| lmk rapport nr. (pqr. nr.): NA | geldigheidsgebied lmk (validity range proc. qualification): | lasserskwalificaties volgens: (welder performance qual. acc.) |
|---|---|---|
| serial nr.: AWS D1.1 '94 | afm. (dim.): All | ASME IX and AWS D1.1 |
| volgens (acc.): | posities (pos.): All | |

| inspectie: (inspection) | rt: - | ut: 007 | mt/pt: - | others: Visual |
|---|---|---|---|---|
| datum: (date) | appr. QA dept. HSM: 14.02.97 | appr. customer: | | appr. insp. auth.: |

## WELD SHAPE SPECIMEN DT2

Intersection between Chord and Brace 1 of DT2




Key :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

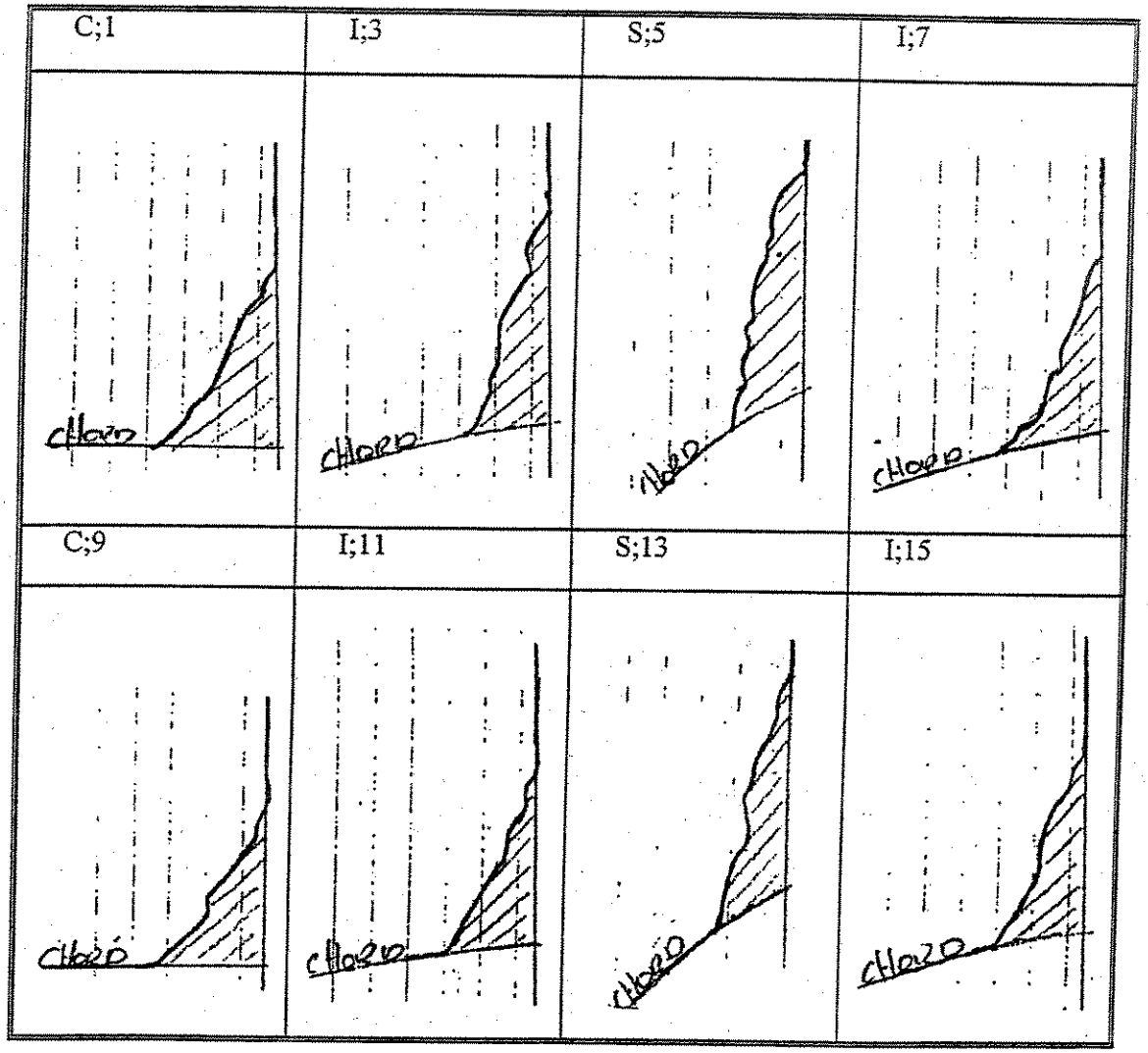
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| Weld leg length | C,1 | I,3 | S,5 | I,7 | C,9 | I,11 | S,13 | I,15 |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 25.8 | 26.2 | 28.3 | 24.2 | 21.8 | 21.7 | 32.7 | 26.7 |
| $L_{chord}$ | 13.8 | 12.7 | 9.0 | 13.5 | 13.4 | 10.6 | 5.2 | 9.4 |

## WELD SHAPE SPECIMEN DT2

Intersection between Chord and Brace 2 of DT2




**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

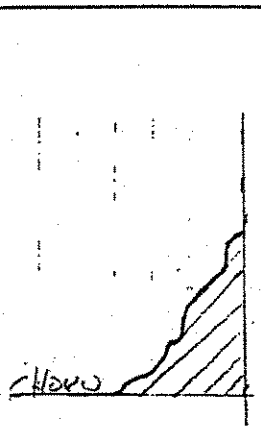
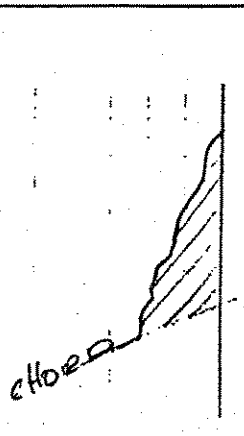
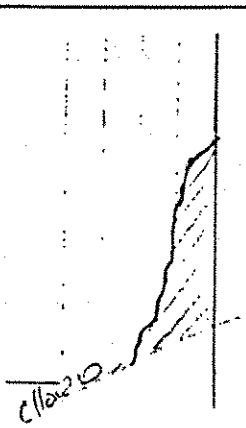
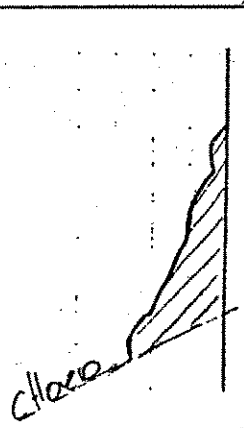
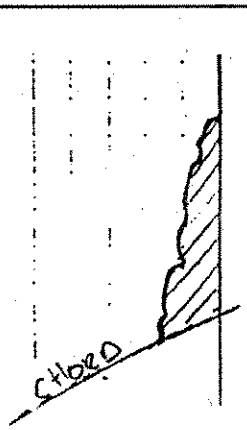
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 26.2 | 29.6 | 30.7 | 24.7 | 22.2 | 25.0 | 30.7 | 26.4 |
| $L_{chord}$ | 17.2 | 12.3 | 11.6 | 15.3 | 15.9 | 13.5 | 11.6 | 13.5 |

## WELD SHAPE SPECIMEN DT3

Intersection between Chord and Brace 1 of DT3

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  | |  |
| C;9 | I;11 | S;13 | I;15 |
| |  | |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

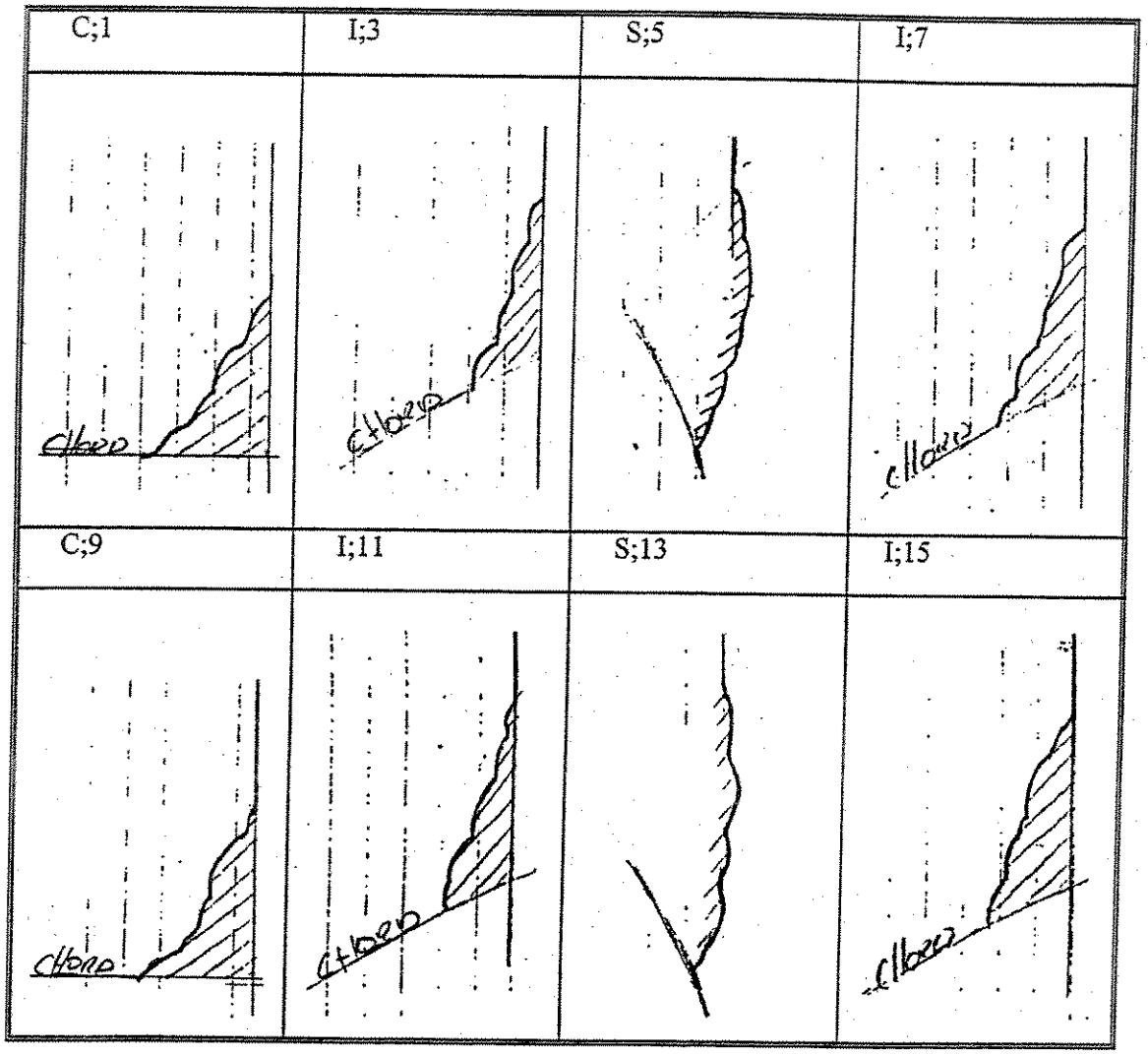
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 22.7 | 23.4 | | 25.7 | 23.4 | 27.8 | | 26.4 |
| $L_{chord}$ | 17.9 | 12.4 | | 12.8 | 18.4 | 9.8 | | 14.9 |

## WELD SHAPE SPECIMEN DT3

Intersection between Chord and Brace 2 of DT3




Key :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

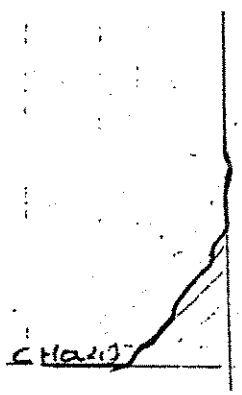
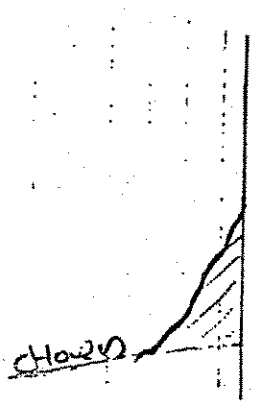
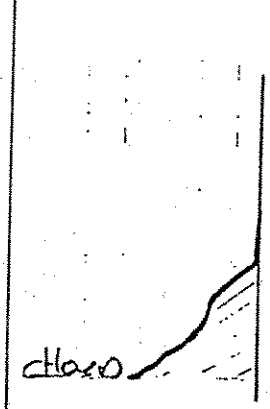
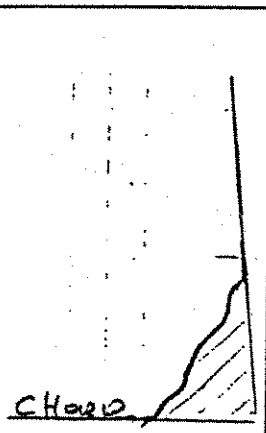
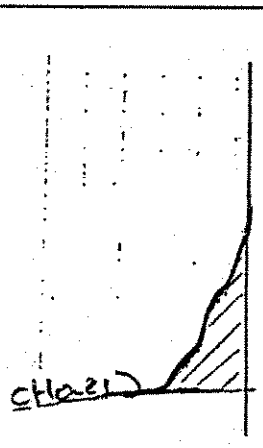
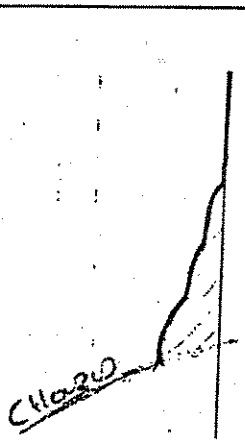
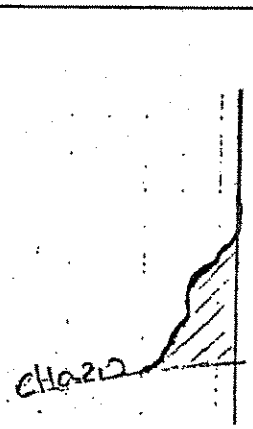
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 23.2 | 22.4 | | 22.3 | 24.9 | 26.2 | | 24.7 |
| $L_{chord}$ | 17.6 | 10.5 | | 13.4 | 16.2 | 10.1 | | 13.0 |

## WELD SHAPE SPECIMEN DT4

Intersection between Chord and Brace 1 of DT4

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  | |  |
| **C;9** | **I;11** | **S;13** | **I;15** |
|  |  |  |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

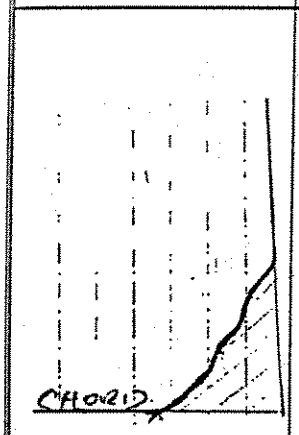
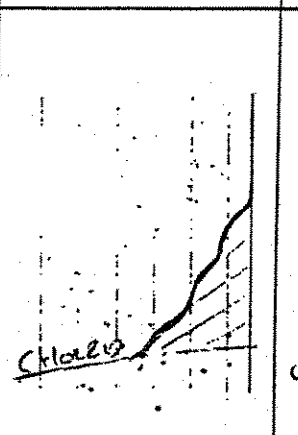
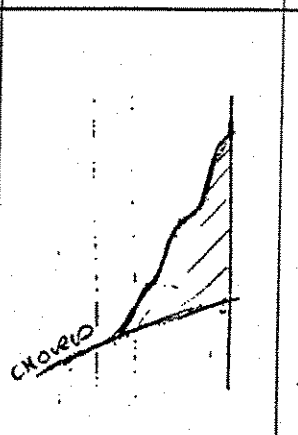
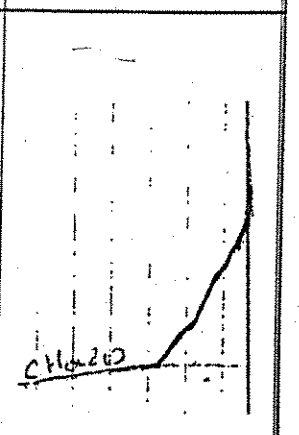
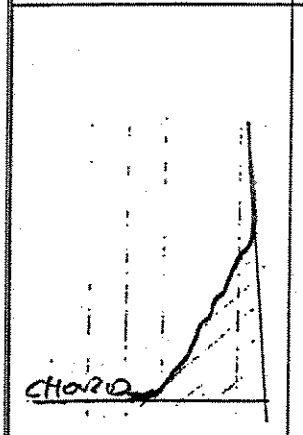
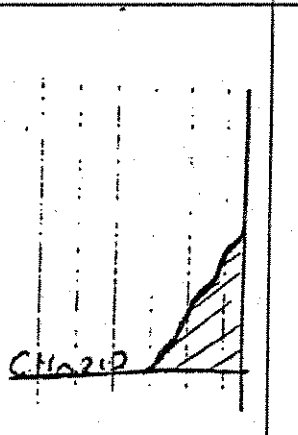
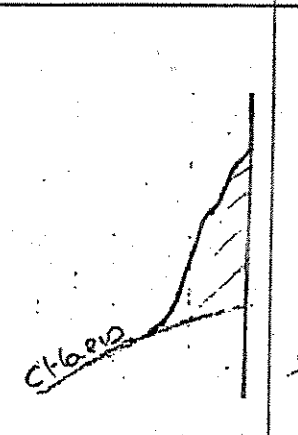
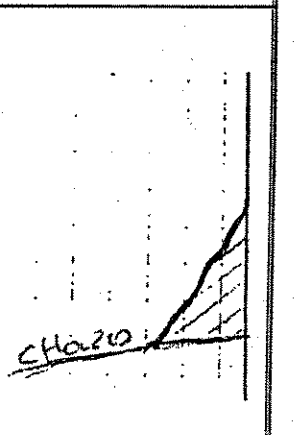
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 21.1 | 19.3 | 19.5 | 18.2 | 22.7 | 22.7 | 24.7 | 18.7 |
| $L_{chord}$ | 14.8 | 13.7 | 13.2 | 17.3 | 14.9 | 12.6 | 8.4 | 12.6 |

## WELD SHAPE SPECIMEN DT4

Intersection between Chord and Brace 2 of DT4

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| C;9 | I;11 | S;13 | I;15 |
|  |  |  |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

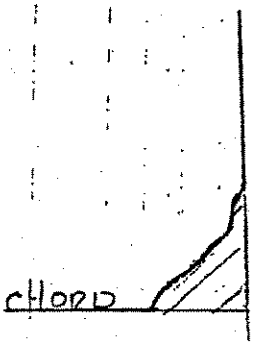
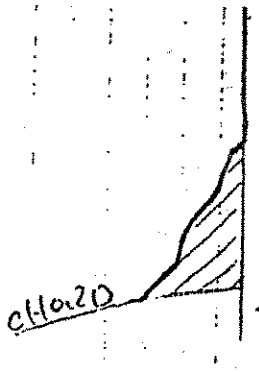
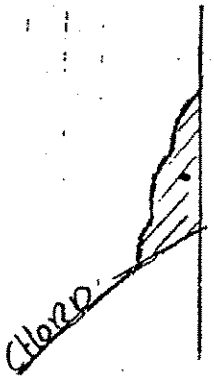
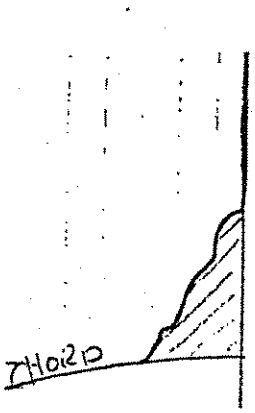
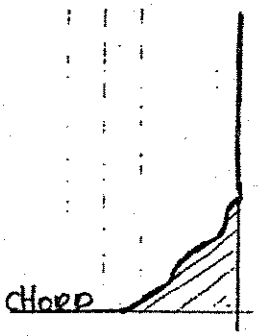
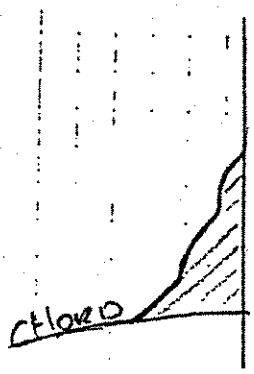
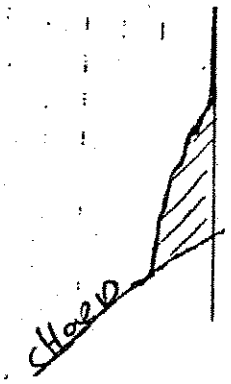
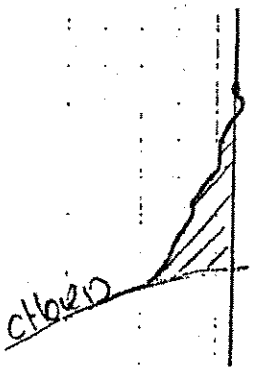
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 21.9 | 20.0 | 23.1 | 21.2 | 23.9 | 19.9 | 23.9 | 18.4 |
| $L_{chord}$ | 18.0 | 15.0 | 17.7 | 12.7 | 18.5 | 12.1 | 14.0 | 13.1 |

## WELD SHAPE SPECIMEN DT5

Intersection between Chord and Brace 1 of DT5

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| **C;9** | **I;11** | **S;13** | **I;15** |
|  |  |  |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

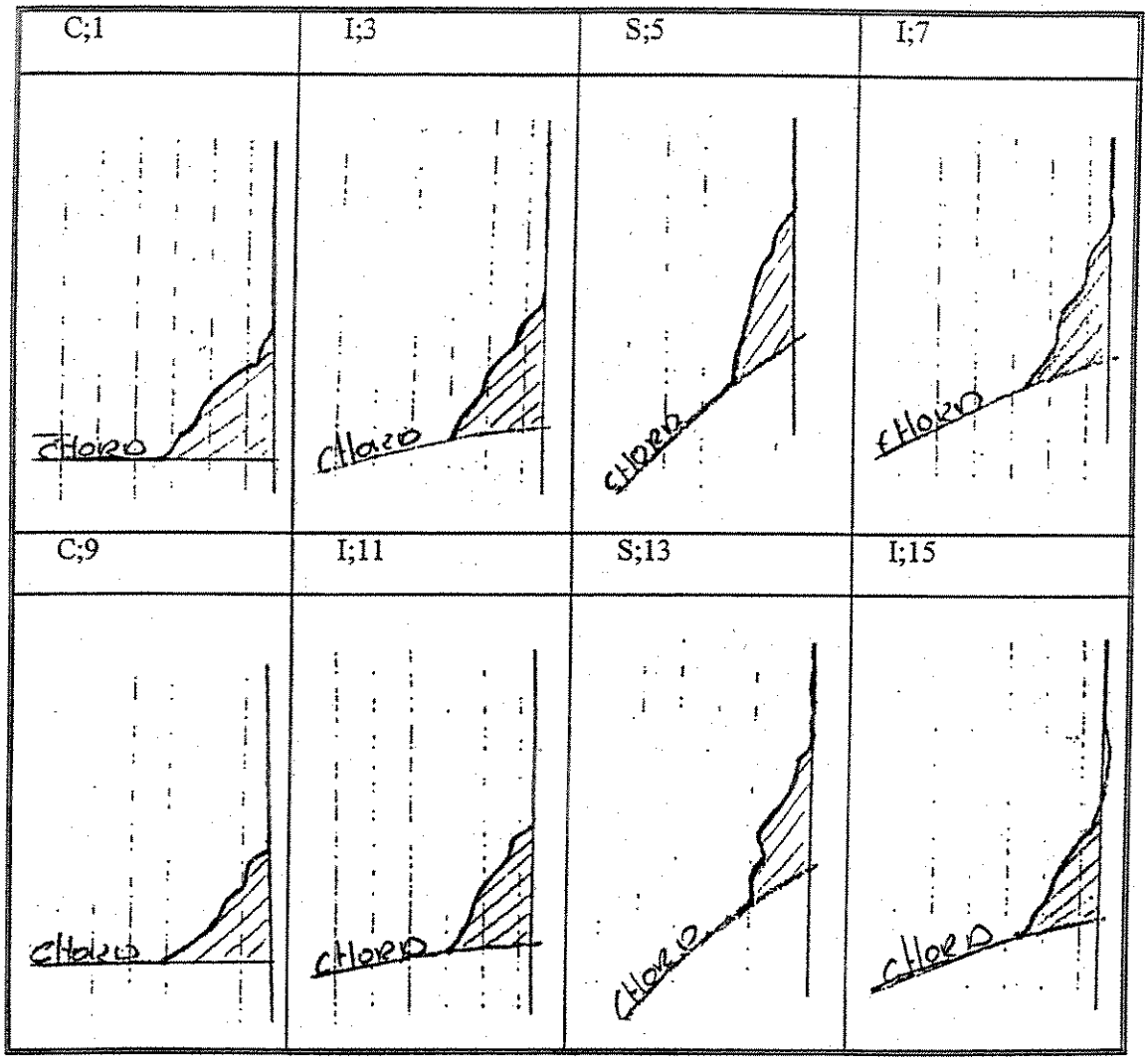
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 17.6 | 19.7 | 19.4 | 20.5 | 15.5 | 22.1 | 20.3 | 20.9 |
| $L_{chord}$ | 13.1 | 14.2 | 10.1 | 13.9 | 15.9 | 15.8 | 10.2 | 11.7 |

## WELD SHAPE SPECIMEN DT5

Intersection between Chord and Brace 2 of DT5




Key :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

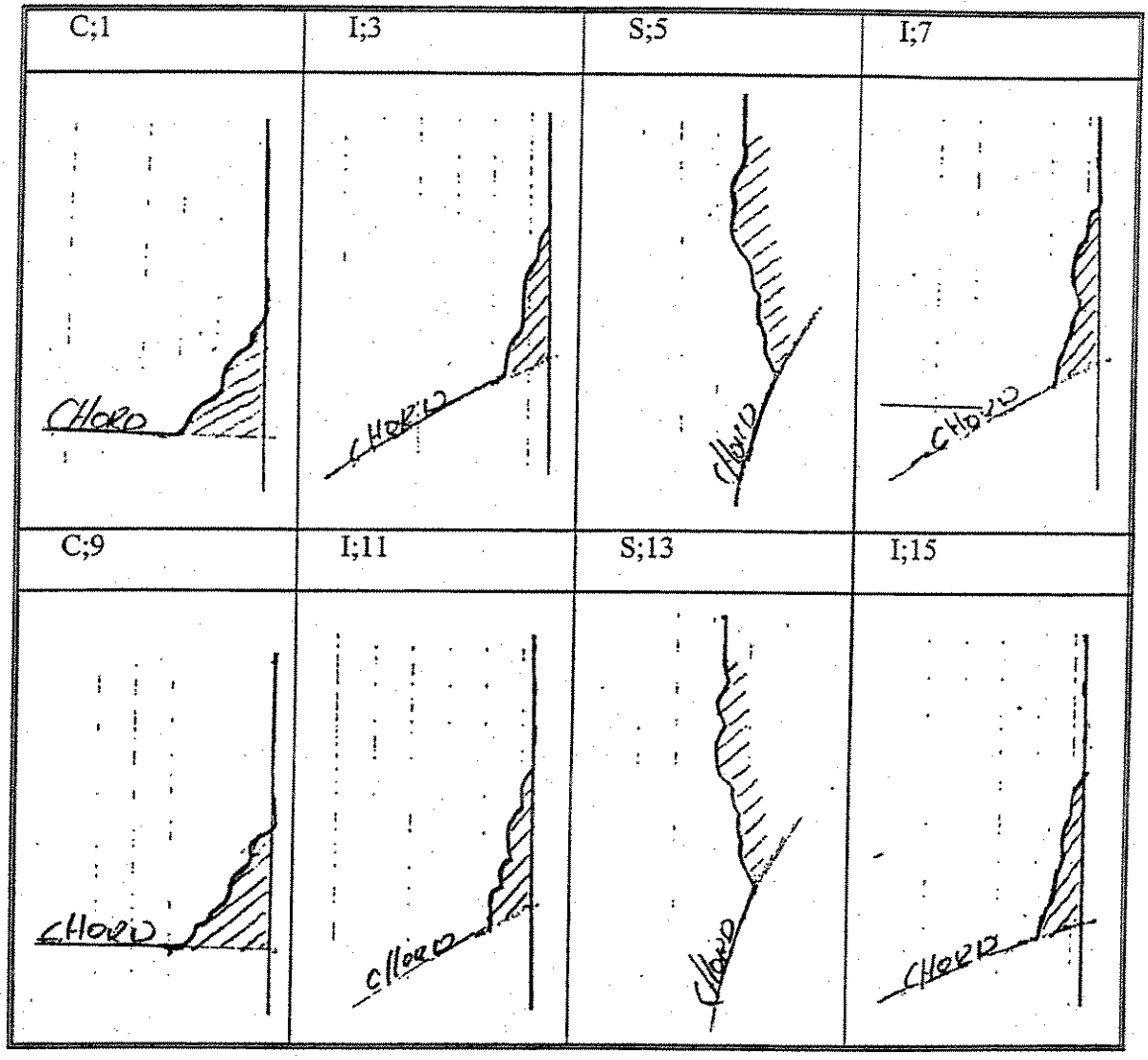
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| Weld leg length | C,1 | I,3 | S,5 | I,7 | C,9 | I,11 | S,13 | I,15 |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 18.4 | 18.1 | 17.8 | 19.1 | 15.5 | 17.7 | 18.0 | 17.6 |
| $L_{chord}$ | 15.9 | 13.0 | 10.6 | 12.3 | 15.0 | 11.9 | 10.2 | 11.3 |

## WELD SHAPE SPECIMEN DT6

Intersection between Chord and Brace 1 of DT6




**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

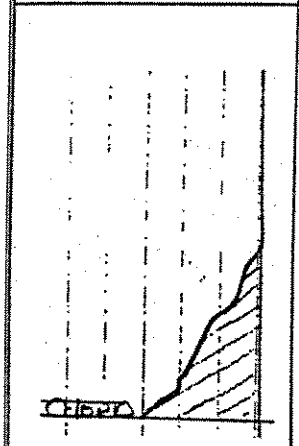
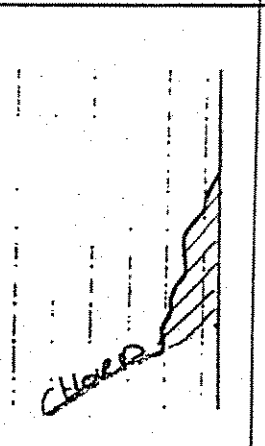
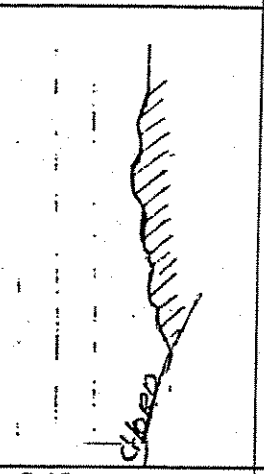
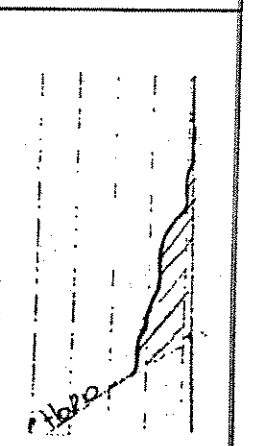
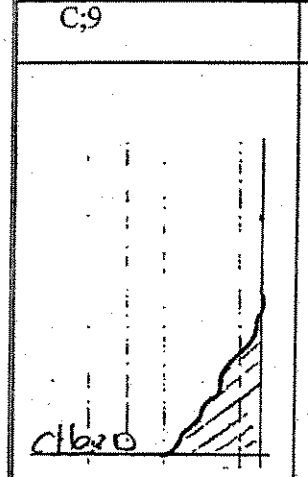
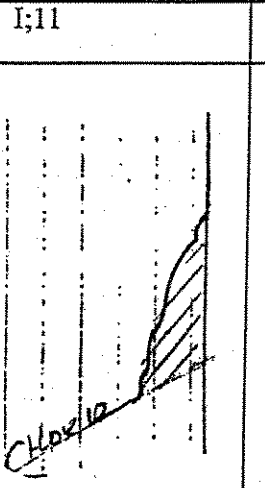
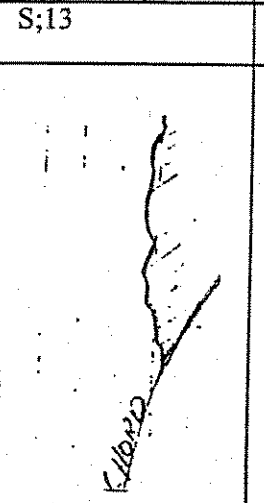
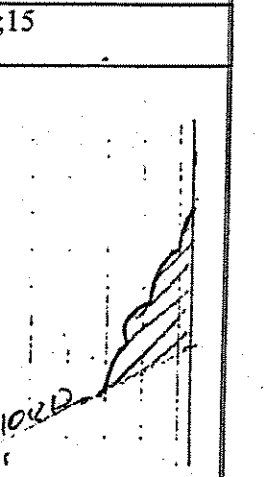
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 18.0 | 18.6 | | 22.6 | 20.2 | 20.0 | | 21.3 |
| $L_{chord}$ | 13.0 | 7.7 | | 7.1 | 15.1 | 6.6 | | 6.9 |

## WELD SHAPE SPECIMEN DT6

Intersection between Chord and Brace 2 of DT6

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| **C;9** | **I;11** | **S;13** | **I;15** |
|  |  |  |  |

**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

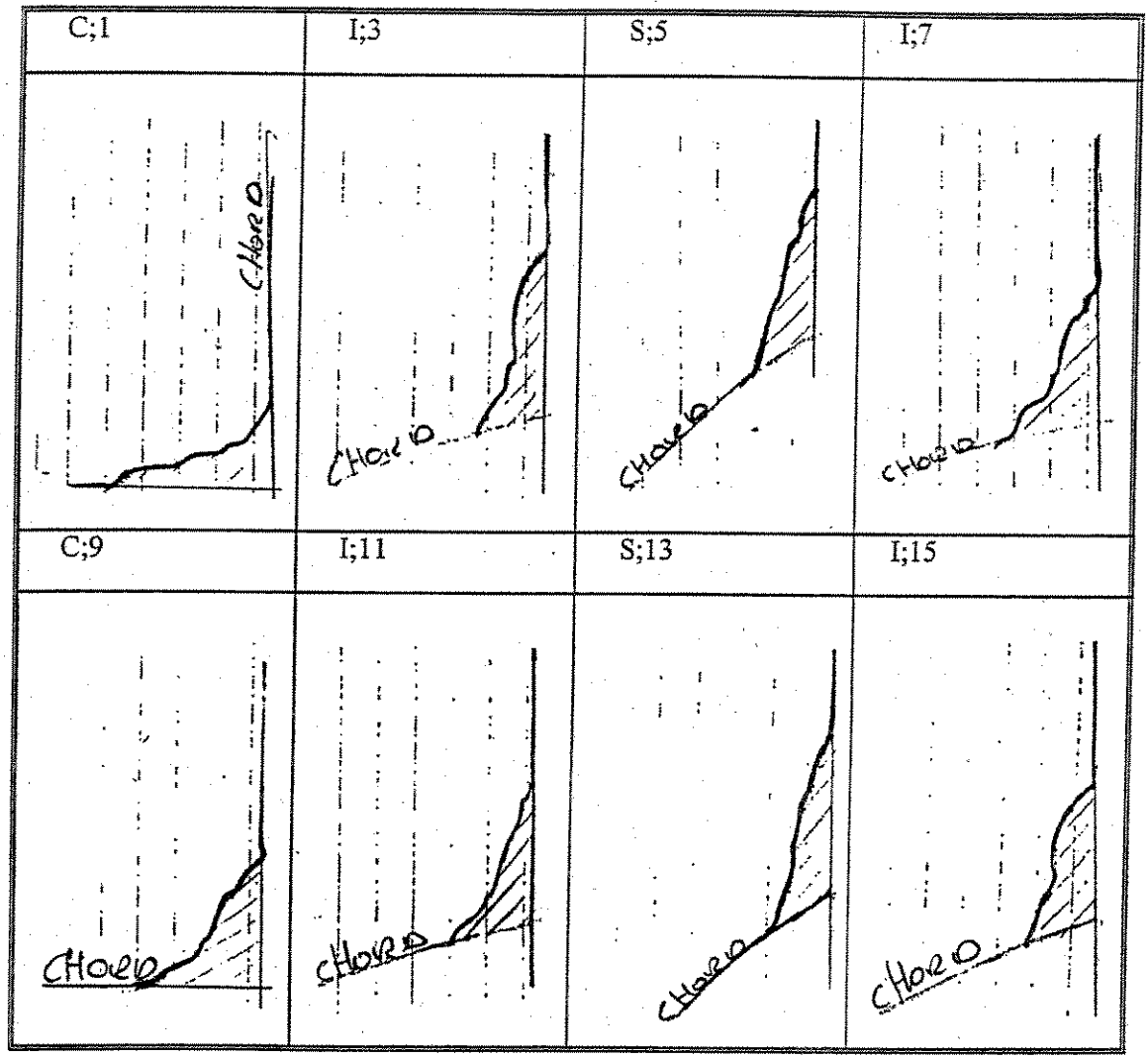
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 24.2 | 21.8 | | 24.1 | 22.3 | 21.1 | | 19.6 |
| $L_{chord}$ | 16.3 | 9.6 | | 9.7 | 13.3 | 11.3 | | 14.2 |

## WELD SHAPE SPECIMEN DT8

Intersection between Chord and Brace 1 of DT8




**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

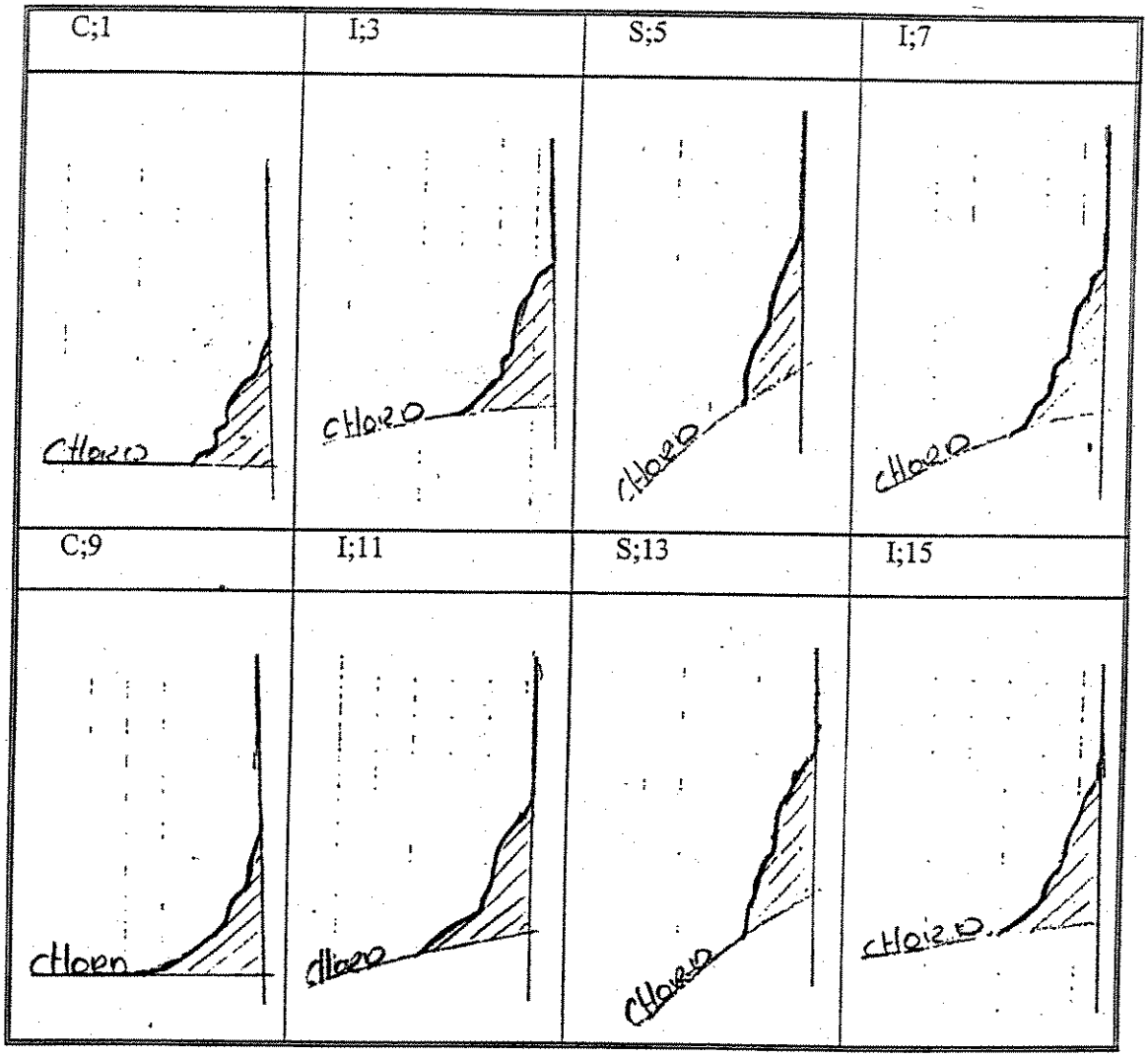
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 23.4 | 23.2 | 20.3 | 21.2 | 20.2 | 19.7 | 24.8 | 18.7 |
| $L_{chord}$ | 12.1 | 9.8 | 10.4 | 14.6 | 16.6 | 12.0 | 10.1 | 10.7 |

## WELD SHAPE SPECIMEN DT8

Intersection between Chord and Brace 2 of DT8




**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

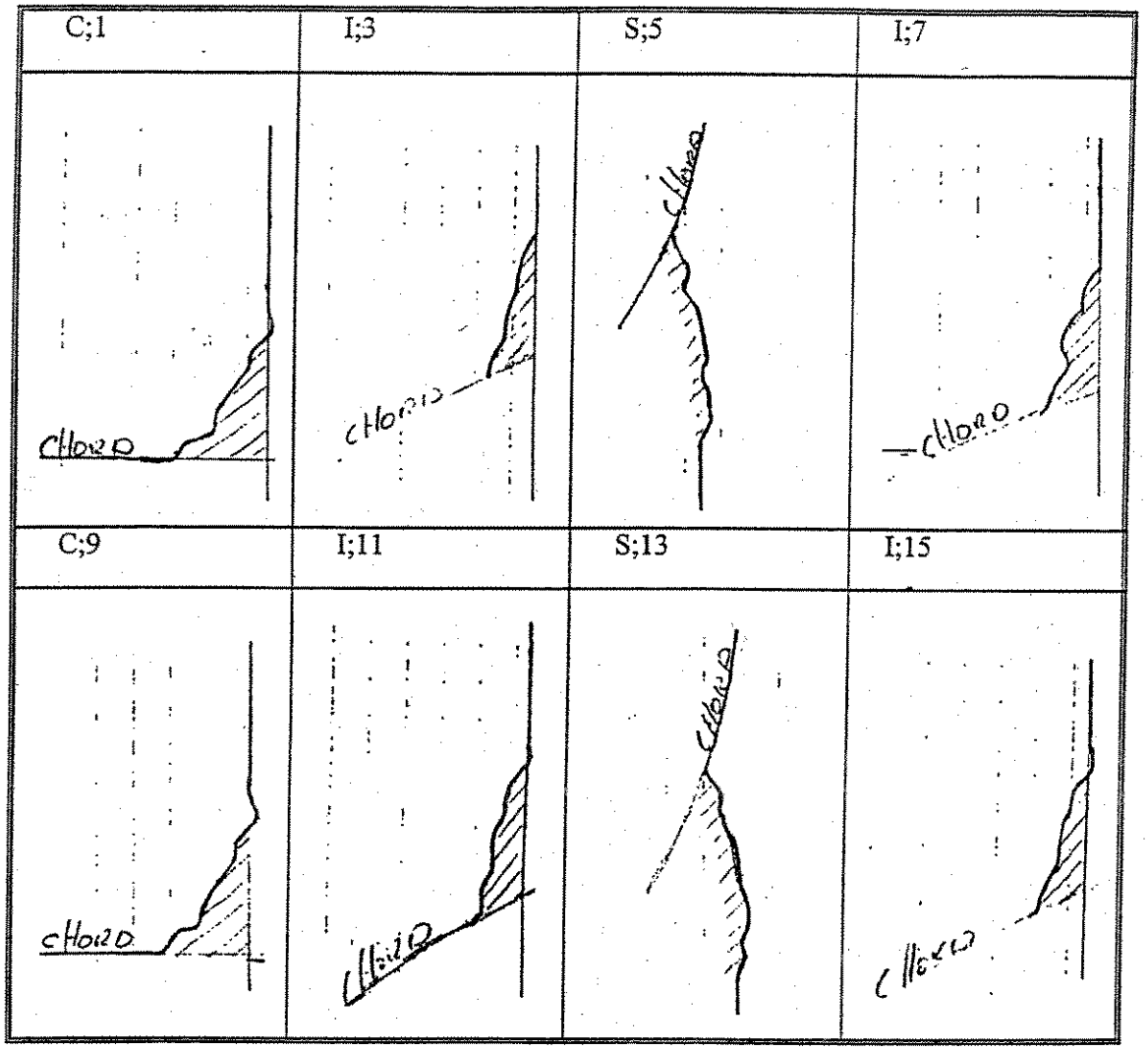
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 19.3 | 19.4 | 20.3 | 21.3 | 21.0 | 20.0 | 20.8 | 22.9 |
| $L_{chord}$ | 11.2 | 13.7 | 9.8 | 12.8 | 16.7 | 16.1 | 11.5 | 13.9 |

## WELD SHAPE SPECIMEN DT9

Intersection between Chord and Brace 1 of DT9




**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

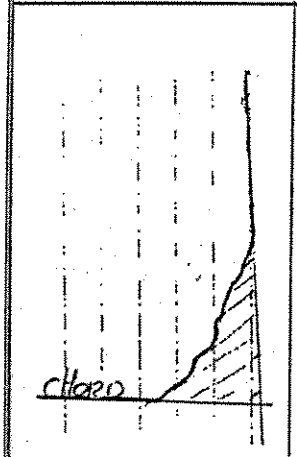
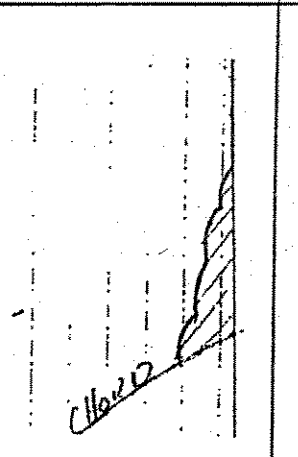
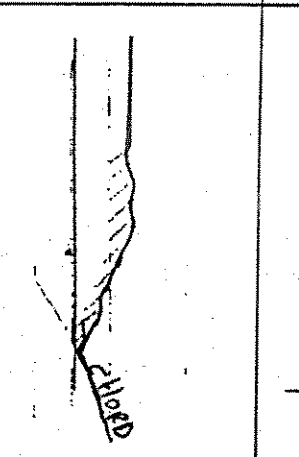
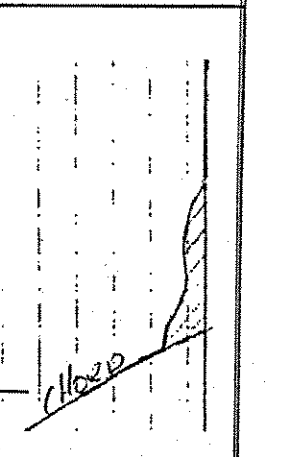
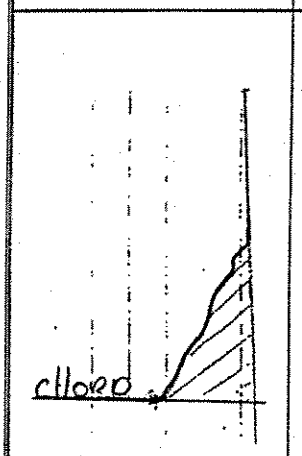
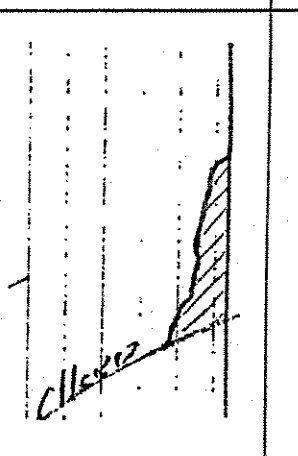
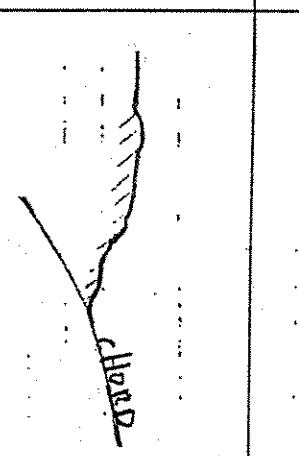
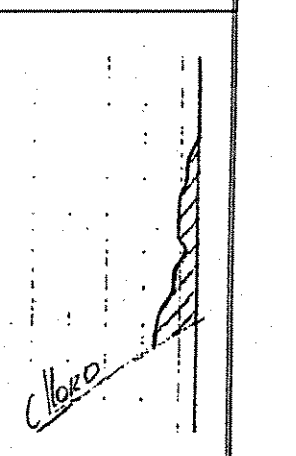
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 21.8 | 17.2 | | 17.9 | 24.3 | 20.8 | | 20.3 |
| $L_{chord}$ | 14.1 | 7.1 | | 8.7 | 12.8 | 7.9 | | 8.4 |

## WELD SHAPE SPECIMEN DT9

Intersection between Chord and Brace 2 of DT9

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| C;9 | I;11 | S;13 | I;15 |
|  |  |  |  |

**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

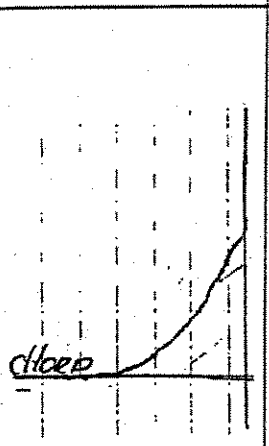
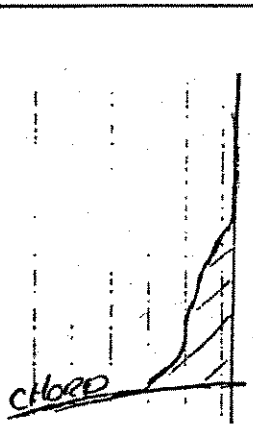
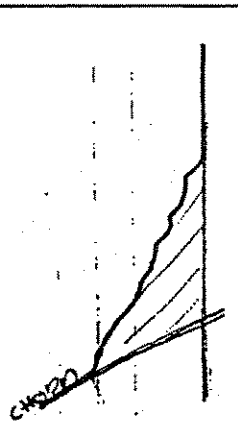
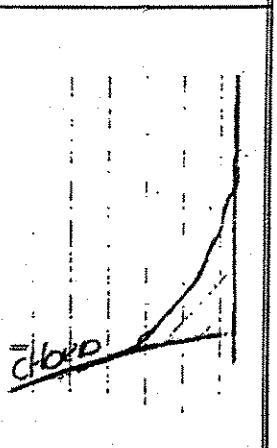
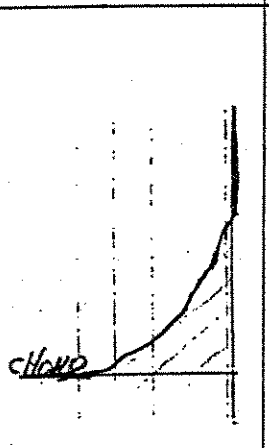
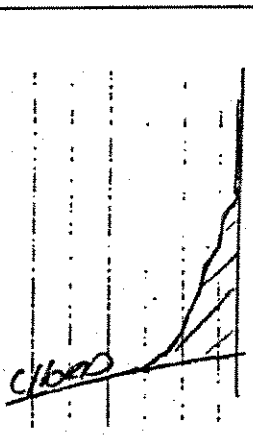
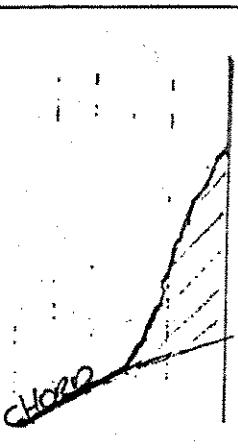
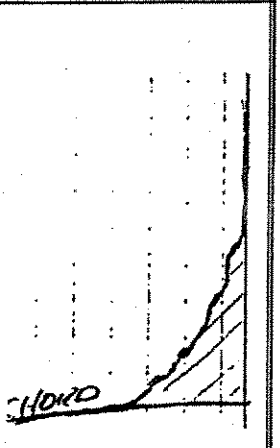
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 24.1 | 23.2 | | 20.8 | 23.7 | 24.7 | | 26.2 |
| $L_{chord}$ | 15.4 | 8.5 | | 6.4 | 14.3 | 9.3 | | 7.3 |

## WELD SHAPE SPECIMEN T1

Intersection between Chord and Brace of T1

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| **C;9** | **I;11** | **S;13** | **I;15** |
|  |  |  |  |

**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

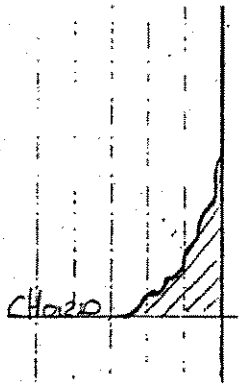
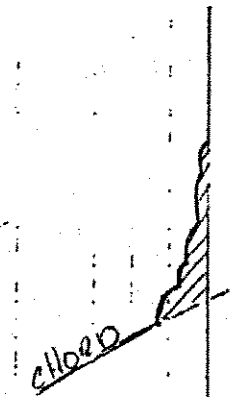
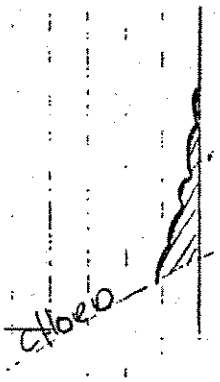
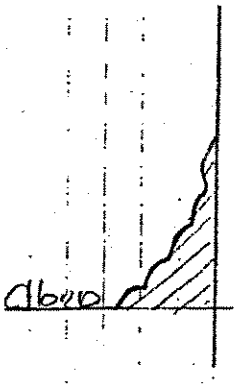
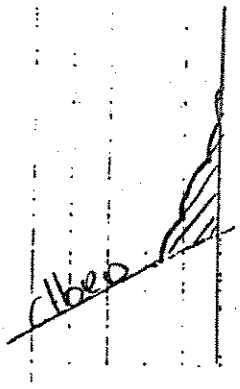
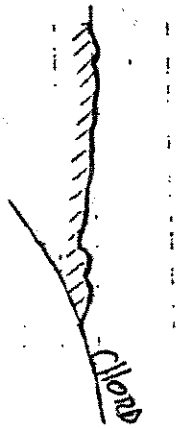
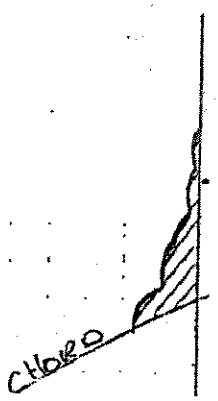
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 20.6 | 23.0 | 22.0 | 20.3 | 22.5 | 22.7 | 27.5 | 25.2 |
| $L_{chord}$ | 18.0 | 12.2 | 17.0 | 14.1 | 20.2 | 13.5 | 14.8 | 17.0 |

## WELD SHAPE SPECIMEN T3

Intersection between Chord and Brace of T3

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  | |  |
| **C;9** | **I;11** | **S;13** | **I;15** |
|  |  |  |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

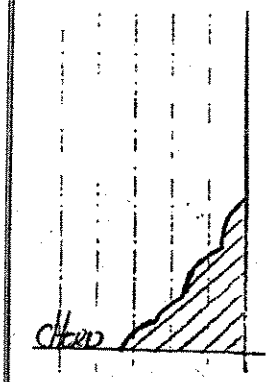
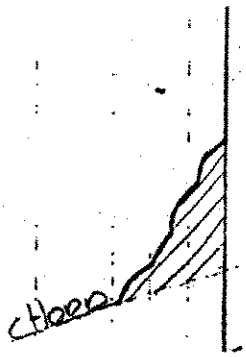
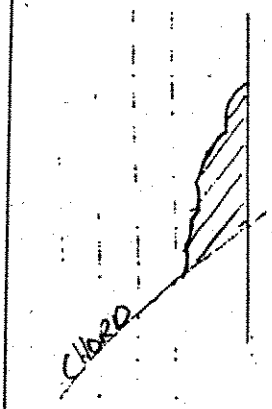
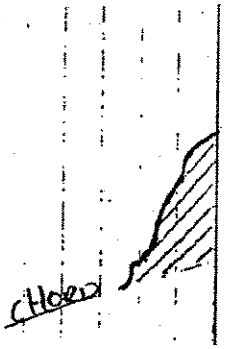
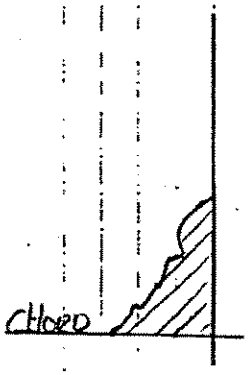
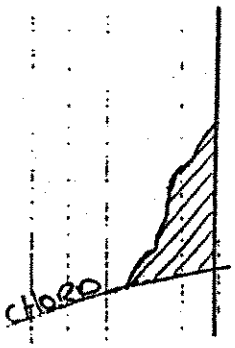
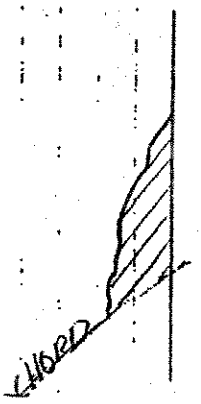
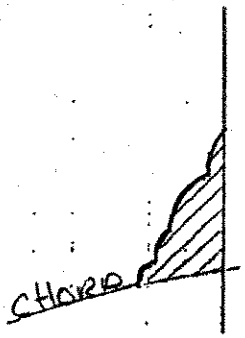
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 23.0 | 22.6 | | 23.6 | 24.6 | 20.7 | | 24.1 |
| $L_{chord}$ | 13.9 | 8.1 | | 7.2 | 14.0 | 8.6 | | 10.0 |

## WELD SHAPE SPECIMEN T5

Intersection between Chord and Brace of T5

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| C;9 | I;11 | S;13 | I;15 |
|  |  |  |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

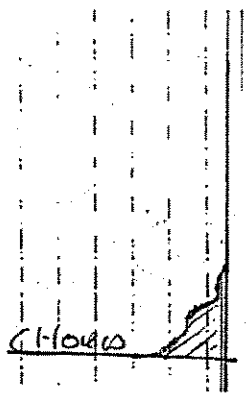
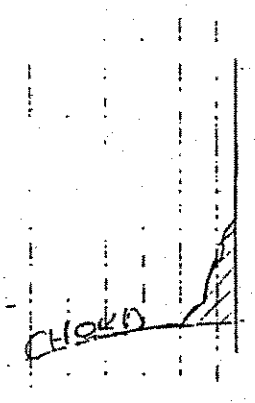
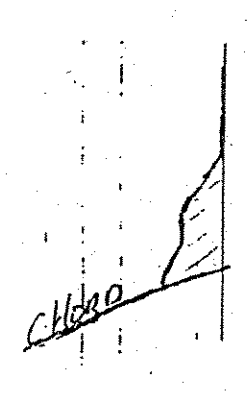
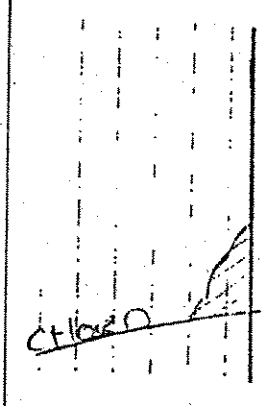
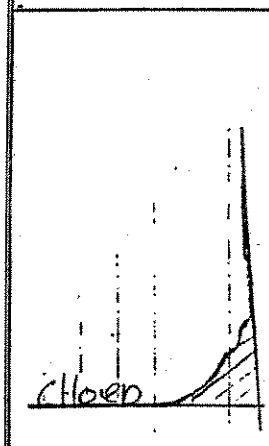
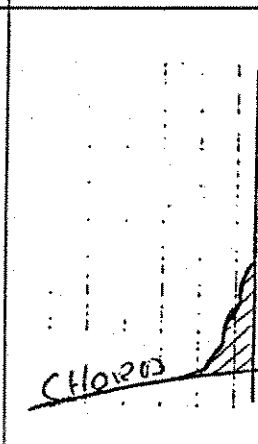
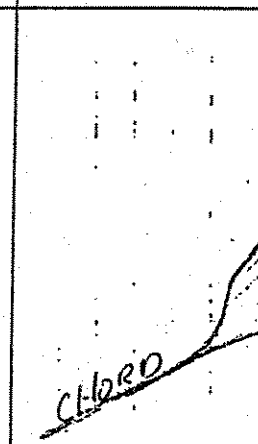
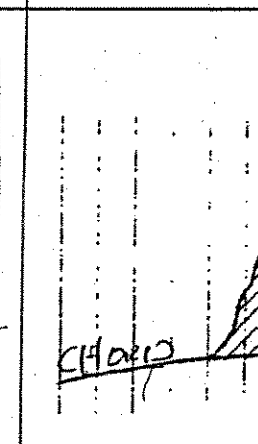
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 21.7 | 18.6 | 20.0 | 18.2 | 20.0 | 20.2 | 22.6 | 19.9 |
| $L_{chord}$ | 17.7 | 15.7 | 11.4 | 13.5 | 14.3 | 13.0 | 10.5 | 12.1 |

## WELD SHAPE SPECIMEN T7

Intersection between Chord and Brace of T7

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  |  |  |
| C;9 | I;11 | S;13 | I;15 |
|  |  |  |  |

**Key** :-

I - Intermediate weld position
C - Crown weld position
S - Saddle weld position

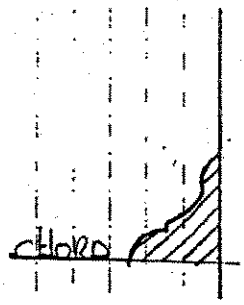
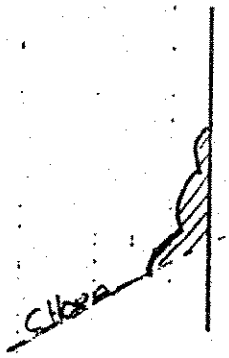
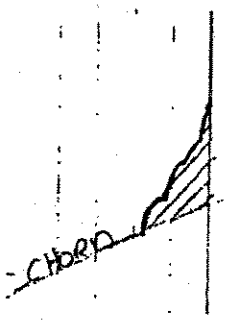
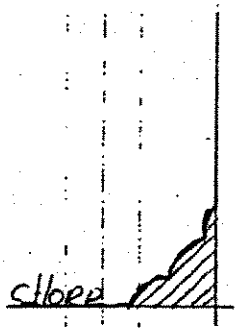
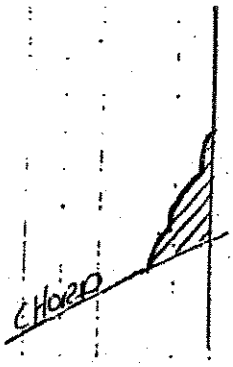
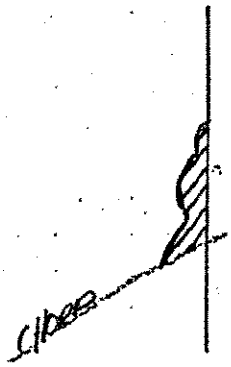
Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 13.6 | 14.3 | 16.5 | 12.7 | 12.8 | 14.9 | 14.0 | 15.4 |
| $L_{chord}$ | 11.9 | 7.7 | 8.6 | 8.6 | 13.1 | 7.6 | 11.8 | 9.9 |

## WELD SHAPE SPECIMEN T9

Intersection between Chord and Brace of T9

| C;1 | I;3 | S;5 | I;7 |
|---|---|---|---|
|  |  | |  |
| C;9 | I;11 | S;13 | I;15 |
|  |  | |  |

**Key** :-

| | | |
|---|---|---|
| I | - | Intermediate weld position |
| C | - | Crown weld position |
| S | - | Saddle weld position |

Refer to Figure A.1 for corresponding numbered weld shape locations.

Weld shape dimensions [mm]

| **Weld leg length** | **C,1** | **I,3** | **S,5** | **I,7** | **C,9** | **I,11** | **S,13** | **I,15** |
|---|---|---|---|---|---|---|---|---|
| $L_{brace}$ | 15.6 | 16.1 | | 14.7 | 15.0 | 15.6 | | 17.2 |
| $L_{chord}$ | 13.1 | 9.5 | | 10.4 | 12.2 | 9.5 | | 7.7 |

# Specification and Procedure for Grouting of Test Specimens

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"This document has been prepared by MSL Engineering Limited for the Participants of the Joint Industry Project on Development of Grouted Tubular Joint Technology for Offshore Strengthening and Repair. This document is confidential to the Participants in the Joint Industry Project, under the terms of their contract for participation in the project"

**JOINT INDUSTRY PROJECT**

# DEVELOPMENT OF GROUTED TUBULAR JOINT TECHNOLOGY FOR OFFSHORE STRENGTHENING AND REPAIR

## SPECIFICATION AND PROCEDURE FOR GROUTING OF TEST SPECIMENS

**DOC REF C14100R006 Rev 2 JANUARY 1995**

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| NUMBER | DETAILS OF REVISION |
|---|---|
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| 1 | Final Issue, December 1994 |
| 2 | Issued with minor amendments, January 1995 |

JOINT INDUSTRY PROJECT

# DEVELOPMENT OF GROUTED TUBULAR JOINT TECHNOLOGY FOR OFFSHORE STRENGTHENING AND REPAIR

## SPECIFICATION AND PROCEDURE FOR GROUTING OF TEST SPECIMENS

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## 1. INTRODUCTION

This document presents a detailed procedure for the chord grout-filling of tubular joints to be used as test specimens in a Joint Industry Project (JIP) on the 'Development of Grouted Tubular Joint Technology for Offshore Strengthening and Repair'.

The tubular joints will be used for SCF tests for the ungrouted and grouted conditions. Once tests are complete for the ungrouted condition, grouting can commence in accordance with the specifications and procedure presented within this document.

This document makes reference to the following American Standards:-

- API Specification 10 - Specification for Materials and Testing for Well Cements
- ASTM Specification C150 - Standard Specification for Portland Cement.

## 2. GROUT FILLING OF SPECIMENS

### 2.1 General Description

The tubular joint specimens comprise T joints and DT/X Joints. Each of the tubular joints is to be chord grout-filled for SNCF measurements and subsequent ultimate strength tests.

The tubular joints are to be cast with the chord placed in the vertical position. This will ensure complete grout filling of the chord and reduce the number of parameters to consider when interpreting test results. Displacement of water whilst grout filling will be a requirement since grouting offshore in strengthening/repairs will also displace water.

The grout mix and testing specification shall conform to Section 3 herein.

Tubular joints shall be grout-filled using the same procedures, mixing equipment and facilities. This will ensure consistency in grout mix, test cube preparation, grout placement and grout strength once cured. Grout mixer capacity may limit the number of specimens that can be grouted in one operation. In this case measures will be taken to ensure consistency between batches.

### 2.2 Grout Connections

Grout connection arrangements are shown in Figures 2.1 and 2.2.

For each tubular joint, one inlet shall be provided at the base of the vertical chord and the outlet in either the top cover plate or the top of the chord. The operation of all valves shall be checked, prior to fitting.

All connections shall be well greased. The grout inlet shall be attached to the chord at the grout inlet point. All grout shall be input through this point.

### 2.3 Filling Chord with Water

The vertical chord members shall be filled with water prior to grout filling. Any leaks identified shall be remedied prior to the grouting operation.

### 2.4 Grouting the Tubular Joints

This operation shall follow immediately after successful filling of the chord with water.



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2.4.1 Mix grout

Grout shall be mixed to a specific gravity of 2.02 ± 0.02 for Oilwell or Portland cement (see Section 3.2 for cement specification). Confirmation of the specific gravity shall be carried out using a pressurised mud-balance. If acceptable, samples will be taken for grout cubes. If the specific gravity is not within the limits specified above, grout shall be mixed until desired density is achieved. Samples for grout cubes will then be taken.

See Section 3 for mixing, sampling and testing of grout.

2.4.2 Grouting operation

- Ensure grout inlet hose is free of any obstructions, 'kinks' or 'crimps' when connected to test specimen.
- Open inlet valves.
- Begin pumping grout through the inlet hose. Pump continuously.
- When good consistency grout flows from the chord outlet point, continue pumping slowly, and take density measurements.
- Following confirmation of satisfactory grout densities, stop pumping, and close inlet valves. Disconnect quick release coupling and reconnect to next specimen. Open inlet valves and begin pumping. When good consistency grout flows from the outlet point, continue pumping slowly and take density measurement. Repeat this cycle for subsequent tubular joints.
- Once all tubular joints are grouted, disconnect grout inlet at quick release union connection, open valve connected to inlet line and pump water down the grout inlet line, to flush.

2.4.3 Short stoppages

If a blockage occurs during grouting of a specimen, adopt the following procedure:-

Stop pumping

Close both inlet valves at inlet point. Disconnect grout line at quick release union connection.

Open grout line inlet valve.

Begin pumping slowly.

If no grout flows, change the inlet grout hose. If grout flows, the problem is not in the hose. Therefore, it is a fault either in the inlet valve, the outlet hose or in the tubular specimen.

Reconnect grout inlet and open inlet valve. Begin pumping. If grout does not flow, then a piece of wire inserted through the outlet point may prove successful in removing any blockage there. If grout still does not flow then the blockage is at the inlet valve or within the tubular specimen and the following course of action may be taken.

- Abort the grouting operation, remedy the fault at the inlet valve or from within the tubular specimen and instigate flushing procedures.

Specimens successfully grouted prior to blockage, shall remain grouted.

2.4.4 Longer stoppages

In the event of a grout flow problem or delay during grouting operations of a specimen, where such delays may exceed one hour, chord flushing procedures must start.

2.4.5 Flushing procedure

Flushing must be carried out if grout flow problems occur which may delay operations for more than one hour.

Specimens successfully grouted prior to blockage, shall remain grouted.

(i) Disconnect grout inlet at quick release union connection, open valve connected to inlet hose and flush inlet hose. Wash out grout mixer.

(ii) Inspect all valves and 'rake out' where necessary.

(iii) Flush specimen through either the inlet or outlet points.

## 2.5 Post Grouting Procedure

Immediately after satisfactory grouting, close all inlet valves, disconnect at quick release union, open valve connected to inlet hose and flush the grout inlet line.

## 3. GROUT MIX AND TESTING SPECIFICATION

### 3.1 Design Requirements

All grout to be used shall achieve a minimum compressive strength of 41.4 $N/mm^2$ (6000 psi) at 28 days.

### 3.2 Materials

Cement shall be class 'B' or 'G', moderate sulphate resistant oilwell cement to API Spec 10. Alternatively, moderate sulphate resisting Portland Cement to ASTM C150 Type II may be substituted and used in the same proportions.

Manufacturer's Certificates of Quality with respect to the materials shall be obtained before use.

The cement shall be stored and transported in accordance with the manufacturer's instructions. The cement shall be kept free from moisture at all times and a careful visual inspection of all materials shall be made prior to their use to ensure their suitability for the work. Cement shall be stored out of direct sunlight.

Drinkable water is to be used for mixing, with a temperature not exceeding 20°C.

### 3.3 Grout Mix Proportions

The grout mix shall be as follows:-

| | | |
|---|---|---|
| Cement | - | 100 parts by weight |
| Water | - | 34 parts by weight (for Oilwell or Portland cement) |

NO ADMIXTURES SHALL BE PERMITTED

Figure 3 shows the rate of gain of strength for Oilwell 'B' grouts cured at 8°C (46°F). This is based upon extensive onshore and offshore test data collated from many years of grouting experience.

## 3.4 Grout Mixing

The grout shall be mixed using a suitable mixer (eg. Craelius CEMIX 175 or Colcrete DD4). An initial mix shall be made to line the mixer. This mix shall be discarded. Subsequent batches shall be used to grout the specimens. All batches shall be mixed for a minimum of two minutes.

## 3.5 Slurry Density Measurements

Measurement of slurry densities shall be made using a pressurised slurry density balance in the manner described in API Spec. 10. Particular attention shall be paid to ensure that the external surfaces of the balance are cleaned and dried after filling and prior to balancing.

Grout shall not be pumped until a specific gravity within the limits noted in Section 2.4.1 is achieved. Slurry densities shall be checked immediately prior to pumping and throughout the grouting operations, sampling every batch mixed.

## 3.6 Cube Preparation and Curing

Cubes shall be cast in accordance with API Spec. 10, with the exception that 75mm (3 inch) cubes shall be used.

The cubes shall be placed in polyurethane bags immediately after casting and cured with and at the same temperature as the grouted joints until removed for demolding or testing.

Cubes may be demolded after 24 hours, during which the time out of the bags must not be more than 1 (one) hour. At or after 28 days, cubes shall be weighed, measured and crushed within 30 minutes of removal from the bags.

The cube age shall be measured from the time the cube is struck to the time it is crushed.

Each cube shall be marked with a unique mark and this mark correlated with the batch number, specimen number, time and date made and slurry density, as measured by a pressurised slurry density balance.

## 3.7 Sampling and Testing Procedures

For each batch 4 N° cubes are to be cast from the grout in the grout mixer.

From the 4 N° cubes cast from the grout in the mixer, three (3 N°) cubes shall be tested at 28 days.

An additional 8 N° cubes are to be cast for each grouted test specimen.

From the 8 N° cubes cast with each specimen;

Three (3 N°) cubes shall be tested at or after 28 days on the commencement of SCF tests on each grouted specimen.

Three (3 N°) cubes shall be tested at the commencement of ultimate strength tests on each grouted specimen.

Each cube shall be crushed in accordance with the procedure given in API Spec. 10, except that the rate of loading will be no faster than 14 $N/mm^2$ per min (2000 $lbf/in^2$ per min).

The following information shall be collated for the final report:-

- Test specimen identification reference
- Cube identification reference
- Time and date of casting of the cube and test specimen
- Time and date of testing of the cube and test specimen
- Fluid grout density at time of casting
- Weight and density of the grout cube
- Failure load and cube strength
- Average strength from 3 N° cubes tested at 28 days.
- Average strength from the 3 N° cubes tested at commencement of SCF test on each grouted specimen and 3 N° cubes tested at commencement of ultimate strength test on each grouted specimen.

## 3.8 Equipment

Calibration certificates are to be supplied for all weighing, balancing, cube making and cube crushing equipment.

# Grout Material Properties

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## Grout material properties

The compressive strength from the cubes were determined and are presented in the following tables.

| Batch | Duration* | Specimen | Cube 1 | Cube 2 | Cube 3 | Average |
|---|---|---|---|---|---|---|
| Taken | 7 days | - | 24.9 | 23 | - | 23.95 |
| from | 14 days | - | 34.6 | 33 | - | 33.80 |
| mix | 21 days | - | 45 | 35 | - | 40.00 |
| drum | 28 days | - | 36.3 | 33.7 | - | 35.00 |
| 1 | " | S-'D1/D2 | 40.7 | 45.2 | 51.4 | 45.77 |
| 2 | " | T5 | 29.7 | 26.2 | 44.9 | 33.60 |
| 3 | " | T3 DT4 | 36.3 | 36 | 34.2 | 35.50 |
| 4 | " | T9 DT8 | 33.8 | 46 | 31.4 | 37.07 |
| 5 | " | DT2 DT5 | 42.3 | 33 | 42 | 39.10 |
| 6 | " | T7 T1 | 40.1 | 28.6 | 43.8 | 37.50 |
| 7 | " | DT9 DT6 | 33.7 | 36.6 | 34.7 | 35.00 |
| 8 | " | DT3 | 39.8 | 46.3 | 29.6 | 38.57 |

*after chord filling

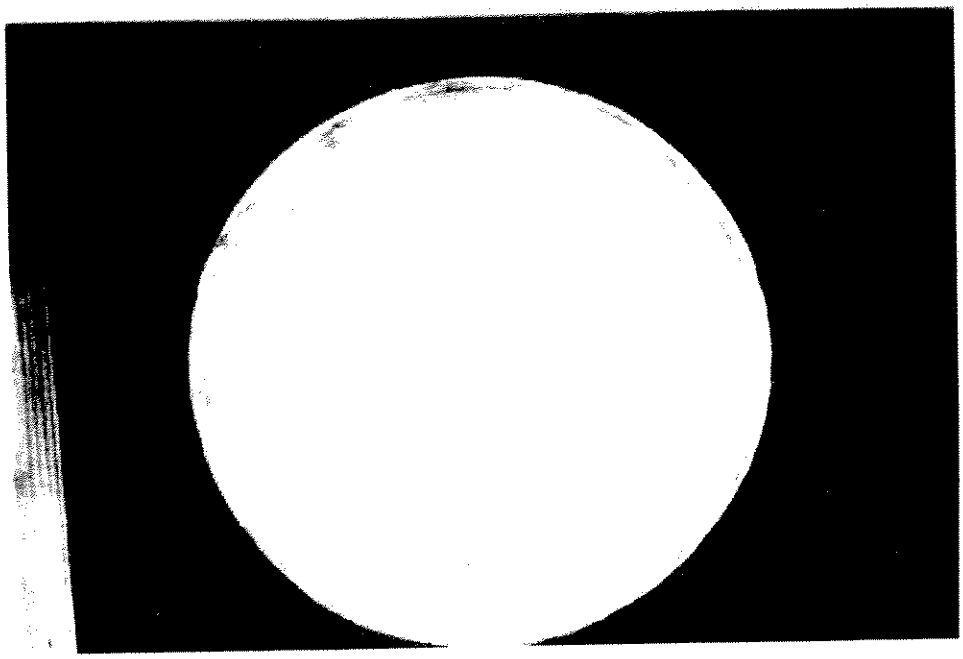
**Compressive strength per batch after 7, 14, 21 and 28 days from chord filling (MPa)**

| Specimen | Cube 1 | Cube 2 | Cube 3 | Cube 4 | Average |
|---|---|---|---|---|---|
| T1 | 37.00 | 33.60 | 39.30 | 46.30 | 39.05 |
| T3 | 34.50 | 37.60 | 38.30 | 38.20 | 37.15 |
| T5 | 34.60 | 41.90 | 49.00 | 47.50 | 43.25 |
| T7 | 52.40 | 39.20 | 38.60 | 44.00 | 43.55 |
| T9 | 42.90 | 43.80 | 42.30 | 37.00 | 41.50 |
| DT2 | 41.40 | 46.30 | 46.30 | 47.90 | 45.48 |
| DT3 | 53.70 | 52.30 | 50.00 | 48.90 | 51.23 |
| DT4 | 42.10 | 39.40 | 33.80 | 41.00 | 39.08 |
| DT5 | 47.30 | 52.90 | 49.10 | 48.40 | 49.43 |
| DT6 | 47.50 | 43.70 | 43.10 | 45.50 | 44.95 |
| DT8 | 53.50 | 51.90 | 33.00 | 49.30 | 46.93 |
| DT9 | 52.80 | 50.50 | 41.30 | 51.60 | 49.05 |

**Compressive strength at time of specimen ultimate test (MPa)**

**Cross sections**

During the grouting procedure two additional tubes (D=350 mm) were grouted and cured inside the laboratory (i.e. D1 & D2). Approximately 6 months after grouting one tube was sliced. The results are presented in the following figures. Cracks within the grout core were not observed. The gap between grout and inside wall of the tubular was extremely fine.



**Cross section of tube fully grouted**



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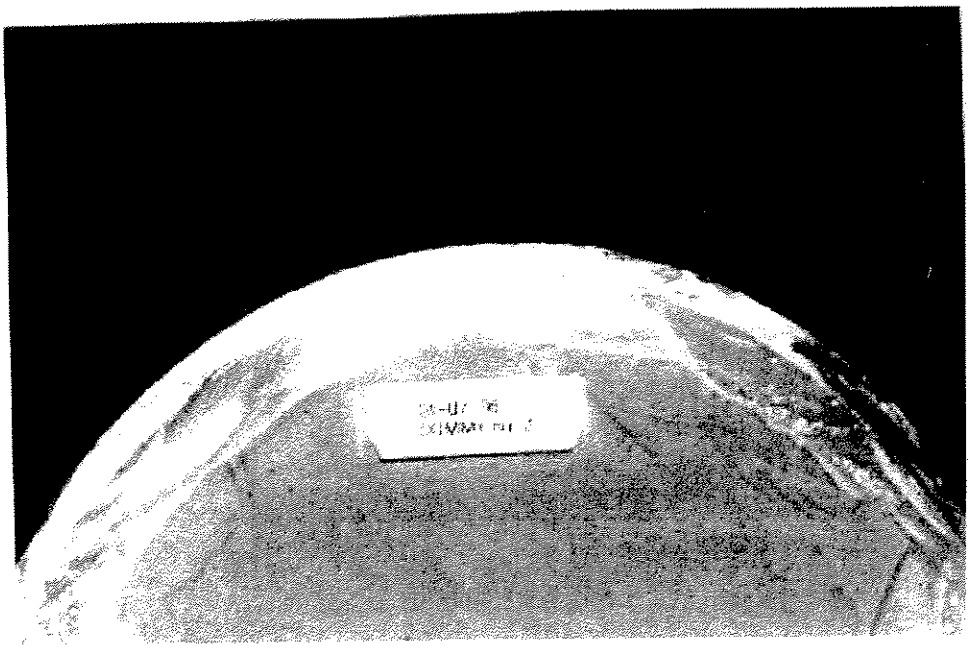

**Magnified cross section of tube fully grouted**



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# Tubular Section Material Properties

**Tensile coupon tests.**

The material properties from the certificates are listed in Table 1. For each reference pipe, two tensile coupon tests have been performed. The yield stress and tensile strength (ultimate strength) are listed in Table 2 and Table 3 respectively.

| SPECIMEN | CERTIFICATE | | | |
|---|---|---|---|---|
| | Yield str. Brace | Yield str. Chord | Ult. str. Brace | Ult. str. Chord |
| T1 | 376 | 318 | 538 | 415 |
| T3 | 397 | 318 | 596 | 415 |
| T5 | 365 | 345 | 503 | 435 |
| T7 | 278 | 351 | 395 | 539 |
| T9 | 351 | 351 | 539 | 539 |
| DT2 | 355 | 318 | 490 | 415 |
| DT3 | 397 | 318 | 596 | 415 |
| DT4 | 395 | 345 | 534 | 435 |
| DT5 | 365 | 345 | 503 | 435 |
| DT6 | 360 | 345 | 575 | 435 |
| DT8 | 353 | 351 | 470 | 539 |
| DT9 | 351 | 351 | 539 | 539 |

**Table 1:Material properties from certificates (MPa).**

| SPECIMEN | LOCATION | REFERENCE TUBULAR | YIELD STRESS | | | ULTIMATE | | |
|---|---|---|---|---|---|---|---|---|
| | | | a | b | average | a | b | average |
| DT4 | Braces | 1 | 330.4 | 348.4 | 339.4 | 547.0 | 553.0 | 550.0 |
| T1 | Brace | 2 | 327.4 | 368.1 | 347.8 | 520.9 | 519.6 | 520.3 |
| T3 | Brace | 3 | 382.5 | 384.0 | 383.3 | 579.9 | 583.3 | 581.6 |
| T7 | Brace | 4 | 263.8 | 227.5 | 245.7 | 409.3 | 400.9 | 405.1 |
| DT8 | Braces | 5 | 315.5 | 341.8 | 328.7 | 511.6 | 508.2 | 509.9 |
| DT4,DT5,DT6,T5 | Chord | 6 | 332.2 | 336.8 | 334.5 | 426.4 | 427.5 | 427.0 |
| DT8,DT9,T7,T9 | Chord | 7-1 | 347.8 | 340.1 | 344.0 | 507.3 | 499.5 | 503.4 |
| DT9,T9 | Braces | 7-2 | 319.9 | 318.5 | 319.2 | 496.2 | 495.0 | 495.6 |
| DT2,DT3,T1,T3 | Chord | 8 | 346.0 | 371.0 | 358.5 | 502.8 | 511.4 | 507.1 |
| DT5,T5 | Braces | 9-1 | 276.2 | 301.5 | 288.9 | 409.9 | 406.1 | 408.0 |
| | Braces | 9-2 | 275.9 | 280.9 | 278.4 | 408.2 | 407.7 | 408.0 |
| DT6 | Brace | 10 | 365.8 | 361.0 | 363.4 | 508.1 | 508.3 | 508.2 |
| DT2 | Brace | 11 | 489.0 | 502.4 | 495.7 | 571.2 | 599.2 | 585.2 |

**Table 2: Tensile coupon tests on pipe sections (MPa)**

| SPECIMEN | COUPON | | | |
|---|---|---|---|---|
| | Yield Str. Brace | Yield Str. Chord | Ult. Str. Brace | Ult. Str. Chord |
| T1 | 347.8 | 358.5 | 520.3 | 507.1 |
| T3 | 383.3 | 358.5 | 281.6 | 507.1 |
| T5 | 283.6 | 334.5 | 408.0 | 427.0 |
| T7 | 245.6 | 331.6 | 405.1 | 499.5 |
| T9 | 331.6 | 331.6 | 599.5 | 499.5 |
| DT2 | 495.7 | 358.5 | 585.2 | 507.1 |
| DT3 | 383.3 | 358.5 | 581.6 | 507.1 |
| DT4 | 339.4 | 334.5 | 550.0 | 427.0 |
| DT5 | 283.6 | 334.5 | 408.0 | 427.0 |
| DT6 | 363.4 | 334.5 | 508.2 | 427.0 |
| DT8 | 328.5 | 331.6 | 509.9 | 499.5 |
| DT9 | 331.6 | 331.6 | 499.5 | 499.5 |

**Table 3: Tensile coupon tests referenced by test speciment (MPa)**



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# Measured Dimensions

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**Piece Reference.**

For the fabrication of test specimens, eleven different tubulars were used. From each type of tube the wall thickness was measured at four points around the circumference. The pieces used for the fabrication of the test specimens are shown in Table 1.

| DT- / T-Joint | Brace 1 | Chord | Brace 2 |
|---|---|---|---|
| DT2 | 11 | 8 | 11 |
| DT3 | 3 | 8 | 3 |
| DT4 | 1 | 6 | 1 |
| DT5 | 9 | 6 | 9 |
| DT6 | 10 | 6 | 10 |
| DT8 | 5 | 7 | 5 |
| DT9 | 7 | 7 | 7 |
| T1 | 2 | 8 | - |
| T3 | 3 | 8 | - |
| T5 | 9 | 6 | - |
| T7 | 4 | 7 | - |
| T9 | 7 | 7 | - |

**Table 1: Tubular references for specimens.**

**Wall thickness measurements.**

The wall thickness measurements were taken using a micrometer. Table 2 presents reference tubular wall thickness measurements taken before specimen fabrication. Table 3 presents sample specimen wall thicknesses measured at one chord end after fabrication. The wall thickness for the braces and chords were also checked by Ultra Sonic measurements and are presented in Tables 4 and 5 respectively.

| | | MEASUREMENTS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | End 1 | | | | End 2 | | | |
| Tub. Ref. | Average | 0° | 90° | 180° | 270° | 0° | 90° | 180° | 270° |
| 1 | 9.95 | 9.52 | 9.64 | 10.41 | 10.02 | 9.69 | 10.51 | 10.37 | 9.40 |
| 2 | 16.32 | 16.22 | 16.68 | 16.38 | 16.16 | 16.51 | 16.54 | 16.11 | 15.96 |
| 3 | 16.10 | 17.17 | 17.39 | 15.11 | 15.19 | 17.25 | 16.54 | 15.15 | 15.02 |
| 4 | 8.31 | 8.46 | 8.30 | 8.23 | 8.03 | 8.30 | 8.19 | 8.16 | 8.77 |
| 5 | 7.88 | 7.82 | 7.98 | 8.17 | 7.69 | 7.90 | 7.76 | 8.12 | 7.57 |
| 6 | 10.25 | 10.05 | 10.60 | 9.97 | 10.47 | 10.03 | 10.78 | 10.42 | 9.66 |
| 7 | 7.90 | 8.05 | 8.44 | 7.74 | 7.54 | 8.03 | 7.93 | 7.68 | 7.78 |
| 7 | | 8.06 | 7.50 | 7.43 | 7.78 | 7.65 | 7.90 | 7.99 | 7.70 |
| 7 | | 7.91 | 8.38 | 7.84 | 7.75 | 8.14 | 8.00 | 8.09 | 8.19 |
| 8 | 16.74 | 16.92 | 17.32 | 16.00 | 16.45 | 16.57 | 17.34 | 16.97 | 16.52 |
| 8 | | 17.14 | 17.39 | 16.84 | 17.00 | 16.08 | 16.26 | 16.59 | 16.40 |
| 9 | 9.82 | 9.58 | 9.84 | 10.00 | 9.85 | 9.81 | 9.68 | 9.85 | 9.96 |
| 10 | 9.62 | 9.63 | 9.36 | 9.75 | 9.97 | 9.57 | 9.39 | 9.85 | 9.43 |
| 11 | 15.76 | 15.88 | 15.45 | 15.70 | 16.24 | 15.86 | 15.65 | 15.62 | 15.68 |

**Table 2: Wall thickness measurements using a micrometer.**

| | | | MEASUREMENTS | | | |
|---|---|---|---|---|---|---|
| Tub. Ref. | Part | Average | 0° | 90° | 180° | 270° |
| 6 | DT4-C | 10.38 | 10.95 | 10.70 | 9.94 | 9.94 |
| 6 | DT5-C | 9.80 | 9.49 | 9.78 | 10.10 | 9.84 |
| 6 | DT6-C | 10.33 | 10.11 | 10.67 | 10.02 | 10.51 |
| 7 | DT8-C | 8.13 | 8.46 | 8.01 | 7.98 | 8.05 |
| 7 | DT9-C | 7.48 | 7.17 | 7.83 | 7.42 | 7.50 |
| 8 | DT2-C | 16.32 | 15.77 | 16.50 | 17.25 | 15.77 |
| 8 | DT3-C | 16.00 | 15.80 | 16.29 | 15.52 | 16.37 |

**Table 3: Sample specimen measurements using a micrometer**

| | | | MEASUREMENTS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Brace 1 | | | | Brace 2 | | | |
| Tub. Ref. | Part | Average | 0° | 90° | 180° | 270° | 0° | 90° | 180° | 270° |
| 1 | DT4-B | 10.19 | 10.40 | 9.80 | 9.90 | 10.60 | 10.00 | 9.60 | 10.40 | 10.80 |
| 2 | T1-B | 16.40 | 15.80 | 16.40 | 17.00 | 16.40 | | | | |
| 3 | DT3-B | 16.46 | 15.90 | 16.10 | 17.20 | 16.20 | 15.40 | 17.40 | 17.10 | 16.40 |
| 3 | T3-B | 15.88 | 16.80 | 15.20 | 15.10 | 16.40 | | | | |
| 4 | T7-B | 8.30 | 8.50 | 8.40 | 8.30 | 8.00 | | | | |
| 5 | DT8-B | 8.18 | 8.40 | 8.30 | 8.20 | 7.80 | 8.40 | 8.10 | 8.10 | 8.10 |
| 7 | DT9-B | 7.91 | 7.80 | 7.70 | 8.00 | 8.10 | 7.80 | 7.80 | 8.10 | 8.00 |
| 7 | T9-B | 8.10 | 8.10 | 8.00 | 8.00 | 8.30 | | | | |
| 9 | DT5-B | 9.98 | 10.40 | 10.00 | 9.70 | 9.90 | 9.80 | 10.20 | 10.00 | 9.80 |
| 9 | T5-B | 9.98 | 10.10 | 9.90 | 9.90 | 10.00 | | | | |
| 10 | DT6-B | 9.93 | 9.80 | 9.90 | 10.20 | 9.70 | 10.00 | 10.00 | 9.60 | 10.20 |
| 11 | DT2-B | 16.05 | 16.20 | 16.00 | 16.30 | 16.50 | 16.00 | 15.40 | 15.80 | 16.20 |

**Table 4: Brace ultra sonic wall thickness measurements**

| | | | MEASUREMENTS | | | |
|---|---|---|---|---|---|---|
| Tub. Ref. | Part | Average | 0° | 90° | 180° | 270° |
| 6 | T5-C | 9.83 | 9.70 | 9.80 | 9.40 | 10.40 |
| 6 | DT4-C | 10.53 | 10.50 | 9.90 | 11.20 | 10.50 |
| 6 | DT5-C | 9.73 | 9.90 | 9.40 | 9.90 | 9.70 |
| 6 | DT6-C | 10.57 | 10.90 | 10.10 | 10.70 | |
| 7 | DT8-C | 8.25 | 8.50 | 8.50 | 8.00 | 8.00 |
| 7 | DT9-C | 7.78 | 8.10 | 7.70 | 7.30 | 8.00 |
| 7 | T7-C | 8.05 | 7.70 | 8.10 | 8.10 | 8.30 |
| 7 | T9-C | 8.25 | 7.90 | 7.90 | 8.50 | 8.70 |
| 8 | DT2-C | 16.18 | 16.30 | 16.00 | 16.10 | 16.30 |
| 8 | DT3-C | 17.03 | 17.00 | 17.50 | 16.70 | 16.90 |
| 8 | T1-C | 16.23 | 15.80 | 16.10 | 16.50 | 16.50 |
| 8 | T3-C | 16.05 | 15.90 | 16.10 | 15.70 | 16.50 |

**Table 5: Chord ultra sonic wall thickness measurements**

**Diameter Measurements.**

The diameter measurements for the reference tubulars and for the specimens (chord and braces) are presented in Table 6 , Table 7 and Table 8.

| | | MEASUREMENTS | | | |
|---|---|---|---|---|---|
| | | End 1 | | End 2 | |
| Tub. Ref. | Average | 0°/180° | 90°/270° | 0°/180° | 90°/270° |
| 1 | 168.73 | 169.40 | 168.60 | 168.10 | 168.80 |
| 2 | 167.83 | 167.90 | 167.90 | 167.70 | 167.80 |
| 3 | 407.28 | 406.90 | 407.30 | 407.90 | 407.00 |
| 4 | 168.53 | 167.70 | 169.30 | 168.40 | 168.70 |
| 5 | 273.35 | 273.30 | 273.70 | 272.70 | 273.70 |
| 6 | 406.45 | 407.00 | 405.10 | 406.20 | 407.50 |
| 7 | 406.80 | 406.30 | 407.30 | 405.30 | 408.30 |
| 8 | 406.56 | 406.60 | 406.60 | 406.60 | 406.70 |
| 8 | | 406.70 | 406.10 | 406.30 | 406.90 |
| 9 | 273.20 | 273.00 | 273.20 | 273.40 | 273.20 |
| 10 | 407.48 | 408.60 | 406.50 | 406.90 | 407.90 |
| 11 | 273.00 | 272.90 | 273.10 | 273.10 | 272.90 |

**Table 6: Specimen diameter measurements**

| | | | MEASUREMENTS | | | |
|---|---|---|---|---|---|---|
| | | | End 1 | | End 2 | |
| Tub. Ref. | Part | Average | 0°/180° | 90°/270° | 0°/180° | 90°/270° |
| 1 | DT4-B | 168.41 | 168.49 | 168.71 | 168.31 | 168.12 |
| 2 | T1-B | 167.80 | 167.90 | 167.70 | | |
| 3 | DT3-B | 407.03 | 405.00 | 405.30 | 408.90 | 408.90 |
| 3 | T3-B | 406.75 | 405.50 | 408.00 | | |
| 4 | T7-B | 168.30 | 168.70 | 167.90 | | |
| 5 | DT8-B | 273.08 | 274.80 | 273.50 | 272.30 | 271.70 |
| 7 | DT9-B | 403.45 | 404.10 | 402.80 | | |
| 7 | T9-B | 407.50 | 405.80 | 409.20 | | |
| 9 | DT5-B | 273.22 | 274.13 | 274.11 | 272.23 | 272.42 |
| 9 | T5-B | 273.60 | 274.40 | 272.80 | | |
| 10 | DT6-B | 407.73 | 404.60 | 404.90 | 411.40 | 410.00 |
| 11 | DT2-B | 273.19 | 272.98 | 272.57 | 273.87 | 273.33 |

**Table 7: Brace diameter measurements**

| | | | MEASUREMENTS | |
|---|---|---|---|---|
| **Tub. Ref.** | **Part** | **Average** | **0°/180°** | **90°/270°** |
| 6 | DT4-C | 407.05 | 404.10 | 410.00 |
| 6 | DT5-C | 406.78 | 411.58 | 401.98 |
| 6 | DT6-C | 407.86 | 408.16 | 407.55 |
| 6 | T5-C | 407.10 | 404.60 | 409.60 |
| 7 | DT8-C | 406.90 | 415.60 | 398.20 |
| 7 | DT9-C | 407.77 | 411.76 | 403.77 |
| 7 | T7-C | 407.80 | 405.60 | 410.00 |
| 7 | T9-C | 407.65 | 407.50 | 407.80 |
| 8 | T1-C | 407.70 | 407.20 | 408.20 |
| 8 | T3-C | 407.20 | 407.30 | 407.10 |
| 8 | DT2-C | 406.76 | 407.96 | 405.56 |
| 8 | DT3-C | 405.90 | 406.50 | 405.30 |

**Table 8: Chord diameter measurements**

**Summary of measured dimensions.**

Table 9 presents a summary of the average actual dimensions.

| | CHORD | | | BRACE | | |
|---|---|---|---|---|---|---|
| **SPECIMEN** | **Tub. Ref.** | **D** | **T** | **Tub. Ref.** | **d** | **t** |
| T1 | 8 | 406.78 | 16.39 | 2 | 167.81 | 16.32 |
| T3 | 8 | 406.78 | 16.39 | 3 | 407.02 | 16.1 |
| T5 | 6 | 407.05 | 10.19 | 9 | 273.34 | 9.82 |
| T7 | 7 | 406.96 | 7.86 | 4 | 168.41 | 8.31 |
| T9 | 7 | 406.96 | 7.86 | 7 | 406.96 | 7.86 |
| DT2 | 8 | 406.78 | 16.39 | 11 | 273.09 | 15.76 |
| DT3 | 8 | 406.78 | 16.39 | 3 | 407.02 | 16.1 |
| DT4 | 6 | 407.05 | 10.19 | 1 | 168.57 | 9.95 |
| DT5 | 6 | 407.05 | 10.19 | 9 | 273.34 | 9.82 |
| DT6 | 6 | 407.05 | 10.19 | 10 | 407.6 | 9.61 |
| DT8 | 7 | 406.96 | 7.86 | 5 | 273.21 | 7.88 |
| DT9 | 7 | 406.96 | 7.86 | 7 | 406.96 | 7.86 |

**Table 9: Summary of averaged measured dimensions**



MSL

# Specification for the Strain Gauging of Test Specimens

# 1. INTRODUCTION

The objective of the grouted joints test programme was to measure Strain Concentration Factors (SNCFs) for both ungrouted and grouted T and DT tubular joints of various geometries.

There are three aspects which need consideration to enable the correct measurement of strains. These are as follows:

- adequate number of strain gauges and correct positioning to enable extrapolation of strain to the weld toe.
- adequate number of strain gauges around the circumferential chord/brace intersect to enable interpolation to the hot spot location.
- rosette gauges are required to enable measurement of principal strains when the principal stress direction is not orthogonal to the chord/brace intersect.

These aspects are addressed in Section 2 which also details current guidance for gauge positions to enable measurement of strains and extrapolation to the weld toe. The strain gauge instrumentation used for the test specimens is contained in Section 3.

## 2. BACKGROUND

Determination of SNCFs at the weld toe can be carried out using either linear or non-linear extrapolation of strain measurements. Either method should not be influenced by the stress concentrating effect of the weld. With the exception of K and Y joints (ungrouted), determination of SNCFs in tubular joints can generally be carried out using linear extrapolation. Due to the variation in gauge locations between each method, it is therefore important to either predict which type of extrapolation is required or make provision for both.

Very little test data exist for SNCF measurements on grouted tubular joints. The type of extrapolation to be used is not known and therefore it is necessary to bound the possibility of either linear or non-linear extrapolation.

Table 1 presents recommended strain gauge positions for the test matrix based on the following guidance:

- HSE and ECSC give essentially the same guidance for strain gauge locations to enable linear extrapolation to the weld toe.
- DNV recommends the first strip gauge location to be 0.25T (where T is the thickness of the tubular) from the weld toe with four subsequent strip gauges at 2 mm centres, for linear extrapolation.
- R S Puthli, et al, give guidance for gauge locations to enable either linear or non-linear extrapolation.

All the above state that the first strip gauge should be located a minimum 4 mm from the weld toe in order to avoid the concentrating effect of the weld. The guides attempt to position the gauges in the region of stress linearity, between the region effected by the weld and where the stress becomes equal to the nominal stress.

Puthli, et al, go one step further by giving guidance for the location of gauges to enable non-linear extrapolation, ie. quadratic extrapolation.

For any of the above methods, extrapolation is made from several strain gauge measurements. This, therefore, influences the number of gauges required to enable either linear or non-linear extrapolation.

Specimen T7, used for the preload investigations and the first specimen to be tested in the grouted condition, was instrumented with addtitional rosette gauges. The resultant SCF/SNCF ratio results were utilised to determine the requirement for the use of rosette gauges on the remaining grouted specimems.

## 3. STRAIN GAUGING

Table 2 presents the strip gauge positions utilised on the specimens to enable either linear or non-linear extrapolation. The gauge region, ie. between the first and last gauges, was sufficient to adequately bound the variation and increase in stress towards the chord/brace intersect. A sufficient number of gauges were mounted, as shown in Figures 1 and 2, on both the brace and chord side of the intersection to enable determination of the hot spot location.

The first, third and fifth gauges of the strip gauge were connected. The first gauge position was 0.4 x (T or t) but not less than 4mm. The HSE recommended first gauge position coincided or was interpolated within the strip gauge. A single gauge was placed at the HSE recommended last gauge position. The second and fourth gauges in each strip acted as contingency, should one of the nominated gauges fail to function.

For both joint types all $\beta = 1.0$ specimens were gauged with additional intermediate gauges between crown and saddle positions on the chord side and brace side. Specimen T9 was instrumented with a full set of gauges on the chord side and brace side. This enabled an assessment of strain distribution around the intersect.

Additional strain gauges are provided on the brace(s) to enable measurement of nominal axial strains and brace bending strains. Depending on joint type, gauges were placed as follows:

T joints

Saddle and crown locations on both the chord and brace as shown in Figure 1. Additionally for $\beta = 1.0$ test specimens, two diagonally opposite quadrants were instrumented with a further two sets of gauges, at equal spacing, on both the chord and brace.

DT joints

Saddle and crown locations on both the chord and brace as shown in Figure 2. Additionally for $\beta = 1.0$ test specimens, the appropriate quadrant on each brace was instrumented with a further two sets of gauges, at equal spacing, on both the chord and brace.

Table 1 presents the strain gauge positions for the first and last gauges for each of the specimens. These positions include the HSE recommendations and bound the gauge positions from the other formulations.

| Specimen Ident. | Geometry | | | | Chord Crown | | | | | | Chord Saddle | | | | | | Brace Crown | | | | | | Brace Saddle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | T | d | t | 1st | | | Last | | | 1st | | | Last | | | 1st | | | Last | | | 1st | | | Last | | |
| | (mm) | (mm) | (mm) | (mm) | HSE | DnV | Puthli | HSE | DnV | Puthli | HSE | DnV | Puthli | HSE | DnV | Puthli | HSE | DnV | Puthli | HSE | DnV | Puthli | HSE | DnV | Puthli | HSE | DnV | Puthli |
| T1 | 406.4 | 16 | 168.30 | 16.0 | 7.3 | 4.0 | 6.4 | 18.3 | 12.0 | 16.0 | 7.3 | 4.0 | 6.4 | 17.7 | 12.0 | 16.0 | 7.3 | 4.0 | 6.4 | 23.9 | 12.0 | 16.0 | 7.3 | 4.0 | 6.4 | 23.9 | 12.0 | 16.0 |
| T3 | 406.4 | 16 | 406.40 | 16.0 | 11.4 | 4.0 | 6.4 | 22.8 | 12.0 | 16.0 | 11.4 | 4.0 | 6.4 | 17.7 | 12.0 | 16.0 | 11.4 | 4.0 | 6.4 | 37.1 | 12.0 | 16.0 | 11.4 | 4.0 | 6.4 | 37.1 | 12.0 | 16.0 |
| T5 | 406.4 | 10 | 273.00 | 10.0 | 7.4 | 4.0 | 4.0 | 16.3 | 12.0 | 10.0 | 7.4 | 4.0 | 4.0 | 17.7 | 12.0 | 10.0 | 7.4 | 4.0 | 4.0 | 24.0 | 12.0 | 10.0 | 7.4 | 4.0 | 4.0 | 24.0 | 12.0 | 10.0 |
| T7 | 406.4 | 7.9 | 168.30 | 8.0 | 5.2 | 4.0 | 4.0 | 12.9 | 12.0 | 8.7 | 5.2 | 4.0 | 4.0 | 17.7 | 12.0 | 8.7 | 5.2 | 4.0 | 4.0 | 16.9 | 12.0 | 8.7 | 5.2 | 4.0 | 4.0 | 16.9 | 12.0 | 8.7 |
| T9 | 406.4 | 7.9 | 406.40 | 7.9 | 8.0 | 4.0 | 4.0 | 16.0 | 12.0 | 8.7 | 8.0 | 4.0 | 4.0 | 17.7 | 12.0 | 8.7 | 8.0 | 4.0 | 4.0 | 26.0 | 12.0 | 8.7 | 8.0 | 4.0 | 4.0 | 26.0 | 12.0 | 8.7 |
| DT2 | 406.4 | 16 | 273.00 | 16.0 | 9.3 | 4.0 | 6.4 | 20.6 | 12.0 | 16.0 | 9.3 | 4.0 | 6.4 | 17.7 | 12.0 | 16.0 | 9.3 | 4.0 | 6.4 | 30.4 | 12.0 | 16.0 | 9.3 | 4.0 | 6.4 | 30.4 | 12.0 | 16.0 |
| DT3 | 406.4 | 16 | 406.40 | 16.0 | 11.4 | 4.0 | 6.4 | 22.8 | 12.0 | 16.0 | 11.4 | 4.0 | 6.4 | 17.7 | 12.0 | 16.0 | 11.4 | 4.0 | 6.4 | 37.1 | 12.0 | 16.0 | 11.4 | 4.0 | 6.4 | 37.1 | 12.0 | 16.0 |
| DT4 | 406.4 | 10 | 168.30 | 10.0 | 5.8 | 4.0 | 4.0 | 14.5 | 12.0 | 10.0 | 5.8 | 4.0 | 4.0 | 17.7 | 12.0 | 10.0 | 5.8 | 4.0 | 4.0 | 18.9 | 12.0 | 10.0 | 5.8 | 4.0 | 4.0 | 18.9 | 12.0 | 10.0 |
| DT5 | 406.4 | 10 | 273.00 | 10.0 | 7.4 | 4.0 | 4.0 | 16.3 | 12.0 | 10.0 | 7.4 | 4.0 | 4.0 | 17.7 | 12.0 | 10.0 | 7.4 | 4.0 | 4.0 | 24.0 | 12.0 | 10.0 | 7.4 | 4.0 | 4.0 | 24.0 | 12.0 | 10.0 |
| DT6 | 406.4 | 10 | 406.40 | 9.5 | 8.8 | 4.0 | 4.0 | 17.8 | 12.0 | 10.0 | 8.8 | 4.0 | 4.0 | 17.7 | 12.0 | 10.0 | 8.8 | 4.0 | 4.0 | 28.6 | 12.0 | 10.0 | 8.8 | 4.0 | 4.0 | 28.6 | 12.0 | 10.0 |
| DT8 | 406.4 | 7.9 | 273.00 | 7.8 | 6.5 | 4.0 | 4.0 | 14.5 | 12.0 | 8.7 | 6.5 | 4.0 | 4.0 | 17.7 | 12.0 | 8.7 | 6.5 | 4.0 | 4.0 | 21.2 | 12.0 | 8.7 | 6.5 | 4.0 | 4.0 | 21.2 | 12.0 | 8.7 |
| DT9 | 406.4 | 7.9 | 406.40 | 7.9 | 8.0 | 4.0 | 4.0 | 16.0 | 12.0 | 8.7 | 8.0 | 4.0 | 4.0 | 17.7 | 12.0 | 8.7 | 8.0 | 4.0 | 4.0 | 26.0 | 12.0 | 8.7 | 8.0 | 4.0 | 4.0 | 26.0 | 12.0 | 8.7 |

**Strip Gauge Locations (in mm) from weld toe defining regions of strain linearity**

**Formulation :-**

| Location | Gauge Position | HSE / ECSC | DnV | Puthli | |
|---|---|---|---|---|---|
| | | | | Linear | Quadratic |
| Chord Crown | 1st | $0.2(rt)^{0.5}$ | 0.25T | 0.4T | 0.4T |
| | Last | $0.4(rtRT)^{0.25}$ | 0.25T + 8mm | 1.0T | 1.4T |
| Chord Saddle | 1st | $0.2(rt)^{0.5}$ | 0.25T | 0.4T | 0.4T |
| | Last | $(5/360)2\pi R$ | 0.25T + 8mm | 1.0T | 1.4T |
| Brace Crown | 1st | $0.2(rt)^{0.5}$ | 0.25t | 0.4t | 0.4t |
| | Last | $0.65(rt)^{0.5}$ | 0.25t + 8mm | 1.0t | 1.4t |
| Brace Saddle | 1st | $0.2(rt)^{0.5}$ | 0.25t | 0.4t | 0.4t |
| | Last | $0.65(rt)^{0.5}$ | 0.25t + 8mm | 1.0t | 1.4t |

**Note :-**

For all , 1st point , 4mm minimum from weld toe

For Puthli :- Linear extrapolation for (T or t) < 10mm Last position = 4mm + 0.6 x (T or t)

Quadratic extrapolation for (T or t) < 10mm Last position = 4mm + 1.0 x (T or t)

For quadratic extrapolation, sufficient number of data points are required between 1st and last

The above dimensions are based on nominal tubular thickness. Gauge positions based on actual tubular thickness may vary.

## Table 1 Guidance for location of strain gauges to enable extrapolation of strains to chord/brace wall intersect

| Specimen Ident. | Geometry | | | | Chord Crown | | Chord Saddle | | Brace Crown | | Brace Saddle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | T | d | t | 1st | Last | 1st | Last | 1st | Last | 1st | Last |
| T1 | 406.4 | 16 | 168.30 | 16.0 | 6.4 | 18.3 | 6.4 | 17.7 | 6.4 | 23.9 | 6.4 | 23.9 |
| T3 | 406.4 | 16 | 406.40 | 16.0 | 6.4 | 22.8 | 6.4 | 17.7 | 6.4 | 37.1 | 6.4 | 37.1 |
| T5 | 406.4 | 10 | 273.00 | 10.0 | 4.0 | 16.3 | 4.0 | 17.7 | 4.0 | 24.0 | 4.0 | 24.0 |
| T7 | 406.4 | 7.9 | 168.30 | 8.0 | 4.0 | 12.9 | 4.0 | 17.7 | 4.0 | 16.9 | 4.0 | 16.9 |
| T9 | 406.4 | 7.9 | 406.40 | 7.9 | 4.0 | 16.0 | 4.0 | 17.7 | 4.0 | 26.0 | 4.0 | 26.0 |
| DT2 | 406.4 | 16 | 273.00 | 16.0 | 6.4 | 20.6 | 6.4 | 17.7 | 6.4 | 30.4 | 6.4 | 30.4 |
| DT3 | 406.4 | 16 | 406.40 | 16.0 | 6.4 | 22.8 | 6.4 | 17.7 | 6.4 | 37.1 | 6.4 | 37.1 |
| DT4 | 406.4 | 10 | 168.30 | 10.0 | 4.0 | 14.5 | 4.0 | 17.7 | 4.0 | 18.9 | 4.0 | 18.9 |
| DT5 | 406.4 | 10 | 273.00 | 10.0 | 4.0 | 16.3 | 4.0 | 17.7 | 4.0 | 24.0 | 4.0 | 24.0 |
| DT6 | 406.4 | 10 | 406.40 | 9.5 | 4.0 | 17.8 | 4.0 | 17.7 | 4.0 | 28.6 | 4.0 | 28.6 |
| DT8 | 406.4 | 7.9 | 273.00 | 7.8 | 4.0 | 14.5 | 4.0 | 17.7 | 4.0 | 21.2 | 4.0 | 21.2 |
| DT9 | 406.4 | 7.9 | 406.40 | 7.9 | 4.0 | 16.0 | 4.0 | 17.7 | 4.0 | 26.0 | 4.0 | 26.0 |

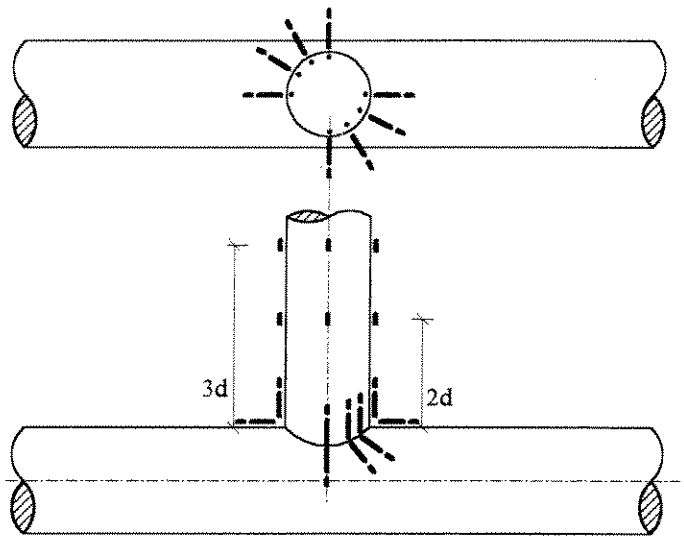
Notes :-

(1) All dimensions given in (mm)
(2) First gauge position based on 0.4 times wall thickness with a minimum of 4mm
(2) Last gauge position based on HSE formulation

The above dimensions are based on nominal tubular dimensions. Gauge positions based on actual tubular dimensions may vary.

**Table 2 Strain gauge locations for 1st and last gauges**

HSE




Note: Intermediate gauges @ 30° & 60° positions on both braces are for $\beta = 1.0$ joints.

Key:

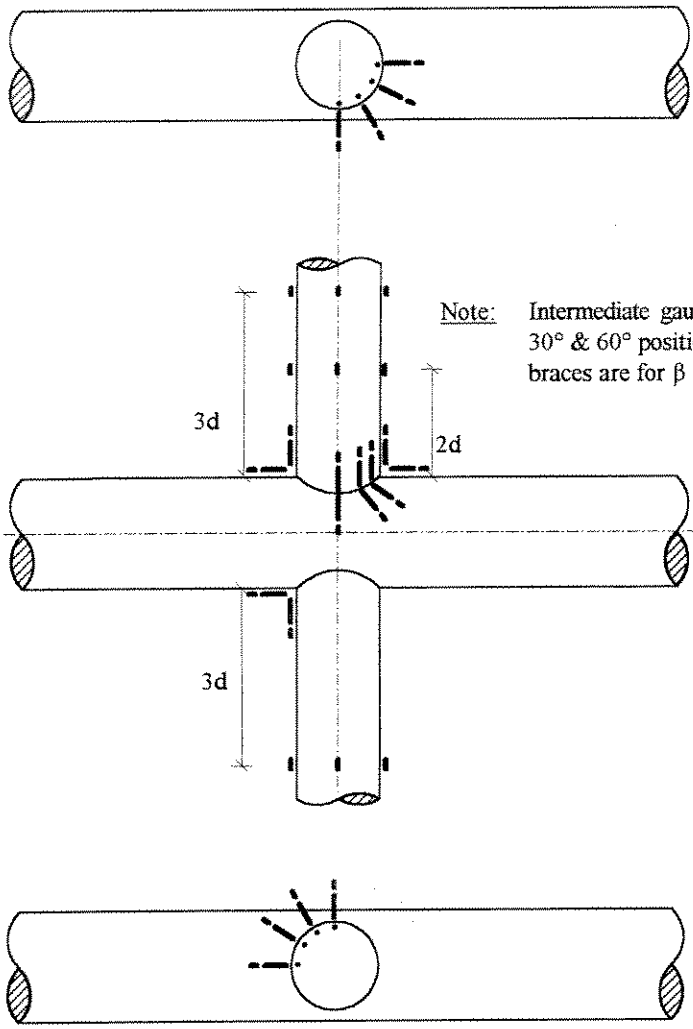
- Strip gauge, consisting of 5 strain gauges, 3 of which are used
- Single strain gauge

№: of gauges per specimen

| Location | $\beta = 0.41$ & 0.67 | | $\beta = 1.0$ | |
|---|---|---|---|---|
| | Strip gauges | Single gauges | Strip gauges | Single gauges |
| **Brace** | 4 | 12 | (+4) 8 | (+4) 16 |
| **Chord** | 4 | 4 | (+4) 8 | (+4) 8 |
| **Total** | 8 | 16 | (+8) 16 | (+8) 24 |

Note: The first $\beta = 1.0$ joint tested was gauged with a full compliment of gauges, by providing additional intermediate gauges.( )

**Figure 1: Strain Gauging of T-joint Specimen**




Key:

- Strip gauge, consisting of 5 strain gauges, 3 of which are used
- Single strain gauge

Nº: of gauges per specimen

| Location | β = 0.41 & 0.67 | | β = 1.0 | |
|---|---|---|---|---|
| | Strip gauges | Single gauges | Strip gauges | Single gauges |
| **Braces** | 4 | 16 | (+6) 8 | (+6) 20 |
| **Chord** | 4 | 4 | (+6) 8 | (+6) 8 |
| **Total** | 8 | 20 | (+12) 16 | (+12) 28 |

Note: The first β = 1.0 joint tested was gauged around the full compressive side of brace & gauged around the full tensile side of the other brace for I.P.B.

**Figure 2: Strain Gauging of DT-joint Specimen**

# Strain Gauge Positions

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**Nominal distance from weld toe to strain gauges for SNCF measurement.**

Strips with five strain gauges, followed by a single strain gauge at the HSE recommended last gauge position, were placed at predefined positions in order to determine a Strain Concentration Factor (SNCF). The distance between the five gauges on the strip was 2 mm. In the following text, the distance between the weld toe and the first gauge on the strip is denoted by $l_{r,min}$ and the distance between the weld toe and the last (single) strain gauge by $l_{r,max}$ . The first, third and fifth single element strain gauges of the strip gauge and the last single strain gauge were used for interpolation and extrapolation of SNCFs. The nominal positions of the strain gauges used to measure the SNCFs at certain locations are based on the average dimensions of the test specimens.

The positions used are presented below:

| | | |
|---|---|---|
| CHORD | $l_{r,min}$ = greater of 0.4 T or 4 mm | for (cc), (cs) |
| | $l_{r,max} = 0.4\ (R\ T\ r\ t)^{1/4}$ | for (cc) |
| | $l_{r,max} = R\ \pi\ 5/180$ | for (cs) |
| BRACE | $l_{r,min}$ = greater of 0.4 t or 4 mm | for (bc), (bs) |
| | $l_{r,max} = 0.65\ (r\ t)^{1/2}$ | for (bc), (bs) |

The nominal distances from the weld toe to the first and to the last strain gauges are given in Table 1. The distance of the last strain gauge to the weld toe for the two intermediate positions between crown and saddle, for test specimens T3, T9, DT3, DT6 and DT9, were determined by linear interpolation of the last strain gauge positions for the crown and saddle positions. The distance to the side of the chord for the nominal brace strain gauges are given in Table 2.

The reference numbers for the gauge positions are given in Figure 1.

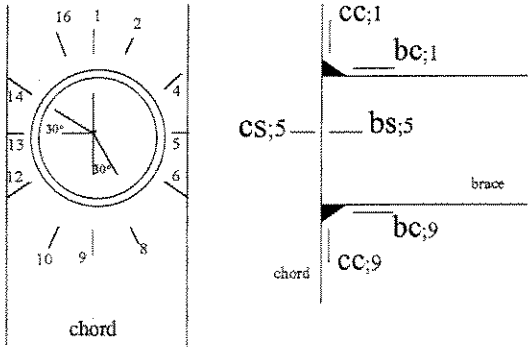


**Figure 1: Position of strain gauges at intersection of brace and chord**

Note: • Strain gauge positions at 30° intervals.
• Locations 2, 4, 6, 8, 10, 12, 14 and 16 represent intermediate gauge positions.

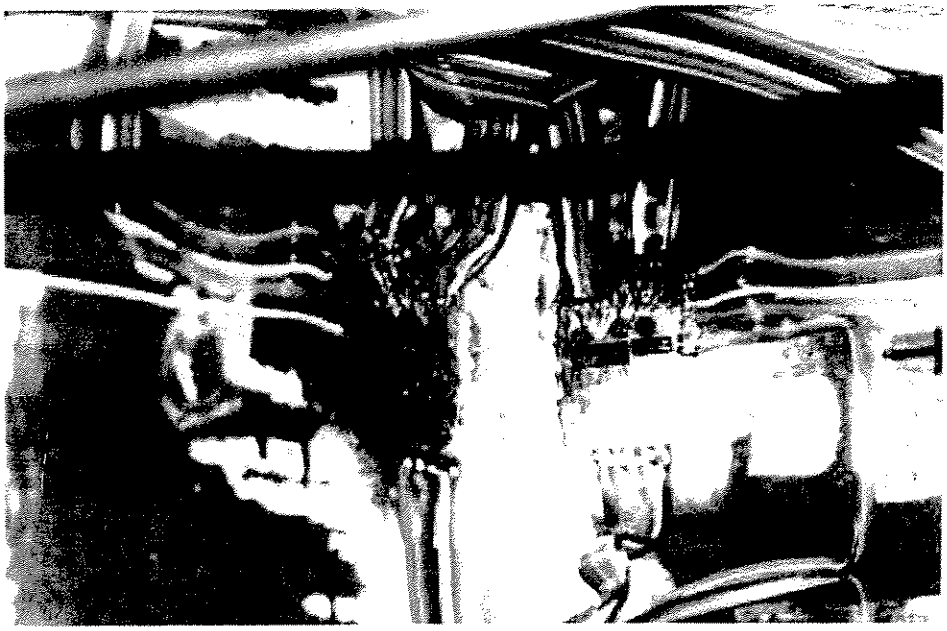

**Figure 2: Strain gauge rosettes placed besides the strip and single gauges (T7)**



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| Specimen | CHORD | | BRACE | | Chord Crown | Chord Saddle | Brace Crown | Brace Saddle |
|---|---|---|---|---|---|---|---|---|
| | Gauge 1 | Gauge 5 | Gauge 1 | Gauge 5 | Gauge 6 | Gauge 6 | Gauge 6 | Gauge 6 |
| T1 | 6.62 | 14.62 | 6.53 | 14.53 | 18.53 | 17.75 | 24.05 | 24.05 |
| T3 | 6.62 | 14.62 | 6.44 | 14.44 | 23.05 | 17.75 | 37.21 | 37.21 |
| T5 | 4.08 | 12.08 | 4.00 | 12.00 | 16.34 | 17.76 | 23.81 | 23.81 |
| T7 | 4.00 | 12.00 | 4.00 | 12.00 | 13.01 | 17.76 | 17.19 | 17.19 |
| T9 | 4.00 | 12.00 | 4.00 | 12.00 | 16.01 | 17.76 | 26.02 | 26.02 |
| DT2 | 6.62 | 14.62 | 6.30 | 14.30 | 20.75 | 17.75 | 30.15 | 30.15 |
| DT3 | 6.62 | 14.62 | 6.44 | 14.44 | 23.05 | 17.75 | 37.21 | 37.21 |
| DT4 | 4.08 | 12.08 | 4.00 | 12.00 | 14.53 | 17.76 | 18.82 | 18.82 |
| DT5 | 4.08 | 12.08 | 4.00 | 12.00 | 16.34 | 17.76 | 23.81 | 23.81 |
| DT6 | 4.08 | 12.08 | 4.00 | 12.00 | 17.96 | 17.76 | 28.76 | 28.76 |
| DT8 | 4.00 | 12.00 | 4.00 | 12.00 | 14.49 | 17.76 | 21.32 | 21.32 |
| DT9 | 4.00 | 12.00 | 4.00 | 12.00 | 16.01 | 17.76 | 26.02 | 26.02 |

Note: Gauge number refer to Figure 3

**Table 1: Distance of strain gauges from weld toe (mm)**

| Brace | First | Second |
|---|---|---|
| 1 | 1.8*d | 3.2*d |
| 2 | 1.8*d | |

Table 2: Distance of circumferencial gauges on brace from joint intersect (mm).

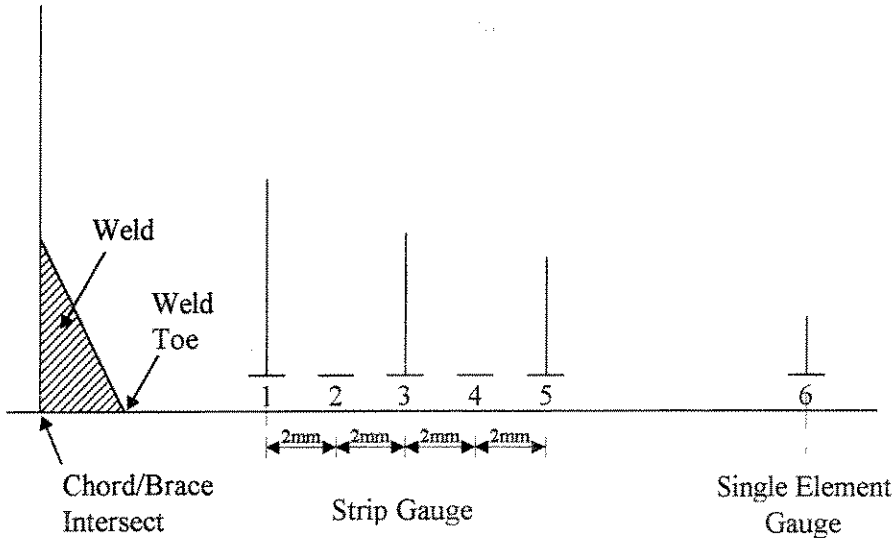



**Figure 3: Diagram indicating position of gauges.**

**Actual distance from weld toe to strain gauges on DT2.**

The actual distance from the weld toe to the first and last strain gauge for test specimen DT2 is given in Table 3.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| S;5,br1 | 6.8 | 19.8 | 6.1 | 29.5 |
| C;9,br1 | 6.3 | 20.3 | 6.4 | 29.6 |
| C;1,br2 | 6.8 | 21.2 | 6.6 | 30.5 |
| S;13,br2 | 6.6 | 19.6 | 6.3 | 28.3 |

**Key:**

| | |
|---|---|
| S: | Saddle |
| C: | Crown |
| #: | Location of gauge |
| br: | Brace |
| I: | Intermediate position |

**Table 3: Actual distance from weld toe to first and last strain gauges on DT2 [mm]**

**Actual distance from weld toe to strain gauges on DT3.**

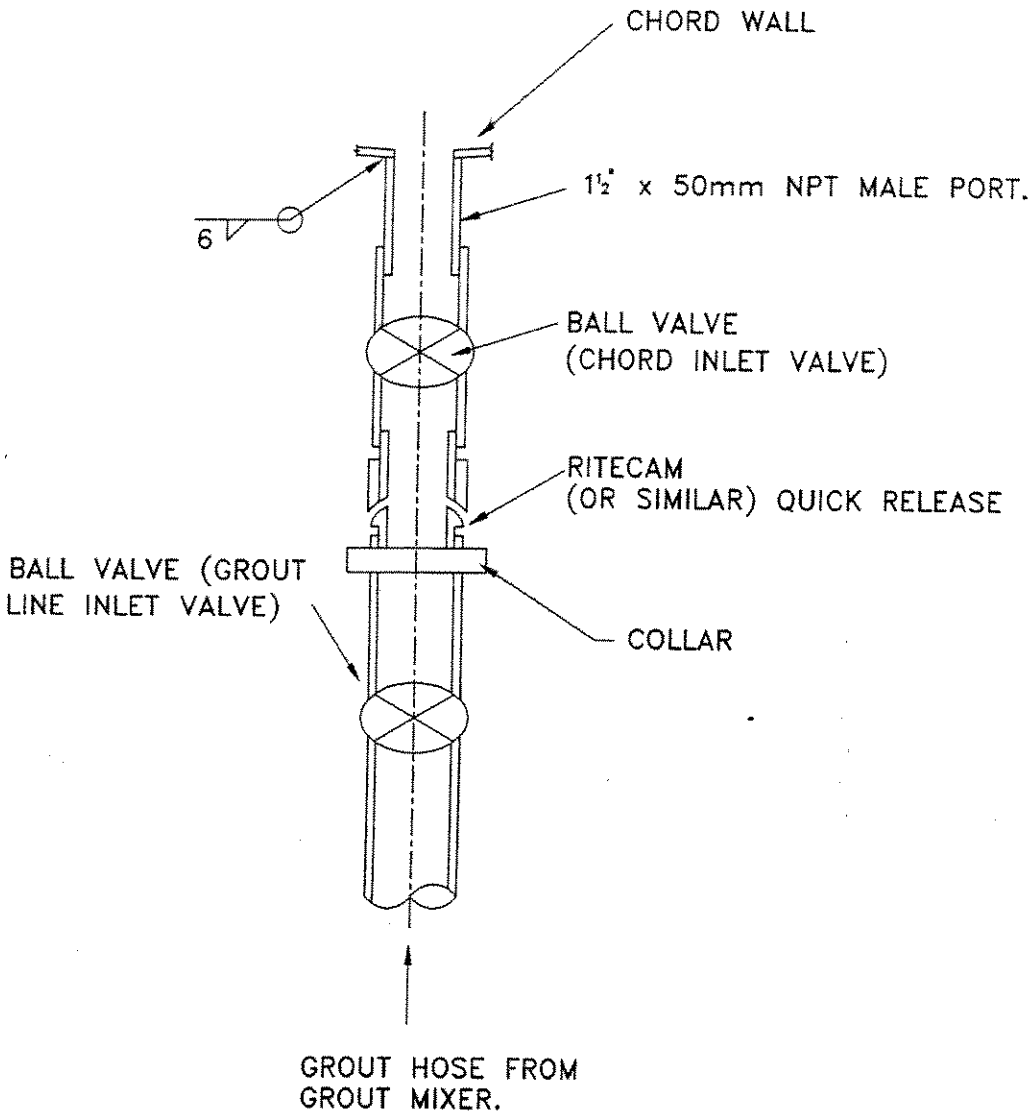
The actual distance from the weld toe to the first and last strain gauge for test specimen DT3 is given in Table 4.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1,br1 | 6.4 | 23.0 | 6.0 | 37.6 |
| I;2,br1 | 6.5 | 21.4 | 6.4 | 37.3 |
| I;4,br1 | 6.4 | 20.3 | 6.5 | 37.4 |
| S;5,br1 | 6.5 | 19.5 | 6.3 | 37.3 |
| C;9,br2 [1] | 6.5 | 22.9 | 6.5 | 37.3 |
| I;10,br2 | 6,6 | 21.3 | 6.5 | 37.2 |
| I,12,br2 | 6.4 | 19.8 | 6.4 | 37.1 |
| S;13,br2 | 6.5 | 19.5 | 6.5 | 37.3 |

1) 3.5 mm from crown

**Table 4: Actual distance from weld toe to first and last strain gauges on DT3 [mm]**

**FIGURES**




NOTES:—
1. DIMENSIONS TO ALLOW CLEARANCES TO OPERATE VALVE HANDLES.
2. ALL VALVES TO BE 1½" BALL VALVES.

FIGURE 2.1. ARRANGEMENT OF CHORD GROUT INLET.

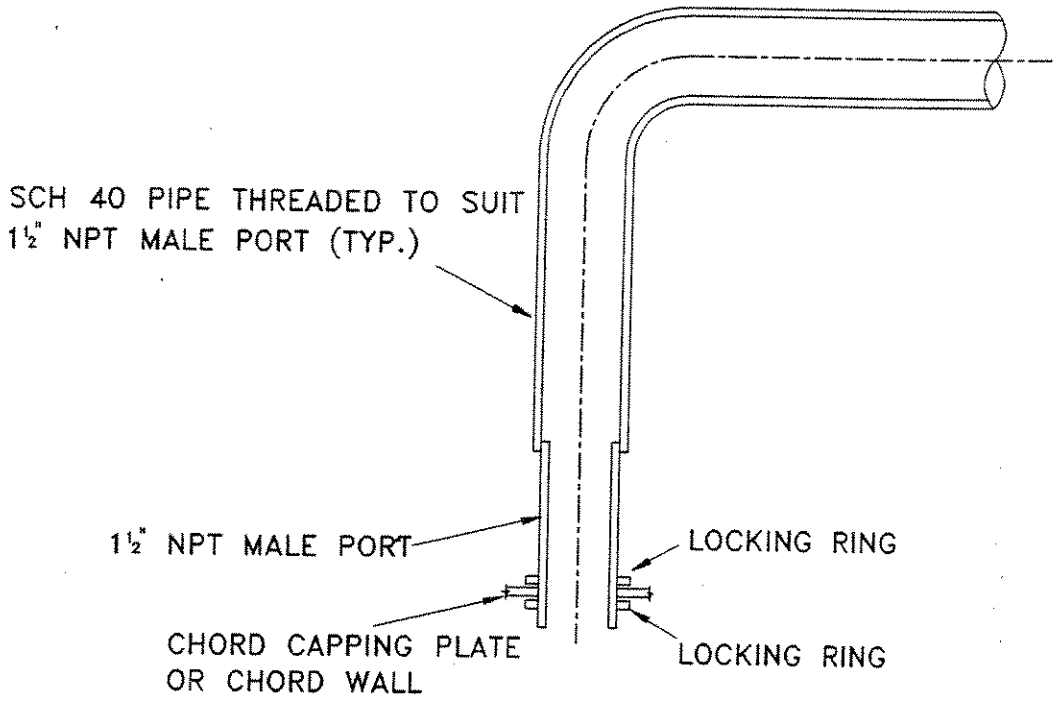



FIGURE 2.2. ARRANGEMENT OF CHORD GROUT OUTLET.

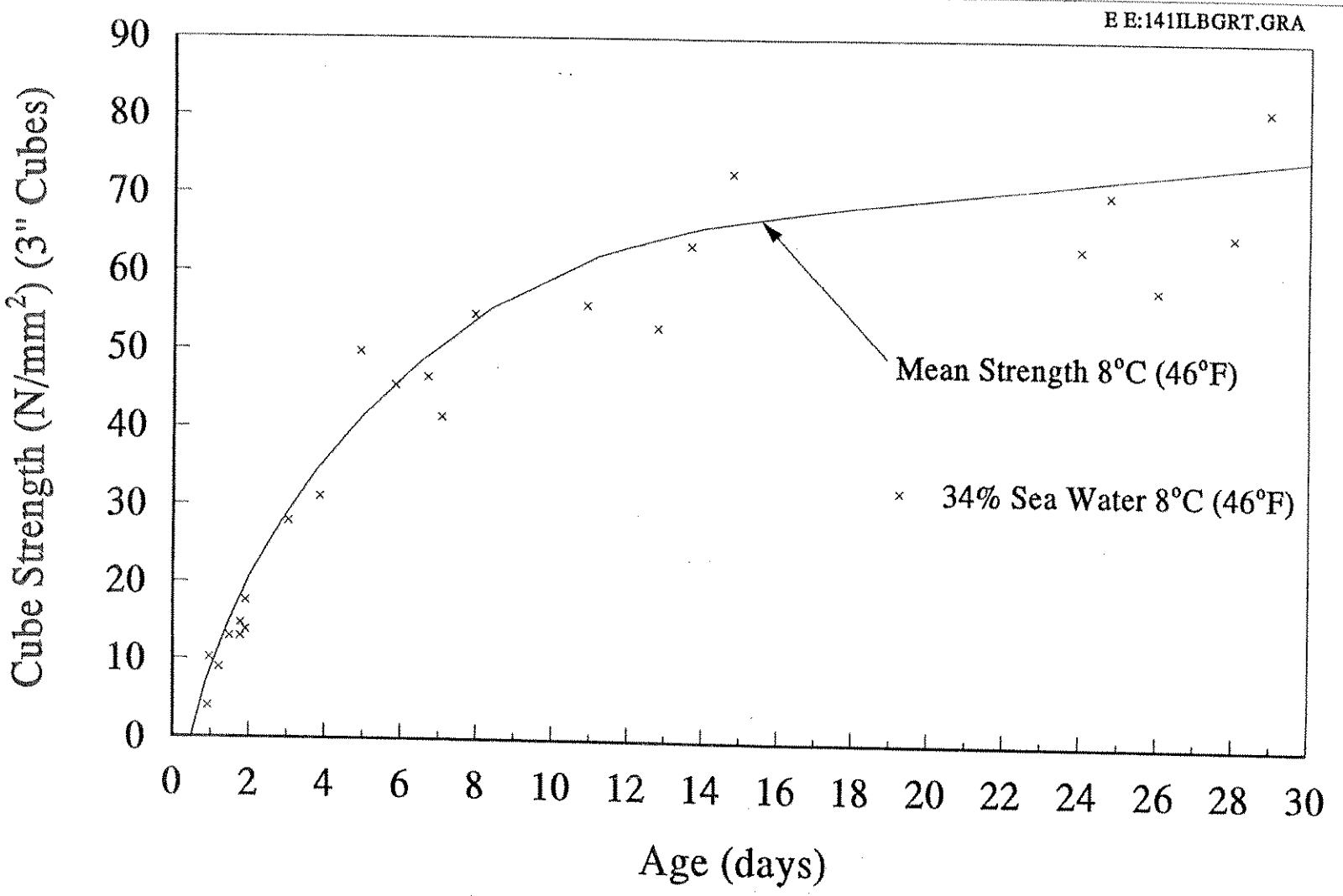



Figure 3 Design Curve for Oilwell B Grout

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**Actual distance from weld toe to strain gauges on DT4.**

The actual distance from the weld toe to the first and last strain gauge for test specimen DT4 is given in Table 5.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1,br1 | 4.1 | 14.5 | 4.1 | 18.8 |
| S;5,br1 | 4.1 | 17.8 | 4.1 | 18.8 |
| C;9,br1 | 4.1 | 14.5 | 4.1 | 18.8 |
| S;13,br1 | 4.1 | 17.8 | 4.1 | 18.8 |
| C;1,br2 | 4.1 | 14.5 | 4.1 | 18.8 |
| S;5,br2 | 4.1 | 17.8 | 4.1 [2] | 18.8 |
| C,9,br2 | 4.1 [1] | 14.5 | 4.1 | 18.8 |
| S;13,br2 | 4.1 | 17.8 | 4.1 | 18.8 |

1) Middle strain gauge inactive of strip
2) First strain gauge inactive of strip

**Table 5: Actual distance from weld toe to first and last strain gauges on DT4 [mm]**

**Actual distance from weld toe to strain gauges on DT5.**

The actual distance from the weld toe to the first and last strain gauge for test specimen DT5 is given in Table 6.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1,br1 | 5.8 | 18.3 | 4.4 | 23.6 |
| S;13,br1 | 4.0 | 17.2 | 4.3 | 23.8 |
| S;5,br2 | 4.7 | 18.1 | 4.0 | 23.6 |
| C;9,br2 | 4.1 | 16.6 | 4.3 | 21.6 |

**Table 6: Actual distance from weld toe to first and last strain gauges on DT5 [mm]**

**Actual distance from weld toe to strain gauges on DT6**

The actual distance from the weld toe to the first and last strain gauge for test specimen DT6 is given in Table 7.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1,br1 | 4.1 | 17.1 | 4.0 | 29.0 |
| I;2,br1 | 4.0 | 17.0 | 4.0 | 29.1 |
| I;4,br1 | 4.1 | 17.2 | 4.0 | 28.8 |
| S;5,br1 | 4.1 | 17.5 | 4.0 | 28.7 |
| C;9,br2 | 4.0 | 17.2 | 4.0 | 28.4 |
| I;10,br2 | 4.0 | 17.4 | 4.0 | 28.8 |
| I,12,br2 | 3.6 | 17.7 | 4.0 | 28.8 |
| S;13,br2 | 4.1 | 17.8 | 4.0 | 29.0 |

**Table 7: Actual distance from weld toe to first and last strain gauges on DT6 [mm]**

**Actual distance from weld toe to strain gauges on DT8**

The actual distance from the weld toe to the first and last strain gauge for test specimen DT8 is given in Table 8.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1,br1 | 4.0 | 16.7 | 3.5 | 21.6 |
| S;13,br1 | 4.0 | 17.0 | 4.2 | 21.5 |
| S;5,br2 | 4.2 | 18.7 | 4.5 | 22.3 |
| C;9,br2 | 4.0 | 17.0 | 4.0 | 21.2 |

**Table 8: Actual distance from weld toe to first and last strain gauges on DT8 [mm]**

**Actual distance from weld toe to strain gauges on DT9.**

The actual distance from the weld toe to the first and last strain gauge for test specimen DT9 is given in Table 9.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1,br1 | 4.0 * | 16.5 | 4.0 | 26.0 |
| I;2,br1 | 4.0 | 16.8 | 4.0 | 26.0 |
| I;4,br1 | 4.0 | 17.5 | 4.0 | 26.5 |
| S;5,br1 | 4.0 | 17.8 | 4.5 | 26.5 |
| C;9,br2 | 4.0 | 16.5 | 4.0 | 26.0 |
| I;10,br2 | 4.0 * | 16.8 | 4.0 | 26.5 |
| I,12,br2 | 4.0 | 17.5 | 4.0 | 25.5 |
| S;13,br2 | 4.0 | 17.8 | 4.0 | 26.0 |

*) Average distance to weld toe.

**Table 9: Actual distance from weld toe to first and last strain gauges on DT9 [mm]**

**Actual distance from weld toe to strain gauges on T1.**

The actual distance from the weld toe to the first and last strain gauge for test specimen T1 is given in Table 10.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1 | 6.0 | 18.75 | 6.5 | 24.1 |
| S;5 | 6.2 | 18.0 | 6.5 | 24.5 |
| C;9 | 6.5 | 18.5 | 6.5 | 23.8 |
| S;13 | 6.0 | 17.9 | 6.5 | 24.1 |

**Table 10: Actual distance from weld toe to first and last strain gauges on T1 [mm]**

**Actual distance from weld toe to strain gauges on T3.**

The actual distance from the weld toe to the first and last strain gauge for test specimen T3 is given in Table 11.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1 | 6.6 | 23.0 | 6.5 | 37.9 |
| I;2 | 6.5 | 21.3 | 6.3 | 37.6 |
| I;4 | 6.5 | 19.6 | 6.5 | 37.1 |
| S;5 | 6.4 | 18.9 | 6.5 | 36.8 |
| C;9 | 6.5 | 21.4 | 6.4 | 36.9 |
| I;10 | 6.5 | 21.5 | 6.5 | 36.9 |
| I,12 | 6.5 | 19.5 | 6.4 | 37.0 |
| S;13 | 6.5 | 19.0 | 6.5 | 37.2 |

**Table 11: Actual distance from weld toe to first and last strain gauges on T3 [mm]**

**Actual distance from weld toe to strain gauges on T5.**

The actual distance from the weld toe to the first and last strain gauge for test specimen T5 is given in Table 12.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1 | 4.1 | 16.0 | 4.0 | 23.8 |
| S;5 | 4.1 | 17.5 | 4.0 | 23.5 |
| C;9 | 4.1 | 16.2 | 4.2 | 23.8 |
| S;13 | 5.0 | 17.0 | 4.0 | 24.4 |

**Table 12: Actual distance from weld toe to first and last strain gauges on T5 [mm]**

**Actual distance from weld toe to strain gauges on T7.**

The actual distance from the weld toe to the first and last strain gauge for test specimen T7 is given in Table 13.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1 | 4.0 | 16.1 | 4.2 | 17.4 |
| S;5 | 4.2 | 17.8 | 4.0 | 17.3 |
| C;9 | 4.0 | 16.1 | 4.0 [1] | 17.7 |
| S;13 | 4.0 | 17.6 | 3.9 | 17.2 |

1) Middle strain gauge strip inactive

**Table 13: Actual distance from weld toe to first and last strain gauges on T7 [mm]**

**Actual distance from weld toe to strain gauges on T9.**

The actual distance from the weld toe to the first and last strain gauge for test specimen T9 is given in Table 14.

| Position | CHORD SIDE | | BRACE SIDE | |
|---|---|---|---|---|
| | Gauge 1 | Gauge 6 | Gauge 1 | Gauge 6 |
| C;1 | 4.1 [1] | 16.6 | 4.0 | 26.0 |
| I;2 | 4.0 | 16.5 | 3.9 | 25.9 |
| I;4 | 4.2 | 17.0 | 4.0 | 25.7 |
| S;5 | 3.8 | 17.6 | 3.8 | 26.2 |
| I;6 | 4.0 | 17.0 | 4.1 | 26.0 |
| I;8 | 4.1 | 16.7 | 4.0 | 26.2 |
| C;9 | 3.8 | 16.6 | 4.0 [2] | 25.8 |
| I;10 | 4.0 | 16.9 | 4.0 | 25.8 |
| I,12 | 4.0 [3] | 17.0 | 3.8 | 25.9 |
| S;13 | 4.1 [4] | 17.8 | 3.9 | 25.7 |
| I;14 | 4.0 [5] | 17.2 | 4.0 | 25.8 |
| I;16 | 3.8 | 16.5 | 4.0 | 25.8 |

1) 3,5 mm from crown in direction of 16
2) 3,5 mm from crown in direction of 10
3) Second strain gauge of strip inactive
4) Last strain gauge of strip inactive
5) First strain gauges of strip inactive

**Table 14: Actual distance from weld toe to first and last strain gauges on T9 [mm]**

# Transducer Positions

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Joint Deformation Measurement of T Specimens ..... 4



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**Joint Deformation of DT Specimen.**

The local joint deformation is measured for all loading conditions. The displacement transducers for out-of-plane deformation are also used to measure the axial deformation under tension and compression. For in-plane bending another four displacement transducers are used to measure the local joint deformation, see Figure 1. The distances of the transducers for local joint deformation are given in Table 1. The displacement transducers for out-of-plane bending are measured from points on both braces located 100 mm from the chord side. For in-plane bending the points on the brace are located 130 mm from the chord side. The distances were chosen to avoid local joint deformation effects and apply to all specimens

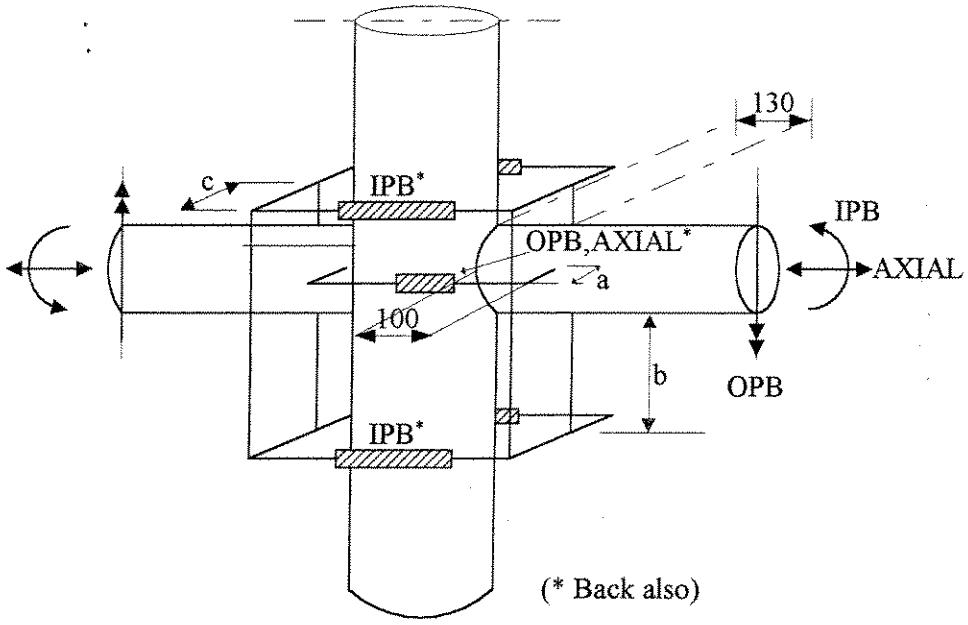


**Figure 1: Positions of displacement transducers for DT specimens.**

| | Instr. C/L to Brace wall (a) | | Instr. C/L to Brace wall (b) | | Instr. C/L to Brace C/L (c) | |
|---|---|---|---|---|---|---|
| **Specimen** | **OPB-front** | **OPB-back** | **IPB-top** | **IPB-bottom** | **IPB-front** | **IPB-back** |
| DT2 | 145 | 145 | 85 | 65 | 270 | 270 |
| DT3 | 145 | 100 | 80 | 55 | 272 | 272 |
| DT4 | 145 | 142.5 | 79 | 70.5 | 270 | 270 |
| DT5 | 145 | 145 | 82.5 | 65 | 270 | 270 |
| DT6 | 145 | 100 | 80 | 55 | 272 | 272 |
| DT8 | 145 | 145 | 82.5 | 74 | 270 | 270 |
| DT9 | 145 | 100 | 75 | 55 | 270 | 270 |

Note: All dimensions in (mm) Instr.= Instrument C/L = Centre line

**Table 1: Position of displacement transducers relative to specimens**

The global rotation of the DT joint under bending was calculated based on the difference between displacements measured at points along the braces. The distance of the points to the chord side are given in Table 2, see also Figure 2.

| Specimen | IPB A | IPB B | OPB A | OPB B |
|---|---|---|---|---|
| DT2 | 355.0 | 955.0 | 437.0 | 1038.0 |
| DT3 | 529.0 | 1425.0 | 651.0 | 1546.0 |
| DT4 | 200.0 | 563.0 | 253.0 | 625.0 |
| DT5 | 355.0 | 955.0 | 437.0 | 1038.0 |
| DT6 | 529.0 | 1425.0 | 651.0 | 1546.0 |
| DT8 | 355.0 | 955.0 | 437.0 | 1038.0 |
| DT9 | 529.0 | 1425.0 | 651.0 | 1546.0 |

**Table 2: Position of displacment transducers along the braces relative to chord side [mm]**

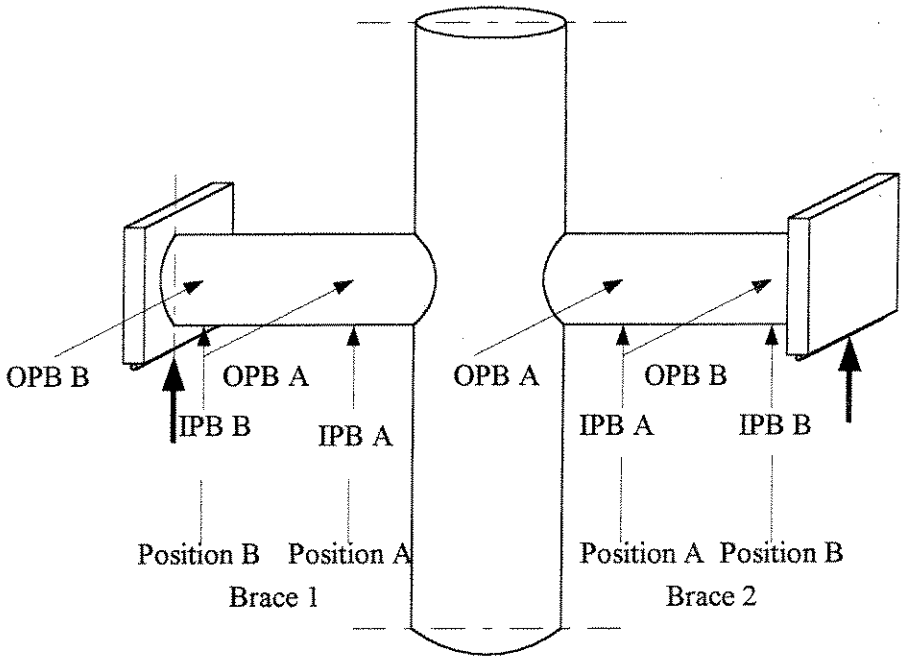


**Figure 2: Figure presenting positions of transducers on DT specimen**

**Joint Deformation of T Specimen.**

The local joint deformation is measured for all loading conditions. The displacement transducers for out-of-plane bending were also used to measure the axial deformation under tension and compression. For in-plane bending, another four displacement transducers were used to measure the local joint deformation, see Figure 3. The distances of the transducers for local joint deformation are given in Table 3. The displacement transducers for out-of-plane bending were measured from a point on the brace located 100 mm from the chord side. For in-plane bending the points on the brace are located 130 mm from the chord side. This was the case for all specimens. The deformation was measured relative to the section of chord diametrically opposite the brace.

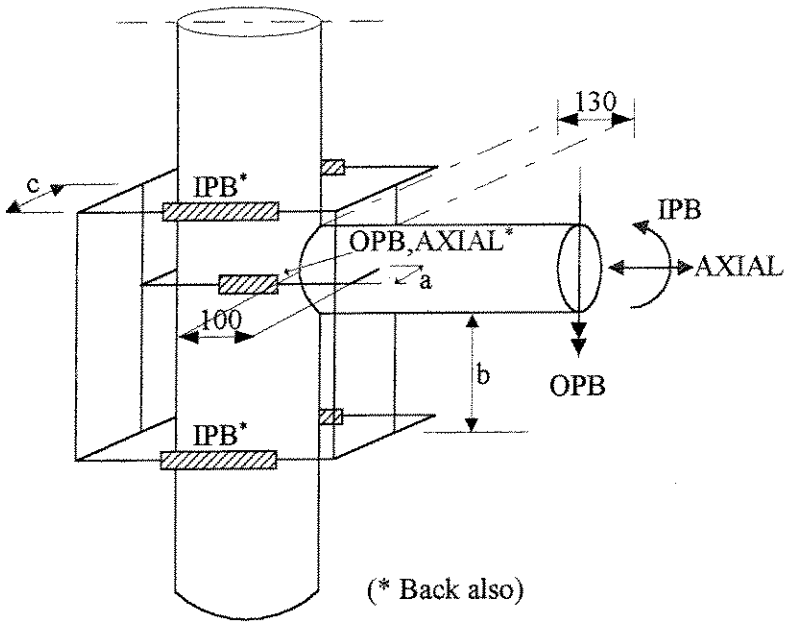


**Figure 3: Positions of displacement transducers for T specimens**

| | Instr. C/L to Brace wall (a) | | Instr. C/L to Brace wall (b) | | Instr. C/L to Brace C/L (c) | |
|---|---|---|---|---|---|---|
| **Specimen** | **OPB-front** | **OPB-back** | **IPB-top** | **IPB-bottom** | **IPB-front** | **IPB-back** |
| T1 | 195 | 140 | 85 | 55 | 270 | 270 |
| T3 | 140 | 93 | 82 | 73 | 270 | 270 |
| T5 | 190 | 140 | 80 | 60 | 270 | 270 |
| T7 | 195 | 140 | 85 | 55 | 270 | 270 |
| T9 | 138 | 95 | 80 | 65 | 270 | 270 |

Note: All dimensions in (mm)

**Table 3: Position of displacement transducers relative to specimens**

The global rotation of the T joint under bending was calculated based on the measured displacement difference between points along the brace. The distance of the points to the chord side are given in Table 4, see also Figure 4.

| Specimen | IPB A | IPB B | OPB A | OPB B |
|---|---|---|---|---|
| T1 | 218 | 587 | 269 | 638 |
| T3 | 520 | 1365 | 651 | 1500 |
| T5 | 355 | 957 | 437 | 1039 |
| T7 | 219 | 589 | 269 | 640 |
| T9 | 520 | 1365 | 651 | 1500 |

**Table 4: Position of displacment transducers along the brace relative to chord side [mm]**

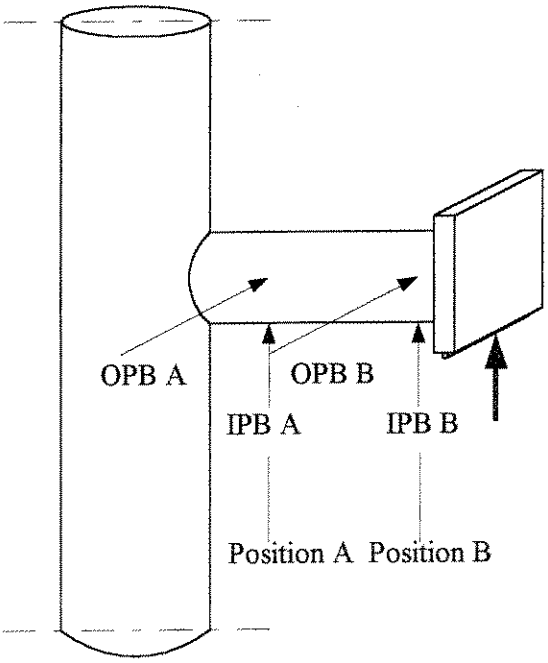


**Figure 4: Figure presenting positions of transducers on T specimens**

## Loading Condition and Dimensions

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**Loading on DT specimen.**

The load for in plane bending was applied by a jack at one end of the chord. The braces were supported at the ends. The distance from the chord side to the centre of the support for each specimen is given in Table 1. Out of plane bending is applied by a force out of plane to the joint at the ends of the braces. The distance of the load position to the side of the chord is given in Table 1, see also Figure 1.

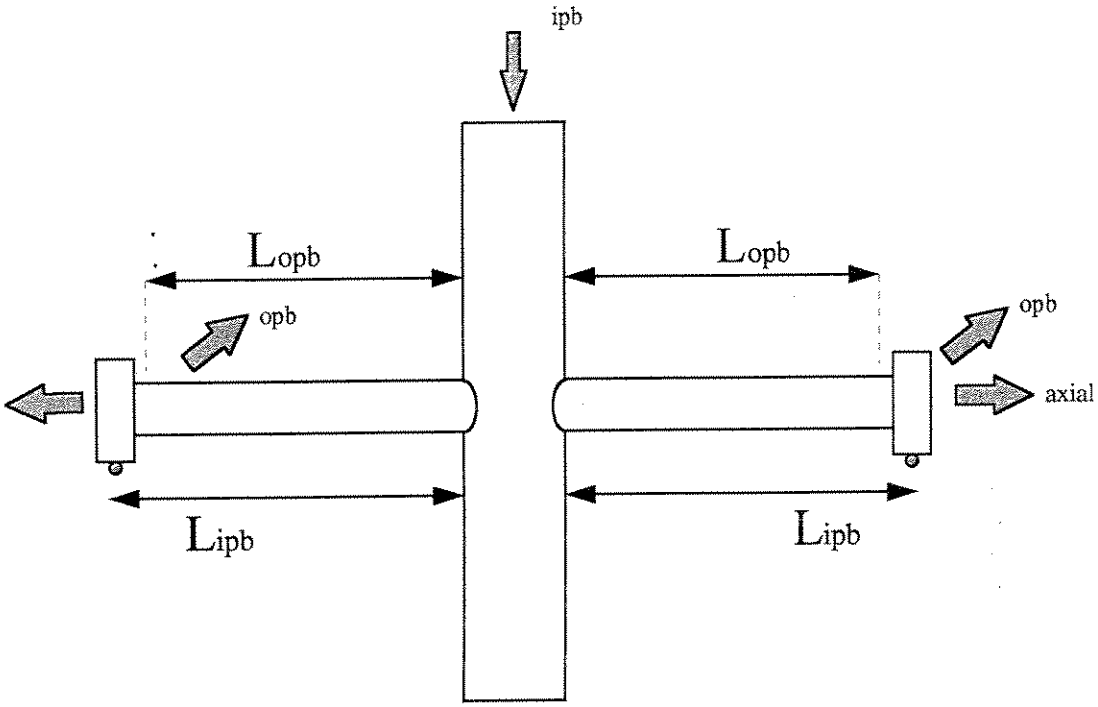


**Figure 1: Definition of Lipb and Lopb.**

| Specimen | L ipb | L opb |
|---|---|---|
| DT2 | 1365 | 1295 |
| DT3 | 2036 | 1945 |
| DT4 | 843 | 788 |
| DT5 | 1365 | 1285 |
| DT6 | 2036 | 1945 |
| DT8 | 1365 | 1285 |
| DT9 | 2036 | 1945 |

**Table 1: Distance to chord side from points of loading [mm].**

**Loading on T specimen.**

In plane and out of plane bending was achieved by applying a force at the end of the brace. The distance from the chord side to the load position for each specimen is given in Table 2, see also Figure 2.

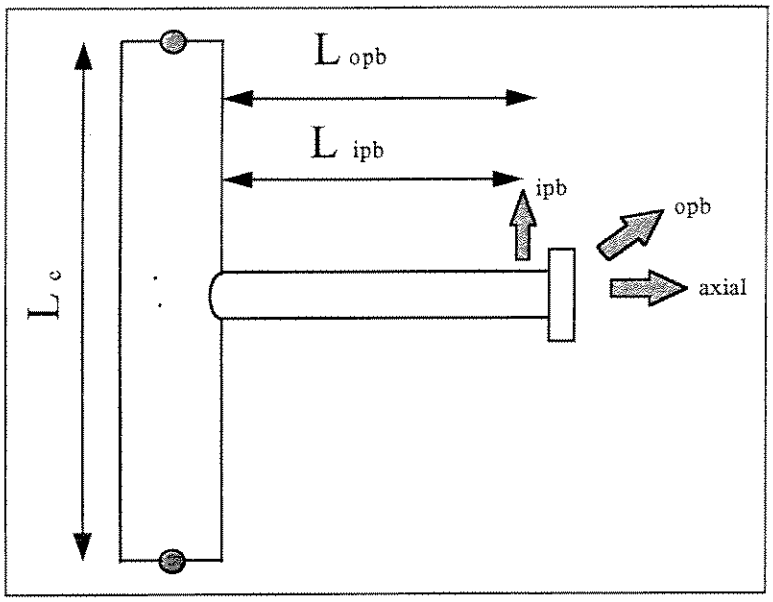


**Figure 2: Definition of Lipb and Lopb.**

| Specimen | L ipb | L opb |
|---|---|---|
| T1 | 755 | 785 |
| T3 | 1965 | 1915 |
| T5 | 1265 | 1315 |
| T7 | 790 | 760 |
| T9 | 1965 | 1915 |

**Table 2: Distance from chord side to points of loading [mm].**



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# APPENDIX B

## Preload Investigations

# Pre-Load Investigation Sequence

## TESTING

### Pre-load Investigations on Specimen T7

Examination and assessment of public domain information indicated that pre-load and the magnitude of pre-load may have a significant effect on the SCF values for a fully grouted tubular joint. It was therefore proposed that the first test specimen (T7) be used to investigate the effects of pre-load. The specimen was investigated for SCF determination for in-plane bending, out-of-plane bending, axial compression and axial tension loading cases, in turn. SCFs were calculated for loading in the above-noted sequence, since in-plane loading results in the lowest SCFs and axial tension gives rise to the highest SCFs. The proposed test procedure and sequence for specimen T7 is presented in the following table and graphically in Figure 1:

| STEP | FORM | LOAD CONDITION |
|---|---|---|
| 1 | Ungrouted | Apply ten cycles of in-plane bending load on the brace at 20% of the predicted ultimate load of the ungrouted joint subjected to in-plane bending. The purpose of this is to `shake' out residual strains. |
| 2 | Ungrouted | Apply in-plane bending loads to the brace in three equal increments, up to a maximum of 20% of the predicted ultimate load of the ungrouted joint subjected to in-plane bending. At each load increment level, measure SNCFs. Reduce the load in three stages, taking SNCF measurements at each load level. |
| 3 | Ungrouted | Repeat steps 1 and 2 for out-of-plane bending, axial compression and axial tension, in turn. For each load condition the shake out loading and the limiting load will be taken as 20% of the appropriate predicted ultimate load of the ungrouted joint for the load condition under investigation. |
| 4 | Grouted | Apply in-plane bending loads to the brace in three equal increments, up to a maximum of 7% of the predicted ultimate load of the grouted joint subjected to in-plane bending. At each load increment level, measure SNCFs. Reduce the load in three stages, taking SNCF measurements of each load level. |



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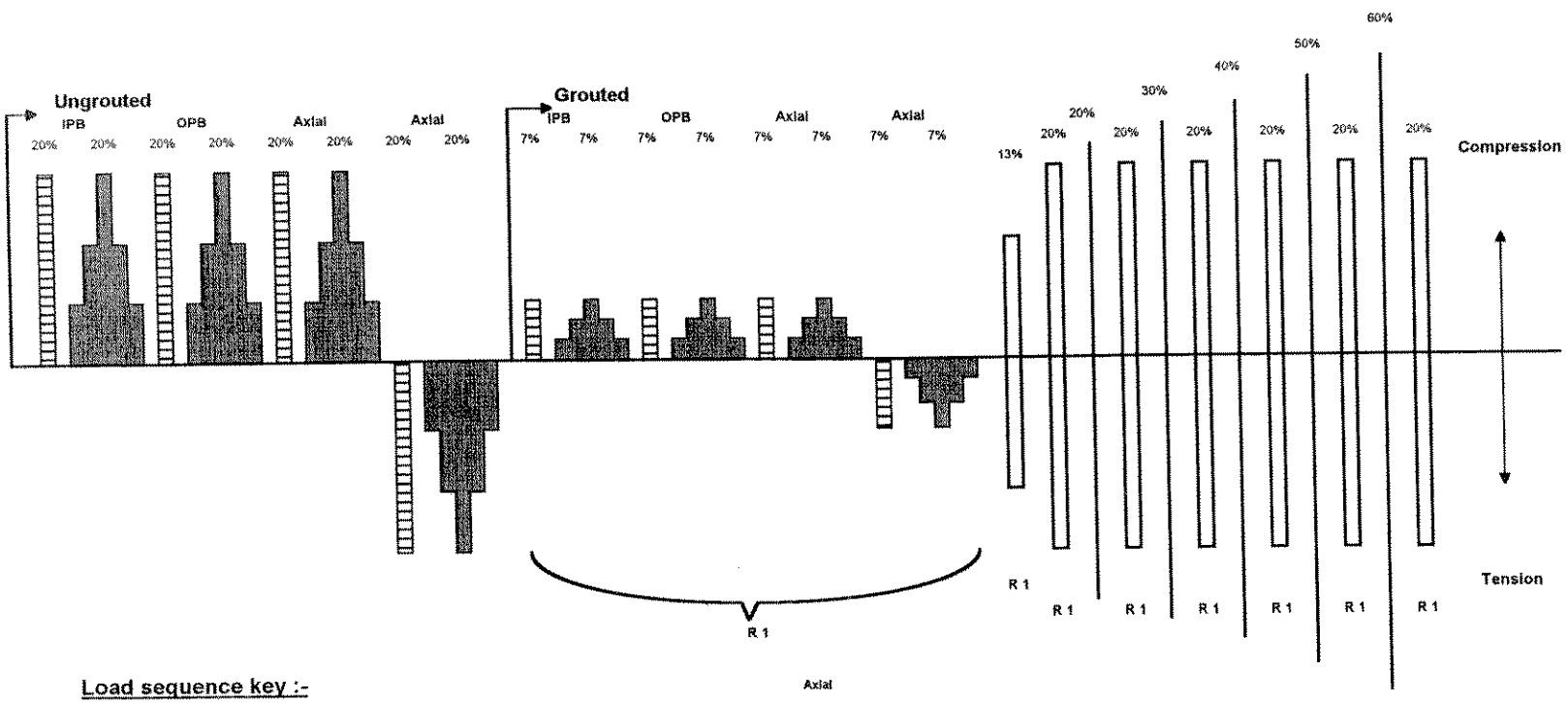
| STEP | FORM | LOAD CONDITION |
|---|---|---|
| 5 | Grouted | Repeat step 4 for out-of-plane bending, axial compression and axial tension, in turn. |
| 6 | Grouted | Repeat steps 4 and 5, but up to a maximum of 13% of the predicted ultimate load of the grouted joint for the load condition under investigation. |
| 7 | Grouted | Repeat steps 4 and 5, but up to a maximum of 20% of the predicted ultimate load of the grouted joint for the load condition under investigation. |
| 8 | Grouted | Apply axial pre-load (compression then tension) to the brace member. The magnitude of pre-load shall be 20% of the predicted ultimate strength of the grouted joint under axial tension. |
| 9 | Grouted | Remove load from the brace member. |
| 10 | Grouted | Repeat step 7. |
| 11 | Grouted | Repeat steps 8 and 9, but with a pre-load of 25%. |
| 12 | Grouted | Repeat step 7. |
| 13 | Grouted | Repeat steps 8, 9 and 7, but with a pre-load of 40%. |
| 14 | Grouted | Repeat steps 8, 9 and 7 for 40% and thereafter in 15% increments of the predicted ultimate strength of the joint under axial tension. |
| 15 | Grouted | Terminate the test at point of threshold - ie. at point where SNCFs begin to decrease or become constant. |




**Load sequence key :-**

IPB 20% — Shake down with application of 10 cycles of in-plane bending load at 20% of predicted ultimate load of joint

Axial 20% — SNCF measurments at three equal increments up to a maximum of 20% of the predicted as-welded ultimate load for axial compression

R 1 — A sequence ( R 1 ) of SNCF measurements and shakedown to be repeated

Axial 20% — SNCF measurments at 20% of as-welded predicted joint capacity to match load level used in as-welded SNCF measurements

50% — Axial pre-load ( compression then tension ) at 50% of predicted as-welded joint strength under axial tension/compression

R 1 — Repeat sequence R1

**Figure 1 Pre-load Investigations on Specimen T7**

# Preload Investigation Results for Specimen T7

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**General Information.**

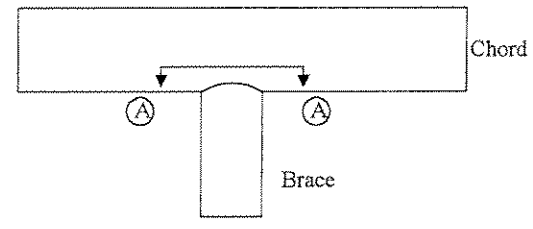
The preload investigation was conducted on specimen T7 in the grouted condition following the measurement and loading cycles presented in the previous section. The preload levels correspond to the ISO predicted as-welded joint capacity. During the preload investigation, specimen T7 was loaded by in-plane bending, out-of-plane bending, axial compression and axial tension. Ten cycles of shake-down were applied, followed by SNCF measurements for each load condition. The SNCF measurements for each loading mode were repeated between applications of increasing preload levels.

**Key to Tables:**

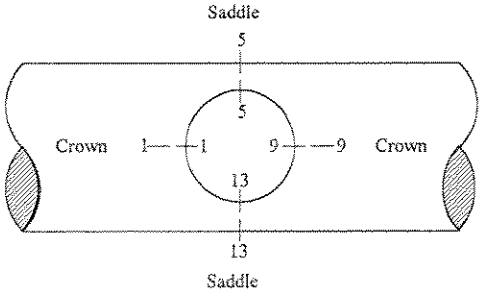
| | |
|---|---|
| Level | Load level (% of capacity) |
| BS | Brace Saddle |
| BC | Brace Crown |
| CS | Chord Saddle |
| CC | Chord Crown |
| # | Gauge position (see diagram below) |
| r | Rosette gauge |
| s | Single gauge |

**Example:**

The diagram below shows all the possible locations of the strain gauges. The outer numbers show the positions of the chord gauges whilst the inner circle of numbers show the position of the brace gauges. In the tables that follow, the gauges are denoted by a two letter code followed by a position number. For example BC;9 denotes brace crown at position 9.




Elevation on T Joint




View 'A' on brace

**First SNCF measurement cycle to 7 % joint as-welded capacity.**

The measured SNCFs for the first cycle for each of the four loading conditions are presented in Table 1. Measurements made with additional strain rosettes are presented in Table 2. The corresponding single strain gauge measurements are also presented for comparison. The applied load levels are also presented in the following tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 3.

| | . level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0179 | -1.81 | 0.16 | 1.59 | -0.16 | -4.29 | 0.28 | 4.35 | -0.46 |
| ipb | 0.0357 | -2.5 | 0.17 | 1.54 | 0.13 | -3.34 | 0.37 | 4.2 | 0.4 |
| ipb | 0.0354 | -2.4 | 0.17 | 1.45 | 0.14 | -3.17 | 0.42 | 4.12 | 0.33 |
| ipb | 0.0170 | -1.83 | 0.12 | 1.49 | -0.1 | -4.44 | 0.26 | 4.69 | -0.46 |
| opb | 0.0066 | 0.39 | -6.8 | 0.05 | 4.87 | 0.97 | -12.07 | 0.5 | 13.44 |
| opb | 0.0125 | 0.15 | -6.21 | -0.09 | 4.21 | 0.9 | -7.84 | 0.5 | 11.68 |
| opb | 0.0126 | 0.15 | -6.08 | 0.14 | 4.19 | 0.84 | -7.86 | 0.38 | 11.74 |
| opb | 0.0074 | 0.31 | -6.73 | 0 | 4.66 | 0.86 | -11.49 | 0.35 | 13.4 |
| axi-c | -0.0035 | 6.78 | 9.12 | -3.41 | 5.77 | 21.91 | 21.13 | -5.23 | 16.24 |
| axi-c | -0.0067 | 6.75 | 7.35 | -1.38 | 3.81 | 14.42 | 16.52 | -0.49 | 10.43 |
| axi-c | -0.0099 | 6.53 | 5.53 | -0.89 | 3.11 | 11.32 | 12.66 | 0.87 | 8.49 |
| axi-c | -0.0099 | 6.62 | 5.56 | -1.15 | 3.05 | 11.32 | 12.25 | 0.75 | 8.64 |
| axi-c | -0.0066 | 7.26 | 6.78 | -2.01 | 4.08 | 15.45 | 14.97 | -1.75 | 11.51 |
| axi-c | -0.0035 | 7.04 | 9.59 | -2.98 | 5.8 | 21.39 | 20.46 | -5.46 | 16.88 |
| axi-t | 0.0035 | -0.49 | 16.42 | 2.5 | -4.68 | 2.23 | 37.51 | 13.17 | -6.84 |
| axi-t | 0.0073 | 0.57 | 10.94 | 1.7 | 0.64 | 4.47 | 24.57 | 8.9 | 2.97 |
| axi-t | 0.0118 | 0.35 | 10.49 | 1.65 | -0.31 | 4.2 | 23.69 | 8.89 | 0.5 |
| axi-t | 0.0119 | 0.42 | 10.21 | 2.36 | -0.01 | 4.33 | 22.83 | 8.73 | 0.94 |
| axi-t | 0.0076 | 0.62 | 13.3 | 2.32 | -2.57 | 5.05 | 29.67 | 9.11 | -3.36 |
| axi-t | 0.0037 | 1.94 | 19.5 | 1.76 | -6.48 | 9.07 | 43.45 | 8.27 | -8.39 |

**Table 1: Measured SNCFs on intersection of brace and chord for T7 at first cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0179 | 1.59 | 1.44 | 4.35 | 4.34 | -0.46 | -0.85 | -0.16 | -0.31 |
| ipb | 0.0357 | 1.54 | 1.45 | 4.2 | 4.17 | 0.4 | 0.04 | 0.13 | -0.06 |
| ipb | 0.0354 | 1.45 | 1.42 | 4.12 | 4.07 | 0.33 | 0.04 | 0.14 | -0.02 |
| ipb | 0.0170 | 1.49 | 1.47 | 4.69 | 4.56 | -0.46 | -0.86 | -0.1 | -0.21 |
| opb | 0.0066 | 0.05 | -0.07 | 0.5 | 0.22 | 13.44 | 13.64 | 4.87 | 4.68 |
| opb | 0.0125 | -0.09 | 0 | 0.5 | 0.38 | 11.68 | 11.89 | 4.21 | 4.01 |
| opb | 0.0126 | 0.14 | 0.02 | 0.38 | 0.45 | 11.74 | 11.98 | 4.19 | 4.22 |
| opb | 0.0074 | 0 | 0.05 | 0.35 | 0.43 | 13.4 | 13.61 | 4.66 | 4.71 |
| axi-c | -3.3194 | -3.41 | -3.17 | -5.23 | -5.32 | 16.24 | 17.98 | 5.77 | 6.32 |
| axi-c | -1.3433 | -1.38 | -1.26 | -0.49 | -0.45 | 10.43 | 11.52 | 3.81 | 4.14 |
| axi-c | -0.8663 | -0.89 | -0.97 | 0.87 | 0.68 | 8.49 | 9.24 | 3.11 | 3.24 |
| axi-c | -1.1194 | -1.15 | -0.89 | 0.75 | 0.78 | 8.64 | 9.07 | 3.05 | 3.02 |
| axi-c | -1.9566 | -2.01 | -1.57 | -1.75 | -1.4 | 11.51 | 12.29 | 4.08 | 4.16 |
| axi-c | -2.9008 | -2.98 | -2.73 | -5.46 | -4.78 | 16.88 | 18.34 | 5.8 | 6.15 |
| axi-t | 2.4336 | 2.5 | 3.3 | 13.17 | 13.54 | -6.84 | -6.73 | -4.68 | -3.96 |
| axi-t | 1.6548 | 1.7 | 2.08 | 8.9 | 8.97 | 2.97 | 2.95 | 0.64 | 0.69 |
| axi-t | 1.6062 | 1.65 | 2.17 | 8.89 | 8.91 | 0.5 | 0.34 | -0.31 | -0.33 |
| axi-t | 2.2973 | 2.36 | 2.15 | 8.73 | 8.49 | 0.94 | 0.83 | -0.01 | -0.14 |
| axi-t | 2.2583 | 2.32 | 2.1 | 9.11 | 8.91 | -3.36 | -3.4 | -2.57 | -2.64 |
| axi-t | 1.7132 | 1.76 | 1.5 | 8.27 | 7.47 | -8.39 | -8.14 | -6.48 | -6.15 |

**Table 2: SNCFs measured with rosettes compared to single strain gauge measurements for first cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0179 | 1.33 | 1.17 | 1.13 | 1.16 |
| ipb | 0.0357 | 1.32 | 1.17 | 1.64 | 0.92 |
| ipb | 0.0354 | 1.32 | 1.18 | 1.92 | 0.4 |
| ipb | 0.0170 | 1.32 | 1.18 | 1.1 | 1.12 |
| opb | 0.0066 | 0.83 | 1.62 | 1.13 | 1.2 |
| opb | 0.0125 | -0.55 | 1.33 | 1.13 | 1.21 |
| opb | 0.0126 | 0.63 | 1.29 | 1.13 | 1.2 |
| opb | 0.0074 | 0.26 | 1.24 | 1.13 | 1.2 |
| axi-c | -0.0035 | 1.28 | 1.42 | 1.14 | 1.23 |
| axi-c | -0.0067 | 1.22 | 1.84 | 1.15 | 1.21 |
| axi-c | -0.0099 | 1.19 | 0.76 | 1.16 | 1.24 |
| axi-c | -0.0099 | 1.22 | 0.76 | 1.16 | 1.25 |
| axi-c | -0.0066 | 1.3 | 1.44 | 1.15 | 1.24 |
| axi-c | -0.0035 | 1.3 | 1.27 | 1.14 | 1.24 |
| axi-t | 0.0035 | 1.37 | 1.16 | 1.07 | 1.16 |
| axi-t | 0.0073 | 1.35 | 1.15 | 1.23 | 1.4 |
| axi-t | 0.0118 | 1.36 | 1.15 | 4.29 | 0.72 |
| axi-t | 0.0119 | 1.37 | 1.16 | 1.55 | 0.12 |
| axi-t | 0.0076 | 1.37 | 1.15 | 1.02 | 1.12 |
| axi-t | 0.0037 | 1.46 | 1.15 | 1.07 | 0.66 |

**Table 3: SCF/SNCF ratio for first cycle of T7.**

**Second SNCF measurement cycle to 13 % joint as-welded capacity.**

The measured SNCFs for the second cycle are presented for each of the four loading conditions in Table 4. Measurements made with additional strain rosettes are presented in Table 5. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 6.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0238 | -1.54 | 0.18 | 1.49 | -0.21 | -4.14 | 0.57 | 4.45 | -0.7 |
| ipb | 0.0466 | -2.22 | 0.2 | 1.51 | 0.05 | -3.45 | 0.52 | 4.35 | 0.1 |
| ipb | 0.0685 | -2.51 | 0.22 | 1.49 | 0.16 | -2.83 | 0.57 | 4.16 | 0.42 |
| ipb | 0.0684 | -2.51 | 0.23 | 1.48 | 0.18 | -2.85 | 0.55 | 4.17 | 0.43 |
| ipb | 0.0483 | -2.36 | 0.2 | 1.56 | 0.1 | -3.53 | 0.48 | 4.48 | 0.21 |
| ipb | 0.0239 | -1.69 | 0.1 | 1.61 | -0.03 | -4.52 | 0.2 | 4.88 | -0.33 |
| opb | 0.0069 | 0.07 | -6.22 | -0.04 | 4.63 | 0.7 | -13 | 0.33 | 13.26 |
| opb | 0.0153 | 0.14 | -6.32 | -0.07 | 4.18 | 0.99 | -8.23 | 0.34 | 11.95 |
| opb | 0.0228 | 0.15 | -5.78 | -0.09 | 4.01 | 1 | -6.24 | 0.4 | 11.2 |
| opb | 0.0204 | 0.12 | -5.9 | -0.1 | 3.98 | 1.07 | -5.67 | 0.46 | 11.13 |
| opb | 0.0124 | 0.09 | -6.78 | -0.04 | 4.37 | 1.03 | -8.17 | 0.39 | 12.18 |
| opb | 0.0048 | -0.05 | -7.67 | -0.09 | 5.11 | 0.97 | -14.14 | 0.49 | 14.26 |
| axi-c | -0.0066 | 7.16 | 7.95 | -2.23 | 3.87 | 16.3 | 17.79 | -2.62 | 10.23 |
| axi-c | -0.0132 | 5.16 | 4.19 | -0.73 | 3.27 | 9.85 | 9.32 | 1.03 | 8.84 |
| axi-c | -0.0199 | 4.11 | 2.68 | -0.19 | 3.72 | 7.51 | 6 | 2.11 | 7.69 |
| axi-c | -0.0199 | 4.1 | 2.71 | -0.19 | 3.78 | 7.5 | 6 | 2.15 | 7.79 |
| axi-c | -0.0132 | 4.27 | 3.02 | -0.92 | 4.97 | 9.81 | 6.72 | 0.43 | 10.52 |
| axi-c | -0.0067 | 5.51 | 5.09 | -2.37 | 5.96 | 15.61 | 11.14 | -3.21 | 15.29 |
| axi-t | 0.0075 | -0.71 | 10.21 | 3.34 | 1.98 | 1.35 | 22.55 | 11.97 | 5.77 |
| axi-t | 0.0137 | 0.1 | 8.57 | 2.35 | 2.35 | 3.31 | 18.93 | 8.95 | 6.91 |
| axi-t | 0.0206 | 0.61 | 7.59 | 1.83 | 2.14 | 4.32 | 16.86 | 7.44 | 6.63 |
| axi-t | 0.0206 | 0.64 | 7.5 | 3.09 | 2.28 | 4.3 | 16.54 | 7.41 | 6.72 |
| axi-t | 0.0133 | 0.67 | 9.66 | 2.51 | 1.15 | 4.6 | 21.19 | 7.5 | 3.64 |
| axi-t | 0.0069 | 0.45 | 12.03 | 2.54 | 0.48 | 4.47 | 26.39 | 8.55 | 1.71 |

**Table 4: Measured SNCFs on intersection of brace and chord for T7 at second cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0238 | 1.49 | 1.48 | 4.45 | 4.44 | -0.7 | -1.09 | -0.21 | -0.32 |
| ipb | 0.0466 | 1.51 | 1.44 | 4.35 | 4.28 | 0.1 | -0.24 | 0.05 | -0.1 |
| ipb | 0.0685 | 1.49 | 1.42 | 4.16 | 4.15 | 0.42 | 0.12 | 0.16 | 0.01 |
| ipb | 0.0684 | 1.48 | 1.42 | 4.17 | 4.16 | 0.43 | 0.15 | 0.18 | 0.02 |
| ipb | 0.0483 | 1.56 | 1.48 | 4.48 | 4.41 | 0.21 | -0.12 | 0.1 | -0.08 |
| ipb | 0.0239 | 1.61 | 1.61 | 4.88 | 4.89 | -0.33 | -0.72 | -0.03 | -0.25 |
| opb | 0.0069 | -0.04 | -0.02 | 0.33 | 0.21 | 13.26 | 13.39 | 4.63 | 4.6 |
| opb | 0.0153 | -0.07 | -0.16 | 0.34 | 0.19 | 11.95 | 12.02 | 4.18 | 4.07 |
| opb | 0.0228 | -0.09 | -0.07 | 0.4 | 0.38 | 11.2 | 11.29 | 4.01 | 3.82 |
| opb | 0.0204 | -0.1 | -0.07 | 0.46 | 0.38 | 11.13 | 11.29 | 3.98 | 3.82 |
| opb | 0.0124 | -0.04 | -0.09 | 0.39 | 0.17 | 12.18 | 12.45 | 4.37 | 4.24 |
| opb | 0.0048 | -0.09 | -0.14 | 0.49 | -0.07 | 14.26 | 14.8 | 5.11 | 4.94 |
| axi-c | -0.0066 | -2.23 | -2.13 | -2.62 | -2.52 | 10.23 | 11.54 | 3.87 | 4.13 |
| axi-c | -0.0132 | -0.73 | -0.78 | 1.03 | 1.01 | 8.84 | 9.38 | 3.27 | 3.34 |
| axi-c | -0.0199 | -0.19 | -0.21 | 2.11 | 2.05 | 7.69 | 8.09 | 3.72 | 3.67 |
| axi-c | -0.0199 | -0.19 | -0.23 | 2.15 | 2.05 | 7.79 | 8.13 | 3.78 | 3.71 |
| axi-c | -0.0132 | -0.92 | -0.84 | 0.43 | 0.36 | 10.52 | 11.04 | 4.97 | 4.94 |
| axi-c | -0.0067 | -2.37 | -2.19 | -3.21 | -3.24 | 15.29 | 16.3 | 5.96 | 6.24 |
| axi-t | 0.0075 | 3.34 | 3.04 | 11.97 | 11.71 | 5.77 | 5.36 | 1.98 | 1.93 |
| axi-t | 0.0137 | 2.35 | 2.14 | 8.95 | 8.88 | 6.91 | 6.79 | 2.35 | 2.26 |
| axi-t | 0.0206 | 1.83 | 1.67 | 7.44 | 7.49 | 6.63 | 6.6 | 2.14 | 2.06 |
| axi-t | 0.0206 | 3.09 | 1.69 | 7.41 | 7.43 | 6.72 | 6.73 | 2.28 | 2.05 |
| axi-t | 0.0133 | 2.51 | 1.7 | 7.5 | 7.57 | 3.64 | 3.67 | 1.15 | 0.95 |
| axi-t | 0.0069 | 2.54 | 1.97 | 8.55 | 8.33 | 1.71 | 1.9 | 0.48 | 0.54 |

Table 5: SNCFs measured with rosettes compared to single strain gauge measurements for second cycle of T7.

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0238 | 1.32 | 1.17 | 1.13 | 1.2 |
| ipb | 0.0466 | 1.32 | 1.17 | 1.07 | 1.05 |
| ipb | 0.0685 | 1.32 | 1.17 | 1.25 | 2.49 |
| ipb | 0.0684 | 1.32 | 1.17 | 1.25 | 2.28 |
| ipb | 0.0483 | 1.32 | 1.17 | 1.01 | 1.03 |
| ipb | 0.0239 | 1.32 | 1.17 | 1.12 | 1.2 |
| opb | 0.0069 | 5.48 | 1.11 | 1.13 | 1.2 |
| opb | 0.0153 | 1.37 | 1.22 | 1.13 | 1.21 |
| opb | 0.0228 | 1.56 | 1.18 | 1.12 | 1.2 |
| opb | 0.0204 | 1.38 | 1.24 | 1.12 | 1.21 |
| opb | 0.0124 | 1.47 | 1.33 | 1.13 | 1.21 |
| opb | 0.0048 | 1.32 | 0.18 | 1.13 | 1.21 |
| axi-c | -0.0066 | 1.26 | 0.74 | 1.15 | 1.22 |
| axi-c | -0.0132 | 1.24 | 0.89 | 1.16 | 1.24 |
| axi-c | -0.0199 | 1.06 | 1.04 | 1.16 | 1.21 |
| axi-c | -0.0199 | 1.07 | 1.04 | 1.16 | 1.22 |
| axi-c | -0.0132 | 1.23 | 0.32 | 1.15 | 1.22 |
| axi-c | -0.0067 | 1.26 | 1.27 | 1.15 | 1.24 |
| axi-t | 0.0075 | 1.36 | 1.15 | 1.19 | 1.31 |
| axi-t | 0.0137 | 1.36 | 1.15 | 1.17 | 1.28 |
| axi-t | 0.0206 | 1.36 | 1.14 | 1.17 | 1.29 |
| axi-t | 0.0206 | 1.36 | 1.15 | 1.16 | 1.27 |
| axi-t | 0.0133 | 1.38 | 1.14 | 1.2 | 1.36 |
| axi-t | 0.0069 | 1.4 | 1.15 | 1.22 | 1.47 |

**Table 6: SCF/SNCF ratio for second cycle of T7.**

**Third SNCF measurement cycle to 20 % joint as-welded capacity.**

The measured SNCFs for the third cycle are presented for each of the four loading conditions in Table 7. Measurements made with additional strain rosettes are presented in Table 8. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 9.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0352 | -1.91 | 0.05 | 1.62 | 0.09 | -4.13 | 0.15 | 4.68 | 0.12 |
| ipb | 0.0679 | -2.52 | 0.14 | 1.57 | 0.23 | -3.01 | 0.38 | 4.35 | 0.6 |
| ipb | 0.1031 | -2.63 | 0.2 | 1.52 | 0.28 | -2.46 | 0.53 | 4.09 | 0.75 |
| ipb | 0.1036 | -2.62 | 0.19 | 1.43 | 0.26 | -2.44 | 0.53 | 4.06 | 0.75 |
| ipb | 0.0691 | -2.56 | 0.16 | 1.53 | 0.2 | -3.07 | 0.41 | 4.42 | 0.61 |
| ipb | 0.0364 | -2.01 | 0.05 | 1.61 | 0.07 | -4.36 | 0.16 | 4.84 | 0.22 |
| opb | 0.0114 | 0.15 | -8.53 | -0.08 | 5.52 | 0.88 | -14.47 | 0.25 | 16.17 |
| opb | 0.0235 | 0.12 | -7.22 | -0.1 | 4.67 | 0.95 | -8.3 | 0.42 | 13.19 |
| opb | 0.0366 | 0.11 | -6.17 | -0.07 | 4.18 | 0.93 | -6.05 | 0.51 | 11.64 |
| opb | 0.0386 | 0.07 | -5.66 | -0.08 | 4.02 | 0.86 | -5.56 | 0.5 | 11.2 |
| opb | 0.0268 | 0.06 | -6.31 | -0.12 | 4.36 | 0.87 | -7.28 | 0.42 | 12.36 |
| opb | 0.0146 | 0.04 | -7.04 | -0.12 | 5.09 | 0.73 | -11.67 | 0.38 | 14.49 |
| axi-c | -0.0100 | 1.77 | 6.14 | 1.71 | 3.66 | 7.96 | 14.14 | 6.96 | 10.94 |
| axi-c | -0.0199 | 1.65 | 2.86 | 1.32 | 3.72 | 5.88 | 6.83 | 5.17 | 8 |
| axi-c | -0.0297 | 1.75 | 2.1 | 1.46 | 3.3 | 5.02 | 5.07 | 4.55 | 6.4 |
| axi-c | -0.0297 | 1.74 | 2.11 | 1.34 | 3.25 | 4.99 | 5.03 | 4.49 | 6.36 |
| axi-c | -0.0199 | 1.62 | 2.67 | 0.91 | 4.14 | 5.86 | 6.18 | 4.88 | 8.62 |
| axi-c | -0.0099 | 1.76 | 4.39 | 0.7 | 5.94 | 7.64 | 9.91 | 5.11 | 13.2 |
| axi-t | 0.0103 | -0.23 | 8.82 | 2.62 | 3.06 | 2.61 | 19.31 | 10.15 | 8.38 |
| axi-t | 0.0208 | 0.37 | 7.75 | 1.9 | 2.57 | 3.94 | 17.17 | 7.89 | 7.27 |
| axi-t | 0.0323 | 0.81 | 7.01 | 1.5 | 2.17 | 4.72 | 15.56 | 6.69 | 6.56 |
| axi-t | 0.0322 | 0.81 | 7.03 | 1.57 | 2.16 | 4.74 | 15.54 | 6.68 | 6.6 |
| axi-t | 0.0206 | 0.43 | 8.01 | 2.03 | 2.43 | 4.02 | 17.68 | 7.87 | 6.95 |
| axi-t | 0.0108 | -0.39 | 8.56 | 2.61 | 3.4 | 2.57 | 18.83 | 10.39 | 9.28 |

**Table 7: Measured SNCFs on intersection of brace and chord for T7 at third cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0352 | 1.62 | 1.54 | 4.68 | 4.62 | 0.12 | -0.16 | 0.09 | -0.06 |
| ipb | 0.0679 | 1.57 | 1.47 | 4.35 | 4.32 | 0.6 | 0.31 | 0.23 | 0.08 |
| ipb | 0.1031 | 1.52 | 1.43 | 4.09 | 4.05 | 0.75 | 0.48 | 0.28 | 0.13 |
| ipb | 0.1036 | 1.43 | 1.42 | 4.06 | 4.03 | 0.75 | 0.46 | 0.26 | 0.11 |
| ipb | 0.0691 | 1.53 | 1.47 | 4.42 | 4.37 | 0.61 | 0.26 | 0.2 | 0.05 |
| ipb | 0.0364 | 1.61 | 1.58 | 4.84 | 4.79 | 0.22 | -0.19 | 0.07 | -0.08 |
| opb | 0.0114 | -0.08 | -0.11 | 0.25 | 0.09 | 16.17 | 18.23 | 5.52 | 5.79 |
| opb | 0.0235 | -0.1 | -0.13 | 0.42 | 0.23 | 13.19 | 14.41 | 4.67 | 4.7 |
| opb | 0.0366 | -0.07 | -0.11 | 0.51 | 0.37 | 11.64 | 12.48 | 4.18 | 4.14 |
| opb | 0.0386 | -0.08 | -0.1 | 0.5 | 0.37 | 11.2 | 10.82 | 4.02 | 3.86 |
| opb | 0.0268 | -0.12 | -0.11 | 0.42 | 0.29 | 12.36 | 11.67 | 4.36 | 4.22 |
| opb | 0.0146 | -0.12 | -0.13 | 0.38 | 0.17 | 14.49 | 13.25 | 5.09 | 4.89 |
| axi-c | -0.0100 | 1.71 | 1.51 | 6.96 | 6.75 | 10.94 | 11.03 | 3.66 | 3.46 |
| axi-c | -0.0199 | 1.32 | 1.21 | 5.17 | 4.98 | 8 | 8.11 | 3.72 | 3.55 |
| axi-c | -0.0297 | 1.46 | 1.37 | 4.55 | 4.42 | 6.4 | 6.51 | 3.3 | 3.12 |
| axi-c | -0.0297 | 1.34 | 1.37 | 4.49 | 4.42 | 6.36 | 6.5 | 3.25 | 3.15 |
| axi-c | -0.0199 | 0.91 | 0.91 | 4.88 | 4.75 | 8.62 | 8.74 | 4.14 | 4.05 |
| axi-c | -0.0099 | 0.7 | 0.71 | 5.11 | 5.12 | 13.2 | 13.58 | 5.94 | 5.66 |
| axi-t | 0.0103 | 2.62 | 2.46 | 10.15 | 10.16 | 8.38 | 8.01 | 3.06 | 2.69 |
| axi-t | 0.0208 | 1.9 | 1.84 | 7.89 | 7.83 | 7.27 | 7.13 | 2.57 | 2.36 |
| axi-t | 0.0323 | 1.5 | 1.45 | 6.69 | 6.68 | 6.56 | 6.53 | 2.17 | 2.09 |
| axi-t | 0.0322 | 1.57 | 1.42 | 6.68 | 6.71 | 6.6 | 6.61 | 2.16 | 2.09 |
| axi-t | 0.0206 | 2.03 | 1.78 | 7.87 | 7.98 | 6.95 | 6.9 | 2.43 | 2.23 |
| axi-t | 0.0108 | 2.61 | 2.52 | 10.39 | 10.41 | 9.28 | 9.06 | 3.4 | 3.06 |

**Table 8: SNCFs measured with rosettes compared to single strain gauge measurements for third cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0352 | 1.32 | 1.17 | 1.12 | 1.1 |
| ipb | 0.0679 | 1.32 | 1.17 | 1.18 | 1.43 |
| ipb | 0.1031 | 1.31 | 1.18 | 1.16 | 1.35 |
| ipb | 0.1036 | 1.31 | 1.18 | 1.17 | 1.41 |
| ipb | 0.0691 | 1.32 | 1.17 | 1.2 | 1.64 |
| ipb | 0.0364 | 1.32 | 1.17 | 1.1 | 1.02 |
| opb | 0.0114 | 1.83 | 1.25 | 1.13 | 1.21 |
| opb | 0.0235 | 1.43 | 1.28 | 1.13 | 1.21 |
| opb | 0.0366 | 1.37 | 1.24 | 1.12 | 1.21 |
| opb | 0.0386 | 1.3 | 1.23 | 1.12 | 1.21 |
| opb | 0.0268 | 1.3 | 1.23 | 1.12 | 1.21 |
| opb | 0.0146 | 1.45 | 1.3 | 1.13 | 1.21 |
| axi-c | -0.0100 | 1.3 | 1.13 | 1.16 | 1.26 |
| axi-c | -0.0199 | 1.29 | 1.12 | 1.17 | 1.21 |
| axi-c | -0.0297 | 1.24 | 1.12 | 1.18 | 1.2 |
| axi-c | -0.0297 | 1.23 | 1.12 | 1.18 | 1.2 |
| axi-c | -0.0199 | 1.33 | 1.11 | 1.16 | 1.19 |
| axi-c | -0.0099 | 1.43 | 1.11 | 1.15 | 1.21 |
| axi-t | 0.0103 | 1.37 | 1.15 | 1.17 | 1.26 |
| axi-t | 0.0208 | 1.37 | 1.15 | 1.17 | 1.26 |
| axi-t | 0.0323 | 1.37 | 1.15 | 1.17 | 1.27 |
| axi-t | 0.0322 | 1.38 | 1.15 | 1.17 | 1.27 |
| axi-t | 0.0206 | 1.38 | 1.15 | 1.16 | 1.26 |
| axi-t | 0.0108 | 1.37 | 1.15 | 1.16 | 1.25 |

**Table 9: SCF/SNCF ratio for third cycle of T7.**

**Fourth SNCF measurement cycle to 20 % joint as-welded capacity, preload at 26 %.**

The measured SNCFs for the fourth cycle are presented for each of the four loading conditions in Table 10. Measurements made with additional strain rosettes are presented in Table 11. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 12.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0350 | -1.89 | 0.12 | 1.59 | 0.06 | -3.99 | 0.26 | 4.63 | 0.02 |
| ipb | 0.0689 | -2.44 | 0.16 | 1.52 | 0.22 | -2.94 | 0.42 | 4.28 | 0.56 |
| ipb | 0.1031 | -2.58 | 0.21 | 1.48 | 0.26 | -2.43 | 0.55 | 4.05 | 0.7 |
| ipb | 0.1031 | -2.56 | 0.2 | 1.46 | 0.26 | -2.43 | 0.54 | 4.06 | 0.71 |
| ipb | 0.0691 | -2.45 | 0.13 | 1.52 | 0.24 | -3.03 | 0.35 | 4.38 | 0.61 |
| ipb | 0.0361 | -1.99 | -0.01 | 1.63 | 0.15 | -4.26 | 0.1 | 4.9 | 0.28 |
| opb | 0.0138 | 0.14 | -6.99 | -0.18 | 5.03 | 0.87 | -12.96 | 0.08 | 14.5 |
| opb | 0.0257 | 0.15 | -6.44 | -0.14 | 4.44 | 0.89 | -8.11 | 0.28 | 12.55 |
| opb | 0.0371 | 0.12 | -5.85 | -0.13 | 4.1 | 0.89 | -6.25 | 0.41 | 11.55 |
| opb | 0.0354 | 0.1 | -5.97 | -0.1 | 4.12 | 0.9 | -6.15 | 0.44 | 11.62 |
| opb | 0.0250 | 0.06 | -6.62 | -0.11 | 4.47 | 0.92 | -7.95 | 0.33 | 12.72 |
| opb | 0.0127 | 0.09 | -7.58 | -0.19 | 5.23 | 0.9 | -13.34 | 0.06 | 15.16 |
| axi-c | -0.0100 | 0.72 | 6.36 | 3.2 | 3.53 | 5.55 | 14.26 | 8.52 | 10.58 |
| axi-c | -0.0198 | 0.65 | 3.07 | 2.1 | 3.3 | 4.77 | 7.24 | 5.92 | 7.79 |
| axi-c | -0.0296 | 0.83 | 2.25 | 2.11 | 2.91 | 4.45 | 5.45 | 5.2 | 6.33 |
| axi-c | -0.0297 | 0.89 | 2.25 | 1.65 | 2.97 | 4.43 | 5.45 | 5.24 | 6.34 |
| axi-c | -0.0199 | 0.8 | 2.99 | 1.52 | 3.68 | 4.95 | 6.88 | 6.02 | 8.29 |
| axi-c | -0.0101 | 0.88 | 5.2 | 1.91 | 5 | 5.89 | 11.93 | 8.43 | 12.5 |
| axi-t | 0.0110 | -0.56 | 7.58 | 2.59 | 3.87 | 1.25 | 16.65 | 11.25 | 11.09 |
| axi-t | 0.0208 | 0.48 | 8.21 | 1.65 | 2.13 | 3.92 | 18.21 | 8 | 6.42 |
| axi-t | 0.0324 | 0.77 | 7.95 | 1.32 | 1.24 | 4.62 | 17.58 | 7.04 | 4.35 |
| axi-t | 0.0323 | 0.78 | 7.99 | 1.79 | 1.35 | 4.6 | 17.65 | 6.96 | 4.51 |
| axi-t | 0.0211 | 0.48 | 8.53 | 1.96 | 2.07 | 4.07 | 18.88 | 7.69 | 6.06 |
| axi-t | 0.0106 | -0.37 | 8.04 | 2.93 | 3.94 | 1.66 | 17.81 | 10.7 | 11.22 |

**Table 10: Measured SNCFs on intersection of brace and chord for T7 at fourth cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0350 | 1.59 | 1.49 | 4.63 | 4.62 | 0.02 | -0.35 | 0.06 | -0.15 |
| ipb | 0.0689 | 1.52 | 1.45 | 4.28 | 4.29 | 0.56 | 0.25 | 0.22 | 0.04 |
| ipb | 0.1031 | 1.48 | 1.41 | 4.05 | 4.01 | 0.7 | 0.41 | 0.26 | 0.1 |
| ipb | 0.1031 | 1.46 | 1.4 | 4.06 | 4.01 | 0.71 | 0.43 | 0.26 | 0.11 |
| ipb | 0.0691 | 1.52 | 1.45 | 4.38 | 4.32 | 0.61 | 0.29 | 0.24 | 0.06 |
| ipb | 0.0361 | 1.63 | 1.57 | 4.9 | 4.85 | 0.28 | -0.11 | 0.15 | -0.03 |
| opb | 0.0138 | -0.18 | -0.13 | 0.08 | -0.11 | 14.5 | 14.54 | 5.03 | 4.94 |
| opb | 0.0257 | -0.14 | -0.14 | 0.28 | 0.17 | 12.55 | 12.71 | 4.44 | 4.29 |
| opb | 0.0371 | -0.13 | -0.1 | 0.41 | 0.3 | 11.55 | 11.75 | 4.1 | 3.98 |
| opb | 0.0354 | -0.1 | -0.11 | 0.44 | 0.31 | 11.62 | 11.86 | 4.12 | 4 |
| opb | 0.0250 | -0.11 | -0.14 | 0.33 | 0.19 | 12.72 | 12.91 | 4.47 | 4.36 |
| opb | 0.0127 | -0.19 | -0.18 | 0.06 | -0.15 | 15.16 | 15.36 | 5.23 | 5.07 |
| axi-c | -0.0100 | 3.2 | 3.38 | 8.52 | 8.27 | 10.58 | 10.83 | 3.53 | 3.61 |
| axi-c | -0.0198 | 2.1 | 2.23 | 5.92 | 5.67 | 7.79 | 7.92 | 3.3 | 3.24 |
| axi-c | -0.0296 | 2.11 | 2.01 | 5.2 | 5.03 | 6.33 | 6.42 | 2.91 | 2.83 |
| axi-c | -0.0297 | 1.65 | 2.08 | 5.24 | 5.1 | 6.34 | 6.29 | 2.97 | 2.89 |
| axi-c | -0.0199 | 1.52 | 1.94 | 6.02 | 5.78 | 8.29 | 8.31 | 3.68 | 3.59 |
| axi-c | -0.0101 | 1.91 | 2.24 | 8.43 | 8.17 | 12.5 | 12.4 | 5 | 4.72 |
| axi-t | 0.0110 | 2.59 | 2.8 | 11.25 | 11.17 | 11.09 | 10.78 | 3.87 | 3.69 |
| axi-t | 0.0208 | 1.65 | 1.8 | 8 | 8.04 | 6.42 | 6.23 | 2.13 | 2.07 |
| axi-t | 0.0324 | 1.32 | 1.49 | 7.04 | 7.09 | 4.35 | 4.22 | 1.24 | 1.25 |
| axi-t | 0.0323 | 1.79 | 1.45 | 6.96 | 6.95 | 4.51 | 4.49 | 1.35 | 1.29 |
| axi-t | 0.0211 | 1.96 | 1.67 | 7.69 | 7.6 | 6.06 | 6.01 | 2.07 | 1.91 |
| axi-t | 0.0106 | 2.93 | 2.45 | 10.7 | 10.44 | 11.22 | 10.87 | 3.94 | 3.75 |

**Table 11: SNCFs measured with rosettes compared to single strain gauge measurements for fourth cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0350 | 1.32 | 1.17 | 1.1 | 1.07 |
| ipb | 0.0689 | 1.32 | 1.17 | 1.2 | 1.76 |
| ipb | 0.1031 | 1.32 | 1.17 | 1.17 | 1.43 |
| ipb | 0.1031 | 1.32 | 1.18 | 1.17 | 1.4 |
| ipb | 0.0691 | 1.32 | 1.17 | 1.18 | 1.55 |
| ipb | 0.0361 | 1.32 | 1.17 | 1.03 | 0.58 |
| opb | 0.0138 | 1.52 | 1.09 | 1.13 | 1.21 |
| opb | 0.0257 | 1.39 | 1.25 | 1.13 | 1.21 |
| opb | 0.0371 | 1.31 | 1.22 | 1.12 | 1.2 |
| opb | 0.0354 | 1.31 | 1.23 | 1.12 | 1.2 |
| opb | 0.0250 | 1.29 | 1.21 | 1.12 | 1.21 |
| opb | 0.0127 | 1.45 | 1.17 | 1.13 | 1.21 |
| axi-c | -0.0100 | 1.23 | 1.15 | 1.16 | 1.26 |
| axi-c | -0.0198 | 1.22 | 1.44 | 1.17 | 1.22 |
| axi-c | -0.0296 | 1.21 | 1.13 | 1.18 | 1.21 |
| axi-c | -0.0297 | 1.22 | 1.13 | 1.18 | 1.21 |
| axi-c | -0.0199 | 1.26 | 1.13 | 1.17 | 1.2 |
| axi-c | -0.0101 | 1.32 | 1.07 | 1.16 | 1.22 |
| axi-t | 0.0110 | 1.36 | 1.15 | 1.15 | 1.26 |
| axi-t | 0.0208 | 1.37 | 1.15 | 1.17 | 1.27 |
| axi-t | 0.0324 | 1.38 | 1.15 | 1.19 | 1.32 |
| axi-t | 0.0323 | 1.38 | 1.15 | 1.19 | 1.31 |
| axi-t | 0.0211 | 1.38 | 1.15 | 1.17 | 1.28 |
| axi-t | 0.0106 | 1.21 | 1.15 | 1.15 | 1.25 |

**Table 12: SCF/SNCF ratio for fourth cycle of T7**

**Fifth SNCF measurement cycle to 20 % joint as-welded capacity, preload at 40 %.**

The measured SNCFs for the fifth cycle are presented for each of the four loading conditions in Table 13. Measurements made with additional strain rosettes are presented in Table 14. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 15.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0328 | -1.81 | 0.18 | 1.53 | -0.04 | -3.94 | 0.44 | 4.54 | -0.22 |
| ipb | 0.0662 | -2.47 | 0.28 | 1.56 | 0.15 | -2.89 | 0.65 | 4.35 | 0.34 |
| ipb | 0.1013 | -2.61 | 0.29 | 1.5 | 0.22 | -2.39 | 0.7 | 4.12 | 0.57 |
| ipb | 0.1008 | -2.63 | 0.28 | 1.46 | 0.22 | -2.41 | 0.7 | 4.15 | 0.58 |
| ipb | 0.0662 | -2.56 | 0.24 | 1.55 | 0.16 | -3.01 | 0.58 | 4.51 | 0.38 |
| ipb | 0.0332 | -2.02 | 0.17 | 1.65 | 0 | -4.28 | 0.39 | 5.06 | -0.11 |
| opb | 0.0125 | 0.2 | -7.01 | -0.35 | 4.82 | 0.94 | -12.14 | 0.1 | 13.88 |
| opb | 0.0248 | 0.15 | -6.37 | -0.16 | 4.23 | 0.99 | -7.27 | 0.34 | 11.99 |
| opb | 0.0382 | -0.12 | -6 | 0.1 | 3.72 | 0.95 | -5.46 | 0.41 | 11.03 |
| opb | 0.0368 | -0.17 | -5.95 | -0.32 | 3.57 | 0.98 | -4.98 | 0.4 | 10.86 |
| opb | 0.0249 | 0.14 | -6.24 | -0.03 | 4.12 | 1.05 | -6.51 | 0.27 | 11.8 |
| opb | 0.0117 | 0.16 | -6.94 | 0.02 | 4.65 | 1.07 | -11.2 | 0.05 | 13.54 |
| axi-c | -0.0099 | 3.16 | 5.16 | 0.36 | 4.19 | 8.64 | 11.68 | 4.62 | 11.73 |
| axi-c | -0.0199 | 2.47 | 2.55 | 0.65 | 4.13 | 5.8 | 5.84 | 4.58 | 8.6 |
| axi-c | -0.0298 | 2.42 | 2.02 | 0.89 | 3.42 | 4.89 | 4.72 | 4.57 | 6.82 |
| axi-c | -0.0298 | 2.41 | 2.07 | 0.86 | 3.4 | 4.86 | 4.78 | 4.58 | 6.77 |
| axi-c | -0.0200 | 2.33 | 2.38 | 0.46 | 4.49 | 5.82 | 5.31 | 4.24 | 9.04 |
| axi-c | -0.0100 | 2.68 | 3.39 | -0.08 | 6.06 | 8.4 | 7.59 | 3.15 | 13.75 |
| axi-t | 0.0111 | 0.46 | 9.31 | 1.91 | 3.08 | 4.49 | 20.67 | 8.23 | 8.59 |
| axi-t | 0.0212 | 0.64 | 9.08 | 1.7 | 1.79 | 4.64 | 19.94 | 7.52 | 5.21 |
| axi-t | 0.0323 | 1.01 | 7.46 | 1.25 | 2.27 | 5.32 | 16.44 | 6.33 | 6.76 |
| axi-t | 0.0324 | 1.08 | 7.4 | 1.4 | 2.24 | 5.37 | 16.32 | 6.3 | 6.74 |
| axi-t | 0.0210 | 0.93 | 8.89 | 1.7 | 2.03 | 5.22 | 19.58 | 7.1 | 5.99 |
| axi-t | 0.0111 | 0.71 | 10.46 | 1.94 | 2.27 | 4.91 | 23.23 | 8.41 | 6.55 |

**Table 13: Measured SNCFs on intersection of brace and chord for T7 at fifth cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0328 | 1.53 | 1.46 | 4.54 | 4.54 | -0.22 | -0.63 | -0.04 | -0.2 |
| ipb | 0.0662 | 1.56 | 1.47 | 4.35 | 4.33 | 0.34 | 0.03 | 0.15 | -0.01 |
| ipb | 0.1013 | 1.5 | 1.43 | 4.12 | 4.07 | 0.57 | 0.29 | 0.22 | 0.06 |
| ipb | 0.1008 | 1.46 | 1.44 | 4.15 | 4.1 | 0.58 | 0.29 | 0.22 | 0.06 |
| ipb | 0.0662 | 1.55 | 1.52 | 4.51 | 4.42 | 0.38 | 0.06 | 0.16 | -0.01 |
| ipb | 0.0332 | 1.65 | 1.68 | 5.06 | 5.05 | -0.11 | -0.46 | 0 | -0.15 |
| opb | 0.0125 | -0.35 | -0.12 | 0.1 | -0.03 | 13.88 | 14 | 4.82 | 4.75 |
| opb | 0.0248 | -0.16 | -0.11 | 0.34 | 0.21 | 11.99 | 12.22 | 4.23 | 4.12 |
| opb | 0.0382 | 0.1 | -0.19 | 0.41 | 0.22 | 11.03 | 11.03 | 3.72 | 3.64 |
| opb | 0.0368 | -0.32 | -0.23 | 0.4 | 0.22 | 10.86 | 10.8 | 3.57 | 3.55 |
| opb | 0.0249 | -0.03 | -0.19 | 0.27 | 0.23 | 11.8 | 11.94 | 4.12 | 4.02 |
| opb | 0.0117 | 0.02 | -0.27 | 0.05 | -0.03 | 13.54 | 13.95 | 4.65 | 4.61 |
| axi-c | -0.0099 | 0.36 | 0.4 | 4.62 | 4.5 | 11.73 | 11.92 | 4.19 | 4.14 |
| axi-c | -0.0199 | 0.65 | 0.57 | 4.58 | 4.49 | 8.6 | 8.69 | 4.13 | 3.92 |
| axi-c | -0.0298 | 0.89 | 0.82 | 4.57 | 4.51 | 6.82 | 6.96 | 3.42 | 3.26 |
| axi-c | -0.0298 | 0.86 | 0.82 | 4.58 | 4.47 | 6.77 | 6.95 | 3.4 | 3.25 |
| axi-c | -0.0200 | 0.46 | 0.46 | 4.24 | 4.05 | 9.04 | 9.27 | 4.49 | 4.32 |
| axi-c | -0.0100 | -0.08 | 0 | 3.15 | 2.99 | 13.75 | 14.22 | 6.06 | 5.97 |
| axi-t | 0.0111 | 1.91 | 1.74 | 8.23 | 8.2 | 8.59 | 8.62 | 3.08 | 2.89 |
| axi-t | 0.0212 | 1.7 | 1.6 | 7.52 | 7.57 | 5.21 | 5.18 | 1.79 | 1.66 |
| axi-t | 0.0323 | 1.25 | 1.23 | 6.33 | 6.36 | 6.76 | 6.84 | 2.27 | 2.16 |
| axi-t | 0.0324 | 1.4 | 1.26 | 6.3 | 6.37 | 6.74 | 6.83 | 2.24 | 2.14 |
| axi-t | 0.0210 | 1.7 | 1.51 | 7.1 | 7.1 | 5.99 | 5.93 | 2.03 | 1.94 |
| axi-t | 0.0111 | 1.94 | 1.76 | 8.41 | 8.46 | 6.55 | 6.39 | 2.27 | 2.11 |

Table 14: SNCFs measured with rosettes compared to single strain gauge measurements for **fifth cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0328 | 1.33 | 1.17 | 1.11 | 1.16 |
| ipb | 0.0662 | 1.32 | 1.17 | 1.48 | -0.28 |
| ipb | 0.1013 | 1.31 | 1.18 | 1.19 | 1.53 |
| ipb | 0.1008 | 1.31 | 1.18 | 1.19 | 1.54 |
| ipb | 0.0662 | 1.32 | 1.17 | 1.4 | -0.65 |
| ipb | 0.0332 | 1.33 | 1.17 | 1.09 | 1.11 |
| opb | 0.0125 | 1.53 | 0.31 | 1.13 | 1.21 |
| opb | 0.0248 | 1.41 | 1.25 | 1.13 | 1.21 |
| opb | 0.0382 | 1.21 | 1.33 | 1.12 | 1.21 |
| opb | 0.0368 | 1.2 | 1.29 | 1.12 | 1.21 |
| opb | 0.0249 | 1.33 | 1.19 | 1.12 | 1.2 |
| opb | 0.0117 | 1.36 | 1.11 | 1.13 | 1.22 |
| axi-c | -0.0099 | 1.5 | 1.1 | 1.15 | 1.24 |
| axi-c | -0.0199 | 1.39 | 1.11 | 1.16 | 1.2 |
| axi-c | -0.0298 | 1.32 | 1.11 | 1.17 | 1.2 |
| axi-c | -0.0298 | 1.32 | 1.11 | 1.17 | 1.2 |
| axi-c | -0.0200 | 1.45 | 1.11 | 1.16 | 1.19 |
| axi-c | -0.0100 | -13.28 | 1.09 | 1.15 | 1.22 |
| axi-t | 0.0111 | 1.37 | 1.14 | 1.16 | 1.26 |
| axi-t | 0.0212 | 1.37 | 1.14 | 1.18 | 1.3 |
| axi-t | 0.0323 | 1.39 | 1.14 | 1.17 | 1.27 |
| axi-t | 0.0324 | 1.38 | 1.14 | 1.17 | 1.27 |
| axi-t | 0.0210 | 1.37 | 1.14 | 1.17 | 1.29 |
| axi-t | 0.0111 | 1.37 | 1.14 | 1.18 | 1.29 |

**Table 15: SCF/SNCF ratio for fifth cycle of T7.**

**Sixth SNCF measurement cycle to 20 % joint as-welded capacity, preload at 52 %.**

The measured SNCFs for the sixth cycle are presented for each of the four loading conditions in Table 16. Measurements made with additional strain rosettes are presented in Table 17. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 18.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0333 | -1.83 | 0.05 | 1.59 | 0.07 | -4.18 | 0.14 | 4.78 | 0.04 |
| ipb | 0.0670 | -2.4 | 0.14 | 1.5 | 0.23 | -3.09 | 0.33 | 4.46 | 0.61 |
| ipb | 0.1010 | -2.6 | 0.18 | 1.47 | 0.27 | -2.52 | 0.46 | 4.2 | 0.77 |
| ipb | 0.1011 | -2.59 | 0.19 | 1.54 | 0.28 | -2.51 | 0.46 | 4.2 | 0.76 |
| ipb | 0.0664 | -2.43 | 0.11 | 1.6 | 0.25 | -3.19 | 0.27 | 4.57 | 0.65 |
| ipb | 0.0338 | -1.87 | 0.01 | 1.71 | 0.12 | -4.45 | 0.04 | 4.98 | 0.2 |
| opb | 0.0108 | 0.06 | -7.31 | -0.12 | 4.26 | 0.94 | -7.67 | 0.74 | 11.83 |
| opb | 0.0234 | 0.04 | -6.25 | -0.06 | 3.93 | 0.86 | -4.72 | 0.76 | 10.87 |
| opb | 0.0349 | 0.06 | -5.58 | -0.08 | 3.72 | 0.82 | -3.79 | 0.76 | 10.28 |
| opb | 0.0357 | 0.08 | -5.68 | 0 | 3.84 | 0.88 | -4.23 | 0.67 | 10.67 |
| opb | 0.0248 | 0.07 | -6.36 | -0.04 | 4.04 | 0.92 | -5.36 | 0.6 | 11.36 |
| opb | 0.0123 | 0.16 | -7.4 | -0.14 | 4.37 | 1.06 | -8.72 | 0.53 | 12.41 |
| axi-c | -0.0098 | 0.95 | 5.31 | 2.16 | 4.42 | 5.79 | 11.81 | 8.55 | 11.91 |
| axi-c | -0.0200 | 1.18 | 2.8 | 1.91 | 3.93 | 4.61 | 6.13 | 6.45 | 8.29 |
| axi-c | -0.0297 | 1.45 | 2.18 | 2.03 | 3.35 | 4.17 | 4.87 | 5.84 | 6.68 |
| axi-c | -0.0297 | 1.43 | 2.07 | 0.99 | 3.33 | 4.16 | 4.9 | 5.81 | 6.76 |
| axi-c | -0.0199 | 1.12 | 2.41 | 0.78 | 4.33 | 4.66 | 5.59 | 6.1 | 9.03 |
| axi-c | -0.0099 | 1.14 | 3.21 | 0.85 | 6.97 | 5.61 | 7.09 | 6.39 | 14.31 |
| axi-t | 0.0105 | -1.41 | 9.41 | 3.65 | 2.49 | -0.46 | 20.92 | 13.67 | 6.89 |
| axi-t | 0.0212 | -0.05 | 8.89 | 2.26 | 1.69 | 3.01 | 19.82 | 9.25 | 5.13 |
| axi-t | 0.0319 | 0.64 | 7.35 | 1.48 | 2.36 | 4.46 | 16.34 | 7.17 | 7.02 |
| axi-t | 0.0319 | 0.65 | 7.4 | 1.77 | 2.39 | 4.44 | 16.25 | 7.19 | 6.99 |
| axi-t | 0.0210 | 0.17 | 8.76 | 2.34 | 2.2 | 3.5 | 19.26 | 8.75 | 6.14 |
| axi-t | 0.0105 | -1.07 | 10.38 | 3.66 | 2.44 | 0.72 | 22.7 | 12.77 | 6.31 |

**Table 16: Measured SNCFs on intersection of brace and chord for T7 at sixth cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0333 | 1.59 | 1.53 | 4.78 | 4.77 | 0.04 | -0.33 | 0.07 | -0.11 |
| ipb | 0.0670 | 1.5 | 1.48 | 4.46 | 4.43 | 0.61 | 0.26 | 0.23 | 0.06 |
| ipb | 0.1010 | 1.47 | 1.45 | 4.2 | 4.17 | 0.77 | 0.46 | 0.27 | 0.12 |
| ipb | 0.1011 | 1.54 | 1.45 | 4.2 | 4.17 | 0.76 | 0.46 | 0.28 | 0.12 |
| ipb | 0.0664 | 1.6 | 1.51 | 4.57 | 4.54 | 0.65 | 0.3 | 0.25 | 0.09 |
| ipb | 0.0338 | 1.71 | 1.6 | 4.98 | 4.93 | 0.2 | -0.22 | 0.12 | -0.07 |
| opb | 0.0108 | -0.12 | -0.05 | 0.74 | 0.7 | 11.83 | 12.09 | 4.26 | 4.11 |
| opb | 0.0234 | -0.06 | -0.03 | 0.76 | 0.67 | 10.87 | 10.95 | 3.93 | 3.8 |
| opb | 0.0349 | -0.08 | -0.05 | 0.76 | 0.7 | 10.28 | 10.48 | 3.72 | 3.58 |
| opb | 0.0357 | 0 | -0.09 | 0.67 | 0.61 | 10.67 | 10.86 | 3.84 | 3.7 |
| opb | 0.0248 | -0.04 | -0.13 | 0.6 | 0.54 | 11.36 | 11.52 | 4.04 | 3.92 |
| opb | 0.0123 | -0.14 | -0.2 | 0.53 | 0.39 | 12.41 | 12.65 | 4.37 | 4.26 |
| axi-c | -0.0098 | 2.16 | 1.65 | 8.55 | 8.24 | 11.91 | 12.07 | 4.42 | 4.11 |
| axi-c | -0.0200 | 1.91 | 1.3 | 6.45 | 6.33 | 8.29 | 8.4 | 3.93 | 3.64 |
| axi-c | -0.0297 | 2.03 | 1.37 | 5.84 | 5.7 | 6.68 | 6.73 | 3.35 | 3.12 |
| axi-c | -0.0297 | 0.99 | 1.4 | 5.81 | 5.72 | 6.76 | 7.17 | 3.33 | 3.2 |
| axi-c | -0.0199 | 0.78 | 1.19 | 6.1 | 6.03 | 9.03 | 9.54 | 4.33 | 4.13 |
| axi-c | -0.0099 | 0.85 | 1.27 | 6.39 | 6.41 | 14.31 | 15.05 | 6.97 | 6.64 |
| axi-t | 0.0105 | 3.65 | 3.75 | 13.67 | 13.65 | 6.89 | 6.59 | 2.49 | 2.08 |
| axi-t | 0.0212 | 2.26 | 2.28 | 9.25 | 9.27 | 5.13 | 5.14 | 1.69 | 1.64 |
| axi-t | 0.0319 | 1.48 | 1.58 | 7.17 | 7.16 | 7.02 | 7.14 | 2.36 | 2.27 |
| axi-t | 0.0319 | 1.77 | 1.6 | 7.19 | 7.25 | 6.99 | 6.97 | 2.39 | 2.23 |
| axi-t | 0.0210 | 2.34 | 2.14 | 8.75 | 8.89 | 6.14 | 6.04 | 2.2 | 2.01 |
| axi-t | 0.0105 | 3.66 | 3.35 | 12.77 | 12.99 | 6.31 | 6.14 | 2.44 | 2.04 |

**Table 17: SNCFs measured with rosettes compared to single strain gauge measurements for sixth cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0333 | 1.33 | 1.17 | 1.09 | 1.05 |
| ipb | 0.0670 | 1.33 | 1.17 | 1.22 | 1.6 |
| ipb | 0.1010 | 1.32 | 1.18 | 1.17 | 1.4 |
| ipb | 0.1011 | 1.32 | 1.18 | 1.16 | 1.38 |
| ipb | 0.0664 | 1.33 | 1.17 | 1.18 | 1.46 |
| ipb | 0.0338 | 1.33 | 1.17 | 1.08 | 0.87 |
| opb | 0.0108 | 1.77 | 1.16 | 1.12 | 1.2 |
| opb | 0.0234 | 1.3 | 1.16 | 1.12 | 1.2 |
| opb | 0.0349 | 1.17 | 1.2 | 1.12 | 1.2 |
| opb | 0.0357 | 1.16 | 1.21 | 1.12 | 1.2 |
| opb | 0.0248 | 1.25 | 1.21 | 1.12 | 1.2 |
| opb | 0.0123 | 1.29 | 1.2 | 1.13 | 1.21 |
| axi-c | -0.0098 | 1.35 | 1.13 | 1.16 | 1.23 |
| axi-c | -0.0200 | 1.34 | 1.13 | 1.16 | 1.19 |
| axi-c | -0.0297 | 1.3 | 1.13 | 1.17 | 1.19 |
| axi-c | -0.0297 | 1.3 | 1.13 | 1.17 | 1.2 |
| axi-c | -0.0199 | 1.34 | 1.13 | 1.16 | 1.2 |
| axi-c | -0.0099 | 1.39 | 1.13 | 1.15 | 1.2 |
| axi-t | 0.0105 | 1.35 | 1.15 | 1.17 | 1.29 |
| axi-t | 0.0212 | 1.36 | 1.15 | 1.18 | 1.3 |
| axi-t | 0.0319 | 1.37 | 1.15 | 1.16 | 1.27 |
| axi-t | 0.0319 | 1.37 | 1.15 | 1.16 | 1.26 |
| axi-t | 0.0210 | 1.36 | 1.15 | 1.17 | 1.27 |
| axi-t | 0.0105 | 1.35 | 1.15 | 1.17 | 1.29 |

**Table 18: SCF/SNCF ratio for sixth cycle of T7.**

**Seventh SNCF measurement cycle to 20 % joint as-welded capacity, preload at 65 %.**

The measured SNCFs for the seventh cycle are presented for each of the four loading conditions in Table 19. Measurements made with additional strain rosettes are presented in Table 20. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 21.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0339 | -2.13 | -0.06 | 1.49 | 0.05 | -4.47 | -0.3 | 4.42 | 0.07 |
| ipb | 0.0662 | -2.25 | 0.06 | 1.52 | 0.26 | -3.09 | 0.21 | 4.32 | 0.65 |
| ipb | 0.1016 | -2.61 | 0.13 | 1.4 | 0.26 | -2.56 | 0.35 | 3.98 | 0.7 |
| ipb | 0.1003 | -2.64 | 0.15 | 1.43 | 0.25 | -2.59 | 0.4 | 4.02 | 0.66 |
| ipb | 0.0649 | -2.47 | 0.09 | 1.6 | 0.24 | -3.31 | 0.25 | 4.74 | 0.53 |
| ipb | 0.0332 | -1.88 | 0.03 | 1.72 | 0.09 | -4.86 | 0.25 | 4.37 | -0.12 |
| opb | 0.0126 | 0.23 | -7.09 | -0.27 | 4.98 | 1.12 | -12.37 | 0.15 | 14.13 |
| opb | 0.0244 | 0.16 | -6.55 | -0.2 | 4.36 | 1.09 | -7.61 | 0.29 | 12.3 |
| opb | 0.0359 | 0.16 | -5.92 | -0.15 | 4.09 | 1.01 | -5.82 | 0.39 | 11.4 |
| opb | 0.0392 | 0.15 | -5.65 | -0.15 | 3.92 | 0.97 | -5.82 | 0.32 | 11.01 |
| opb | 0.0274 | 0.16 | -6.16 | -0.2 | 4.09 | 1.03 | -7.5 | 0.18 | 11.69 |
| opb | 0.0082 | 0.28 | -5.12 | -0.3 | 4.34 | 0.85 | -11.8 | -0.5 | 12.92 |
| axi-c | -0.0097 | 1.02 | 4.39 | 1.61 | 5.59 | 5.9 | 9.88 | 7.42 | 12.62 |
| axi-c | -0.0196 | 1.1 | 2.64 | 1.33 | 4.22 | 5.02 | 5.85 | 5.84 | 8.4 |
| axi-c | -0.0294 | 1.34 | 1.98 | 1.36 | 3.59 | 4.54 | 4.6 | 5.33 | 6.78 |
| axi-c | -0.0294 | 1.35 | 1.93 | 1.23 | 3.59 | 4.54 | 4.61 | 5.34 | 6.79 |
| axi-c | -0.0197 | 1.19 | 2.29 | 0.97 | 4.62 | 5.11 | 5.26 | 5.38 | 9.06 |
| axi-c | -0.0098 | 1.53 | 2.67 | 0.75 | 7.77 | 6.47 | 5.87 | 5.27 | 15.04 |
| axi-t | 0.0108 | 1.23 | 11.98 | 0.87 | -0.07 | 6.25 | 27.04 | 6.2 | 0.75 |
| axi-t | 0.0211 | 1.15 | 9.69 | 1.11 | 1.07 | 5.8 | 21.45 | 6.18 | 3.74 |
| axi-t | 0.0322 | 1.01 | 6.57 | 1.07 | 3.34 | 5.3 | 14.53 | 5.98 | 9.71 |
| axi-t | 0.0323 | 1.03 | 6.51 | 1.23 | 3.34 | 5.32 | 14.43 | 5.95 | 9.65 |
| axi-t | 0.0208 | 0.79 | 7.88 | 1.58 | 3.21 | 4.95 | 17.4 | 6.89 | 9.07 |
| axi-t | 0.0108 | -0.05 | 9.74 | 2.53 | 2.59 | 3.35 | 21.7 | 9.53 | 7.38 |

**Table 19: Measured SNCFs on intersection of brace and chord for T7 at seventh cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0339 | 1.49 | 1.39 | 4.42 | 3.94 | 0.07 | -0.26 | 0.05 | -0.1 |
| ipb | 0.0662 | 1.52 | 1.43 | 4.32 | 4.33 | 0.65 | 0.3 | 0.26 | 0.07 |
| ipb | 0.1016 | 1.4 | 1.38 | 3.98 | 4.01 | 0.7 | 0.42 | 0.26 | 0.11 |
| ipb | 0.1003 | 1.43 | 1.4 | 4.02 | 4.06 | 0.66 | 0.39 | 0.25 | 0.1 |
| ipb | 0.0649 | 1.6 | 1.5 | 4.74 | 4.34 | 0.53 | 0.22 | 0.24 | 0.07 |
| ipb | 0.0332 | 1.72 | 1.38 | 4.37 | 4.85 | -0.12 | -0.34 | 0.09 | -0.13 |
| opb | 0.0126 | -0.27 | -0.17 | 0.15 | -0.16 | 14.13 | 14.33 | 4.98 | 4.76 |
| opb | 0.0244 | -0.2 | -0.15 | 0.29 | 0.16 | 12.3 | 12.49 | 4.36 | 4.23 |
| opb | 0.0359 | -0.15 | -0.14 | 0.39 | 0.24 | 11.4 | 11.53 | 4.09 | 3.94 |
| opb | 0.0392 | -0.15 | -0.16 | 0.32 | 0.18 | 11.01 | 11.17 | 3.92 | 3.79 |
| opb | 0.0274 | -0.2 | -0.18 | 0.18 | 0.04 | 11.69 | 11.92 | 4.09 | 3.97 |
| opb | 0.0082 | -0.3 | -0.33 | -0.5 | -0.91 | 12.92 | 13.11 | 4.34 | 4.14 |
| axi-c | -0.0097 | 1.61 | 1.47 | 7.42 | 7.2 | 12.62 | 12.81 | 5.59 | 5.23 |
| axi-c | -0.0196 | 1.33 | 1.16 | 5.84 | 5.73 | 8.4 | 8.56 | 4.22 | 4.01 |
| axi-c | -0.0294 | 1.36 | 1.21 | 5.33 | 5.25 | 6.78 | 6.91 | 3.59 | 3.43 |
| axi-c | -0.0294 | 1.23 | 1.21 | 5.34 | 5.29 | 6.79 | 6.99 | 3.59 | 3.45 |
| axi-c | -0.0197 | 0.97 | 0.92 | 5.38 | 5.24 | 9.06 | 9.31 | 4.62 | 4.46 |
| axi-c | -0.0098 | 0.75 | 0.76 | 5.27 | 5.02 | 15.04 | 15.55 | 7.77 | 7.61 |
| axi-t | 0.0108 | 0.87 | 0.99 | 6.2 | 6.24 | 0.75 | 0.94 | -0.07 | -0.11 |
| axi-t | 0.0211 | 1.11 | 1.16 | 6.18 | 6.19 | 3.74 | 3.79 | 1.07 | 1.08 |
| axi-t | 0.0322 | 1.07 | 1.12 | 5.98 | 6 | 9.71 | 9.97 | 3.34 | 3.3 |
| axi-t | 0.0323 | 1.23 | 1.12 | 5.95 | 6.09 | 9.65 | 9.92 | 3.34 | 3.29 |
| axi-t | 0.0208 | 1.58 | 1.32 | 6.89 | 7.06 | 9.07 | 9.2 | 3.21 | 3.13 |
| axi-t | 0.0108 | 2.53 | 2.21 | 9.53 | 9.97 | 7.38 | 7.52 | 2.59 | 2.57 |

**Table 20: SNCFs measured with rosettes compared to single strain gauge measurements for seventh cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0339 | 1.28 | 1.18 | 1.06 | 0.99 |
| ipb | 0.0662 | 1.33 | 1.17 | 1.2 | 1.44 |
| ipb | 0.1016 | 1.32 | 1.17 | 1.18 | 1.41 |
| ipb | 0.1003 | 1.32 | 1.17 | 1.18 | 1.42 |
| ipb | 0.0649 | 1.31 | 1.17 | 1.23 | 1.45 |
| ipb | 0.0332 | 1.33 | 1.17 | 1.09 | 1.19 |
| opb | 0.0126 | 1.62 | 1.08 | 1.13 | 1.22 |
| opb | 0.0244 | 1.49 | 1.31 | 1.12 | 1.21 |
| opb | 0.0359 | 1.4 | 1.32 | 1.12 | 1.2 |
| opb | 0.0392 | 1.37 | 1.31 | 1.12 | 1.2 |
| opb | 0.0274 | 1.42 | 1.45 | 1.12 | 1.21 |
| opb | 0.0082 | 1.51 | 1.18 | 1.13 | 1.23 |
| axi-c | -0.0097 | 1.36 | 1.13 | 1.16 | 1.21 |
| axi-c | -0.0196 | 1.34 | 1.13 | 1.17 | 1.19 |
| axi-c | -0.0294 | 1.31 | 1.12 | 1.17 | 1.19 |
| axi-c | -0.0294 | 1.31 | 1.12 | 1.17 | 1.19 |
| axi-c | -0.0197 | 1.35 | 1.12 | 1.16 | 1.18 |
| axi-c | -0.0098 | 1.39 | 1.12 | 1.15 | 1.19 |
| axi-t | 0.0108 | 1.46 | 1.14 | 1.48 | -0.84 |
| axi-t | 0.0211 | 1.42 | 1.14 | 1.21 | 1.35 |
| axi-t | 0.0322 | 1.41 | 1.14 | 1.15 | 1.25 |
| axi-t | 0.0323 | 1.42 | 1.15 | 1.15 | 1.24 |
| axi-t | 0.0208 | 1.41 | 1.14 | 1.16 | 1.25 |
| axi-t | 0.0108 | 1.38 | 1.15 | 1.16 | 1.26 |

Table 21: SCF/SNCF ratio for seventh cycle of T7.

**Eighth SNCF measurement cycle to 20 % joint as-welded capacity, preload at 78 %.**

The measured SNCFs for the eighth cycle are presented for each of the four loading conditions in Table 22. Measurements made with the additional strain rosettes are presented in Table 23. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 24.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0334 | -1.54 | 0.03 | 1.51 | -0.03 | -4.12 | 0.1 | 4.55 | -0.2 |
| ipb | 0.0664 | -2.14 | 0.01 | 1.53 | 0.12 | -4.1 | 0.03 | 4.5 | 0.31 |
| ipb | 0.1017 | -2.48 | 0.09 | 1.5 | 0.2 | -3.17 | 0.28 | 4.21 | 0.54 |
| ipb | 0.1009 | -2.51 | 0.1 | 1.53 | 0.2 | -3.19 | 0.27 | 4.24 | 0.54 |
| ipb | 0.0658 | -2.2 | 0.03 | 1.59 | 0.12 | -4.21 | 0.08 | 4.67 | 0.27 |
| ipb | 0.0341 | -1.67 | -0.05 | 1.59 | 0.01 | -4.47 | -0.03 | 4.84 | -0.09 |
| opb | 0.0126 | 0.14 | -6.66 | -0.22 | 5.6 | 0.52 | -15.36 | -0.39 | 16.28 |
| opb | 0.0261 | 0.12 | -6.77 | -0.12 | 4.81 | 0.67 | -11.99 | 0 | 13.73 |
| opb | 0.0364 | 0.14 | -6.44 | -0.12 | 4.44 | 0.71 | -9.28 | 0.17 | 12.56 |
| opb | 0.0359 | 0.14 | -6.25 | -0.1 | 4.25 | 0.65 | -8.78 | 0.25 | 12.04 |
| opb | 0.0241 | 0.15 | -6.47 | -0.14 | 4.52 | 0.57 | -11.91 | 0.07 | 12.97 |
| opb | 0.0122 | 0.16 | -6 | -0.15 | 5.19 | 0.46 | -13.92 | -0.23 | 15.01 |
| axi-c | -0.0098 | 4.04 | 5.67 | -0.34 | 7.03 | 12.66 | 11.56 | 3.77 | 18.17 |
| axi-c | -0.0197 | 2.8 | 3.06 | -0.49 | 5.73 | 8.4 | 6.58 | 4.58 | 12.7 |
| axi-c | -0.0295 | 2.51 | 2.4 | -0.02 | 4.91 | 6.97 | 5.38 | 4.89 | 9.92 |
| axi-c | -0.0295 | 2.58 | 2.33 | 0.36 | 5.03 | 6.97 | 5.22 | 4.89 | 10.04 |
| axi-c | -0.0196 | 2.68 | 2.33 | -0.02 | 6.58 | 8.39 | 5.19 | 4.1 | 13.68 |
| axi-c | -0.0097 | 3.6 | 2.41 | -0.5 | 9.71 | 12.11 | 5.18 | 2.64 | 23.07 |
| axi-t | 0.0108 | -0.64 | 9.21 | 2.87 | 1.87 | 1.79 | 20.37 | 11.82 | 5.3 |
| axi-t | 0.0208 | 0.46 | 9.02 | 1.8 | 0.74 | 4.4 | 19.97 | 8.78 | 2.94 |
| axi-t | 0.0321 | 0.82 | 8.31 | 1.39 | 0.35 | 5.15 | 18.56 | 7.49 | 2.27 |
| axi-t | 0.0323 | 0.91 | 8.31 | 1.65 | 0.36 | 5.24 | 18.49 | 7.47 | 2.2 |
| axi-t | 0.0209 | 0.65 | 9.38 | 1.97 | 0.21 | 4.74 | 20.8 | 8.54 | 1.53 |
| axi-t | 0.0107 | -0.24 | 10.55 | 2.89 | 0.4 | 2.73 | 23.42 | 11.4 | 1.31 |

**Table 22: Measured SNCFs on intersection of brace and chord for T7 at eighth cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0334 | 1.51 | 1.42 | 4.55 | 4.49 | -0.2 | -0.61 | -0.03 | -0.2 |
| ipb | 0.0664 | 1.53 | 1.47 | 4.5 | 4.47 | 0.31 | -0.04 | 0.12 | -0.03 |
| ipb | 0.1017 | 1.5 | 1.45 | 4.21 | 4.18 | 0.54 | 0.23 | 0.2 | 0.05 |
| ipb | 0.1009 | 1.53 | 1.47 | 4.24 | 4.23 | 0.54 | 0.23 | 0.2 | 0.05 |
| ipb | 0.0658 | 1.59 | 1.55 | 4.67 | 4.57 | 0.27 | -0.08 | 0.12 | -0.05 |
| ipb | 0.0341 | 1.59 | 1.55 | 4.84 | 4.85 | -0.09 | -0.47 | 0.01 | -0.17 |
| opb | 0.0126 | -0.22 | -0.23 | -0.39 | -0.61 | 16.28 | 16.64 | 5.6 | 5.47 |
| opb | 0.0261 | -0.12 | -0.12 | 0 | -0.2 | 13.73 | 14.04 | 4.81 | 4.72 |
| opb | 0.0364 | -0.12 | -0.11 | 0.17 | -0.02 | 12.56 | 12.83 | 4.44 | 4.33 |
| opb | 0.0359 | -0.1 | -0.07 | 0.25 | 0.06 | 12.04 | 12.26 | 4.25 | 4.15 |
| opb | 0.0241 | -0.14 | -0.08 | 0.07 | -0.16 | 12.97 | 13.13 | 4.52 | 4.45 |
| opb | 0.0122 | -0.15 | -0.12 | -0.23 | -0.54 | 15.01 | 15.18 | 5.19 | 5.08 |
| axi-c | -0.0098 | -0.34 | -0.18 | 3.77 | 3.89 | 18.17 | 19.01 | 7.03 | 7.06 |
| axi-c | -0.0197 | -0.49 | 0.29 | 4.58 | 4.48 | 12.7 | 12.96 | 5.73 | 5.63 |
| axi-c | -0.0295 | -0.02 | 0.46 | 4.89 | 4.77 | 9.92 | 10.05 | 4.91 | 4.76 |
| axi-c | -0.0295 | 0.36 | 0.49 | 4.89 | 4.77 | 10.04 | 10.15 | 5.03 | 4.84 |
| axi-c | -0.0196 | -0.02 | 0.18 | 4.1 | 4.01 | 13.68 | 13.87 | 6.58 | 6.38 |
| axi-c | -0.0097 | -0.5 | -0.49 | 2.64 | 2.39 | 23.07 | 23.56 | 9.71 | 9.52 |
| axi-t | 0.0108 | 2.87 | 2.86 | 11.82 | 11.98 | 5.3 | 5.09 | 1.87 | 1.71 |
| axi-t | 0.0208 | 1.8 | 1.9 | 8.78 | 8.89 | 2.94 | 2.8 | 0.74 | 0.66 |
| axi-t | 0.0321 | 1.39 | 1.48 | 7.49 | 7.59 | 2.27 | 2.23 | 0.35 | 0.35 |
| axi-t | 0.0323 | 1.65 | 1.44 | 7.47 | 7.49 | 2.2 | 2.21 | 0.36 | 0.36 |
| axi-t | 0.0209 | 1.97 | 1.73 | 8.54 | 8.45 | 1.53 | 1.5 | 0.21 | 0.18 |
| axi-t | 0.0107 | 2.89 | 2.59 | 11.4 | 11.28 | 1.31 | 1.12 | 0.4 | 0.14 |

Table 23: SNCFs measured with rosettes compared to single strain gauge measurements for eighth cycle of T7.

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0334 | 1.33 | 1.17 | 1.12 | 1.15 |
| ipb | 0.0664 | 1.33 | 1.17 | 0.72 | 0.67 |
| ipb | 0.1017 | 1.32 | 1.18 | 1.22 | 1.55 |
| ipb | 0.1009 | 1.32 | 1.18 | 1.22 | 1.63 |
| ipb | 0.0658 | 1.32 | 1.18 | 0.9 | 0.89 |
| ipb | 0.0341 | 1.33 | 1.17 | 1.1 | 1.18 |
| opb | 0.0126 | 1.43 | 1.12 | 1.13 | 1.22 |
| opb | 0.0261 | 1.48 | 1.01 | 1.13 | 1.21 |
| opb | 0.0364 | 1.46 | -0.07 | 1.12 | 1.21 |
| opb | 0.0359 | 1.66 | 1.76 | 1.12 | 1.21 |
| opb | 0.0241 | 1.76 | 0.97 | 1.13 | 1.21 |
| opb | 0.0122 | 1.76 | 1.12 | 1.13 | 1.22 |
| axi-c | -0.0098 | 0.75 | 1.07 | 1.15 | 1.24 |
| axi-c | -0.0197 | 1.69 | 1.1 | 1.16 | 1.23 |
| axi-c | -0.0295 | 1.51 | 1.11 | 1.16 | 1.21 |
| axi-c | -0.0295 | 1.47 | 1.11 | 1.16 | 1.21 |
| axi-c | -0.0196 | 1.74 | 1.1 | 1.15 | 1.22 |
| axi-c | -0.0097 | 1.14 | 1.03 | 1.15 | 1.23 |
| axi-t | 0.0108 | 1.36 | 1.15 | 1.2 | 1.34 |
| axi-t | 0.0208 | 1.37 | 1.14 | 1.02 | 1.53 |
| axi-t | 0.0321 | 1.38 | 1.14 | 1.3 | 1.76 |
| axi-t | 0.0323 | 1.39 | 1.14 | 1.3 | 1.7 |
| axi-t | 0.0209 | 1.38 | 1.14 | 2 | 4.69 |
| axi-t | 0.0107 | 1.37 | 1.15 | 1.49 | 2.54 |

**Table 24: SCF/SNCF ratio for eighth cycle of T7.**

**Ninth SNCF measurement cycle to 20 % joint as-welded capacity, preload at 90 %.**

The measured SNCFs for the ninth cycle are presented for each of the four loading conditions in Table 25. Measurements made with additional strain rosettes are presented in Table 26. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 27.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0315 | -1.58 | 0.03 | 1.49 | -0.01 | -4.22 | -0.03 | 4.63 | -0.11 |
| ipb | 0.0637 | -1.92 | 0.01 | 1.51 | 0.02 | -4.38 | -0.03 | 4.51 | -0.02 |
| ipb | 0.0988 | -2.4 | 0.07 | 1.48 | 0.11 | -3.47 | 0.15 | 4.27 | 0.3 |
| ipb | 0.0985 | -2.41 | 0.05 | 1.54 | 0.12 | -3.48 | 0.13 | 4.29 | 0.34 |
| ipb | 0.0645 | -2.04 | -0.06 | 1.61 | 0.07 | -4.52 | -0.11 | 4.67 | 0.12 |
| ipb | 0.0306 | -1.73 | -0.09 | 1.67 | 0.1 | -4.56 | -0.19 | 5.01 | 0.12 |
| opb | 0.0125 | 0.16 | -6.25 | -0.13 | 5.02 | 0.28 | -13.92 | 0.13 | 14.22 |
| opb | 0.0235 | 0.15 | -6.41 | -0.05 | 4.54 | 0.47 | -11.99 | 0.25 | 12.88 |
| opb | 0.0358 | 0.12 | -6.31 | -0.08 | 4.22 | 0.58 | -9.04 | 0.32 | 11.86 |
| opb | 0.0380 | 0.12 | -6.72 | 0 | 4.63 | 0.56 | -10.33 | 0.24 | 13.11 |
| opb | 0.0246 | 0.14 | -7.12 | 0.03 | 5.24 | 0.39 | -14.17 | 0.12 | 14.91 |
| opb | 0.0149 | 0.17 | -7.5 | -0.01 | 6.03 | 0.29 | -16.77 | -0.02 | 17.33 |
| axi-c | -0.0099 | 0.49 | 5.72 | 2.88 | 8 | 5.47 | 12.77 | 12.72 | 20.93 |
| axi-c | -0.0199 | 1.01 | 3.48 | 2 | 7.41 | 5.42 | 7.66 | 9.34 | 14.41 |
| axi-c | -0.0296 | 1.2 | 2.8 | 1.68 | 5.99 | 5.2 | 6.11 | 8.01 | 11.21 |
| axi-c | -0.0296 | 1.2 | 2.76 | 1.57 | 5.96 | 5.16 | 6.06 | 8.05 | 11.26 |
| axi-c | -0.0198 | 1.13 | 3 | 1.58 | 7.98 | 5.66 | 6.64 | 8.69 | 15.48 |
| axi-c | -0.0100 | 0.8 | 3.11 | 2.07 | 11.78 | 5.93 | 6.43 | 10.66 | 26.59 |
| axi-t | 0.0106 | -1.03 | 7.73 | 3.3 | 3.04 | 0.66 | 17.15 | 13.16 | 8.7 |
| axi-t | 0.0212 | 0.78 | 9.81 | 1.76 | -0.47 | 5.03 | 22.09 | 8.37 | 0.1 |
| axi-t | 0.0318 | 1.08 | 7.67 | 1.28 | 1.32 | 5.71 | 17.27 | 7 | 4.54 |
| axi-t | 0.0318 | 1.08 | 7.7 | 1.41 | 1.36 | 5.71 | 17.08 | 7 | 4.68 |
| axi-t | 0.0211 | 0.83 | 9.19 | 1.79 | 0.76 | 5.3 | 20.27 | 8.21 | 3.12 |
| axi-t | 0.0110 | 0.08 | 11.26 | 2.77 | 0.1 | 3.35 | 24.8 | 10.97 | 0.85 |

**Table 25: Measured SNCFs on intersection of brace and chord for T7 at ninth cycle.**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0315 | 1.49 | 1.47 | 4.63 | 4.54 | -0.11 | -0.49 | -0.01 | -0.16 |
| ipb | 0.0637 | 1.51 | 1.48 | 4.51 | 4.45 | -0.02 | -0.38 | 0.02 | -0.14 |
| ipb | 0.0988 | 1.48 | 1.46 | 4.27 | 4.22 | 0.3 | -0.03 | 0.11 | -0.04 |
| ipb | 0.0985 | 1.54 | 1.47 | 4.29 | 4.25 | 0.34 | 0.01 | 0.12 | -0.02 |
| ipb | 0.0645 | 1.61 | 1.53 | 4.67 | 4.62 | 0.12 | -0.26 | 0.07 | -0.1 |
| ipb | 0.0306 | 1.67 | 1.57 | 5.01 | 4.96 | 0.12 | -0.3 | 0.1 | -0.09 |
| opb | 0.0125 | -0.13 | 0 | 0.13 | -0.19 | 14.22 | 14.33 | 5.02 | 4.79 |
| opb | 0.0235 | -0.05 | -0.01 | 0.25 | 0 | 12.88 | 13.07 | 4.54 | 4.39 |
| opb | 0.0358 | -0.08 | -0.02 | 0.32 | 0.1 | 11.86 | 12.05 | 4.22 | 4.07 |
| opb | 0.0380 | 0 | -0.07 | 0.24 | 0.06 | 13.11 | 13.36 | 4.63 | 4.52 |
| opb | 0.0246 | 0.03 | -0.07 | 0.12 | -0.07 | 14.91 | 15.17 | 5.24 | 5.07 |
| opb | 0.0149 | -0.01 | -0.07 | -0.02 | -0.31 | 17.33 | 17.52 | 6.03 | 5.89 |
| axi-c | -0.0099 | 2.88 | 2.56 | 12.72 | 12.78 | 20.93 | 20.99 | 8 | 7.59 |
| axi-c | -0.0199 | 2 | 1.75 | 9.34 | 9.18 | 14.41 | 14.54 | 7.41 | 7.1 |
| axi-c | -0.0296 | 1.68 | 1.47 | 8.01 | 7.86 | 11.21 | 11.32 | 5.99 | 5.7 |
| axi-c | -0.0296 | 1.57 | 1.51 | 8.05 | 7.82 | 11.26 | 11.35 | 5.96 | 5.69 |
| axi-c | -0.0198 | 1.58 | 1.57 | 8.69 | 8.5 | 15.48 | 15.62 | 7.98 | 7.68 |
| axi-c | -0.0100 | 2.07 | 2.05 | 10.66 | 10.4 | 26.59 | 26.85 | 11.78 | 11.5 |
| axi-t | 0.0106 | 3.3 | 3.13 | 13.16 | 13.18 | 8.7 | 8.37 | 3.04 | 3.01 |
| axi-t | 0.0212 | 1.76 | 1.74 | 8.37 | 8.54 | 0.1 | 0.1 | -0.47 | -0.43 |
| axi-t | 0.0318 | 1.28 | 1.28 | 7 | 7.08 | 4.54 | 4.66 | 1.32 | 1.35 |
| axi-t | 0.0318 | 1.41 | 1.3 | 7 | 7.1 | 4.68 | 4.69 | 1.36 | 1.31 |
| axi-t | 0.0211 | 1.79 | 1.66 | 8.21 | 8.34 | 3.12 | 2.92 | 0.76 | 0.67 |
| axi-t | 0.0110 | 2.77 | 2.48 | 10.97 | 11.11 | 0.85 | 0.27 | 0.1 | -0.08 |

**Table 26: SNCFs measured with rosettes compared to single strain gauge measurements for ninth cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0315 | 1.33 | 1.17 | 1.14 | 1.11 |
| ipb | 0.0637 | 1.33 | 1.17 | 1.1 | 1.07 |
| ipb | 0.0988 | 1.32 | 1.18 | 0.4 | 0.7 |
| ipb | 0.0985 | 1.32 | 1.18 | 3.44 | 0.3 |
| ipb | 0.0645 | 1.32 | 1.17 | 1.07 | 1.04 |
| ipb | 0.0306 | 1.33 | 1.17 | 1.1 | 1.04 |
| opb | 0.0125 | -13.77 | 1.03 | 1.13 | 1.22 |
| opb | 0.0235 | 3.34 | 8.5 | 1.12 | 1.21 |
| opb | 0.0358 | 2.44 | 1.48 | 1.12 | 1.21 |
| opb | 0.0380 | 1.55 | 1.99 | 1.12 | 1.21 |
| opb | 0.0246 | 1.7 | 0.56 | 1.13 | 1.21 |
| opb | 0.0149 | 1.73 | 0.93 | 1.13 | 1.22 |
| axi-c | -0.0099 | 1.37 | 1.14 | 1.15 | 1.25 |
| axi-c | -0.0199 | 1.38 | 1.13 | 1.16 | 1.21 |
| axi-c | -0.0296 | 1.38 | 1.13 | 1.16 | 1.2 |
| axi-c | -0.0296 | 1.37 | 1.13 | 1.16 | 1.2 |
| axi-c | -0.0198 | 1.37 | 1.13 | 1.15 | 1.2 |
| axi-c | -0.0100 | 1.37 | 1.13 | 1.14 | 1.22 |
| axi-t | 0.0106 | 1.36 | 1.15 | 1.17 | 1.28 |
| axi-t | 0.0212 | 1.37 | 1.15 | 5.21 | 0.65 |
| axi-t | 0.0318 | 1.39 | 1.14 | 1.21 | 1.35 |
| axi-t | 0.0318 | 1.4 | 1.14 | 1.2 | 1.35 |
| axi-t | 0.0211 | 1.38 | 1.14 | 1.25 | 1.49 |
| axi-t | 0.0110 | 1.38 | 1.14 | 2.47 | -1.12 |

**Table 27: SCF/SNCF ratio for ninth cycle of T7.**

**Tenth SNCF measurement cycle at 20 % joint as-welded capacity, preload at 105 %.**

The measured SNCFs for the tenth cycle are presented for each of the four loading conditions in Table 28. Measurements made with additional strain rosettes are presented in Table 29. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 30.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0325 | -1.68 | -0.01 | 1.61 | -0.03 | -4.45 | 0.08 | 5.02 | -0.23 |
| ipb | 0.0651 | -1.85 | -0.15 | 1.61 | 0 | -4.68 | -0.31 | 4.68 | -0.08 |
| ipb | 0.1003 | -2.29 | -0.07 | 1.57 | 0.07 | -4.36 | -0.12 | 4.38 | 0.16 |
| ipb | 0.1009 | -2.28 | -0.07 | 1.57 | 0.07 | -4.34 | -0.14 | 4.35 | 0.18 |
| ipb | 0.0660 | -1.85 | -0.12 | 1.63 | 0 | -4.71 | -0.31 | 4.74 | -0.09 |
| ipb | 0.0331 | -1.71 | -0.05 | 1.58 | 0.01 | -4.52 | -0.12 | 4.86 | -0.12 |
| opb | 0.0123 | 0.23 | -6.84 | -0.3 | 5.42 | 0.63 | -15.27 | -0.78 | 15.7 |
| opb | 0.0256 | 0.27 | -6.28 | -0.14 | 4.64 | 0.64 | -13.03 | -0.28 | 13.32 |
| opb | 0.0370 | 0.23 | -6.44 | -0.1 | 4.42 | 0.6 | -11.19 | 0.02 | 12.46 |
| opb | 0.0364 | 0.25 | -6.38 | -0.04 | 4.4 | 0.59 | -11.08 | 0.05 | 12.35 |
| opb | 0.0240 | 0.32 | -6.35 | -0.05 | 4.83 | 0.55 | -13.4 | -0.17 | 13.69 |
| opb | 0.0122 | 0.31 | -6.58 | -0.2 | 5.41 | 0.83 | -15.16 | -0.7 | 15.68 |
| axi-c | -0.0098 | 6.37 | -4.99 | -3.24 | 17.15 | 18.53 | -11.85 | -5.89 | 35.29 |
| axi-c | -0.0197 | 4.41 | -1.03 | -1.37 | 10.8 | 12.83 | -2.68 | -0.45 | 19.6 |
| axi-c | -0.0296 | 3.61 | -0.32 | -0.74 | 8.74 | 10.44 | -1.02 | 1.24 | 14.61 |
| axi-c | -0.0296 | 3.74 | -0.38 | -0.89 | 8.76 | 10.79 | -1.06 | 0.82 | 14.7 |
| axi-c | -0.0197 | 4.66 | -2.03 | -1.78 | 11.96 | 13.59 | -4.83 | -1.46 | 21.28 |
| axi-c | -0.0099 | 6.78 | -5.53 | -3.8 | 18.28 | 19.68 | -12.91 | -7.08 | 38.63 |
| axi-t | 0.0110 | -0.46 | 8.16 | 2.95 | 2.17 | 1.62 | 18.42 | 11.88 | 5.27 |
| axi-t | 0.0214 | 0.24 | 8.56 | 2.34 | 0.58 | 3.65 | 19.1 | 9.85 | 1.88 |
| axi-t | 0.0322 | 0.65 | 7.03 | 1.78 | 1.53 | 4.61 | 15.76 | 8.33 | 4.59 |
| axi-t | 0.0322 | 0.61 | 7.04 | 1.86 | 1.47 | 4.59 | 15.52 | 8.33 | 4.78 |
| axi-t | 0.0212 | 0.38 | 8.7 | 2.26 | 0.52 | 4.05 | 19 | 9.5 | 2.31 |
| axi-t | 0.0112 | 0.12 | 10.79 | 2.87 | -0.53 | 3.05 | 23.65 | 10.92 | -1.03 |

**Table 28: Measured SNCFs on intersection of brace and chord for T7 at tenth cycle**

| | level | BC;9-s | BC;9-r | CC;9-s | CC;9-r | CS;13-s | CS;13-r | BS;13-s | BS;13-r |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0325 | 1.61 | 1.56 | 5.02 | 4.78 | -0.23 | -0.59 | -0.03 | -0.18 |
| ipb | 0.0651 | 1.61 | 1.54 | 4.68 | 4.58 | -0.08 | -0.42 | 0 | -0.15 |
| ipb | 0.1003 | 1.57 | 1.5 | 4.38 | 4.31 | 0.16 | -0.17 | 0.07 | -0.08 |
| ipb | 0.1009 | 1.57 | 1.48 | 4.35 | 4.29 | 0.18 | -0.16 | 0.07 | -0.08 |
| ipb | 0.0660 | 1.63 | 1.56 | 4.74 | 4.69 | -0.09 | -0.48 | 0 | -0.17 |
| ipb | 0.0331 | 1.58 | 1.57 | 4.86 | 4.95 | -0.12 | -0.52 | 0.01 | -0.17 |
| opb | 0.0123 | -0.3 | -0.2 | -0.78 | -1.01 | 15.7 | 16.39 | 5.42 | 5.38 |
| opb | 0.0256 | -0.14 | -0.07 | -0.28 | -0.44 | 13.32 | 13.74 | 4.64 | 4.61 |
| opb | 0.0370 | -0.1 | -0.06 | 0.02 | -0.18 | 12.46 | 12.82 | 4.42 | 4.33 |
| opb | 0.0364 | -0.04 | -0.08 | 0.05 | -0.16 | 12.35 | 12.61 | 4.4 | 4.29 |
| opb | 0.0240 | -0.05 | -0.11 | -0.17 | -0.45 | 13.69 | 13.99 | 4.83 | 4.67 |
| opb | 0.0122 | -0.2 | -0.21 | -0.7 | -0.9 | 15.68 | 16.18 | 5.41 | 5.32 |
| axi-c | -0.0098 | -3.24 | -3.28 | -5.89 | -6.29 | 35.29 | 36.79 | 17.15 | 17.14 |
| axi-c | -0.0197 | -1.37 | -1.41 | -0.45 | -0.63 | 19.6 | 20.48 | 10.8 | 10.66 |
| axi-c | -0.0296 | -0.74 | -0.72 | 1.24 | 1.1 | 14.61 | 15.17 | 8.74 | 8.6 |
| axi-c | -0.0296 | -0.89 | -0.89 | 0.82 | 0.67 | 14.7 | 15.32 | 8.76 | 8.66 |
| axi-c | -0.0197 | -1.78 | -1.79 | -1.46 | -1.79 | 21.28 | 22.28 | 11.96 | 11.83 |
| axi-c | -0.0099 | -3.8 | -3.73 | -7.08 | -7.39 | 38.63 | 40.36 | 18.28 | 18.33 |
| axi-t | 0.0110 | 2.95 | 2.89 | 11.88 | 11.88 | 5.27 | 4.95 | 2.17 | 1.88 |
| axi-t | 0.0214 | 2.34 | 2.25 | 9.85 | 10 | 1.88 | 1.69 | 0.58 | 0.45 |
| axi-t | 0.0322 | 1.78 | 1.73 | 8.33 | 8.39 | 4.59 | 4.53 | 1.53 | 1.42 |
| axi-t | 0.0322 | 1.86 | 1.76 | 8.33 | 8.39 | 4.78 | 4.62 | 1.47 | 1.4 |
| axi-t | 0.0212 | 2.26 | 2.11 | 9.5 | 9.61 | 2.31 | 1.98 | 0.52 | 0.41 |
| axi-t | 0.0112 | 2.87 | 2.66 | 10.92 | 11.11 | -1.03 | -1.67 | -0.53 | -0.66 |

**Table 29: SNCFs measured with rosettes compared to single strain gauge measurements for tenth cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0325 | 1.33 | 1.17 | 1.11 | 1.2 |
| ipb | 0.0651 | 1.33 | 1.18 | 1.11 | 1.12 |
| ipb | 0.1003 | 1.32 | 1.18 | 1.07 | 1.04 |
| ipb | 0.1009 | 1.32 | 1.18 | 1.06 | 1.05 |
| ipb | 0.0660 | 1.32 | 1.17 | 1.1 | 1.14 |
| ipb | 0.0331 | 1.33 | 1.17 | 1.12 | 1.14 |
| opb | 0.0123 | 1.54 | 1.11 | 1.13 | 1.22 |
| opb | 0.0256 | 2.01 | 1.08 | 1.12 | 1.21 |
| opb | 0.0370 | 1.96 | 0.92 | 1.12 | 1.21 |
| opb | 0.0364 | 1.72 | 0.88 | 1.12 | 1.21 |
| opb | 0.0240 | 1.69 | 1.03 | 1.13 | 1.21 |
| opb | 0.0122 | 1.59 | 1.11 | 1.13 | 1.22 |
| axi-c | -0.0098 | 1.3 | 1.23 | 1.14 | 1.21 |
| axi-c | -0.0197 | 1.26 | 1.7 | 1.15 | 1.21 |
| axi-c | -0.0296 | 1.24 | 0.89 | 1.15 | 1.2 |
| axi-c | -0.0296 | 1.26 | 0.69 | 1.15 | 1.2 |
| axi-c | -0.0197 | 1.29 | 1.37 | 1.14 | 1.21 |
| axi-c | -0.0099 | 1.31 | 1.23 | 1.14 | 1.21 |
| axi-t | 0.0110 | 1.34 | 1.15 | 1.2 | 1.28 |
| axi-t | 0.0214 | 1.36 | 1.15 | 1.36 | 1.59 |
| axi-t | 0.0322 | 1.37 | 1.15 | 1.21 | 1.33 |
| axi-t | 0.0322 | 1.36 | 1.15 | 1.21 | 1.33 |
| axi-t | 0.0212 | 1.36 | 1.15 | 1.33 | 1.65 |
| axi-t | 0.0112 | 1.34 | 1.14 | 0.91 | 0.93 |

**Table 30: SCF/SNCF ratio for tenth cycle of T7.**

**Eleventh SNCF measurement cycle to 20 % joint as-welded capacity, preload at 130 %.**

The measured SNCFs for the eleventh cycle are presented for each of the four loading conditions in Table 31. Measurements made with additional strain rosettes are presented in Table 32. The applied load levels are presented in the tables. The SCF/SNCF ratio as calculated from the strain rosettes is presented in Table 33.

| | level | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0329 | -1.75 | -0.01 | 1.51 | -0.07 | -4.26 | -0.01 | 4.58 | -0.26 |
| ipb | 0.0661 | -1.74 | -0.2 | 1.57 | -0.05 | -4.46 | -0.42 | 4.48 | -0.24 |
| ipb | 0.1010 | -1.99 | -0.17 | 1.56 | -0.06 | -4.67 | -0.35 | 4.34 | -0.19 |
| ipb | 0.1020 | -1.97 | -0.17 | 1.56 | -0.04 | -4.62 | -0.35 | 4.28 | -0.19 |
| ipb | 0.0658 | -1.8 | -0.19 | 1.61 | -0.07 | -4.53 | -0.39 | 4.6 | -0.33 |
| ipb | 0.0325 | -1.71 | -0.04 | 1.52 | -0.01 | -4.33 | -0.05 | 4.76 | -0.27 |
| opb | 0.0079 | 0.29 | -6.77 | -0.46 | 5.78 | 1.28 | -15.59 | -1.28 | 16.35 |
| opb | 0.0207 | 0.42 | -6.07 | -0.08 | 4.81 | 0.9 | -13.02 | -0.46 | 13.48 |
| opb | 0.0331 | 0.33 | -6.01 | -0.06 | 4.45 | 0.77 | -12.21 | -0.16 | 12.44 |
| opb | 0.0360 | 0.11 | -6.36 | 0.2 | 4.86 | 0.18 | -13.14 | 0.41 | 13.7 |
| opb | 0.0237 | 0.04 | -6.66 | 0.29 | 5.45 | -0.06 | -14.53 | 0.47 | 15.33 |
| opb | 0.0112 | -0.33 | -7.66 | 0.37 | 6.66 | -0.83 | -17.55 | 0.91 | 19.09 |
| axi-c | -0.0100 | 4.48 | 0.57 | -1.7 | 10.45 | 15.59 | 0.91 | -0.74 | 29.03 |
| axi-c | -0.0199 | 3.76 | 1.28 | -0.63 | 10.22 | 12.87 | 2.47 | 2.53 | 26.12 |
| axi-c | -0.0298 | 3.46 | 1.65 | -0.11 | 9.34 | 11.3 | 3.48 | 3.48 | 19.73 |
| axi-c | -0.0298 | 3.46 | 1.65 | -0.16 | 9.32 | 11.26 | 3.5 | 3.52 | 19.7 |
| axi-c | -0.0200 | 3.95 | 0.76 | -0.85 | 11.01 | 13.17 | 1.28 | 2.07 | 27.8 |
| axi-c | -0.0100 | 4.71 | -2.33 | -2.22 | 13.89 | 16.53 | -5.51 | -1.57 | 38.14 |
| axi-t | 0.0106 | 0.37 | 7.34 | 2.18 | 1.68 | 4.03 | 15.59 | 8.82 | 5.4 |
| axi-t | 0.0213 | 0.82 | 6.03 | 1.74 | 2.49 | 5.05 | 12.99 | 7.52 | 7.39 |
| axi-t | 0.0319 | 1.12 | 5.22 | 1.39 | 2.85 | 5.7 | 11.33 | 6.74 | 8.37 |
| axi-t | 0.0320 | 1.11 | 5.19 | 1.13 | 2.81 | 5.65 | 11.44 | 6.69 | 8.27 |
| axi-t | 0.0208 | 0.78 | 6 | 1.42 | 2.43 | 5 | 13.2 | 7.52 | 7.09 |
| axi-t | 0.0107 | -0.04 | 7.45 | 2.32 | 1.42 | 2.72 | 16.6 | 10.18 | 4.25 |

**Table 31: Measured SNCFs on intersection of brace and chord for T7 at eleventh cycle.**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ipb | 0.0329 | 1.51 | 1.54 | 4.58 | 4.47 | -0.26 | -0.7 | -0.07 | -0.2 |
| ipb | 0.0661 | 1.57 | 1.51 | 4.48 | 4.46 | -0.24 | -0.62 | -0.05 | -0.2 |
| ipb | 0.1010 | 1.56 | 1.53 | 4.34 | 4.32 | -0.19 | -0.57 | -0.06 | -0.21 |
| ipb | 0.1020 | 1.56 | 1.51 | 4.28 | 4.28 | -0.19 | -0.55 | -0.04 | -0.2 |
| ipb | 0.0658 | 1.61 | 1.57 | 4.6 | 4.55 | -0.33 | -0.74 | -0.07 | -0.24 |
| ipb | 0.0325 | 1.52 | 1.53 | 4.76 | 4.69 | -0.27 | -0.7 | -0.01 | -0.23 |
| opb | 0.0079 | -0.46 | -0.34 | -1.28 | -1.43 | 16.35 | 16.64 | 5.78 | 5.62 |
| opb | 0.0207 | -0.08 | -0.06 | -0.46 | -0.59 | 13.48 | 13.75 | 4.81 | 4.74 |
| opb | 0.0331 | -0.06 | -0.03 | -0.16 | -0.38 | 12.44 | 12.64 | 4.45 | 4.33 |
| opb | 0.0360 | 0.2 | 0.16 | 0.41 | 0.2 | 13.7 | 13.87 | 4.86 | 4.76 |
| opb | 0.0237 | 0.29 | 0.22 | 0.47 | 0.25 | 15.33 | 15.55 | 5.45 | 5.3 |
| opb | 0.0112 | 0.37 | 0.28 | 0.91 | 0.6 | 19.09 | 19.27 | 6.66 | 6.54 |
| axi-c | -0.0100 | -1.7 | -1.8 | -0.74 | -0.77 | 29.03 | 30.3 | 10.45 | 10.47 |
| axi-c | -0.0199 | -0.63 | -0.68 | 2.53 | 2.35 | 26.12 | 26.93 | 10.22 | 10.11 |
| axi-c | -0.0298 | -0.11 | -0.18 | 3.48 | 3.36 | 19.73 | 20.31 | 9.34 | 9.22 |
| axi-c | -0.0298 | -0.16 | -0.18 | 3.52 | 3.34 | 19.7 | 20.22 | 9.32 | 9.22 |
| axi-c | -0.0200 | -0.85 | -0.84 | 2.07 | 1.89 | 27.8 | 28.54 | 11.01 | 10.9 |
| axi-c | -0.0100 | -2.22 | -2.29 | -1.57 | -1.97 | 38.14 | 39.29 | 13.89 | 13.83 |
| axi-t | 0.0106 | 2.18 | 1.79 | 8.82 | 8.82 | 5.4 | 4.91 | 1.68 | 1.57 |
| axi-t | 0.0213 | 1.74 | 1.45 | 7.52 | 7.57 | 7.39 | 7.22 | 2.49 | 2.39 |
| axi-t | 0.0319 | 1.39 | 1.17 | 6.74 | 6.78 | 8.37 | 8.39 | 2.85 | 2.75 |
| axi-t | 0.0320 | 1.13 | 1.19 | 6.69 | 6.8 | 8.27 | 8.31 | 2.81 | 2.74 |
| axi-t | 0.0208 | 1.42 | 1.5 | 7.52 | 7.62 | 7.09 | 7.04 | 2.43 | 2.36 |
| axi-t | 0.0107 | 2.32 | 2.44 | 10.18 | 10.25 | 4.25 | 3.84 | 1.42 | 1.33 |

**Table 32: SNCFs measured with rosettes compared to single strain gauge measurements for eleventh cycle of T7.**

| | level | BC;9 | CC;9 | CS;13 | BS;13 |
|---|---|---|---|---|---|
| ipb | 0.0329 | 1.32 | 1.17 | 1.13 | 1.16 |
| ipb | 0.0661 | 1.32 | 1.17 | 1.12 | 1.16 |
| ipb | 0.1010 | 1.32 | 1.18 | 1.11 | 1.14 |
| ipb | 0.1020 | 1.32 | 1.18 | 1.11 | 1.15 |
| ipb | 0.0658 | 1.33 | 1.18 | 1.12 | 1.2 |
| ipb | 0.0325 | 1.33 | 1.17 | 1.13 | 1.18 |
| opb | 0.0079 | 1.33 | 1.14 | 1.13 | 1.21 |
| opb | 0.0207 | 2.24 | 1.07 | 1.13 | 1.21 |
| opb | 0.0331 | 2.93 | 1 | 1.12 | 1.21 |
| opb | 0.0360 | 1.07 | 1.47 | 1.12 | 1.21 |
| opb | 0.0237 | 1.1 | 1.45 | 1.13 | 1.21 |
| opb | 0.0112 | 1.21 | 1.27 | 1.13 | 1.21 |
| axi-c | -0.0100 | 1.27 | 1.61 | 1.14 | 1.24 |
| axi-c | -0.0199 | 1.19 | 1.01 | 1.14 | 1.23 |
| axi-c | -0.0298 | 0.83 | 1.07 | 1.15 | 1.22 |
| axi-c | -0.0298 | 0.83 | 1.06 | 1.15 | 1.22 |
| axi-c | -0.0200 | 1.2 | 0.97 | 1.14 | 1.23 |
| axi-c | -0.0100 | 1.27 | 1.37 | 1.14 | 1.22 |
| axi-t | 0.0106 | 1.4 | 1.15 | 1.19 | 1.35 |
| axi-t | 0.0213 | 1.38 | 1.14 | 1.17 | 1.29 |
| axi-t | 0.0319 | 1.4 | 1.14 | 1.17 | 1.27 |
| axi-t | 0.0320 | 1.39 | 1.14 | 1.17 | 1.27 |
| axi-t | 0.0208 | 1.43 | 1.14 | 1.17 | 1.27 |
| axi-t | 0.0107 | 1.4 | 1.15 | 1.22 | 1.33 |

**Table 33: SCF/SNCF ratio for eleventh cycle of T7.**

# APPENDIX C

## Measured SNCFs and LJFs

# As-welded SNCF Measurements

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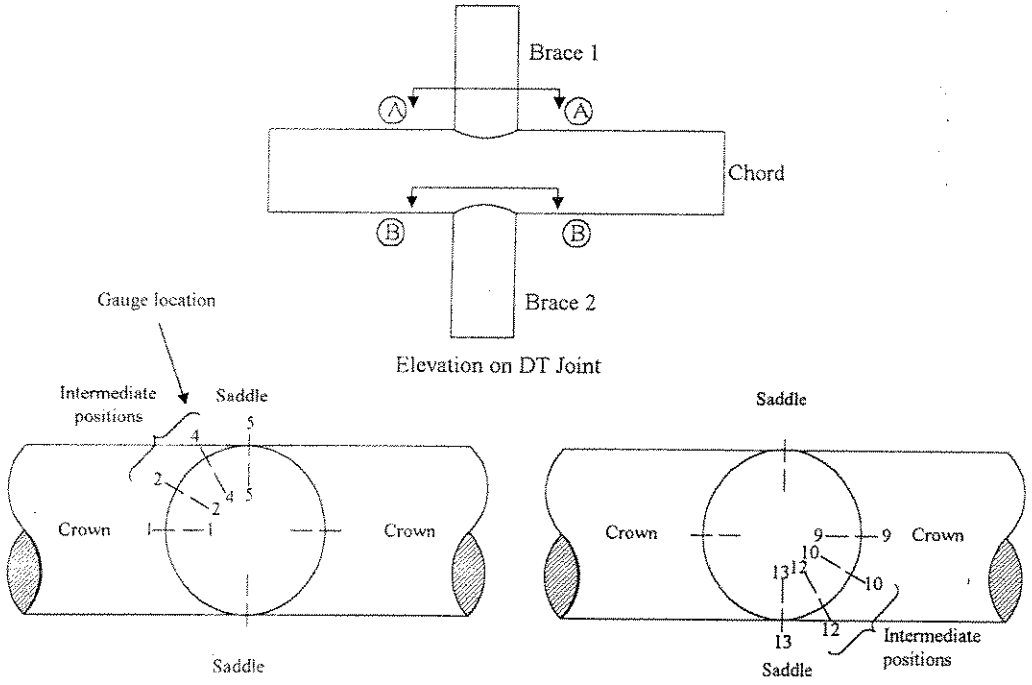
MSL

## General Information

**KEY:-**

| | |
|---|---|
| BC | Brace Crown |
| BS | Brace Saddle |
| BI | Brace Intermediate |
| CC | Chord Crown |
| CS | Chord Saddle |
| CI | Chord Intermediate |
| br1 | Brace 1 |
| br2 | Brace 2 |
| # | Gauge location (see figure) |

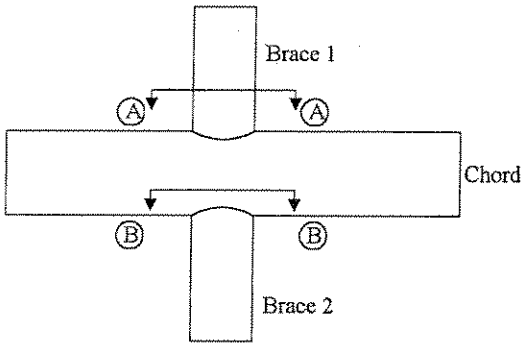
The table rows correspond to SNCF measurements taken at 3 equal increments up to approximately 20 % as-welded joint capacity and 3 equal decrements back down to zero load. This has been repeated for each of the four loading modes.



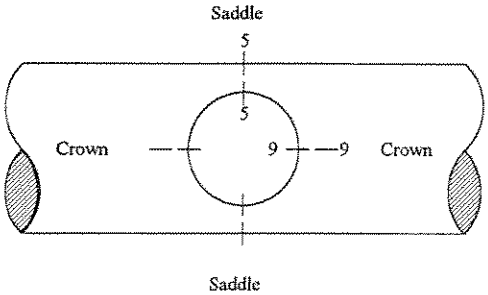
**SNCFs ungrouted Test Specimen: DT2.**

| DT2 | BC;1,br2 | BS;5,br1 | BC;9,br1 | BS;13,br2 | CC;1,br2 | CS;5,br1 | CC;9,br1 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 1.52 | 0.09 | -1.66 | 0.11 | 3.31 | 0.07 | -3.64 | 0.18 |
| ipb 2/3 | 1.47 | 0.08 | -1.58 | 0.18 | 3.24 | 0.07 | -3.51 | 0.35 |
| ipb 3/3 | 1.45 | 0.07 | -1.54 | 0.21 | 3.12 | 0.1 | -3.45 | 0.39 |
| ipb 3/3 | 1.45 | 0.07 | -1.54 | 0.21 | 3.12 | 0.1 | -3.41 | 0.39 |
| ipb 2/3 | 1.48 | 0.08 | -1.57 | 0.22 | 3.2 | 0.09 | -3.53 | 0.41 |
| ipb 1/3 | 1.52 | 0.1 | -1.65 | 0.08 | 3.3 | 0.09 | -3.66 | 0.19 |
| opb 1/3 | -0.04 | 4.96 | -0.05 | -4.14 | -0.07 | 5.96 | -0.2 | -7.5 |
| opb 2/3 | -0.03 | 4.8 | -0.03 | -4.38 | 0 | 5.7 | -0.11 | -7.93 |
| opb 3/3 | -0.05 | 4.78 | -0.03 | -4.24 | -0.04 | 5.71 | -0.07 | -7.69 |
| opb 3/3 | -0.04 | 4.74 | -0.03 | -4.2 | -0.03 | 5.7 | -0.08 | -7.61 |
| opb 2/3 | -0.03 | 4.82 | -0.03 | -4.26 | -0.02 | 5.77 | -0.12 | -7.72 |
| opb 1/3 | -0.02 | 4.65 | -0.09 | -4.24 | 0.02 | 5.58 | -0.2 | -7.67 |
| axi-c 1/3 | -0.12 | 9.11 | 0.27 | 8.86 | 1.29 | 10.62 | 2.29 | 15.4 |
| axi-c 2/3 | 0.07 | 9.28 | 0.05 | 8.86 | 1.76 | 10.78 | 1.79 | 15.42 |
| axi-c 3/3 | 0.08 | 9.65 | 0.01 | 8.6 | 1.78 | 11.15 | 1.7 | 15.01 |
| axi-c 3/3 | 0.09 | 9.68 | 0 | 8.6 | 1.77 | 11.13 | 1.68 | 15.05 |
| axi-c 2/3 | 0.22 | 9.91 | -0.12 | 8.47 | 2.01 | 11.48 | 1.38 | 14.84 |
| axi-c 1/3 | -0.07 | 10.17 | -0.04 | 8.12 | 1.61 | 11.63 | 1.66 | 14.33 |
| axi-t 1/3 | 0 | 10.12 | 0.21 | 8.24 | 1.45 | 11.53 | 2.12 | 14.29 |
| axi-t 2/3 | -0.04 | 10.01 | 0.19 | 8.52 | 1.46 | 11.46 | 2.06 | 14.98 |
| axi-t 3/3 | -0.04 | 10.06 | 0.18 | 8.4 | 1.43 | 11.44 | 2.1 | 16.41 |
| axi-t 3/3 | -0.09 | 10.06 | 0.21 | 8.46 | 1.4 | 11.52 | 2.07 | 14.52 |
| axi-t 2/3 | -0.04 | 10.08 | 0.22 | 8.48 | 1.41 | 11.54 | 2.11 | 14.25 |
| axi-t 1/3 | -0.09 | 10.12 | 0.25 | 8.39 | 1.36 | 11.6 | 2.17 | 13.17 |

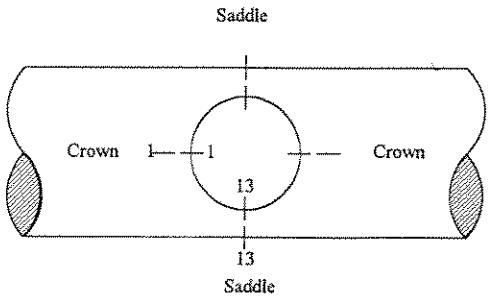
**Table 1: Measured SNCFs on intersections of brace 1,2 and chord for DT2**




Elevation on DT Joint




View 'A' on brace 1

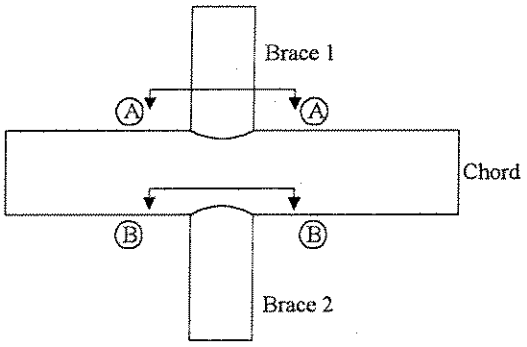



View 'B' on brace 2

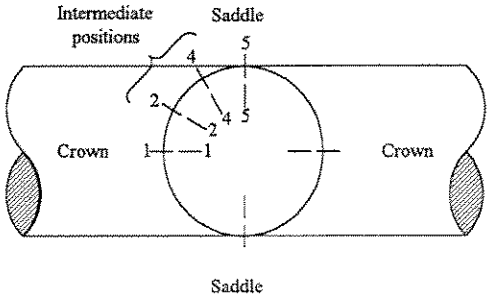
**SNCFs ungrouted Test Specimen: DT3.**

| DT3 | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 1.39 | 1.65 | 2.28 | -0.15 | -1.05 | -1.43 | -1.84 | -0.09 |
| ipb 2/3 | 1.36 | 1.61 | 2.29 | -0.13 | -1.04 | -1.43 | -1.82 | -0.12 |
| ipb 3/3 | 1.32 | 1.6 | 2.28 | -0.1 | -1.03 | -1.43 | -1.8 | -0.12 |
| ipb 3/3 | 1.33 | 1.59 | 2.28 | -0.11 | -1.02 | -1.42 | -1.79 | -0.12 |
| ipb 2/3 | 1.37 | 1.61 | 2.31 | -0.13 | -1.05 | -1.45 | -1.81 | -0.14 |
| ipb 1/3 | 1.41 | 1.64 | 2.39 | -0.16 | -1.04 | -1.48 | -1.82 | -0.12 |
| opb 1/3 | -0.07 | 0.36 | 1.32 | 2.29 | -0.03 | -0.41 | -0.95 | -1.94 |
| opb 2/3 | -0.07 | 0.4 | 1.33 | 2.29 | -0.06 | -0.43 | -0.95 | -1.93 |
| opb 3/3 | -0.07 | 0.39 | 1.31 | 2.28 | -0.05 | -0.43 | -0.93 | -1.95 |
| opb 3/3 | -0.07 | 0.38 | 1.32 | 2.28 | -0.05 | -0.44 | -0.93 | -1.95 |
| opb 2/3 | -0.06 | 0.39 | 1.36 | 2.33 | -0.07 | -0.45 | -0.94 | -1.9 |
| opb 1/3 | -0.05 | 0.38 | 1.38 | 2.38 | -0.06 | -0.51 | -1 | -1.92 |
| axi-c 1/3 | 0.46 | 0.91 | 2.45 | 4.2 | 0.87 | 1.37 | 2.28 | 3.09 |
| axi-c 2/3 | 0.8 | 1.24 | 2.92 | 4.32 | 0.63 | 1.01 | 1.79 | 2.93 |
| axi-c 3/3 | 0.85 | 1.28 | 2.95 | 4.24 | 0.59 | 0.93 | 1.75 | 2.93 |
| axi-c 3/3 | 0.85 | 1.25 | 2.97 | 4.24 | 0.59 | 0.93 | 1.75 | 2.9 |
| axi-c 2/3 | 0.85 | 1.24 | 3.01 | 4.33 | 0.61 | 0.95 | 1.74 | 2.83 |
| axi-c 1/3 | 0.68 | 1.05 | 2.78 | 4.19 | 0.72 | 1.1 | 1.98 | 2.89 |
| axi-t 1/3 | 0.72 | 1.13 | 2.55 | 3.7 | 0.65 | 1.07 | 2.02 | 3.3 |
| axi-t 2/3 | 0.79 | 1.18 | 2.65 | 3.88 | 0.63 | 1.03 | 1.91 | 3.12 |
| axi-t 3/3 | 0.79 | 1.17 | 2.73 | 3.99 | 0.64 | 1.04 | 1.92 | 3.14 |
| axi-t 3/3 | 0.82 | 1.17 | 2.73 | 3.99 | 0.61 | 1.04 | 1.92 | 3.13 |
| axi-t 2/3 | 0.83 | 1.2 | 2.67 | 3.88 | 0.61 | 1.03 | 1.91 | 3.12 |
| axi-t 1/3 | 0.86 | 1.12 | 2.54 | 3.71 | 0.57 | 1.06 | 2.03 | 3.31 |

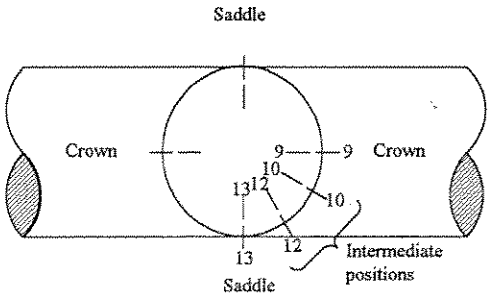
**Table 2: Measured SNCFs on intersection on brace 1 and brace2 for DT3**




Elevation on DT Joint



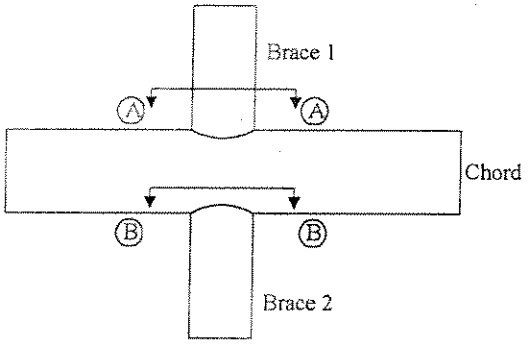

View 'A' on brace 1



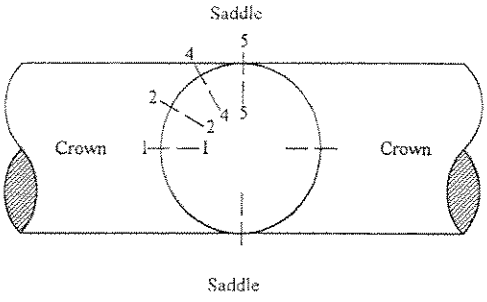

View 'B' on brace 2

| DT3 | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 2.67 | 2.39 | 2.18 | -0.16 | -2.21 | -2.47 | -2.79 | -0.06 |
| ipb 2/3 | 2.6 | 2.4 | 2.15 | -0.18 | -2.21 | -2.44 | -2.79 | -0.11 |
| ipb 3/3 | 2.58 | 2.36 | 2.16 | -0.16 | -2.18 | -2.45 | -2.77 | -0.13 |
| ipb 3/3 | 2.59 | 2.36 | 2.14 | -0.17 | -2.2 | -2.39 | -2.78 | -0.13 |
| ipb 2/3 | 2.65 | 2.39 | 2.17 | -0.2 | -2.22 | -2.46 | -2.83 | -0.15 |
| ipb 1/3 | 2.73 | 2.43 | 2.2 | -0.28 | -2.26 | -2.53 | -2.82 | -0.14 |
| opb 1/3 | -0.21 | 0.16 | 1 | 2.5 | -0.15 | -0.27 | -1.04 | -2.62 |
| opb 2/3 | -0.21 | 0.14 | 1 | 2.5 | -0.22 | -0.32 | -1.09 | -2.64 |
| opb 3/3 | -0.21 | 0.13 | 0.97 | 2.49 | -0.2 | -0.32 | -1.07 | -2.66 |
| opb 3/3 | -0.19 | 0.13 | 0.97 | 2.49 | -0.2 | -0.32 | -1.07 | -2.64 |
| opb 2/3 | -0.19 | 0.14 | 1.02 | 2.6 | -0.24 | -0.32 | -1.07 | -2.58 |
| opb 1/3 | -0.21 | 0.2 | 1.09 | 2.59 | -0.29 | -0.39 | -1.16 | -2.58 |
| axi-c 1/3 | 0.15 | 0.46 | 1.79 | 3.72 | 1.22 | 1.52 | 2.96 | 3.21 |
| axi-c 2/3 | 0.6 | 0.91 | 2.26 | 3.8 | 0.67 | 1.03 | 2.33 | 2.94 |
| axi-c 3/3 | 0.73 | 1.02 | 2.28 | 3.73 | 0.57 | 0.89 | 2.23 | 3.07 |
| axi-c 3/3 | 0.72 | 1.02 | 2.29 | 3.7 | 0.59 | 0.88 | 2.23 | 3.1 |
| axi-c 2/3 | 0.68 | 0.97 | 2.32 | 3.78 | 0.62 | 0.92 | 2.2 | 3 |
| axi-c 1/3 | 0.41 | 0.69 | 2.09 | 3.67 | 0.92 | 1.19 | 2.38 | 3.1 |
| axi-t 1/3 | 0.57 | 0.93 | 1.98 | 2.98 | 0.65 | 1.04 | 2.71 | 3.65 |
| axi-t 2/3 | 0.65 | 0.9 | 2.06 | 3.32 | 0.65 | 0.95 | 2.53 | 3.4 |
| axi-t 3/3 | 0.66 | 0.93 | 2.12 | 3.41 | 0.67 | 1.01 | 2.54 | 3.36 |
| axi-t 3/3 | 0.66 | 0.9 | 2.12 | 3.43 | 0.67 | 1.01 | 2.49 | 3.36 |
| axi-t 2/3 | 0.67 | 0.88 | 2.08 | 3.38 | 0.66 | 0.95 | 2.42 | 3.39 |
| axi-t 1/3 | 0.65 | 0.85 | 1.89 | 3.15 | 0.67 | 0.94 | 2.55 | 3.7 |

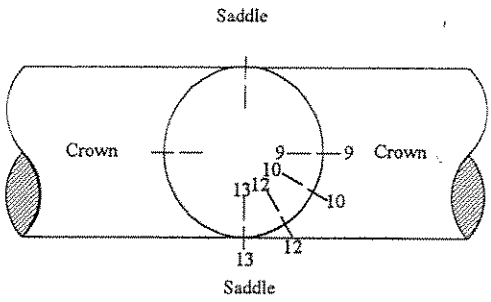
**Table 3: Measured SNCFs on intersection of chord with braces 1 and 2 for DT3**




Elevation on DT Joint




View 'A' on brace 1

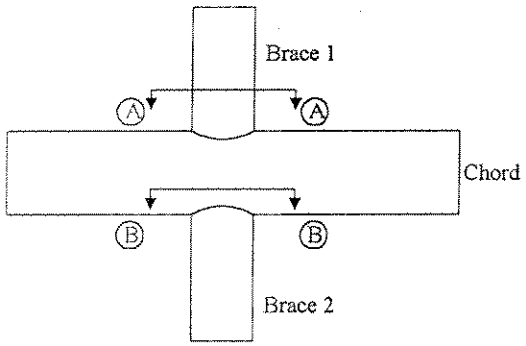



View 'B' on brace 2

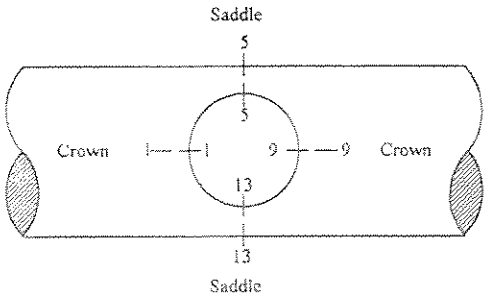
**SNCFs ungrouted Test Specimen: DT4.**

| DT4 | BC;1,br1 | BS;5,br1 | BC;9,br1 | BS;13,br1 | CC;1,br1 | CS;5,br1 | CC;9,br1 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 2.22 | 0.17 | -2.67 | -0.3 | 4.3 | 0.19 | -5.09 | -0.67 |
| ipb 2/3 | 2.17 | 0.04 | -2.46 | -0.26 | 4.1 | -0.05 | -4.9 | -0.52 |
| ipb 3/3 | 2.09 | 0.06 | -2.38 | -0.24 | 4 | -0.09 | -4.84 | -0.44 |
| ipb 3/3 | 2.1 | 0.04 | -2.34 | -0.23 | 4.01 | -0.08 | -4.88 | -0.47 |
| ipb 2/3 | 2.17 | 0.03 | -2.39 | -0.22 | 4.21 | -0.03 | -5 | -0.54 |
| ipb 1/3 | 2.25 | 0.08 | -2.5 | -0.26 | 4.3 | 0.03 | -5.24 | -0.68 |
| opb 1/3 | 0.17 | 5.89 | 0.19 | -4.25 | 0.2 | 12.55 | -0.06 | -11.46 |
| opb 2/3 | -0.05 | 5.23 | 0.07 | -3.98 | 0.12 | 11.28 | 0.29 | -11.06 |
| opb 3/3 | 0.06 | 4.64 | 0.04 | -3.54 | 0.09 | 10.05 | 0.08 | -9.27 |
| opb 3/3 | -0.05 | 3.72 | 0.09 | -2.69 | 0.16 | 7.89 | 0.18 | -7.31 |
| opb 2/3 | -0.17 | 5.13 | 0.03 | -3.71 | 0.2 | 10.91 | 0.43 | -10.31 |
| opb 1/3 | -0.16 | 4.58 | 0.07 | -2.67 | 0.38 | 9.67 | 0.33 | -8.41 |
| axi-c 1/3 | -1.12 | 13.82 | 0.13 | 9.01 | 1.84 | 29.65 | 5.61 | 23.71 |
| axi-c 2/3 | -0.98 | 13.18 | -0.14 | 9.34 | 2.26 | 28.63 | 4.84 | 24.43 |
| axi-c 3/3 | -0.79 | 13.02 | -0.27 | 9.39 | 2.6 | 28.31 | 4.51 | 24.69 |
| axi-c 3/3 | -0.84 | 13.02 | -0.18 | 9.4 | 2.51 | 28.34 | 4.62 | 24.66 |
| axi-c 2/3 | -1.06 | 13.25 | -0.09 | 9.27 | 2.3 | 28.77 | 4.85 | 24.25 |
| axi-c 1/3 | -1.5 | 13.88 | 0.46 | 8.95 | 1.32 | 30.08 | 5.9 | 23.35 |
| axi-t 1/3 | 1.96 | -12.63 | -0.72 | -11.1 | -1.03 | -27.37 | -6.82 | -27.09 |
| axi-t 2/3 | 1.14 | -12.24 | 0 | -10.66 | -2.04 | -26.36 | -5.19 | -26.85 |
| axi-t 3/3 | 1.02 | -12.19 | 0.18 | -10.36 | -2.3 | -26.34 | -4.77 | -26.4 |
| axi-t 3/3 | 0.97 | -12.02 | 0.23 | -10.17 | -2.29 | -25.97 | -4.63 | -26.53 |
| axi-t 2/3 | 1.07 | -12.15 | 0.11 | -10.1 | -2.12 | -26.21 | -4.91 | -26.27 |
| axi-t 1/3 | 1.59 | -12.47 | -0.2 | -10.12 | -1.47 | -27.02 | -5.8 | -26.08 |

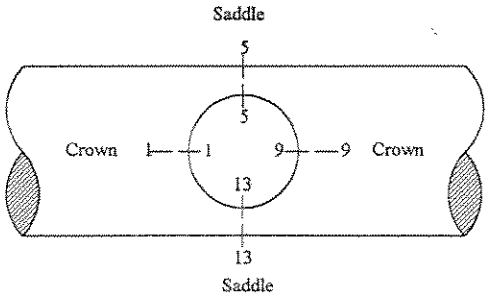
**Table 4: Measured SNCFs on intersection of brace 1 and chord for DT4**




Elevation on DT Joint



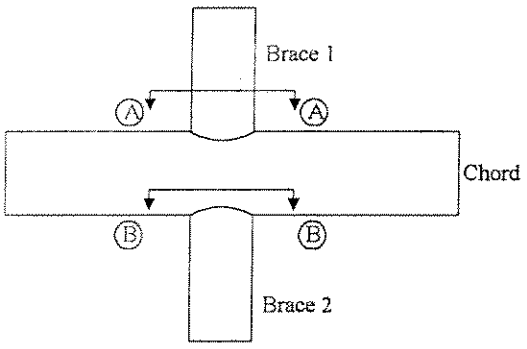

View 'A' on brace 1



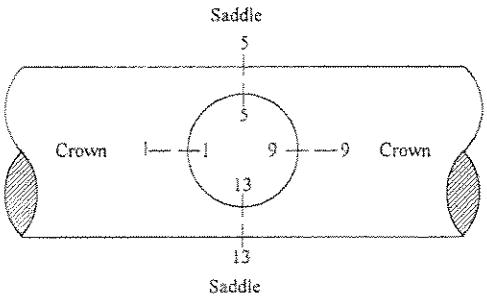

View 'B' on brace 2

| DT4 | BC;1,br2 | BS;5,br2 | BC;9,br2 | BS;13,br2 | CC;1,br2 | CS;5,br2 | CC;9,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 2.83 | -0.09 | 2.65 | 0.16 | 4.35 | 0.15 | -3.96 | -0.09 |
| ipb 2/3 | 2.71 | 0.03 | 0.18 | 0.28 | 4.24 | -0.07 | -3.9 | 0.14 |
| ipb 3/3 | 2.62 | -0.13 | -0.63 | 0.24 | 4.15 | -0.13 | -3.83 | 0.16 |
| ipb 3/3 | 2.62 | -0.13 | -2.77 | 0.22 | 4.15 | -0.14 | -3.94 | 0.13 |
| ipb 2/3 | 2.73 | -0.06 | -2.87 | 0.14 | 4.29 | -0.01 | -4.05 | 0.03 |
| ipb 1/3 | 2.82 | -0.09 | -2.97 | 0.11 | 4.41 | 0.04 | -4.21 | -0.11 |
| opb 1/3 | -0.16 | 2.5 | -0.04 | -4.84 | -0.21 | 9.61 | -0.16 | -9.27 |
| opb 2/3 | -0.02 | 2.11 | -0.28 | -4.9 | -0.04 | 9.97 | -0.18 | -9.09 |
| opb 3/3 | -0.16 | 2.58 | -0.29 | -4.92 | -0.21 | 9.7 | -0.25 | -9.26 |
| opb 3/3 | -0.04 | 2.93 | -0.21 | -5.1 | -0.12 | 10.97 | -0.3 | -9.81 |
| opb 2/3 | 0.07 | 3.25 | -0.13 | -4.82 | -0.01 | 11.12 | -0.33 | -9.36 |
| opb 1/3 | 0.17 | 3.48 | -0.42 | -4.87 | 0.04 | 11.56 | -0.45 | -9.48 |
| axi-c 1/3 | -2.14 | 7.2 | -0.42 | 14.48 | 2.2 | 25.59 | 5.42 | 26.86 |
| axi-c 2/3 | -1.52 | 7.18 | -0.94 | 14.62 | 3.1 | 24.81 | 4.28 | 27.23 |
| axi-c 3/3 | -1.31 | 7.03 | -1.17 | 14.79 | 3.46 | 24.4 | 4 | 27.63 |
| axi-c 3/3 | -1.39 | 7.01 | -1.12 | 14.71 | 3.38 | 24.49 | 4.12 | 27.55 |
| axi-c 2/3 | -1.59 | 7.13 | -0.92 | 14.6 | 3.02 | 24.71 | 4.52 | 27.35 |
| axi-c 1/3 | -2.51 | 7.18 | 0.04 | 14.25 | 1.8 | 25.47 | 5.74 | 26.69 |
| axi-t 1/3 | 4.86 | -6.2 | -0.02 | -17.54 | -2.9 | -21.03 | -5.87 | -32.94 |
| axi-t 2/3 | 2.87 | -6.25 | 0.74 | -16.51 | -3.44 | -21.72 | -4.69 | -30.7 |
| axi-t 3/3 | 2.27 | -6.48 | 0.98 | -15.89 | -3.57 | -22.48 | -4.27 | -29.47 |
| axi-t 3/3 | 1.36 | -6.43 | 1.07 | -15.97 | -3.26 | -21.95 | -4.18 | -29.49 |
| axi-t 2/3 | 1.48 | -6.18 | 0.93 | -16.44 | -3.06 | -21.09 | -4.43 | -30.4 |
| axi-t 1/3 | 1.89 | -5.8 | 0.46 | -17.47 | -2.56 | -19.8 | -5.07 | -32.35 |

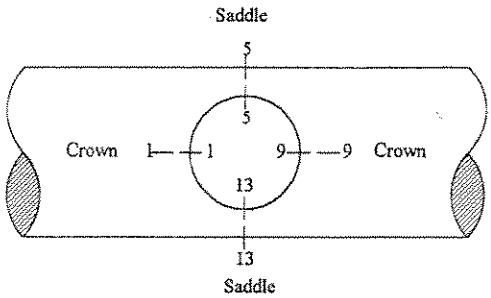
**Table 5: Measured SNCFs on intersection of brace 2 and chord for DT4**




Elevation on DT Joint




View 'A' on brace 1

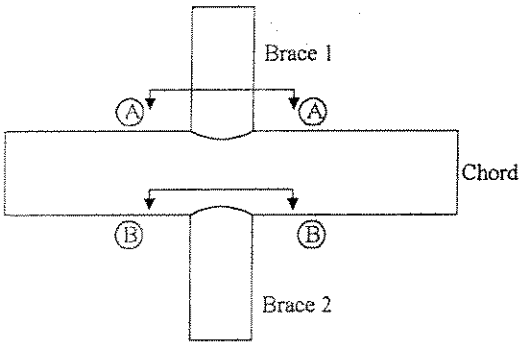



View 'B' on brace 2

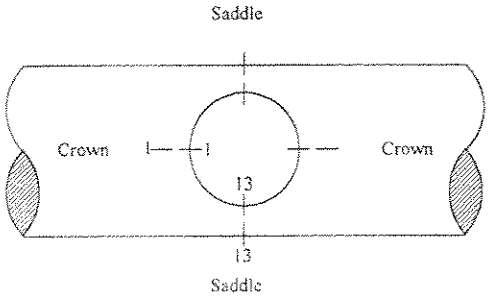
**SNCFs ungrouted Test Specimen: DT5.**

| DT5 | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 1.6 | -0.06 | -1.93 | 0.12 | 6.37 | -2.04 | -4.48 | 0 |
| ipb 2/3 | 1.5 | 0 | -1.82 | 0.13 | 6.03 | -1.87 | -4.22 | 0.03 |
| ipb 3/3 | 1.45 | -0.04 | -1.78 | 0.22 | 5.88 | -1.92 | -4.09 | 0.16 |
| ipb 3/3 | 1.44 | -0.03 | -1.78 | 0.22 | 5.88 | -1.92 | -4.08 | 0.17 |
| ipb 2/3 | 1.48 | 0.01 | -1.83 | 0.14 | 5.99 | -1.83 | -4.2 | 0.04 |
| ipb 1/3 | 1.58 | 0 | -1.96 | 0.09 | 6.3 | -1.98 | -4.48 | 0 |
| opb 1/3 | 0.08 | 8.11 | 0.08 | -6.92 | -6.7 | 19.33 | 0.3 | -11.04 |
| opb 2/3 | 0.1 | 7.87 | 0.06 | -7.19 | -6.6 | 18.84 | 0.24 | -11.59 |
| opb 3/3 | 0.07 | 7.73 | 0.05 | -7.33 | -6.46 | 18.4 | 0.23 | -11.82 |
| opb 3/3 | 0.07 | 7.54 | 0.05 | -7.61 | -6.26 | 17.92 | 0.21 | -12.33 |
| opb 2/3 | 0.07 | 7.69 | 0.06 | -7.52 | -6.38 | 18.33 | 0.19 | -12.13 |
| opb 1/3 | 0.15 | 7.38 | 0.08 | -7.64 | -6 | 17.52 | 0.2 | -12.33 |
| axi-c 1/3 | 0.38 | 13.18 | -0.44 | 19.2 | -5.92 | 29.15 | -0.02 | 30.69 |
| axi-c 2/3 | 0.23 | 14.51 | -0.38 | 17.23 | -7.41 | 32.23 | 0.49 | 27.65 |
| axi-c 3/3 | 0.2 | 14.42 | -0.34 | 17.2 | -7.45 | 32.16 | 0.51 | 27.69 |
| axi-c 3/3 | 0.2 | 14.44 | -0.34 | 17.12 | -7.45 | 32.2 | 0.54 | 27.59 |
| axi-c 2/3 | 0.25 | 14.47 | -0.4 | 17.3 | -7.16 | 32.01 | 0.47 | 27.91 |
| axi-c 1/3 | 0.37 | 14.16 | -0.44 | 17.89 | -6.48 | 31.22 | 0.2 | 28.77 |
| axi-t 1/3 | -0.32 | 15.83 | 0.4 | 15.03 | -10.29 | 35.57 | 2.36 | 23.97 |
| axi-t 2/3 | -0.2 | 15.65 | 0.28 | 15.28 | -9.8 | 35.03 | 2.1 | 24.47 |
| axi-t 3/3 | -0.21 | 15.76 | 0.29 | 15.32 | -9.58 | 35.15 | 2.02 | 24.52 |
| axi-t 3/3 | -0.19 | 15.72 | 0.29 | 15.31 | -9.54 | 35.11 | 2.02 | 24.42 |
| axi-t 2/3 | -0.17 | 15.79 | 0.34 | 15.14 | -9.62 | 35.23 | 2.14 | 24.21 |
| axi-t 1/3 | -0.27 | 16.06 | 0.47 | 14.57 | -10.24 | 35.99 | 2.5 | 23.34 |

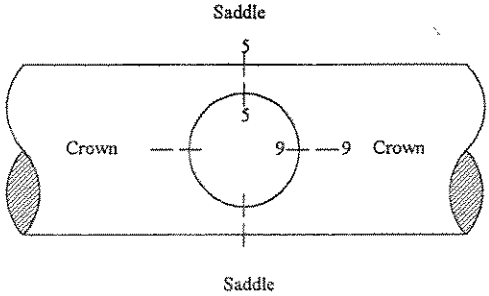
**Table 6: Measured SNCFs on intersection of brace 1 and 2 with chord for DT5**




Elevation on DT Joint




View 'A' on brace 1

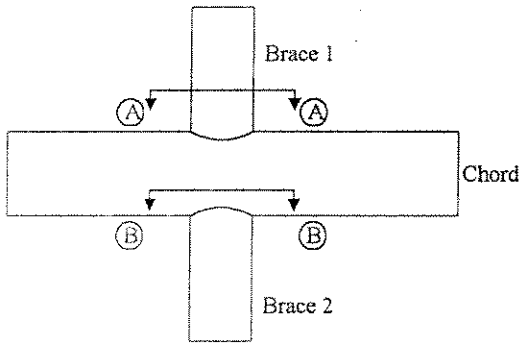



View 'B' on brace 2

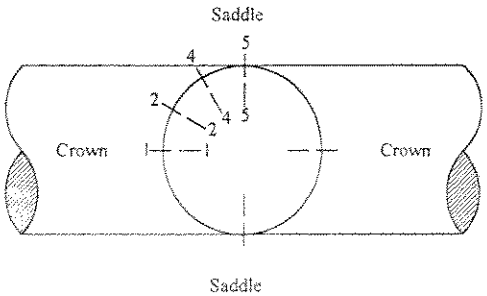
**SNCFs ungrouted Test Specimen: DT6.**

| DT6 | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 1.51 | 1.65 | 2.26 | 0 | -1.31 | -1.44 | -2.7 | -0.02 |
| ipb 2/3 | 1.47 | 1.59 | 2.17 | -0.01 | -1.25 | -1.37 | -2.56 | -0.01 |
| ipb 3/3 | 1.45 | 1.56 | 2.14 | 0.04 | -1.23 | -1.36 | -2.52 | 0.03 |
| ipb 3/3 | 1.46 | 1.56 | 2.13 | 0.03 | -1.22 | -1.37 | -2.52 | 0.03 |
| ipb 2/3 | 1.48 | 1.58 | 2.17 | -0.01 | -1.25 | -1.39 | -2.59 | -0.02 |
| ipb 1/3 | 1.54 | 1.67 | 2.32 | -0.06 | -1.31 | -1.46 | -2.75 | -0.07 |
| opb 1/3 | -0.15 | 0.32 | 1.07 | 2.35 | -0.05 | -0.51 | -1.37 | -2.42 |
| opb 2/3 | -0.19 | 0.33 | 1.11 | 2.44 | -0.08 | -0.53 | -1.33 | -2.36 |
| opb 3/3 | -0.18 | 0.34 | 1.15 | 2.59 | -0.07 | -0.53 | -1.32 | -2.23 |
| opb 3/3 | -0.17 | 0.35 | 1.14 | 2.56 | -0.07 | -0.51 | -1.32 | -2.26 |
| opb 2/3 | -0.17 | 0.33 | 1.09 | 2.43 | -0.1 | -0.53 | -1.34 | -2.42 |
| opb 1/3 | -0.18 | 0.32 | 1.12 | 2.54 | -0.15 | -0.5 | -1.35 | -2.34 |
| axi-c 1/3 | -0.09 | 0.07 | 0.58 | 4.09 | 1.86 | 2.19 | 4.55 | 4.31 |
| axi-c 2/3 | 0.51 | 0.77 | 1.64 | 4.73 | 1.36 | 1.52 | 3.45 | 3.98 |
| axi-c 3/3 | 0.76 | 1.08 | 2.15 | 4.86 | 1.09 | 1.24 | 2.88 | 3.88 |
| axi-c 3/3 | 0.76 | 1.05 | 2.12 | 4.84 | 1.09 | 1.24 | 2.85 | 3.92 |
| axi-c 2/3 | 0.69 | 0.97 | 1.97 | 4.87 | 1.2 | 1.36 | 3.02 | 3.87 |
| axi-c 1/3 | 0.17 | 0.42 | 1.18 | 4.76 | 1.6 | 1.76 | 3.86 | 3.8 |
| axi-t 1/3 | 1.2 | 1.38 | 2.32 | 3.92 | 0.86 | 0.89 | 2.55 | 4.55 |
| axi-t 2/3 | 1.11 | 1.27 | 2.34 | 4.04 | 0.85 | 0.97 | 2.51 | 4.35 |
| axi-t 3/3 | 1.09 | 1.27 | 2.28 | 4.1 | 0.86 | 0.99 | 2.56 | 4.27 |
| axi-t 3/3 | 1.09 | 1.3 | 2.28 | 4.1 | 0.86 | 0.99 | 2.59 | 4.24 |
| axi-t 2/3 | 1.14 | 1.36 | 2.32 | 4.02 | 0.85 | 0.98 | 2.55 | 4.25 |
| axi-t 1/3 | 1.2 | 1.41 | 2.23 | 3.94 | 0.86 | 0.88 | 2.5 | 4.17 |

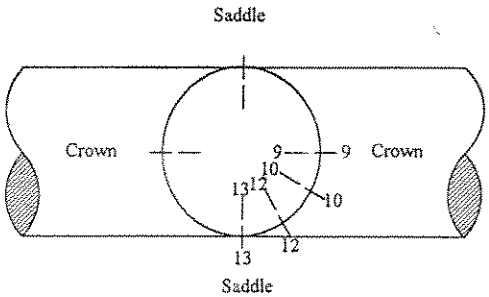
**Table 7: Measured SNCFs on intersection of brace 1 and 2 on brace for DT6**




Elevation on DT Joint



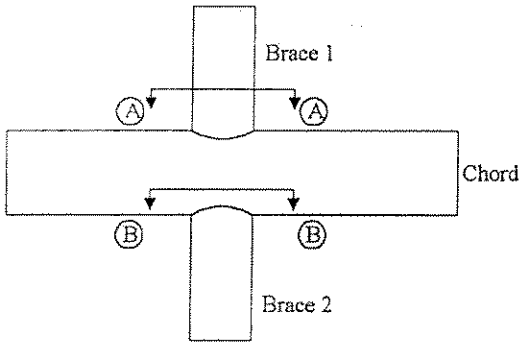

View 'A' on brace 1



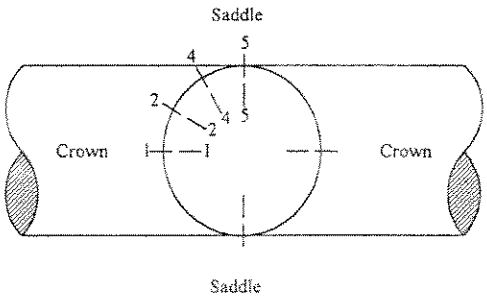

View 'B' on brace 2

| DT6 | CC;1,br1 | Cl;2,br1 | Cl;4,br1 | CS;5,br1 | CC;9,br2 | Cl;10,br2 | Cl;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 2.65 | 3.42 | 4.19 | -0.08 | -2.74 | -2.74 | -3.75 | 0.14 |
| ipb 2/3 | 2.55 | 3.3 | 3.98 | -0.11 | -2.64 | -2.6 | -3.58 | 0.16 |
| ipb 3/3 | 2.51 | 3.24 | 3.94 | -0.02 | -2.6 | -2.56 | -3.51 | 0.19 |
| ipb 3/3 | 2.51 | 3.23 | 3.93 | -0.01 | -2.63 | -2.51 | -3.53 | 0.19 |
| ipb 2/3 | 2.54 | 3.32 | 4.05 | -0.08 | -2.66 | -2.55 | -3.62 | 0.13 |
| ipb 1/3 | 2.65 | 3.55 | 4.31 | -0.15 | -2.78 | -2.74 | -3.85 | 0.03 |
| opb 1/3 | -0.39 | 0.15 | 1.62 | 5.06 | -0.31 | -0.25 | -1.06 | -3.37 |
| opb 2/3 | -0.47 | 0.08 | 1.74 | 5.32 | -0.32 | -0.29 | -1.04 | -3.3 |
| opb 3/3 | -0.44 | 0.07 | 1.81 | 5.65 | -0.29 | -0.33 | -0.99 | -3.01 |
| opb 3/3 | -0.41 | 0.08 | 1.79 | 5.58 | -0.27 | -0.33 | -0.98 | -3.06 |
| opb 2/3 | -0.43 | 0.03 | 1.74 | 5.32 | -0.35 | -0.29 | -1.01 | -3.31 |
| opb 1/3 | -0.44 | 0.04 | 1.81 | 5.6 | -0.35 | -0.34 | -0.94 | -3.08 |
| axi-c 1/3 | -1.48 | -1.39 | 0.39 | 8.02 | 2.42 | 2.62 | 5.28 | 4.96 |
| axi-c 2/3 | -0.37 | -0.13 | 2.34 | 9.55 | 1.42 | 1.62 | 3.9 | 4.54 |
| axi-c 3/3 | 0.12 | 0.49 | 3.1 | 9.84 | 0.86 | 1.11 | 3.24 | 4.43 |
| axi-c 3/3 | 0.13 | 0.45 | 3.08 | 9.83 | 0.85 | 1.12 | 3.25 | 4.44 |
| axi-c 2/3 | -0.04 | 0.27 | 2.8 | 9.92 | 1.14 | 1.32 | 3.51 | 4.3 |
| axi-c 1/3 | -1 | -1.04 | 1.34 | 9.88 | 2.05 | 2.22 | 4.63 | 4.21 |
| axi-t 1/3 | 0.76 | 1.35 | 3.67 | 7.92 | 0.03 | 0.5 | 2.57 | 5.12 |
| axi-t 2/3 | 0.77 | 1.28 | 3.66 | 8.15 | 0.18 | 0.54 | 2.61 | 5.06 |
| axi-t 3/3 | 0.7 | 1.2 | 3.6 | 8.3 | 0.33 | 0.61 | 2.63 | 4.98 |
| axi-t 3/3 | 0.69 | 1.19 | 3.61 | 8.3 | 0.37 | 0.61 | 2.63 | 4.98 |
| axi-t 2/3 | 0.79 | 1.27 | 3.7 | 8.18 | 0.3 | 0.59 | 2.53 | 5.02 |
| axi-t 1/3 | 0.81 | 1.28 | 3.73 | 7.97 | 0.28 | 0.56 | 2.43 | 4.96 |

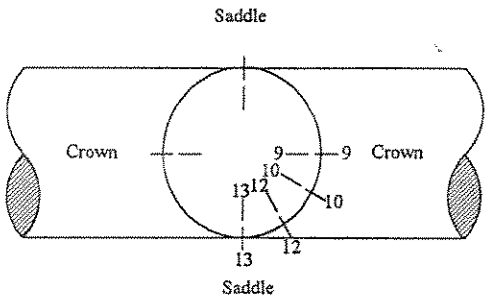
**Table 8: Measured SNCFs on intersection of brace 1 and 2 on chord for DT6**




Elevation on DT Joint




View 'A' on brace 1

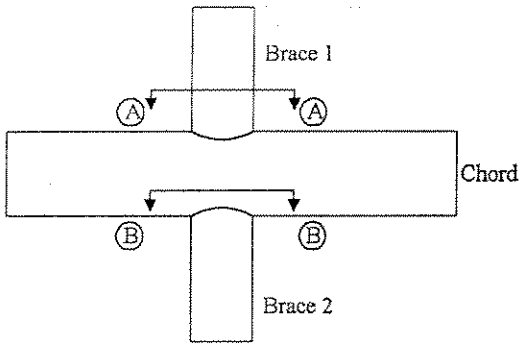



View 'B' on brace 2

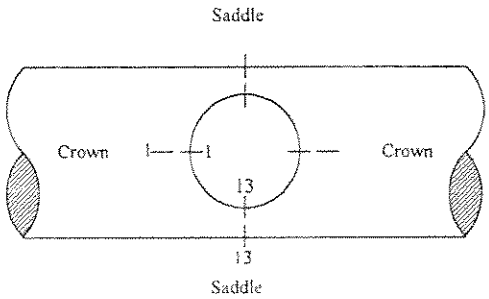
**SNCFs ungrouted Test Specimen: DT8.**

| DT8 | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 1.73 | 0.21 | -1.7 | -0.3 | 4.39 | 0.17 | -4.12 | -0.41 |
| ipb 2/3 | 1.62 | 0.18 | -1.61 | -0.16 | 4.16 | 0.15 | -3.88 | -0.18 |
| ipb 3/3 | 1.56 | 0.27 | -1.56 | -0.11 | 4.01 | 0.05 | -3.82 | -0.11 |
| ipb 3/3 | 1.58 | 0.23 | -1.58 | -0.1 | 4.05 | 0.13 | -3.86 | -0.11 |
| ipb 2/3 | 1.62 | 0.15 | -1.64 | -0.13 | 4.2 | 0.24 | -3.94 | -0.26 |
| ipb 1/3 | 1.74 | 0.02 | -1.76 | -0.23 | 4.45 | 0.28 | -4.19 | -0.43 |
| opb 1/3 | 0.09 | 8.13 | 0 | -9.32 | 0.29 | 18.33 | 0 | -17.47 |
| opb 2/3 | 0.05 | 8.48 | 0.04 | -9.55 | 0.2 | 19.1 | 0.02 | -17.98 |
| opb 3/3 | 0.05 | 8.36 | 0.04 | -9.02 | 0.19 | 18.78 | 0.06 | -17.47 |
| opb 3/3 | 0.06 | 8.42 | 0.04 | -9.26 | 0.17 | 18.91 | 0.03 | -17.16 |
| opb 2/3 | 0.11 | 8.17 | 0.06 | -8.53 | 0.28 | 18.45 | 0.12 | -16.06 |
| opb 1/3 | 0.16 | 7.87 | 0.12 | -8.46 | 0.54 | 17.83 | 0.26 | -15.89 |
| axi-c 1/3 | -0.83 | 16.31 | -0.02 | 19.42 | 0.22 | 36.56 | 2.64 | 36.35 |
| axi-c 2/3 | -0.57 | 16.72 | -0.22 | 19.08 | 0.84 | 37.35 | 2.04 | 35.63 |
| axi-c 3/3 | -0.5 | 16.58 | -0.34 | 19.25 | 1.21 | 37.23 | 1.69 | 36 |
| axi-c 3/3 | -0.48 | 16.62 | -0.41 | 19.29 | 1.27 | 37.21 | 1.52 | 36.01 |
| axi-c 2/3 | -0.5 | 16.9 | -0.33 | 19.08 | 1.07 | 37.66 | 1.7 | 35.68 |
| axi-c 1/3 | -0.69 | 17.33 | -0.26 | 18.73 | 0.54 | 38.33 | 2.11 | 34.84 |
| axi-t 1/3 | -0.54 | 17.41 | -0.22 | 18.47 | 0.93 | 39.03 | 1.77 | 34.45 |
| axi-t 2/3 | -0.6 | 17.53 | -0.2 | 18.44 | 0.81 | 39.35 | 1.79 | 34.36 |
| axi-t 3/3 | -0.6 | 17.64 | -0.27 | 18.65 | 0.92 | 39.47 | 1.68 | 34.65 |
| axi-t 3/3 | -0.64 | 17.65 | -0.27 | 18.57 | 0.89 | 39.51 | 1.79 | 34.59 |
| axi-t 2/3 | -0.66 | 17.77 | -0.19 | 18.35 | 0.74 | 39.81 | 1.94 | 34.18 |
| axi-t 1/3 | -0.79 | 18.72 | -0.08 | 18.12 | 0.71 | 41.97 | 2.12 | 33.71 |

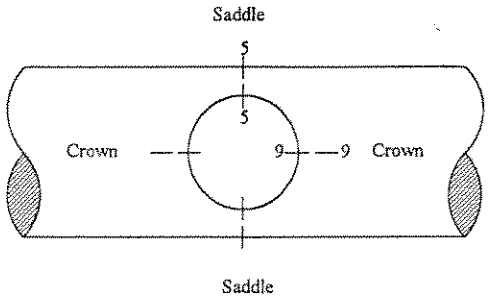
**Table 9: Measured SNCFs on intersection of brace 1 and 2 with chord for DT8**




Elevation on DT Joint




View 'A' on brace 1

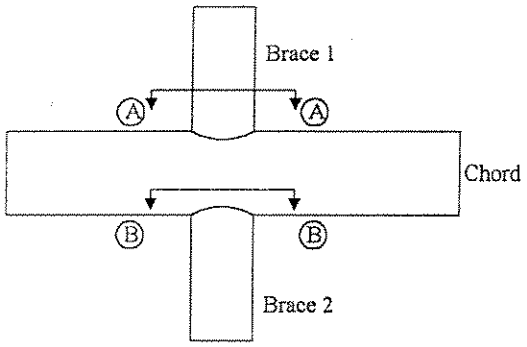



View 'B' on brace 2

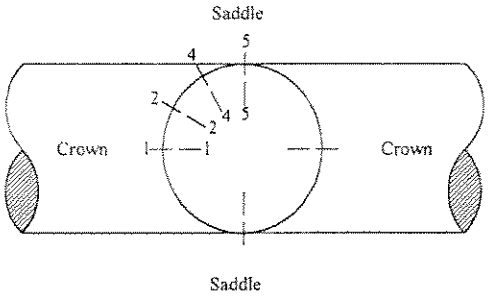
**SNCFs ungrouted Test Specimen: DT9.**

| DT9 | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 1.55 | 1.49 | 1.93 | -0.04 | -1.32 | -1.07 | -2.02 | 0.19 |
| ipb 2/3 | 1.5 | 1.45 | 1.86 | -0.06 | -1.27 | -1.03 | -1.96 | 0.14 |
| ipb 3/3 | 1.46 | 1.43 | 1.82 | -0.03 | -1.25 | -1.01 | -1.92 | 0.14 |
| ipb 3/3 | 1.47 | 1.43 | 1.83 | -0.02 | -1.26 | -1.02 | -1.93 | 0.13 |
| ipb 2/3 | 1.49 | 1.45 | 1.88 | -0.08 | -1.27 | -1.05 | -2 | 0.07 |
| ipb 1/3 | 1.57 | 1.5 | 1.98 | -0.07 | -1.35 | -1.09 | -2.09 | 0.1 |
| opb 1/3 | 0.03 | 0.46 | 0.91 | 2.11 | -0.02 | -0.43 | -0.92 | -2.39 |
| opb 2/3 | 0.02 | 0.49 | 0.9 | 2.23 | -0.02 | -0.42 | -0.88 | -2.29 |
| opb 3/3 | 0.04 | 0.5 | 0.89 | 2.25 | -0.02 | -0.42 | -0.88 | -2.28 |
| opb 3/3 | 0.03 | 0.49 | 0.89 | 2.27 | -0.01 | -0.4 | -0.88 | -2.26 |
| opb 2/3 | 0.06 | 0.49 | 0.85 | 2.28 | -0.03 | -0.42 | -0.87 | -2.22 |
| opb 1/3 | 0.12 | 0.5 | 0.85 | 2.31 | 0 | -0.34 | -0.8 | -2.15 |
| axi-c 1/3 | 1.04 | 1.31 | 1.91 | 4.16 | 1.13 | 1.27 | 2.16 | 3.14 |
| axi-c 2/3 | 1.15 | 1.49 | 2.27 | 4.75 | 0.95 | 0.99 | 1.72 | 2.71 |
| axi-c 3/3 | 1.3 | 1.62 | 2.47 | 4.83 | 0.79 | 0.87 | 1.52 | 2.65 |
| axi-c 3/3 | 1.27 | 1.59 | 2.47 | 4.8 | 0.77 | 0.83 | 1.49 | 2.61 |
| axi-c 2/3 | 1.31 | 1.63 | 2.56 | 4.84 | 0.77 | 0.78 | 1.42 | 2.51 |
| axi-c 1/3 | 1.23 | 1.64 | 2.46 | 4.76 | 0.78 | 0.83 | 1.47 | 2.34 |
| axi-t 1/3 | 1.21 | 1.21 | 1.94 | 3.52 | 0.89 | 1.08 | 1.65 | 2.79 |
| axi-t 2/3 | 1.21 | 1.31 | 2.09 | 4.01 | 0.91 | 1 | 1.76 | 2.98 |
| axi-t 3/3 | 1.18 | 1.34 | 2.13 | 4.16 | 0.94 | 1.01 | 1.76 | 2.97 |
| axi-t 3/3 | 1.18 | 1.37 | 2.11 | 4.18 | 0.91 | 1.01 | 1.73 | 2.97 |
| axi-t 2/3 | 1.17 | 1.36 | 2.06 | 4.08 | 0.88 | 1.05 | 1.74 | 2.96 |
| axi-t 1/3 | 1.11 | 1.29 | 1.84 | 3.75 | 0.87 | 1.08 | 1.69 | 2.86 |

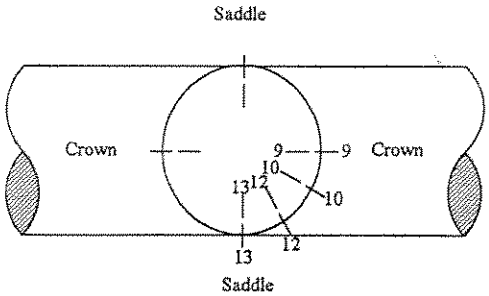
**Table 10: Measured SNCFs on intersection of brace 1 and 2 on brace for DT9**




Elevation on DT Joint



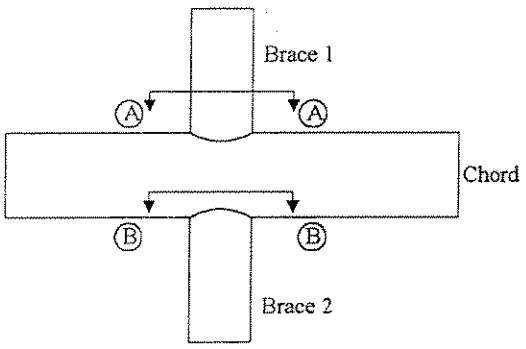

View 'A' on brace 1



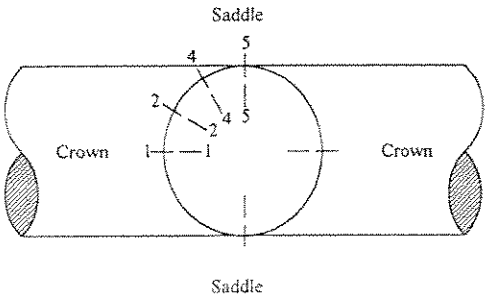

View 'B' on brace 2

| DT9 | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 2.94 | 3.33 | 3.95 | 0.12 | -3.13 | -2.8 | -3.93 | 0.56 |
| ipb 2/3 | 2.85 | 3.22 | 3.79 | 0.03 | -2.98 | -2.67 | -3.8 | 0.43 |
| ipb 3/3 | 2.79 | 3.17 | 3.7 | 0.08 | -2.95 | -2.62 | -3.71 | 0.46 |
| ipb 3/3 | 2.79 | 3.19 | 3.73 | 0.08 | -2.97 | -2.63 | -3.74 | 0.46 |
| ipb 2/3 | 2.81 | 3.24 | 3.84 | -0.03 | -3.01 | -2.69 | -3.85 | 0.3 |
| ipb 1/3 | 2.89 | 3.38 | 4.09 | -0.02 | -3.14 | -2.83 | -4.07 | 0.33 |
| opb 1/3 | -0.03 | 0.06 | 1.19 | 4.24 | -0.11 | -0.07 | -1.27 | -7.31 |
| opb 2/3 | 0.04 | 0.05 | 1.13 | 4.42 | -0.09 | -0.07 | -1.2 | -7.05 |
| opb 3/3 | 0.03 | 0.05 | 1.1 | 4.48 | -0.12 | -0.09 | -1.16 | -7.07 |
| opb 3/3 | 0.03 | 0.08 | 1.09 | 4.51 | -0.1 | -0.09 | -1.16 | -7.04 |
| opb 2/3 | 0.07 | 0.09 | 1.02 | 4.62 | -0.09 | -0.09 | -1.13 | -6.83 |
| opb 1/3 | 0.28 | 0.21 | 0.89 | 4.6 | -0.01 | -0.06 | -1.06 | -6.81 |
| axi-c 1/3 | 0.27 | 0.5 | 2.51 | 7.54 | 1.2 | 1.21 | 3.36 | 9.59 |
| axi-c 2/3 | 0.56 | 0.84 | 3.19 | 8.8 | 0.76 | 0.9 | 2.76 | 8.19 |
| axi-c 3/3 | 0.77 | 1.11 | 3.59 | 8.97 | 0.36 | 0.6 | 2.32 | 7.96 |
| axi-c 3/3 | 0.77 | 1.11 | 3.6 | 8.98 | 0.35 | 0.6 | 2.32 | 7.97 |
| axi-c 2/3 | 0.84 | 1.2 | 3.75 | 9.16 | 0.35 | 0.57 | 2.21 | 7.74 |
| axi-c 1/3 | 0.62 | 1.07 | 3.54 | 8.9 | 0.53 | 0.77 | 2.42 | 7.62 |
| axi-t 1/3 | 0.6 | 0.91 | 2.81 | 6.61 | 0.5 | 0.59 | 2.39 | 8.71 |
| axi-t 2/3 | 0.66 | 0.87 | 3 | 7.43 | 0.54 | 0.67 | 2.53 | 9.07 |
| axi-t 3/3 | 0.63 | 0.9 | 3.03 | 7.77 | 0.57 | 0.73 | 2.54 | 8.98 |
| axi-t 3/3 | 0.68 | 0.89 | 3.02 | 7.74 | 0.57 | 0.73 | 2.53 | 9.03 |
| axi-t 2/3 | 0.71 | 0.86 | 3.03 | 7.47 | 0.62 | 0.73 | 2.49 | 9.04 |
| axi-t 1/3 | 0.69 | 0.76 | 2.75 | 6.72 | 0.62 | 0.64 | 2.51 | 8.8 |

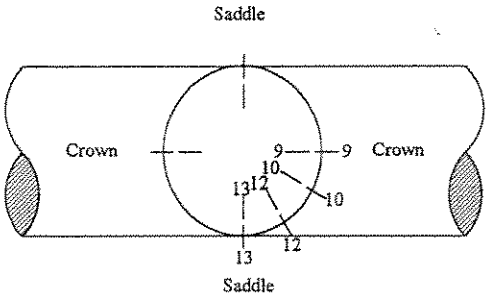
**Table 11: Measured SNCFs on intersection of brace 1 and 2 on chord for DT9**




Elevation on DT Joint




View 'A' on brace 1

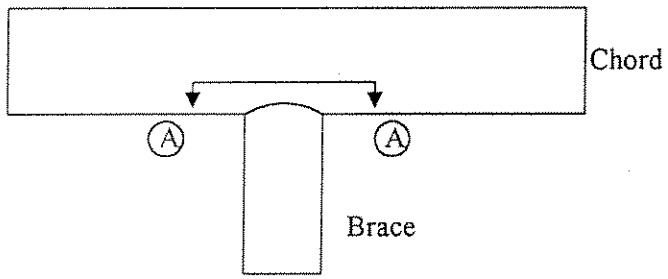



View 'B' on brace 2

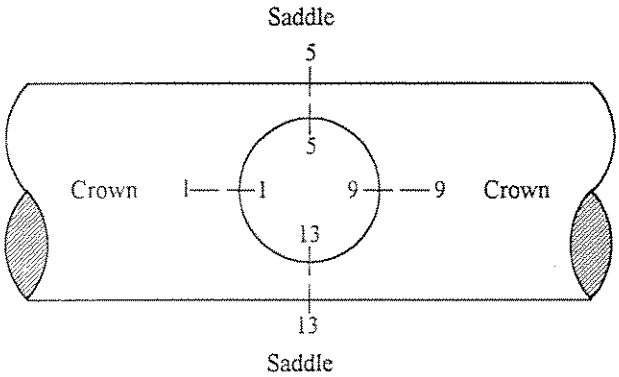
**SNCFs ungrouted Test Specimen: T1.**

| T1 | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.32 | -0.04 | 1.34 | 0.03 | -2.45 | -0.08 | 2.39 | 0.09 |
| ipb 2/3 | -1.3 | -0.06 | 1.36 | 0.02 | -2.43 | -0.08 | 2.4 | 0.1 |
| ipb 3/3 | -1.31 | -0.06 | 1.36 | 0.03 | -2.45 | -0.07 | 2.42 | 0.09 |
| ipb 3/3 | -1.32 | -0.05 | 1.37 | 0.04 | -2.45 | -0.07 | 2.42 | 0.09 |
| ipb 2/3 | -1.33 | -0.06 | 1.38 | 0.03 | -2.48 | -0.08 | 2.43 | 0.08 |
| ipb 1/3 | -1.37 | -0.05 | 1.4 | 0.06 | -2.48 | -0.08 | 2.46 | 0.09 |
| opb 1/3 | 0.02 | -3.24 | -0.07 | 3.03 | 0.03 | -6.08 | -0.1 | 6.24 |
| opb 2/3 | 0.02 | -3.19 | -0.04 | 2.98 | 0.03 | -6 | -0.1 | 6.15 |
| opb 3/3 | 0.02 | -3.18 | -0.05 | 2.97 | 0.03 | -6 | -0.07 | 6.12 |
| opb 3/3 | 0.02 | -3.17 | -0.04 | 2.97 | 0.03 | -6.02 | -0.08 | 6.16 |
| opb 2/3 | 0.02 | -3.17 | -0.03 | 2.99 | 0.04 | -6.04 | -0.1 | 6.13 |
| opb 1/3 | 0.03 | -3.17 | 0 | 2.97 | 0.05 | -6.04 | -0.13 | 6.12 |
| axi-c 1/3 | 1.02 | 6.35 | -0.62 | 4.56 | 7.66 | 10.56 | 3.94 | 8.09 |
| axi-c 2/3 | 0.9 | 5.71 | -0.39 | 5.1 | 7.3 | 9.32 | 4.3 | 9.33 |
| axi-c 3/3 | 0.83 | 5.78 | -0.33 | 5 | 7.07 | 9.47 | 4.47 | 9.24 |
| axi-c 3/3 | 0.81 | 5.79 | -0.32 | 4.98 | 7.06 | 9.48 | 4.47 | 9.22 |
| axi-c 2/3 | 0.97 | 5.44 | -0.48 | 5.3 | 7.41 | 8.86 | 4.26 | 9.96 |
| axi-c 1/3 | 1.07 | 5.58 | -0.62 | 5.33 | 7.71 | 9.08 | 3.86 | 9.71 |
| axi-t 1/3 | 1.07 | 3.88 | -0.71 | 5.92 | 7.2 | 5.94 | 3.51 | 11.24 |
| axi-t 2/3 | 0.91 | 4.14 | -0.42 | 5.75 | 6.81 | 6.42 | 3.85 | 10.99 |
| axi-t 3/3 | 0.77 | 4.34 | -0.29 | 5.59 | 6.47 | 6.85 | 4.13 | 10.54 |
| axi-t 3/3 | 0.78 | 4.35 | -0.26 | 5.59 | 6.78 | 6.86 | 4.08 | 10.52 |
| axi-t 2/3 | 0.9 | 4.26 | -0.46 | 5.65 | 6.93 | 6.63 | 3.73 | 10.7 |
| axi-t 1/3 | 1.18 | 4.21 | -0.72 | 5.58 | 7.39 | 6.53 | 3.06 | 10.68 |

**Table 12: Measured SNCFs on intersection of brace and chord for T1**




Elevation on T Joint

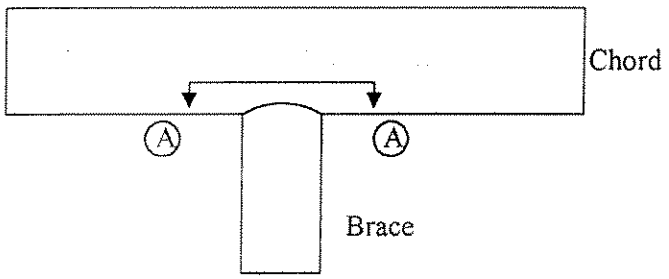



View 'A' on brace

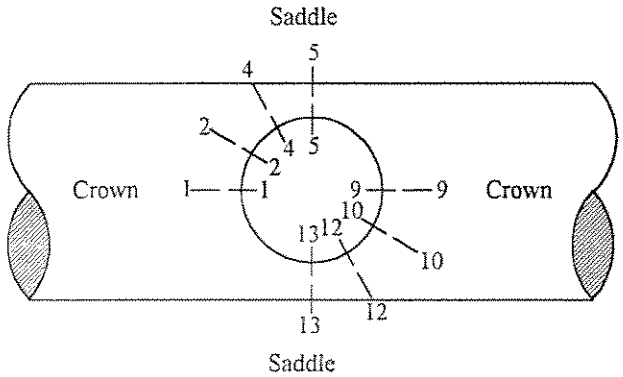
**SNCFs ungrouted Test Specimen: T3.**

| T3 | BC;1 | BI;2 | BI;4 | BS;5 | BC;9 | BI;10 | BI;12 | BS;13 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.13 | -1.07 | -1.32 | 0.04 | 1.18 | 1.25 | 1.36 | -0.08 |
| ipb 2/3 | -1.13 | -1.1 | -1.35 | 0.02 | 1.16 | 1.29 | 1.37 | -0.06 |
| ipb 3/3 | -1.13 | -1.11 | -1.33 | 0.02 | 1.17 | 1.29 | 1.37 | -0.05 |
| ipb 3/3 | -1.14 | -1.11 | -1.33 | 0.03 | 1.15 | 1.27 | 1.36 | -0.04 |
| ipb 2/3 | -1.14 | -1.1 | -1.33 | 0.02 | 1.18 | 1.29 | 1.38 | -0.04 |
| ipb 1/3 | -1.16 | -1.12 | -1.33 | 0.04 | 1.19 | 1.31 | 1.37 | -0.1 |
| opb 1/3 | 0.03 | -0.3 | -2.16 | -4.66 | -0.1 | 0.38 | 2.29 | 4.94 |
| opb 2/3 | 0.01 | -0.34 | -2.21 | -4.66 | -0.03 | 0.44 | 2.3 | 4.96 |
| opb 3/3 | 0 | -0.34 | -2.22 | -4.64 | -0.02 | 0.44 | 2.32 | 4.98 |
| opb 3/3 | 0.01 | -0.34 | -2.22 | -4.64 | -0.01 | 0.44 | 2.32 | 4.95 |
| opb 2/3 | 0.02 | -0.33 | -2.21 | -4.68 | -0.04 | 0.44 | 2.31 | 4.98 |
| opb 1/3 | 0.06 | -0.33 | -2.18 | -4.7 | -0.08 | 0.37 | 2.24 | 5.04 |
| axi-c 1/3 | 3.04 | 3.65 | 6.18 | 5.55 | 1.05 | 1.89 | 3.06 | 3.01 |
| axi-c 2/3 | 2.66 | 3.24 | 5.93 | 5.87 | 1.47 | 2.25 | 3.36 | 2.71 |
| axi-c 3/3 | 2.51 | 3.08 | 5.57 | 5.36 | 1.59 | 2.43 | 3.8 | 3.2 |
| axi-c 3/3 | 2.51 | 3.05 | 5.58 | 5.35 | 1.61 | 2.42 | 3.77 | 3.21 |
| axi-c 2/3 | 2.61 | 3.11 | 5.79 | 5.64 | 1.58 | 2.36 | 3.5 | 2.97 |
| axi-c 1/3 | 2.87 | 3.19 | 5.68 | 5.16 | 1.39 | 2.19 | 3.5 | 3.61 |
| axi-t 1/3 | 3.16 | 3.45 | 5.15 | 2.58 | 1.06 | 2.08 | 4.74 | 6.15 |
| axi-t 2/3 | 2.88 | 3.22 | 4.93 | 2.56 | 1.21 | 2.32 | 4.89 | 6.08 |
| axi-t 3/3 | 2.85 | 3.18 | 4.88 | 2.79 | 1.34 | 2.43 | 4.97 | 5.93 |
| axi-t 3/3 | 2.85 | 3.2 | 4.91 | 2.79 | 1.35 | 2.43 | 4.97 | 5.89 |
| axi-t 2/3 | 2.97 | 3.29 | 4.83 | 2.24 | 1.2 | 2.34 | 5.07 | 6.46 |
| axi-t 1/3 | 3.24 | 3.42 | 4.91 | 1.75 | 1.07 | 2.19 | 5.13 | 7.13 |

**Table 13: Measured SNCFs on intersection of brace and chord for T3**



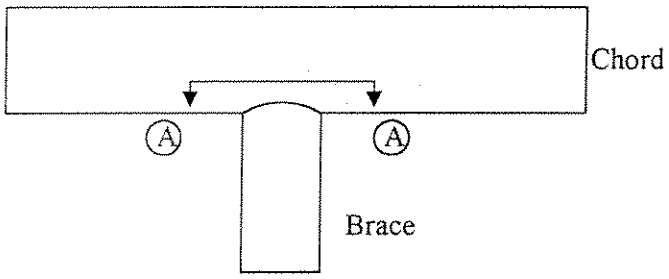

Elevation on T Joint



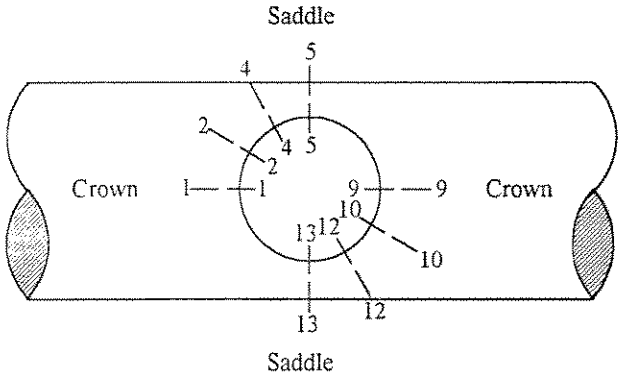

View 'A' on brace

| T3 | CC;1 | CI;2 | CI;4 | CS;5 | CC;9 | CI;10 | CI;12 | CS;13 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -2.51 | -2.24 | -1.3 | 0.05 | 3.11 | 2.6 | 1.23 | -0.08 |
| ipb 2/3 | -2.51 | -2.23 | -1.29 | 0.05 | 3.1 | 2.58 | 1.26 | -0.08 |
| ipb 3/3 | -2.51 | -2.24 | -1.31 | 0.05 | 3.09 | 2.57 | 1.26 | -0.06 |
| ipb 3/3 | -2.51 | -2.39 | -1.32 | 0.06 | 3.09 | 4.52 | 1.25 | -0.05 |
| ipb 2/3 | -2.56 | -2.28 | -1.31 | 0.05 | 3.08 | 2.51 | 1.3 | -0.05 |
| ipb 1/3 | -2.54 | -2.24 | -1.35 | 0.03 | 3.11 | 2.5 | 1.27 | -0.06 |
| opb 1/3 | 0.16 | -0.48 | -3.28 | -7.35 | -0.17 | 0.49 | 2.88 | 6.63 |
| opb 2/3 | 0.09 | -0.55 | -3.33 | -7.36 | -0.1 | 0.52 | 2.9 | 6.66 |
| opb 3/3 | 0.06 | -0.57 | -3.3 | -7.35 | -0.08 | 0.56 | 2.92 | 6.66 |
| opb 3/3 | 0.05 | -0.56 | -3.29 | -7.34 | -0.07 | 0.47 | 2.95 | 6.65 |
| opb 2/3 | 0.06 | -0.54 | -3.31 | -7.36 | -0.09 | 0.42 | 2.92 | 6.69 |
| opb 1/3 | 0.15 | -0.48 | -3.26 | -7.33 | -0.17 | 0.35 | 2.86 | 6.7 |
| axi-c 1/3 | 10 | 8.24 | 7.57 | 5.49 | 7.07 | 4.37 | 3.18 | 0.59 |
| axi-c 2/3 | 9.19 | 7.64 | 7.36 | 5.87 | 7.9 | 5.23 | 3.46 | 0.08 |
| axi-c 3/3 | 8.8 | 7.35 | 7.16 | 5.13 | 8.24 | 6.05 | 4.24 | 0.75 |
| axi-c 3/3 | 8.82 | 7.34 | 7.15 | 5.09 | 8.23 | 5.88 | 4.23 | 0.75 |
| axi-c 2/3 | 9.15 | 7.44 | 7.1 | 5.53 | 8.17 | 5.61 | 3.72 | 0.41 |
| axi-c 1/3 | 9.66 | 7.53 | 6.63 | 4.63 | 7.77 | 4.94 | 3.25 | 1.18 |
| axi-t 1/3 | 10.19 | 8.92 | 7.06 | 0.61 | 6.56 | 5.45 | 6.02 | 4.76 |
| axi-t 2/3 | 9.72 | 8.27 | 6.63 | 0.73 | 7.11 | 5.72 | 6.26 | 4.65 |
| axi-t 3/3 | 9.52 | 8.12 | 6.57 | 1.08 | 7.57 | 5.98 | 6.29 | 4.41 |
| axi-t 3/3 | 9.55 | 8.14 | 6.5 | 1.11 | 7.61 | 5.9 | 6.31 | 4.41 |
| axi-t 2/3 | 9.88 | 8.37 | 6.35 | 0.19 | 7.11 | 5.51 | 6.39 | 5.17 |
| axi-t 1/3 | 10.34 | 8.92 | 6.65 | -0.54 | 6.72 | 5.21 | 6.6 | 6.06 |

**Table 14: Measured SNCFs on intersection of brace and chord for T3**




Elevation on T Joint

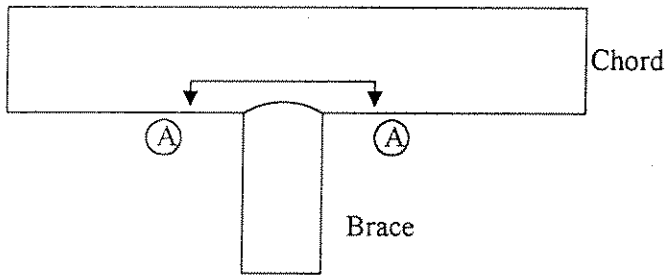



View 'A' on brace

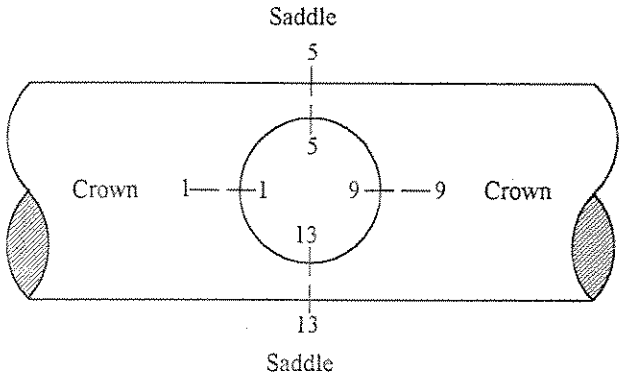
**SNCFs ungrouted Test Specimen: T5.**

| T5 | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.38 | 0.08 | 1.56 | 0.15 | -3.16 | -0.18 | 3.85 | 0.3 |
| ipb 2/3 | -1.41 | 0.13 | 1.56 | 0.09 | -3.2 | -0.07 | 3.92 | 0.2 |
| ipb 3/3 | -1.42 | 0.13 | 1.57 | 0.08 | -3.23 | -0.08 | 3.95 | 0.18 |
| ipb 3/3 | -1.43 | 0.13 | 1.61 | 0.08 | -3.23 | -0.08 | 3.96 | 0.19 |
| ipb 2/3 | -1.51 | 0.15 | 1.66 | 0.09 | -3.39 | -0.06 | 4.16 | 0.19 |
| ipb 1/3 | -1.46 | 0.14 | 1.6 | 0.08 | -3.31 | -0.1 | 4.02 | 0.2 |
| opb 1/3 | -0.03 | -7.83 | -0.06 | 7.66 | 0.07 | -14.41 | -0.31 | 13.88 |
| opb 2/3 | -0.05 | -7.76 | -0.04 | 7.67 | 0.01 | -14.3 | -0.29 | 13.84 |
| opb 3/3 | -0.03 | -7.79 | -0.05 | 7.7 | 0.02 | -14.36 | -0.32 | 13.85 |
| opb 3/3 | -0.03 | -7.77 | -0.05 | 7.71 | -0.01 | -14.33 | -0.32 | 13.83 |
| opb 2/3 | -0.04 | -7.69 | -0.06 | 7.66 | -0.01 | -14.19 | -0.3 | 13.7 |
| opb 1/3 | -0.06 | -7.63 | -0.06 | 7.55 | 0.02 | -14.08 | -0.28 | 13.61 |
| axi-c 1/3 | 0.21 | 14.5 | 1.99 | 7.44 | 5.9 | 24.37 | 11.59 | 11.3 |
| axi-c 2/3 | 0.52 | 12 | 1.69 | 9.93 | 6.6 | 19.85 | 10.66 | 15.74 |
| axi-c 3/3 | 0.52 | 10.88 | 1.63 | 11.03 | 6.61 | 17.82 | 10.48 | 17.7 |
| axi-c 3/3 | 0.55 | 10.88 | 1.63 | 11 | 6.61 | 17.83 | 10.45 | 17.7 |
| axi-c 2/3 | 0.35 | 10.71 | 1.9 | 11.33 | 6.15 | 17.42 | 11.1 | 18.27 |
| axi-c 1/3 | -0.06 | 12.43 | 2.36 | 9.78 | 5.25 | 20.4 | 12.27 | 15.54 |
| axi-t 1/3 | 1.34 | 9.28 | 0.7 | 12.36 | 8.12 | 15.23 | 7.78 | 20.16 |
| axi-t 2/3 | 1.15 | 9.92 | 0.88 | 11.74 | 7.79 | 16.24 | 8.21 | 19.04 |
| axi-t 3/3 | 1.11 | 9.43 | 0.95 | 12.26 | 7.57 | 15.39 | 8.41 | 19.78 |
| axi-t 3/3 | 1.09 | 9.43 | 0.95 | 12.21 | 7.58 | 15.31 | 8.47 | 19.93 |
| axi-t 2/3 | 1.16 | 9.89 | 0.81 | 11.79 | 7.91 | 16.18 | 8.21 | 19.18 |
| axi-t 1/3 | 1.19 | 9.42 | 0.67 | 11.98 | 7.95 | 15.3 | 7.93 | 19.8 |

**Table 15: Measured SNCFs on intersection of brace and chord for T5**




Elevation on T Joint

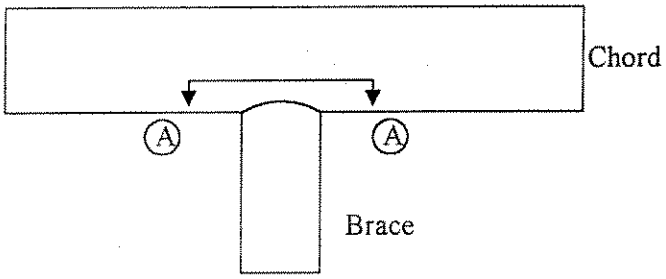



View 'A' on brace

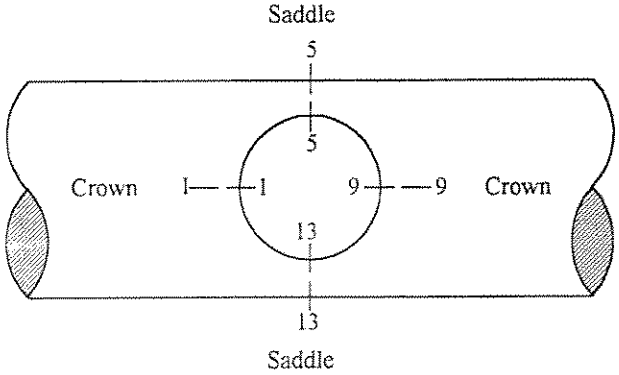
**SNCFs ungrouted Test Specimen: T7.**

| T7 | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.63 | -0.01 | 1.63 | -0.08 | -4.46 | 0.05 | 4.9 | -0.35 |
| ipb 2/3 | -1.65 | -0.02 | 1.64 | -0.06 | -4.49 | -0.01 | 4.97 | -0.35 |
| ipb 3/3 | -1.66 | -0.03 | 1.65 | -0.09 | -4.5 | 0.01 | 5.01 | -0.42 |
| ipb 3/3 | -1.67 | -0.02 | 1.67 | -0.09 | -4.5 | 0.01 | 4.97 | -0.38 |
| ipb 2/3 | -1.67 | -0.01 | 1.67 | -0.07 | -4.5 | 0.02 | 4.99 | -0.34 |
| ipb 1/3 | -1.68 | 0.04 | 1.69 | -0.06 | -4.51 | 0.13 | 5.02 | -0.33 |
| opb 1/3 | -0.07 | -6.16 | -0.25 | 5.45 | 0.35 | -14.79 | -0.47 | 15.99 |
| opb 2/3 | 0.05 | -6.88 | -0.26 | 6.05 | 0.36 | -16.44 | -0.45 | 17.85 |
| opb 3/3 | 0.04 | -6.88 | -0.24 | 6.09 | 0.27 | -16.56 | -0.44 | 17.95 |
| opb 3/3 | 0.11 | -7.25 | -0.18 | 6.39 | 0.32 | -17.46 | -0.52 | 18.91 |
| opb 2/3 | 0.12 | -7.2 | -0.18 | 6.29 | 0.36 | -17.26 | -0.54 | 18.68 |
| opb 1/3 | 0.14 | -7.69 | -0.41 | 6.77 | 0.54 | -18.54 | -0.81 | 20 |
| axi-c 1/3 | 0.32 | 4.47 | 1.53 | 15.96 | 6.56 | 9.76 | 10.6 | 46.51 |
| axi-c 2/3 | 0.49 | 7.77 | 1.36 | 13.04 | 7.02 | 17.72 | 9.97 | 37.93 |
| axi-c 3/3 | 0.53 | 9.26 | 1.37 | 11.74 | 7.1 | 21.21 | 9.93 | 34.15 |
| axi-c 3/3 | 0.53 | 9.25 | 1.35 | 11.73 | 7.12 | 21.18 | 9.89 | 34.1 |
| axi-c 2/3 | 0.59 | 7.98 | 1.38 | 12.93 | 7.09 | 18.13 | 9.91 | 37.67 |
| axi-c 1/3 | 0.3 | 5.14 | 1.61 | 15.51 | 6.27 | 11.24 | 10.71 | 45.13 |
| axi-t 1/3 | 0.47 | 14.78 | 1.41 | 5.8 | 6.51 | 34.21 | 9.48 | 16.55 |
| axi-t 2/3 | 1.07 | 13.92 | 0.8 | 6.75 | 8.07 | 32.27 | 7.87 | 19.3 |
| axi-t 3/3 | 1.26 | 13.33 | 0.68 | 7.47 | 8.59 | 30.73 | 7.43 | 21.37 |
| axi-t 3/3 | 1.3 | 13.23 | 0.64 | 7.57 | 8.69 | 30.44 | 7.37 | 21.71 |
| axi-t 2/3 | 1.28 | 13.66 | 0.71 | 6.99 | 8.46 | 31.56 | 7.42 | 19.91 |
| axi-t 1/3 | 0.8 | 14.24 | 1.12 | 5.85 | 7.05 | 32.99 | 8.34 | 16.72 |

**Table 16: Measured SNCFs on intersection of brace and chord for T7**




Elevation on T Joint

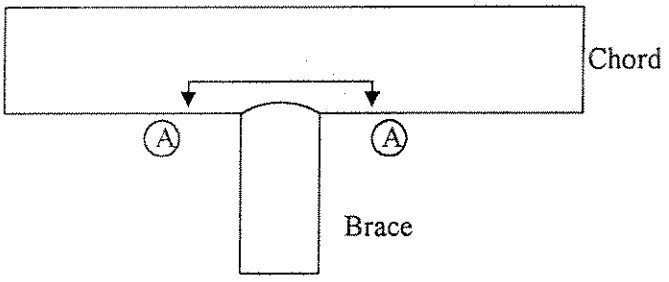



View 'A' on brace

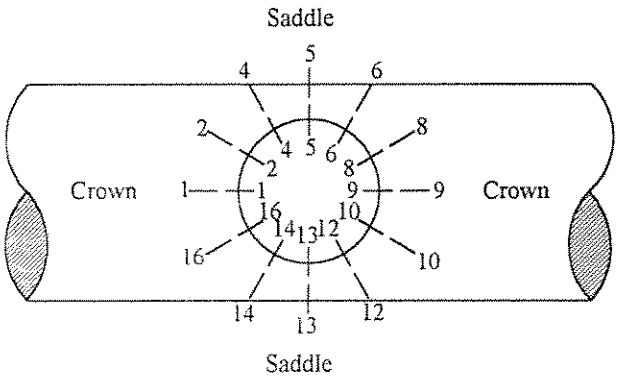
**SNCFs ungrouted Test Specimen: T9.**

| T9 | BC;1 | BI;2 | BI;4 | BS;5 | BI;6 | BI;8 | BC;9 | BI;10 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.35 | -1.36 | -1.35 | -0.37 | 1.11 | 1.17 | 1.29 | 1.44 |
| ipb 2/3 | -1.42 | -1.41 | -1.37 | -0.21 | 1.24 | 1.24 | 1.36 | 1.5 |
| ipb 3/3 | -1.44 | -1.43 | -1.39 | -0.19 | 1.27 | 1.26 | 1.37 | 1.52 |
| ipb 3/3 | -1.45 | -1.43 | -1.38 | -0.2 | 1.27 | 1.26 | 1.37 | 1.51 |
| ipb 2/3 | -1.44 | -1.41 | -1.38 | -0.21 | 1.25 | 1.25 | 1.37 | 1.5 |
| ipb 1/3 | -1.35 | -1.34 | -1.35 | -0.35 | 1.1 | 1.21 | 1.32 | 1.46 |
| opb 1/3 | -0.02 | -0.63 | -2.55 | -7.41 | -2.44 | -0.63 | 0.07 | 0.69 |
| opb 2/3 | -0.02 | -0.6 | -2.56 | -7.51 | -2.42 | -0.63 | 0.04 | 0.74 |
| opb 3/3 | -0.02 | -0.57 | -2.55 | -7.53 | -2.42 | -0.66 | 0.04 | 0.75 |
| opb 3/3 | -0.02 | -0.56 | -2.55 | -7.53 | -2.42 | -0.66 | 0.04 | 0.76 |
| opb 2/3 | -0.02 | -0.58 | -2.54 | -7.46 | -2.37 | -0.65 | 0.04 | 0.76 |
| opb 1/3 | -0.07 | -0.61 | -2.5 | -7.39 | -2.36 | -0.61 | 0.07 | 0.75 |
| axi-c 1/3 | 2.85 | 3.28 | 5.73 | 7.94 | 4.41 | 2.3 | 1.56 | 2.25 |
| axi-c 2/3 | 2.51 | 3.07 | 5.74 | 8.45 | 4.82 | 2.54 | 1.84 | 2.48 |
| axi-c 3/3 | 2.44 | 3.01 | 5.71 | 8.72 | 5.01 | 2.61 | 1.91 | 2.52 |
| axi-c 3/3 | 2.4 | 3.01 | 5.67 | 8.68 | 5.02 | 2.63 | 1.93 | 2.52 |
| axi-c 2/3 | 2.57 | 3.14 | 5.89 | 8.89 | 4.93 | 2.56 | 1.85 | 2.35 |
| axi-c 1/3 | 2.92 | 3.49 | 6.13 | 8.8 | 4.58 | 2.32 | 1.55 | 2.1 |
| axi-t 1/3 | 2.81 | 3.48 | 5.4 | 7.03 | 4.27 | 1.76 | 1.42 | 2.31 |
| axi-t 2/3 | 3.09 | 3.75 | 5.72 | 7.23 | 4.15 | 1.62 | 1.25 | 2.06 |
| axi-t 3/3 | 2.75 | 3.48 | 5.56 | 7.77 | 4.62 | 1.92 | 1.53 | 2.29 |
| axi-t 3/3 | 2.75 | 3.47 | 5.55 | 7.72 | 4.6 | 1.89 | 1.53 | 2.29 |
| axi-t 2/3 | 2.92 | 3.59 | 5.41 | 6.75 | 4.14 | 1.63 | 1.39 | 2.26 |
| axi-t 1/3 | 2.75 | 3.25 | 4.56 | 4.71 | 3.56 | 1.59 | 1.5 | 2.53 |

**Table 17: Measured SNCFs on intersection of brace and chord for T9**



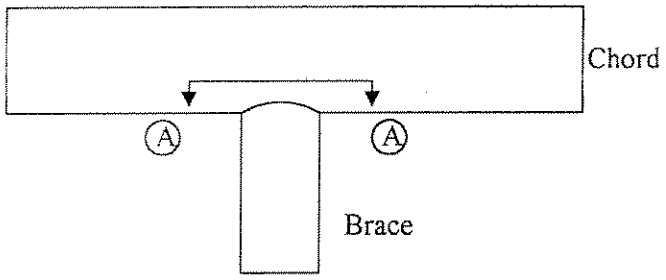

Elevation on T Joint



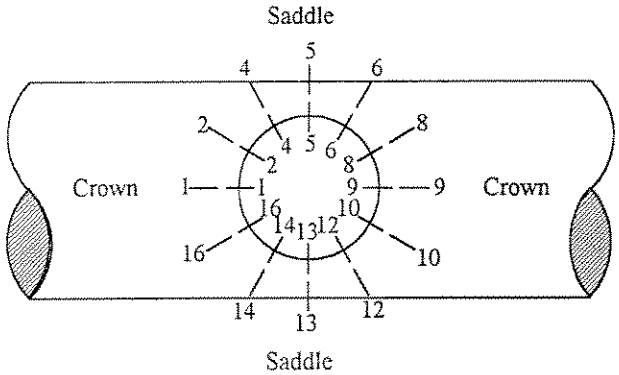

View 'A' on brace

| T9 | CC;1 | CI;2 | CI;4 | CS;5 | CI;6 | CI;8 | CC;9 | CI;10 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -2.35 | -2.39 | -1.84 | -0.65 | 1.76 | 2.51 | 2.68 | 2.18 |
| ipb 2/3 | -2.46 | -2.55 | -1.97 | -0.35 | 2.05 | 2.77 | 2.82 | 2.22 |
| ipb 3/3 | -2.51 | -2.62 | -2.01 | -0.3 | 2.12 | 2.82 | 2.88 | 2.24 |
| ipb 3/3 | -2.51 | -2.62 | -2 | -0.32 | 2.13 | 2.82 | 2.89 | 2.24 |
| ipb 2/3 | -2.48 | -2.59 | -1.99 | -0.36 | 2.06 | 2.78 | 2.88 | 2.25 |
| ipb 1/3 | -2.36 | -2.47 | -1.88 | -0.67 | 1.77 | 2.58 | 2.77 | 2.21 |
| opb 1/3 | -0.01 | -0.71 | -3.77 | -16.64 | -3.12 | -0.26 | 0 | 0.24 |
| opb 2/3 | -0.06 | -0.72 | -3.79 | -16.89 | -3.06 | -0.2 | 0.01 | 0.21 |
| opb 3/3 | -0.05 | -0.7 | -3.84 | -17 | -3.03 | -0.21 | -0.04 | 0.16 |
| opb 3/3 | -0.06 | -0.66 | -3.82 | -16.98 | -3.01 | -0.21 | -0.04 | 0.18 |
| opb 2/3 | -0.09 | -0.68 | -3.79 | -16.78 | -2.93 | -0.2 | -0.03 | 0.17 |
| opb 1/3 | -0.12 | -0.67 | -3.77 | -16.48 | -2.98 | -0.23 | 0.04 | 0.26 |
| axi-c 1/3 | 8.03 | 8.21 | 9.21 | 14.05 | 5.69 | 5.29 | 7.54 | 6.15 |
| axi-c 2/3 | 7.57 | 7.85 | 9.21 | 15.22 | 6.36 | 5.95 | 7.96 | 6.43 |
| axi-c 3/3 | 7.33 | 7.63 | 9.05 | 15.8 | 6.88 | 6.28 | 8.1 | 6.44 |
| axi-c 3/3 | 7.41 | 7.62 | 9 | 15.78 | 6.85 | 6.3 | 8.08 | 6.45 |
| axi-c 2/3 | 7.69 | 8.05 | 9.52 | 16.32 | 6.38 | 5.89 | 7.88 | 6.46 |
| axi-c 1/3 | 8.28 | 8.72 | 10.11 | 16.18 | 5.54 | 5.17 | 7.31 | 6.13 |
| axi-t 1/3 | 8.26 | 6.98 | 6.39 | 11.62 | 7.76 | 6.71 | 6.9 | 4.4 |
| axi-t 2/3 | 8.66 | 7.48 | 6.72 | 11.91 | 7.92 | 6.54 | 6.45 | 3.87 |
| axi-t 3/3 | 7.96 | 6.81 | 6.49 | 13.15 | 8.58 | 7.1 | 6.99 | 4.25 |
| axi-t 3/3 | 7.93 | 6.82 | 6.49 | 13.1 | 8.6 | 7.1 | 6.98 | 4.24 |
| axi-t 2/3 | 8.28 | 7.09 | 6.23 | 10.92 | 8.04 | 6.81 | 6.7 | 4 |
| axi-t 1/3 | 7.84 | 6.71 | 5.1 | 6.6 | 7.23 | 6.78 | 6.88 | 4.36 |

**Table 18 Measured SNCFs on intersection of brace and chord for T9**



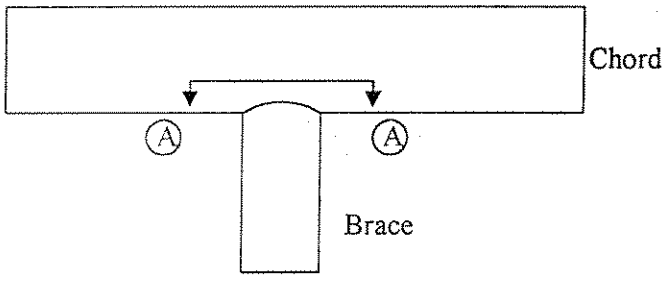

Elevation on T Joint



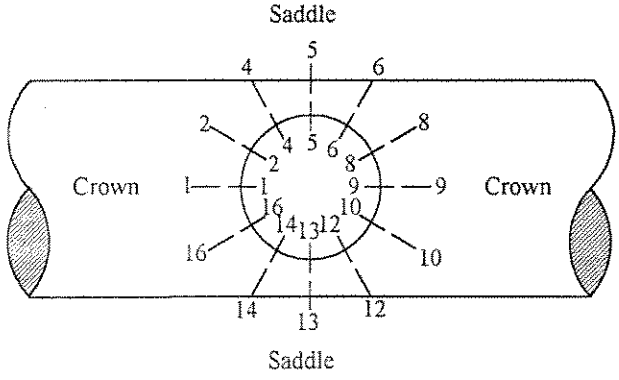

View 'A' on brace

| T9 | BC;1 | BI;16 | BI;14 | BS;13 | BI;12 | BI;10 | BC;9 | BI;8 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.35 | -1.2 | -1 | 0.25 | 1.52 | 1.44 | 1.29 | 1.17 |
| ipb 2/3 | -1.42 | -1.27 | -1.11 | 0.12 | 1.53 | 1.5 | 1.36 | 1.24 |
| ipb 3/3 | -1.44 | -1.29 | -1.13 | 0.11 | 1.54 | 1.52 | 1.37 | 1.26 |
| ipb 3/3 | -1.45 | -1.28 | -1.14 | 0.12 | 1.54 | 1.51 | 1.37 | 1.26 |
| ipb 2/3 | -1.44 | -1.26 | -1.12 | 0.12 | 1.53 | 1.5 | 1.37 | 1.25 |
| ipb 1/3 | -1.35 | -1.19 | -1.03 | 0.24 | 1.52 | 1.46 | 1.32 | 1.21 |
| opb 1/3 | -0.02 | 0.6 | 2.37 | 6.49 | 2.48 | 0.69 | 0.07 | -0.63 |
| opb 2/3 | -0.02 | 0.61 | 2.39 | 6.53 | 2.52 | 0.74 | 0.04 | -0.63 |
| opb 3/3 | -0.02 | 0.61 | 2.44 | 6.58 | 2.5 | 0.75 | 0.04 | -0.66 |
| opb 3/3 | -0.02 | 0.6 | 2.41 | 6.56 | 2.49 | 0.76 | 0.04 | -0.66 |
| opb 2/3 | -0.02 | 0.6 | 2.4 | 6.51 | 2.47 | 0.76 | 0.04 | -0.65 |
| opb 1/3 | -0.07 | 0.6 | 2.31 | 6.42 | 2.46 | 0.75 | 0.07 | -0.61 |
| axi-c 1/3 | 2.85 | 3.1 | 5.2 | 6.23 | 4.66 | 2.25 | 1.56 | 2.3 |
| axi-c 2/3 | 2.51 | 2.81 | 4.75 | 5.76 | 4.69 | 2.48 | 1.84 | 2.54 |
| axi-c 3/3 | 2.44 | 2.66 | 4.62 | 5.52 | 4.66 | 2.52 | 1.91 | 2.61 |
| axi-c 3/3 | 2.4 | 2.64 | 4.63 | 5.5 | 4.64 | 2.52 | 1.93 | 2.63 |
| axi-c 2/3 | 2.57 | 2.77 | 4.72 | 5.37 | 4.51 | 2.35 | 1.85 | 2.56 |
| axi-c 1/3 | 2.92 | 3.1 | 5.1 | 5.43 | 4.3 | 2.1 | 1.55 | 2.32 |
| axi-t 1/3 | 2.81 | 3.04 | 5.53 | 6.71 | 4.47 | 2.31 | 1.42 | 1.76 |
| axi-t 2/3 | 3.09 | 3.21 | 5.67 | 6.62 | 4.15 | 2.06 | 1.25 | 1.62 |
| axi-t 3/3 | 2.75 | 2.89 | 5.16 | 5.96 | 4.21 | 2.29 | 1.53 | 1.92 |
| axi-t 3/3 | 2.75 | 2.9 | 5.16 | 5.96 | 4.22 | 2.29 | 1.53 | 1.89 |
| axi-t 2/3 | 2.92 | 3.16 | 5.72 | 7.03 | 4.45 | 2.26 | 1.39 | 1.63 |
| axi-t 1/3 | 2.75 | 3.19 | 6.22 | 8.78 | 5.27 | 2.53 | 1.5 | 1.59 |

**Table 19: Measured SNCFs on intersection of brace and chord for T9**



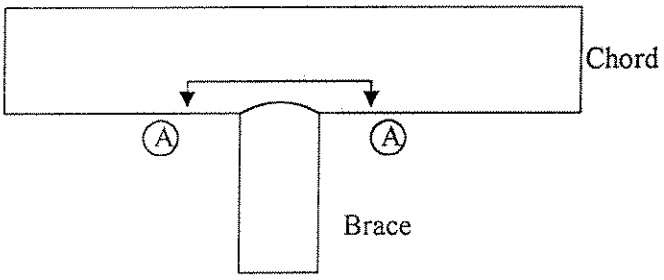

Elevation on T Joint



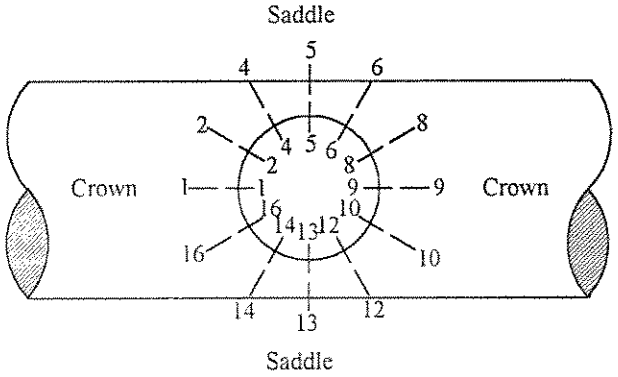

View 'A' on brace

| T9 | CC;1 | CI;16 | CI;14 | CS;13 | CI;12 | CI;10 | CC;9 | CI;8 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -2.35 | -2.37 | -1.71 | 0.56 | 1.82 | 2.18 | 2.68 | 2.51 |
| ipb 2/3 | -2.46 | -2.47 | -1.76 | 0.29 | 1.75 | 2.22 | 2.82 | 2.77 |
| ipb 3/3 | -2.51 | -2.5 | -1.75 | 0.28 | 1.72 | 2.24 | 2.88 | 2.82 |
| ipb 3/3 | -2.51 | -2.5 | -1.74 | 0.28 | 1.72 | 2.24 | 2.89 | 2.82 |
| ipb 2/3 | -2.48 | -2.48 | -1.73 | 0.27 | 1.74 | 2.25 | 2.88 | 2.78 |
| ipb 1/3 | -2.36 | -2.38 | -1.67 | 0.51 | 1.81 | 2.21 | 2.77 | 2.58 |
| opb 1/3 | -0.01 | 0.35 | 2.75 | 15.2 | 2.9 | 0.24 | 0 | -0.26 |
| opb 2/3 | -0.06 | 0.35 | 2.83 | 15.37 | 2.81 | 0.21 | 0.01 | -0.2 |
| opb 3/3 | -0.05 | 0.39 | 2.96 | 15.45 | 2.75 | 0.16 | -0.04 | -0.21 |
| opb 3/3 | -0.06 | 0.39 | 2.9 | 15.42 | 2.73 | 0.18 | -0.04 | -0.21 |
| opb 2/3 | -0.09 | 0.36 | 2.83 | 15.33 | 2.71 | 0.17 | -0.03 | -0.2 |
| opb 1/3 | -0.12 | 0.28 | 2.58 | 15.17 | 2.74 | 0.26 | 0.04 | -0.23 |
| axi-c 1/3 | 8.03 | 7.26 | 6.4 | 9.82 | 7.51 | 6.15 | 7.54 | 5.29 |
| axi-c 2/3 | 7.57 | 6.7 | 5.49 | 8.81 | 7.57 | 6.43 | 7.96 | 5.95 |
| axi-c 3/3 | 7.33 | 6.53 | 5.37 | 8.49 | 7.41 | 6.44 | 8.1 | 6.28 |
| axi-c 3/3 | 7.41 | 6.53 | 5.34 | 8.44 | 7.39 | 6.45 | 8.08 | 6.3 |
| axi-c 2/3 | 7.69 | 6.76 | 5.23 | 8.04 | 7.57 | 6.46 | 7.88 | 5.89 |
| axi-c 1/3 | 8.28 | 7.27 | 5.78 | 8.15 | 7.45 | 6.13 | 7.31 | 5.17 |
| axi-t 1/3 | 8.26 | 8.51 | 8.44 | 11.54 | 4.91 | 4.4 | 6.9 | 6.71 |
| axi-t 2/3 | 8.66 | 9.03 | 8.85 | 11.48 | 4.34 | 3.87 | 6.45 | 6.54 |
| axi-t 3/3 | 7.96 | 8.37 | 8.16 | 9.98 | 4.31 | 4.25 | 6.99 | 7.1 |
| axi-t 3/3 | 7.93 | 8.37 | 8.26 | 10.04 | 4.32 | 4.24 | 6.98 | 7.1 |
| axi-t 2/3 | 8.28 | 8.84 | 9.01 | 12.37 | 4.52 | 4 | 6.7 | 6.81 |
| axi-t 1/3 | 7.84 | 8.58 | 9.38 | 16.3 | 5.61 | 4.36 | 6.88 | 6.78 |

**Table 20: Measured SNCFs on intersection of brace and chord for T9**




Elevation on T Joint



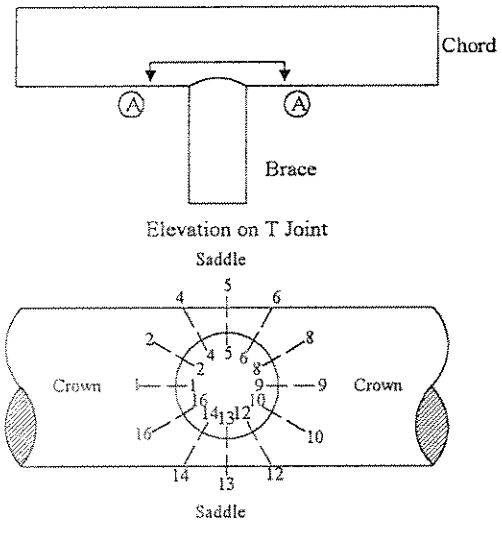

View 'A' on brace

**SNCFs ungrouted Test Specimen: T9 second.**

Following the first set of ungrouted SNCF measurements, specimen T9 was removed and replaced into the test rig and received a second set of ungrouted SNCF measurements. The following Tables present the SNCF measurements for this second cycle.

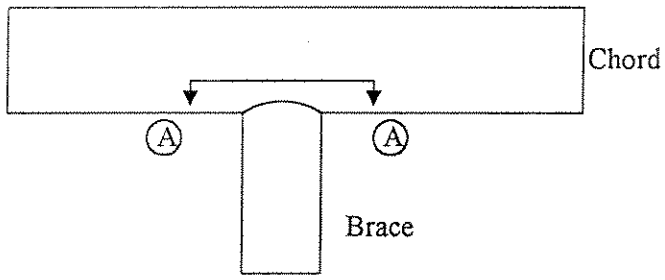
| T9-s | BC;1 | BI;2 | BI;4 | BS;5 | BI;6 | BI;8 | BC;9 | BI;10 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.39 | -1.38 | -1.33 | -0.13 | 1.23 | 1.24 | 1.32 | 1.47 |
| ipb 2/3 | -1.43 | -1.41 | -1.33 | -0.08 | 1.28 | 1.27 | 1.35 | 1.48 |
| ipb 3/3 | -1.45 | -1.42 | -1.34 | -0.06 | 1.3 | 1.27 | 1.36 | 1.5 |
| ipb 3/3 | -1.44 | -1.41 | -1.32 | -0.03 | 1.3 | 1.26 | 1.36 | 1.43 |
| ipb 2/3 | -1.46 | -1.44 | -1.33 | 0 | 1.33 | 1.28 | 1.39 | 1.52 |
| ipb 1/3 | -1.42 | -1.41 | -1.32 | -0.07 | 1.28 | 1.26 | 1.37 | 1.52 |
| opb 1/3 | 0.05 | -0.52 | -2.46 | -7.43 | -2.4 | -0.75 | -0.01 | 0.64 |
| opb 2/3 | 0.05 | -0.55 | -2.52 | -7.45 | -2.45 | -0.73 | -0.03 | 0.69 |
| opb 3/3 | 0.03 | -0.55 | -2.53 | -7.45 | -2.44 | -0.72 | -0.01 | 0.69 |
| opb 3/3 | 0.02 | -0.55 | -2.53 | -7.44 | -2.45 | -0.72 | 0 | 0.7 |
| opb 2/3 | 0.04 | -0.56 | -2.51 | -7.39 | -2.4 | -0.72 | -0.02 | 0.68 |
| opb 1/3 | 0.02 | -0.52 | -2.53 | -7.36 | -2.43 | -0.76 | 0 | 0.68 |
| axi-c 1/3 | 3.35 | 3.72 | 5.51 | 5.92 | 3.34 | 1.61 | 1.23 | 1.98 |
| axi-c 2/3 | 2.95 | 3.52 | 5.87 | 7.92 | 4.41 | 2.1 | 1.5 | 2.15 |
| axi-c 3/3 | 2.63 | 3.26 | 5.76 | 8.37 | 4.83 | 2.4 | 1.79 | 2.4 |
| axi-c 3/3 | 2.64 | 3.25 | 5.74 | 8.37 | 4.83 | 2.4 | 1.77 | 2.39 |
| axi-c 2/3 | 2.86 | 3.44 | 5.96 | 8.37 | 4.63 | 2.24 | 1.57 | 2.2 |
| axi-c 1/3 | 3.39 | 3.88 | 6.29 | 8.16 | 4.13 | 1.82 | 1.12 | 1.73 |
| axi-t 1/3 | 2.62 | 3.67 | 6.51 | 10.86 | 5.68 | 2.33 | 1.68 | 2.21 |
| axi-t 2/3 | 2.76 | 3.51 | 5.79 | 8.26 | 4.82 | 2.07 | 1.65 | 2.36 |
| axi-t 3/3 | 2.72 | 3.4 | 5.49 | 7.63 | 4.64 | 2.11 | 1.68 | 2.42 |
| axi-t 3/3 | 2.73 | 3.4 | 5.49 | 7.58 | 4.62 | 2.08 | 1.7 | 2.44 |
| axi-t 2/3 | 2.83 | 3.55 | 5.59 | 7.64 | 4.57 | 1.93 | 1.67 | 2.38 |
| axi-t 1/3 | 2.91 | 3.58 | 5.4 | 6.82 | 4.22 | 1.73 | 1.62 | 2.52 |

**Table 21: Measured SNCFs on intersection of brace and chord for T9-second**

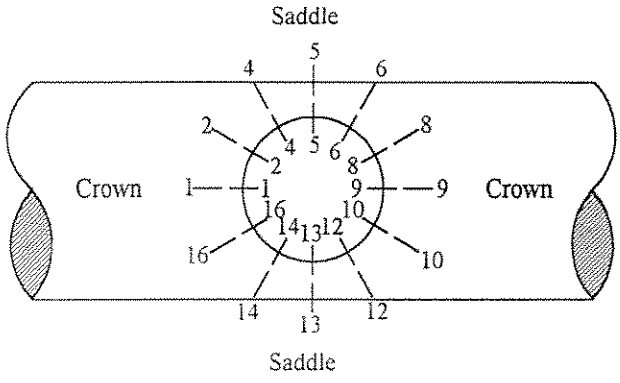


| T9-s | CC;1 | CI;2 | CI;4 | CS;5 | CI;6 | CI;8 | CC;9 | CI;10 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -2.43 | -2.5 | -1.83 | -0.16 | 2 | 2.7 | 2.8 | 2.18 |
| ipb 2/3 | -2.47 | -2.57 | -1.89 | -0.05 | 2.11 | 2.79 | 2.84 | 2.19 |
| ipb 3/3 | -2.51 | -2.6 | -1.9 | -0.01 | 2.13 | 2.8 | 2.87 | 2.21 |
| ipb 3/3 | -2.5 | -2.59 | -1.89 | 0.05 | 2.14 | 2.79 | 2.86 | 2.2 |
| ipb 2/3 | -2.53 | -2.63 | -1.93 | 0.11 | 2.21 | 2.86 | 2.92 | 2.24 |
| ipb 1/3 | -2.48 | -2.6 | -1.92 | 0 | 2.09 | 2.77 | 2.84 | 2.22 |
| opb 1/3 | 0.12 | -0.65 | -3.86 | -16.54 | -3 | -0.34 | -0.21 | 0.13 |
| opb 2/3 | 0.05 | -0.72 | -3.92 | -16.69 | -2.96 | -0.29 | -0.17 | 0.04 |
| opb 3/3 | 0.03 | -0.73 | -3.92 | -16.76 | -2.95 | -0.25 | -0.15 | 0.02 |
| opb 3/3 | 0.03 | -0.74 | -3.92 | -16.75 | -2.97 | -0.23 | -0.15 | 0 |
| opb 2/3 | 0.07 | -0.75 | -3.89 | -16.61 | -2.93 | -0.22 | -0.16 | 0 |
| opb 1/3 | 0.06 | -0.78 | -3.9 | -16.45 | -3 | -0.24 | -0.17 | 0.04 |
| axi-c 1/3 | 9.14 | 8.98 | 8.41 | 9.44 | 4.66 | 4.82 | 6.47 | 5.09 |
| axi-c 2/3 | 8.4 | 8.38 | 8.8 | 13.81 | 6.36 | 5.71 | 7.23 | 5.48 |
| axi-c 3/3 | 7.9 | 7.82 | 8.59 | 14.91 | 7.09 | 6.38 | 7.78 | 5.83 |
| axi-c 3/3 | 7.89 | 7.77 | 8.58 | 14.86 | 7.06 | 6.34 | 7.77 | 5.85 |
| axi-c 2/3 | 8.32 | 8.26 | 9.01 | 14.76 | 6.52 | 5.88 | 7.4 | 5.66 |
| axi-c 1/3 | 9.2 | 9.18 | 9.62 | 14.38 | 5.5 | 4.73 | 6.45 | 5.05 |
| axi-t 1/3 | 7.86 | 7.15 | 7.86 | 19.97 | 10.05 | 7.48 | 7.56 | 4.61 |
| axi-t 2/3 | 8.09 | 7.2 | 6.92 | 14.29 | 8.63 | 7.23 | 7.39 | 4.68 |
| axi-t 3/3 | 7.99 | 7.16 | 6.86 | 12.93 | 8.07 | 7.05 | 7.45 | 4.88 |
| axi-t 3/3 | 7.99 | 7.14 | 6.86 | 12.84 | 8.09 | 7.07 | 7.46 | 4.87 |
| axi-t 2/3 | 8.18 | 7.16 | 6.7 | 12.78 | 8.44 | 7.2 | 7.33 | 4.51 |
| axi-t 1/3 | 8.39 | 7.04 | 6.06 | 11.02 | 8.39 | 7.29 | 7.26 | 4.22 |

**Table 22: Measured SNCFs on intersection of brace and chord for T9-second**



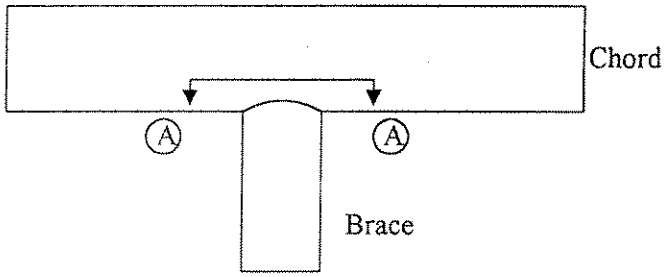

Elevation on T Joint



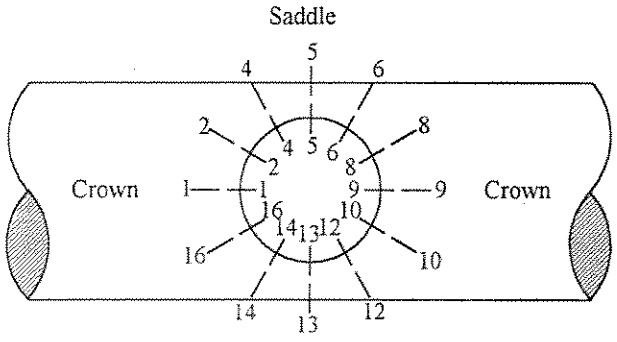

View 'A' on brace

| T9-s | BC;1 | BI;16 | BI;14 | BS;13 | BI;12 | BI;10 | BC;9 | BI;8 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -1.39 | -1.23 | -1.11 | 0.01 | 1.47 | 1.47 | 1.32 | 1.24 |
| ipb 2/3 | -1.43 | -1.28 | -1.14 | 0.01 | 1.47 | 1.48 | 1.35 | 1.27 |
| ipb 3/3 | -1.45 | -1.29 | -1.16 | 0 | 1.49 | 1.5 | 1.36 | 1.27 |
| ipb 3/3 | -1.44 | -1.29 | -1.16 | -0.01 | 1.48 | 1.43 | 1.36 | 1.26 |
| ipb 2/3 | -1.46 | -1.31 | -1.18 | -0.04 | 1.48 | 1.52 | 1.39 | 1.28 |
| ipb 1/3 | -1.42 | -1.29 | -1.15 | 0.01 | 1.47 | 1.52 | 1.37 | 1.26 |
| opb 1/3 | 0.05 | 0.65 | 2.52 | 6.43 | 2.39 | 0.64 | -0.01 | -0.75 |
| opb 2/3 | 0.05 | 0.67 | 2.49 | 6.46 | 2.4 | 0.69 | -0.03 | -0.73 |
| opb 3/3 | 0.03 | 0.66 | 2.5 | 6.43 | 2.41 | 0.69 | -0.01 | -0.72 |
| opb 3/3 | 0.02 | 0.65 | 2.51 | 6.43 | 2.42 | 0.7 | 0 | -0.72 |
| opb 2/3 | 0.04 | 0.65 | 2.5 | 6.43 | 2.41 | 0.68 | -0.02 | -0.72 |
| opb 1/3 | 0.02 | 0.67 | 2.53 | 6.44 | 2.43 | 0.68 | 0 | -0.76 |
| axi-c 1/3 | 3.35 | 3.63 | 6.21 | 7.85 | 4.62 | 1.98 | 1.23 | 1.61 |
| axi-c 2/3 | 2.95 | 3.13 | 5.2 | 6.07 | 4.34 | 2.15 | 1.5 | 2.1 |
| axi-c 3/3 | 2.63 | 2.8 | 4.77 | 5.64 | 4.47 | 2.4 | 1.79 | 2.4 |
| axi-c 3/3 | 2.64 | 2.82 | 4.77 | 5.61 | 4.46 | 2.39 | 1.77 | 2.4 |
| axi-c 2/3 | 2.86 | 3.06 | 5 | 5.7 | 4.31 | 2.2 | 1.57 | 2.24 |
| axi-c 1/3 | 3.39 | 3.53 | 5.45 | 5.89 | 3.95 | 1.73 | 1.12 | 1.82 |
| axi-t 1/3 | 2.62 | 2.42 | 3.96 | 3.23 | 3.46 | 2.21 | 1.68 | 2.33 |
| axi-t 2/3 | 2.76 | 2.83 | 4.89 | 5.46 | 4.16 | 2.36 | 1.65 | 2.07 |
| axi-t 3/3 | 2.72 | 2.85 | 5.03 | 5.93 | 4.39 | 2.42 | 1.68 | 2.11 |
| axi-t 3/3 | 2.73 | 2.85 | 5.02 | 5.94 | 4.4 | 2.44 | 1.7 | 2.08 |
| axi-t 2/3 | 2.83 | 2.96 | 5.16 | 6.07 | 4.34 | 2.38 | 1.67 | 1.93 |
| axi-t 1/3 | 2.91 | 3.1 | 5.56 | 6.91 | 4.54 | 2.52 | 1.62 | 1.73 |

**Table 23: Measured SNCFs on intersection of brace and chord for T9-second**



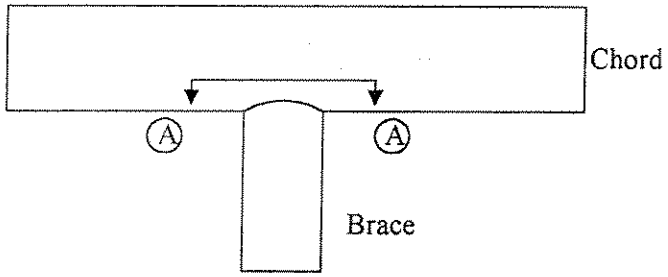

Elevation on T Joint



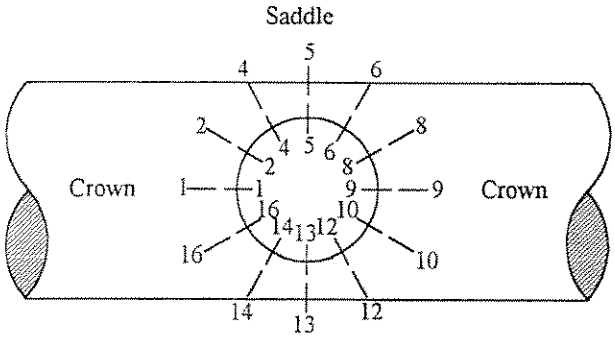

View 'A' on brace

| T9-s | CC;1 | CI;16 | CI;14 | CS;13 | CI;12 | CI;10 | CC;9 | CI;8 |
|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -2.43 | -2.41 | -1.74 | 0.09 | 1.66 | 2.18 | 2.8 | 2.7 |
| ipb 2/3 | -2.47 | -2.47 | -1.73 | 0.04 | 1.63 | 2.19 | 2.84 | 2.79 |
| ipb 3/3 | -2.51 | -2.5 | -1.74 | -0.01 | 1.66 | 2.21 | 2.87 | 2.8 |
| ipb 3/3 | -2.5 | -2.5 | -1.71 | -0.04 | 1.65 | 2.2 | 2.86 | 2.79 |
| ipb 2/3 | -2.53 | -2.54 | -1.75 | -0.09 | 1.65 | 2.24 | 2.92 | 2.86 |
| ipb 1/3 | -2.48 | -2.5 | -1.61 | -0.03 | 1.67 | 2.22 | 2.84 | 2.77 |
| opb 1/3 | 0.12 | 0.78 | 3 | 14.91 | 2.61 | 0.13 | -0.21 | -0.34 |
| opb 2/3 | 0.05 | 0.7 | 3.19 | 15.13 | 2.54 | 0.04 | -0.17 | -0.29 |
| opb 3/3 | 0.03 | 0.67 | 3.21 | 15.11 | 2.53 | 0.02 | -0.15 | -0.25 |
| opb 3/3 | 0.03 | 0.68 | 3.28 | 15.12 | 2.54 | 0 | -0.15 | -0.23 |
| opb 2/3 | 0.07 | 0.72 | 3.24 | 15.1 | 2.51 | 0 | -0.16 | -0.22 |
| opb 1/3 | 0.06 | 0.76 | 3.38 | 15.07 | 2.51 | 0.04 | -0.17 | -0.24 |
| axi-c 1/3 | 9.14 | 8.56 | 7.6 | 13.99 | 7.13 | 5.09 | 6.47 | 4.82 |
| axi-c 2/3 | 8.4 | 7.78 | 6.46 | 9.85 | 6.52 | 5.48 | 7.23 | 5.71 |
| axi-c 3/3 | 7.9 | 7.2 | 5.85 | 8.96 | 6.6 | 5.83 | 7.78 | 6.38 |
| axi-c 3/3 | 7.89 | 7.21 | 5.91 | 8.97 | 6.62 | 5.85 | 7.77 | 6.34 |
| axi-c 2/3 | 8.32 | 7.59 | 6.29 | 9.13 | 6.64 | 5.66 | 7.4 | 5.88 |
| axi-c 1/3 | 9.2 | 8.38 | 6.96 | 9.52 | 6.57 | 5.05 | 6.45 | 4.73 |
| axi-t 1/3 | 7.86 | 8.09 | 6.39 | 3.56 | 3.4 | 4.61 | 7.56 | 7.48 |
| axi-t 2/3 | 8.09 | 8.26 | 7.47 | 8.76 | 4.54 | 4.68 | 7.39 | 7.23 |
| axi-t 3/3 | 7.99 | 8.08 | 7.42 | 9.88 | 5.1 | 4.88 | 7.45 | 7.05 |
| axi-t 3/3 | 7.99 | 8.06 | 7.42 | 10 | 5.12 | 4.87 | 7.46 | 7.07 |
| axi-t 2/3 | 8.18 | 8.42 | 8.02 | 10.35 | 4.68 | 4.51 | 7.33 | 7.2 |
| axi-t 1/3 | 8.39 | 8.9 | 9.02 | 12.35 | 4.62 | 4.22 | 7.26 | 7.29 |

**Table 24: Measured SNCFs on intersection of brace and chord for T9-second**




Elevation on T Joint




View 'A' on brace

SCF/SNCF ratios for Test Specimen: T7.

| PRELOAD LEVEL | IPB-BC | IPB-CC | OPB-BS | OPB-CS |
|---|---|---|---|---|
| 7 | 1.32 | 1.175 | 1.13 | 1.205 |
| 13 | 1.32 | 1.17 | 1.12 | 1.205 |
| 20 | 1.31 | 1.18 | 1.335 | 1.235 |
| 26 | 1.32 | 1.175 | 1.12 | 1.2 |
| 40 | 1.31 | 1.18 | 1.12 | 1.21 |
| 52 | 1.32 | 1.18 | 1.12 | 1.2 |
| 65 | 1.32 | 1.17 | 1.12 | 1.2 |
| 78 | 1.32 | 1.18 | 1.12 | 1.21 |
| 90 | 1.32 | 1.18 | 1.12 | 1.21 |
| 105 | 1.32 | 1.18 | 1.12 | 1.21 |
| 130 | 1.32 | 1.18 | 1.12 | 1.21 |

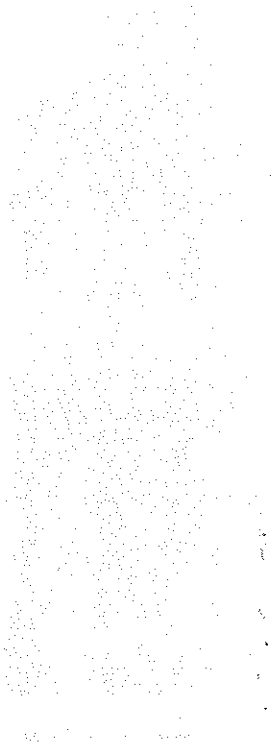
**Table 25 SCF/SNCF ratios for specimen T7 under ipb and opb**

| PRELOAD LEVEL | AC-BC | AC-CC | AC-BS | AC-CS |
|---|---|---|---|---|
| 7 | 1.205 | 0.76 | 1.16 | 1.245 |
| 13 | 1.065 | 1.04 | 1.16 | 1.215 |
| 20 | 1.235 | 1.12 | 1.18 | 1.2 |
| 26 | 1.215 | 1.13 | 1.18 | 1.21 |
| 40 | 1.32 | 1.11 | 1.17 | 1.2 |
| 52 | 1.3 | 1.13 | 1.17 | 1.195 |
| 65 | 1.31 | 1.12 | 1.17 | 1.19 |
| 78 | 1.49 | 1.11 | 1.16 | 1.21 |
| 90 | 1.375 | 1.13 | 1.16 | 1.2 |
| 105 | 1.25 | 0.79 | 1.15 | 1.2 |
| 130 | 0.83 | 1.065 | 1.15 | 1.22 |

**Table 26 SCF/SNCF ratios for specimen T7 under axial compression**

| PRELOAD LEVEL | AT-BC | AT-CC | AT-BS | AT-CS |
|---|---|---|---|---|
| 7 | 1.365 | 1.155 | 2.92 | 0.42 |
| 13 | 1.36 | 1.145 | 1.165 | 1.28 |
| 20 | 1.375 | 1.15 | 1.17 | 1.27 |
| 26 | 1.38 | 1.15 | 1.19 | 1.315 |
| 40 | 1.385 | 1.14 | 1.17 | 1.27 |
| 52 | 1.37 | 1.15 | 1.16 | 1.265 |
| 65 | 1.415 | 1.145 | 1.15 | 1.245 |
| 78 | 1.385 | 1.14 | 1.3 | 1.73 |
| 90 | 1.395 | 1.14 | 1.205 | 1.35 |
| 105 | 1.365 | 1.15 | 1.21 | 1.33 |
| 130 | 1.395 | 1.14 | 1.17 | 1.27 |

**Table 27 SCF/SNCF ratios for specimen T7 under axial tension**



# SNCFs Grouted Specimens

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MSL

**Key:**

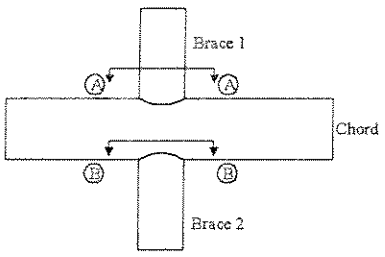
| | |
|---|---|
| pl. cap | Plastic Capacity (%) |
| design | ISO Design Load Level |
| BS | Brace Saddle |
| BC | Brace Crown |
| CS | Chord Saddle |
| CC | Chord Crown |
| br1 | Brace 1 |
| br2 | Brace 2 |

**Example:** .

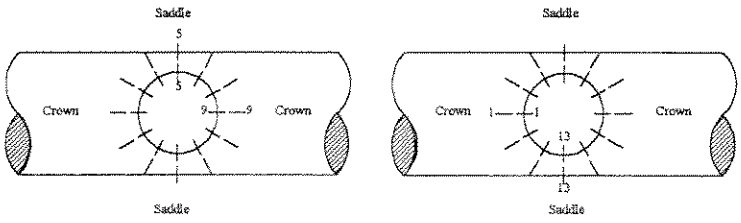
For the test setup shown below, brace 1 has strain gauges located at positions 5 and 9 on both the chord and the brace. Note that the brace gauge positions are shown inside the brace and the chord gauges are shown on the outside. Similarly on the second brace, they are located at positions 1 and 13.

Key to Tables :-

BC9;br1: Brace Crown position 9 on brace 1.




Elevation on DT Joint




View 'A' on brace 1 View 'B' on brace 2

## SNCFs grouted Test Specimen: DT2.

| DT2 | pl. cap | design | BC;1,br2 | BS;5,br1 | BC;9,br1 | BS;13,br2 | CC;1,br2 | CS;5,br1 | CC;9,br1 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0277 | -0.0506 | 2.33 | -0.16 | -1.7 | -0.11 | 3.41 | -0.26 | -3.2 | -0.19 |
| ipb 2/3 | -0.0541 | -0.0985 | 2.5 | -0.19 | -1.62 | -0.15 | 2.55 | -0.23 | -2.9 | -0.24 |
| ipb 3/3 | -0.0801 | -0.1459 | 2.43 | -0.2 | -1.58 | -0.18 | 2.16 | -0.25 | -2.74 | -0.29 |
| ipb 3/3 | -0.0805 | -0.1468 | 2.44 | -0.21 | -1.6 | -0.17 | 2.19 | -0.24 | -2.77 | -0.29 |
| ipb 2/3 | -0.0547 | -0.0996 | 2.58 | -0.2 | -1.68 | -0.13 | 2.67 | -0.22 | -3.03 | -0.22 |
| ipb 1/3 | -0.0273 | -0.0498 | 2.44 | -0.26 | -1.79 | 0 | 3.72 | -0.24 | -3.41 | -0.05 |
| opb 1/3 | -0.0139 | -0.0475 | 0.02 | -4.7 | -0.04 | 4.26 | 0.05 | -5.61 | 0.11 | 7.61 |
| opb 2/3 | -0.0284 | -0.0975 | 0.01 | -4.03 | -0.04 | 3.55 | -0.06 | -4.88 | 0.01 | 5.81 |
| opb 3/3 | -0.0435 | -0.149 | -0.01 | -3.57 | -0.03 | 2.95 | -0.1 | -4.25 | -0.08 | 4.29 |
| opb 3/3 | -0.0438 | -0.15 | -0.02 | -3.56 | 0 | 2.96 | -0.1 | -4.25 | -0.07 | 4.3 |
| opb 2/3 | -0.0287 | -0.0985 | 0 | -4.02 | 0.05 | 3.58 | 0 | -4.77 | 0.03 | 5.86 |
| opb 1/3 | -0.014 | -0.0481 | 0.08 | -4.71 | 0.11 | 4.27 | -0.02 | -5.63 | 0.16 | 7.85 |
| axi-c 1/3 | -0.0105 | -0.0546 | 0.6 | 6.69 | 1.72 | 5.26 | 2.51 | 7.77 | 4.34 | 9.21 |
| axi-c 2/3 | -0.0209 | -0.1089 | 1.62 | 4.23 | 1.4 | 3.63 | 3.27 | 5.36 | 3.19 | 6.86 |
| axi-c 3/3 | -0.0317 | -0.1651 | 1.68 | 3.24 | 1.39 | 2.61 | 2.6 | 4.28 | 2.34 | 5.11 |
| axi-c 3/3 | -0.0317 | -0.1651 | 1.68 | 3.24 | 1.39 | 2.61 | 2.6 | 4.28 | 2.34 | 5.11 |
| axi-c 2/3 | -0.0209 | -0.109 | 1.73 | 4.39 | 1.26 | 3.54 | 3.41 | 5.63 | 3.08 | 6.72 |
| axi-c 1/3 | -0.0106 | -0.0549 | 1.22 | 6.97 | 1.24 | 5.2 | 3.48 | 8.06 | 3.53 | 9.11 |
| axi-t 1/3 | 0.0107 | 0.0444 | 0.6 | 7.06 | 0.78 | 4.17 | 1.52 | 8.19 | 2.36 | 7.01 |
| axi-t 2/3 | 0.0212 | 0.0883 | 0.71 | 5.14 | 0.8 | 3.49 | 1.54 | 5.97 | 2.05 | 5.81 |
| axi-t 3/3 | 0.0317 | 0.1322 | 0.77 | 4.43 | 0.82 | 3.04 | 1.56 | 5.16 | 1.98 | 5.05 |
| axi-t 3/3 | 0.0317 | 0.1322 | 0.75 | 4.45 | 0.82 | 3.04 | 1.54 | 5.19 | 1.99 | 5.05 |
| axi-t 2/3 | 0.0211 | 0.0878 | 0.73 | 5.23 | 0.75 | 3.55 | 1.53 | 6.04 | 2 | 5.84 |
| axi-t 1/3 | 0.0106 | 0.0443 | 0.63 | 7.17 | 0.62 | 4.35 | 1.84 | 8.21 | 2.09 | 7.21 |

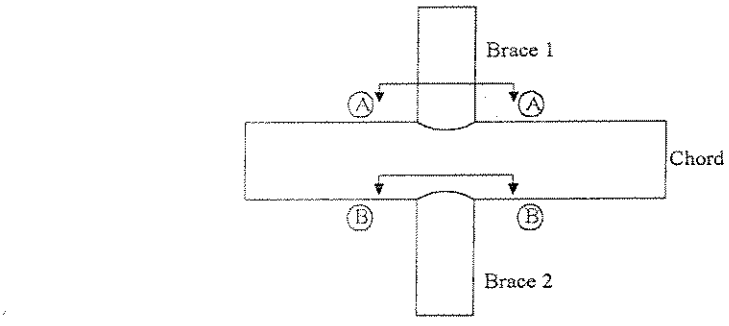
**Table 1: Measured SNCFs on intersections of brace 1,2 and chord for DT2 before preloading**

| DT2 | pl. cap | design | BC;1,br2 | BS;5,br1 | BC;9,br1 | BS;13,br2 | CC;1,br2 | CS;5,br1 | CC;9,br1 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0273 | -0.0498 | 2.39 | -0.22 | -1.72 | -0.08 | 3.44 | -0.25 | -3.21 | -0.07 |
| ipb 2/3 | -0.0524 | -0.0955 | 2.54 | -0.23 | -1.63 | -0.12 | 2.57 | -0.27 | -2.98 | -0.17 |
| ipb 3/3 | -0.0524 | -0.0955 | 2.54 | -0.23 | -1.63 | -0.12 | 2.57 | -0.27 | -2.98 | -0.17 |
| ipb 3/3 | -0.0799 | -0.1456 | 2.52 | -0.2 | -1.62 | -0.11 | 2.18 | -0.26 | -2.79 | -0.2 |
| ipb 2/3 | -0.0533 | -0.0971 | 2.63 | -0.24 | -1.71 | -0.08 | 2.65 | -0.26 | -3.05 | -0.12 |
| ipb 1/3 | -0.027 | -0.0493 | 2.43 | -0.22 | -1.8 | 0.06 | 3.69 | -0.35 | -3.4 | 0.04 |
| opb 1/3 | -0.0142 | -0.0486 | 0.07 | -4.81 | -0.01 | 4.28 | 0 | -5.66 | 0.13 | 7.72 |
| opb 2/3 | -0.029 | -0.0995 | 0.01 | -4.09 | 0.01 | 3.67 | -0.05 | -4.79 | 0.02 | 5.97 |
| opb 3/3 | -0.0439 | -0.1504 | -0.03 | -3.64 | -0.01 | 3.07 | -0.12 | -4.31 | -0.07 | 4.48 |
| opb 3/3 | -0.044 | -0.1506 | -0.02 | -3.66 | 0 | 3.07 | -0.11 | -4.4 | -0.09 | 4.51 |
| opb 2/3 | -0.029 | -0.0993 | 0 | -4.12 | 0.03 | 3.71 | 0 | -4.96 | 0.01 | 6.07 |
| opb 1/3 | -0.0143 | -0.0491 | 0.08 | -4.8 | 0.08 | 4.31 | 0.05 | -5.9 | 0.07 | 7.83 |
| axi-c 1/3 | -0.0105 | -0.0547 | 0.11 | 6.22 | 2.25 | 6.24 | 1.45 | 7.2 | 5.36 | 10.75 |
| axi-c 2/3 | -0.021 | -0.1092 | 1.37 | 4.45 | 1.81 | 3.88 | 2.97 | 5.54 | 3.93 | 7.45 |
| axi-c 3/3 | -0.0317 | -0.1651 | 1.66 | 3.48 | 1.67 | 2.76 | 2.49 | 4.61 | 2.94 | 5.55 |
| axi-c 3/3 | -0.0317 | -0.1651 | 1.66 | 3.48 | 1.67 | 2.76 | 2.49 | 4.56 | 2.95 | 5.56 |
| axi-c 2/3 | -0.0209 | -0.1089 | 1.6 | 4.64 | 1.58 | 3.84 | 3.27 | 5.74 | 3.8 | 7.35 |
| axi-c 1/3 | -0.0105 | -0.0545 | 0.74 | 6.99 | 1.48 | 5.82 | 2.55 | 7.93 | 4.1 | 10.13 |
| axi-t 1/3 | 0.0107 | 0.0444 | 0.65 | 5.29 | 0.45 | 5.28 | 1.57 | 6.15 | 1.78 | 8.96 |
| axi-t 2/3 | 0.0211 | 0.0881 | 0.68 | 4.54 | 0.64 | 4.08 | 1.48 | 5.23 | 1.95 | 6.68 |
| axi-t 3/3 | 0.0319 | 0.1328 | 0.72 | 4.09 | 0.75 | 3.4 | 1.46 | 4.77 | 1.91 | 5.59 |
| axi-t 3/3 | 0.0318 | 0.1326 | 0.66 | 4.14 | 0.78 | 3.39 | 1.43 | 4.83 | 1.92 | 5.48 |
| axi-t 2/3 | 0.0212 | 0.0883 | 0.64 | 4.62 | 0.71 | 4.06 | 1.51 | 5.38 | 1.89 | 6.58 |
| axi-t 1/3 | 0.0106 | 0.0443 | 0.62 | 5.78 | 0.45 | 5.43 | 1.6 | 6.71 | 1.94 | 8.88 |

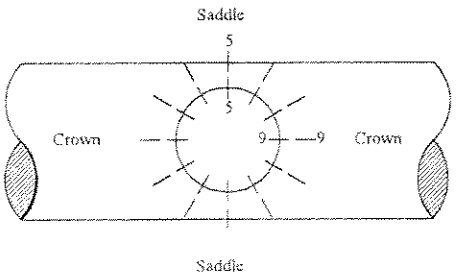
Table 2: Measured SNCFs on intersections of brace 1,2 and chord for DT2 after preload level of 50 %

| DT2 | pi. cap | design | BC;1,br2 | BS;5,br1 | BC;9,br1 | BS;13,br2 | CC;1,br2 | CS;5,br1 | CC;9,br1 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0265 | -0.0483 | 1.79 | 0.1 | -1.76 | 0.34 | 3.49 | 0.12 | -3.42 | 0.54 |
| ipb 2/3 | -0.0541 | -0.0985 | 2.21 | 0 | -1.7 | 0.14 | 3.13 | -0.02 | -3.09 | 0.19 |
| ipb 3/3 | -0.0801 | -0.146 | 2.37 | -0.04 | -1.64 | 0.05 | 2.57 | -0.05 | -2.89 | 0.03 |
| ipb 3/3 | -0.0802 | -0.1461 | 2.38 | -0.05 | -1.63 | 0.05 | 2.55 | -0.06 | -2.86 | 0.03 |
| ipb 2/3 | -0.0541 | -0.0986 | 2.3 | 0.02 | -1.7 | 0.15 | 3.19 | 0.02 | -3.11 | 0.22 |
| ipb 1/3 | -0.0282 | -0.0514 | 1.95 | 0.2 | -1.84 | 0.33 | 3.69 | 0.2 | -3.51 | 0.53 |
| opb 1/3 | -0.0134 | -0.046 | -0.01 | -4.4 | -0.06 | 4.32 | -0.02 | -5.48 | 0.12 | 8.41 |
| opb 2/3 | -0.0291 | -0.0998 | -0.02 | -3.93 | -0.04 | 3.94 | 0.01 | -4.82 | 0.06 | 6.63 |
| opb 3/3 | -0.0434 | -0.1489 | -0.04 | -3.59 | -0.03 | 3.29 | -0.07 | -4.27 | -0.02 | 5.05 |
| opb 3/3 | -0.0438 | -0.1501 | -0.04 | -3.6 | -0.02 | 3.36 | -0.07 | -4.24 | -0.04 | 5.14 |
| opb 2/3 | -0.0286 | -0.0981 | -0.02 | -4 | -0.02 | 4.13 | 0.03 | -4.8 | 0.08 | 6.99 |
| opb 1/3 | -0.0135 | -0.0461 | -0.01 | -4.27 | -0.01 | 4.61 | 0.07 | -5.16 | 0.07 | 8.48 |
| axi-c 1/3 | -0.0105 | -0.0545 | -0.28 | 7.86 | 1.23 | 7.33 | 1.24 | 9.12 | 3.75 | 12.93 |
| axi-c 2/3 | -0.0209 | -0.1088 | 1.09 | 6.4 | 1.25 | 4.85 | 3.06 | 7.54 | 3.56 | 8.92 |
| axi-c 3/3 | -0.0318 | -0.1652 | 1.49 | 5.07 | 1.35 | 3.29 | 3.06 | 6.31 | 3.14 | 6.51 |
| axi-c 3/3 | -0.0318 | -0.1652 | 1.52 | 5.05 | 1.35 | 3.32 | 3.06 | 6.27 | 3.18 | 6.53 |
| axi-c 2/3 | -0.0209 | -0.109 | 1.24 | 6.5 | 1.14 | 4.87 | 3.29 | 7.73 | 3.49 | 8.93 |
| axi-c 1/3 | -0.0105 | -0.0545 | 0.22 | 8.72 | 0.69 | 6.86 | 2.21 | 10.14 | 2.88 | 12.11 |
| axi-t 1/3 | 0.0111 | 0.0463 | 0.61 | 5.58 | 0.62 | 3.34 | 1.38 | 6.46 | 1.82 | 5.73 |
| axi-t 2/3 | 0.0214 | 0.089 | 0.7 | 4.78 | 0.7 | 2.81 | 1.4 | 5.48 | 1.78 | 4.78 |
| axi-t 3/3 | 0.032 | 0.1334 | 0.78 | 4.24 | 0.79 | 2.54 | 1.42 | 4.89 | 1.79 | 4.33 |
| axi-t 3/3 | 0.032 | 0.1334 | 0.76 | 4.21 | 0.79 | 2.6 | 1.37 | 4.86 | 1.79 | 4.31 |
| axi-t 2/3 | 0.0212 | 0.0884 | 0.72 | 4.78 | 0.62 | 2.92 | 1.46 | 5.49 | 1.64 | 4.74 |
| axi-t 1/3 | 0.0107 | 0.0448 | 0.92 | 5.92 | 0.38 | 3.52 | 1.76 | 6.78 | 1.31 | 5.64 |

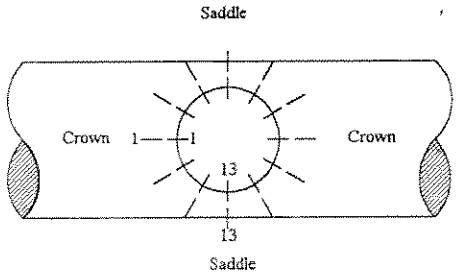
**Table 3: Measured SNCFs on intersections of brace 1,2 and chord for DT2 after preload level of 100%**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

SNCFs grouted Test Specimen: DT3.

| DT3 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0274 | -0.041 | 2.61 | 1.51 | 1.6 | 0.31 | -1.3 | -1.55 | -1.28 | -0.05 |
| ipb 2/3 | -0.055 | -0.0822 | 2.62 | 1.45 | 1.28 | 0.19 | -1.2 | -1.5 | -1.12 | -0.06 |
| ipb 3/3 | -0.0813 | -0.1216 | 2.51 | 1.45 | 1.11 | 0.12 | -1.19 | -1.45 | -1.02 | -0.06 |
| ipb 3/3 | -0.0813 | -0.1216 | 2.51 | 1.45 | 1.11 | 0.12 | -1.19 | -1.46 | -1.01 | -0.06 |
| ipb 2/3 | -0.0549 | -0.0821 | 2.67 | 1.47 | 1.31 | 0.18 | -1.23 | -1.52 | -1.14 | -0.06 |
| ipb 1/3 | -0.027 | -0.0405 | 2.71 | 1.6 | 1.7 | 0.31 | -1.31 | -1.67 | -1.31 | -0.06 |
| opb 1/3 | -0.0229 | -0.0482 | 0.02 | -0.42 | -1.24 | -2.27 | -0.02 | 0.41 | 0.93 | 1.96 |
| opb 2/3 | -0.0475 | -0.0999 | 0.03 | -0.4 | -1.17 | -2.16 | -0.04 | 0.37 | 0.9 | 1.92 |
| opb 3/3 | -0.0728 | -0.153 | 0.02 | -0.39 | -1.12 | -2.06 | -0.04 | 0.36 | 0.82 | 1.79 |
| opb 3/3 | -0.0729 | -0.1531 | 0.02 | -0.38 | -1.12 | -2.06 | -0.02 | 0.35 | 0.82 | 1.79 |
| opb 2/3 | -0.0479 | -0.1006 | 0.03 | -0.39 | -1.19 | -2.14 | 0 | 0.38 | 0.93 | 1.96 |
| opb 1/3 | -0.0235 | -0.0494 | 0.05 | -0.37 | -1.25 | -2.26 | 0.02 | 0.39 | 0.95 | 1.98 |
| axi-c 1/3 | -0.0146 | -0.0372 | 1.05 | 1.49 | 3.13 | 4.31 | 0.54 | 0.72 | 1.66 | 2.93 |
| axi-c 2/3 | -0.0291 | -0.0742 | 1.07 | 1.49 | 3.39 | 4.43 | 0.45 | 0.64 | 1.35 | 2.8 |
| axi-c 3/3 | -0.0436 | -0.1111 | 1.05 | 1.41 | 3.14 | 4.22 | 0.53 | 0.58 | 1.15 | 2.49 |
| axi-c 3/3 | -0.0436 | -0.1111 | 1.05 | 1.41 | 3.12 | 4.22 | 0.53 | 0.58 | 1.15 | 2.49 |
| axi-c 2/3 | -0.0291 | -0.0742 | 1.1 | 1.61 | 3.44 | 4.45 | 0.42 | 0.61 | 1.36 | 2.83 |
| axi-c 1/3 | -0.0146 | -0.0371 | 1.2 | 1.71 | 3.57 | 4.49 | 0.39 | 0.57 | 1.4 | 2.86 |
| axi-t 1/3 | 0.0144 | 0.0482 | 0.94 | 1.35 | 2.41 | 3.49 | 0.71 | 0.93 | 1.59 | 2.58 |
| axi-t 2/3 | 0.0286 | 0.0962 | 1.02 | 1.29 | 2.1 | 2.87 | 0.64 | 0.86 | 1.43 | 2.1 |
| axi-t 3/3 | 0.0428 | 0.1436 | 1.05 | 1.32 | 1.91 | 2.45 | 0.63 | 0.83 | 1.31 | 1.79 |
| axi-t 3/3 | 0.0428 | 0.1436 | 1.05 | 1.31 | 1.89 | 2.44 | 0.63 | 0.81 | 1.31 | 1.77 |
| axi-t 2/3 | 0.0286 | 0.0959 | 1.02 | 1.32 | 2.12 | 2.92 | 0.62 | 0.82 | 1.47 | 2.14 |
| axi-t 1/3 | 0.0143 | 0.0479 | 0.94 | 1.27 | 2.34 | 3.44 | 0.63 | 0.89 | 1.64 | 2.7 |

**Table 4: Measured SNCFs on brace of intersections of brace and chord for DT3**

| DT3 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0274 | -0.041 | 2.18 | 1.92 | 1.41 | 0.28 | -2.07 | -2.35 | -1.76 | -0.17 |
| ipb 2/3 | -0.055 | -0.0822 | 1.7 | 1.62 | 1.16 | 0.1 | -1.84 | -2.17 | -1.54 | -0.18 |
| ipb 3/3 | -0.0813 | -0.1216 | 1.52 | 1.42 | 1.02 | 0.01 | -1.75 | -2.08 | -1.43 | -0.21 |
| ipb 3/3 | -0.0813 | -0.1216 | 1.52 | 1.43 | 1 | 0.01 | -1.75 | -2.07 | -1.43 | -0.22 |
| ipb 2/3 | -0.0549 | -0.0821 | 1.76 | 1.69 | 1.17 | 0.1 | -1.88 | -2.22 | -1.57 | -0.19 |
| ipb 1/3 | -0.027 | -0.0405 | 2.35 | 2.05 | 1.48 | 0.22 | -2.21 | -2.5 | -1.81 | -0.15 |
| opb 1/3 | -0.0229 | -0.0482 | 0.13 | -0.17 | -0.93 | -2.45 | 0 | 0.22 | 1.15 | 2.7 |
| opb 2/3 | -0.0475 | -0.0999 | 0.14 | -0.14 | -0.86 | -2.42 | -0.04 | 0.19 | 1.08 | 2.65 |
| opb 3/3 | -0.0728 | -0.153 | 0.12 | -0.15 | -0.84 | -2.38 | -0.07 | 0.17 | 1 | 2.59 |
| opb 3/3 | -0.0729 | -0.1531 | 0.1 | -0.15 | -0.83 | -2.39 | -0.08 | 0.17 | 1.01 | 2.61 |
| opb 2/3 | -0.0479 | -0.1006 | 0.11 | -0.14 | -0.86 | -2.42 | -0.07 | 0.2 | 1.1 | 2.72 |
| opb 1/3 | -0.0235 | -0.0494 | 0.15 | -0.13 | -0.89 | -2.46 | 0.03 | 0.26 | 1.13 | 2.82 |
| axi-c 1/3 | -0.0146 | -0.0372 | 1.09 | 1.15 | 2.46 | 3.95 | 0.5 | 0.63 | 1.83 | 3.21 |
| axi-c 2/3 | -0.0291 | -0.0742 | 1.31 | 1.35 | 2.58 | 3.99 | 0.47 | 0.6 | 1.61 | 2.87 |
| axi-c 3/3 | -0.0436 | -0.1111 | 1.43 | 1.44 | 2.38 | 3.87 | 0.62 | 0.68 | 1.44 | 2.67 |
| axi-c 3/3 | -0.0436 | -0.1111 | 1.43 | 1.48 | 2.38 | 3.87 | 0.62 | 0.72 | 1.48 | 2.67 |
| axi-c 2/3 | -0.0291 | -0.0742 | 1.42 | 1.51 | 2.64 | 3.97 | 0.36 | 0.54 | 1.62 | 2.9 |
| axi-c 1/3 | -0.0146 | -0.0371 | 1.52 | 1.61 | 2.8 | 4.01 | 0.25 | 0.51 | 1.69 | 3.03 |
| axi-t 1/3 | 0.0144 | 0.0482 | 0.76 | 0.86 | 1.67 | 3.45 | 0.83 | 1.14 | 2.27 | 2.97 |
| axi-t 2/3 | 0.0286 | 0.0962 | 0.83 | 1 | 1.54 | 3.19 | 0.88 | 1.11 | 2.11 | 3.02 |
| axi-t 3/3 | 0.0428 | 0.1436 | 0.94 | 1.14 | 1.53 | 3.22 | 0.92 | 1.14 | 1.99 | 2.97 |
| axi-t 3/3 | 0.0428 | 0.1436 | 0.94 | 1.14 | 1.52 | 3.18 | 0.92 | 1.14 | 1.97 | 2.98 |
| axi-t 2/3 | 0.0286 | 0.0959 | 0.83 | 1.01 | 1.64 | 3.14 | 0.89 | 1.13 | 2.1 | 3.04 |
| axi-t 1/3 | 0.0143 | 0.0479 | 0.69 | 0.87 | 1.71 | 3.2 | 0.82 | 1.15 | 2.33 | 3.06 |

**Table 5: Measured SNCFs on chord of intersections of brace and chord for DT3**



MSL

| DT3 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0272 | -0.0407 | 2.91 | 1.39 | 1.28 | -0.14 | -1.28 | -1.57 | -1.3 | -0.24 |
| ipb 2/3 | -0.0534 | -0.0799 | 2.78 | 1.36 | 1.06 | -0.13 | -1.22 | -1.51 | -1.13 | -0.17 |
| ipb 3/3 | -0.081 | -0.1213 | 2.62 | 1.38 | 0.93 | -0.11 | -1.21 | -1.46 | -1.02 | -0.15 |
| ipb 3/3 | -0.0811 | -0.1213 | 2.61 | 1.37 | 0.94 | -0.12 | -1.21 | -1.46 | -1.02 | -0.15 |
| ipb 2/3 | -0.0548 | -0.082 | 2.79 | 1.36 | 1.08 | -0.14 | -1.24 | -1.52 | -1.15 | -0.19 |
| ipb 1/3 | -0.0273 | -0.0409 | 2.99 | 1.48 | 1.32 | -0.19 | -1.34 | -1.63 | -1.37 | -0.25 |
| opb 1/3 | -0.0232 | -0.0487 | 0.06 | -0.35 | -1.28 | -2.33 | 0.01 | 0.35 | 0.82 | 1.94 |
| opb 2/3 | -0.0476 | -0.1001 | 0.05 | -0.36 | -1.25 | -2.3 | -0.03 | 0.34 | 0.85 | 1.88 |
| opb 3/3 | -0.0724 | -0.1521 | 0.03 | -0.36 | -1.18 | -2.17 | -0.03 | 0.33 | 0.84 | 1.88 |
| opb 3/3 | -0.0733 | -0.1541 | 0.04 | -0.38 | -1.2 | -2.19 | -0.05 | 0.33 | 0.85 | 1.89 |
| opb 2/3 | -0.0486 | -0.1021 | 0.04 | -0.38 | -1.21 | -2.21 | -0.06 | 0.34 | 0.91 | 2.02 |
| opb 1/3 | -0.0243 | -0.051 | 0.04 | -0.34 | -1.09 | -1.84 | -0.15 | 0.17 | 0.83 | 2.02 |
| axi-c 1/3 | -0.0146 | -0.0373 | 0.46 | 0.79 | 2.33 | 4.38 | 1.2 | 1.53 | 2.34 | 3.08 |
| axi-c 2/3 | -0.0291 | -0.0743 | 0.56 | 0.93 | 2.53 | 4.13 | 0.99 | 1.23 | 1.95 | 2.97 |
| axi-c 3/3 | -0.0436 | -0.1112 | 0.65 | 0.94 | 2.39 | 3.78 | 1.13 | 1.12 | 1.65 | 2.69 |
| axi-c 3/3 | -0.0436 | -0.1112 | 0.65 | 0.94 | 2.37 | 3.79 | 1.11 | 1.12 | 1.65 | 2.69 |
| axi-c 2/3 | -0.0291 | -0.0742 | 0.6 | 0.94 | 2.54 | 4.16 | 0.99 | 1.25 | 1.96 | 3 |
| axi-c 1/3 | -0.0146 | -0.0373 | 0.46 | 0.87 | 2.31 | 4.38 | 1.12 | 1.45 | 2.28 | 3.03 |
| axi-t 1/3 | 0.0147 | 0.0492 | 0.68 | 1.16 | 2.84 | 4.33 | 0.67 | 0.98 | 1.68 | 2.48 |
| axi-t 2/3 | 0.0288 | 0.0968 | 0.81 | 1.14 | 2.62 | 3.91 | 0.7 | 0.95 | 1.62 | 2.62 |
| axi-t 3/3 | 0.0431 | 0.1448 | 0.88 | 1.18 | 2.33 | 3.31 | 0.7 | 0.89 | 1.47 | 2.23 |
| axi-t 3/3 | 0.0431 | 0.1447 | 0.88 | 1.21 | 2.36 | 3.34 | 0.72 | 0.89 | 1.47 | 2.25 |
| axi-t 2/3 | 0.0288 | 0.0966 | 0.81 | 1.19 | 2.66 | 3.99 | 0.72 | 0.95 | 1.67 | 2.68 |
| axi-t 1/3 | 0.0146 | 0.0489 | 0.68 | 1.24 | 2.94 | 4.4 | 0.77 | 0.94 | 1.65 | 2.43 |

**Table 6: Measured SNCFs on brace of intersections of brace and chord for DT3 at preload level of 50%**

| DT3 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0272 | -0.0407 | 2.01 | 1.74 | 1.05 | -0.11 | -2.11 | -2.39 | -1.73 | -0.18 |
| ipb 2/3 | -0.0534 | -0.0799 | 1.62 | 1.49 | 0.91 | -0.13 | -1.9 | -2.21 | -1.52 | -0.15 |
| ipb 3/3 | -0.081 | -0.1213 | 1.44 | 1.31 | 0.81 | -0.17 | -1.77 | -2.08 | -1.39 | -0.17 |
| ipb 3/3 | -0.0811 | -0.1213 | 1.44 | 1.32 | 0.83 | -0.17 | -1.77 | -2.09 | -1.38 | -0.19 |
| ipb 2/3 | -0.0548 | -0.082 | 1.64 | 1.5 | 0.92 | -0.14 | -1.89 | -2.23 | -1.52 | -0.17 |
| ipb 1/3 | -0.0273 | -0.0409 | 2.13 | 1.82 | 1.17 | -0.14 | -2.2 | -2.54 | -1.79 | -0.23 |
| opb 1/3 | -0.0232 | -0.0487 | 0.18 | -0.16 | -0.9 | -2.55 | -0.05 | 0.15 | 1.05 | 2.58 |
| opb 2/3 | -0.0476 | -0.1001 | 0.13 | -0.13 | -0.9 | -2.54 | -0.08 | 0.15 | 1.02 | 2.53 |
| opb 3/3 | -0.0724 | -0.1521 | 0.12 | -0.15 | -0.83 | -2.39 | -0.07 | 0.17 | 1.06 | 2.59 |
| opb 3/3 | -0.0733 | -0.1541 | 0.11 | -0.14 | -0.84 | -2.43 | -0.08 | 0.17 | 1.05 | 2.62 |
| opb 2/3 | -0.0486 | -0.1021 | 0.13 | -0.13 | -0.83 | -2.39 | -0.09 | 0.18 | 1.12 | 2.73 |
| opb 1/3 | -0.0243 | -0.051 | 0.17 | -0.08 | -0.65 | -1.92 | -0.31 | 0.02 | 1.11 | 2.79 |
| axi-c 1/3 | -0.0146 | -0.0373 | -0.03 | 0.34 | 1.71 | 3.89 | 1.74 | 1.91 | 3.07 | 3.24 |
| axi-c 2/3 | -0.0291 | -0.0743 | 0.51 | 0.68 | 1.74 | 3.69 | 1.54 | 1.58 | 2.57 | 3.18 |
| axi-c 3/3 | -0.0436 | -0.1112 | 0.83 | 0.89 | 1.73 | 3.48 | 1.59 | 1.47 | 2.18 | 2.95 |
| axi-c 3/3 | -0.0436 | -0.1112 | 0.83 | 0.85 | 1.76 | 3.48 | 1.58 | 1.46 | 2.18 | 2.95 |
| axi-c 2/3 | -0.0291 | -0.0742 | 0.56 | 0.65 | 1.85 | 3.75 | 1.55 | 1.57 | 2.55 | 3.16 |
| axi-c 1/3 | -0.0146 | -0.0373 | 0.06 | 0.34 | 1.71 | 3.96 | 1.64 | 1.77 | 3.07 | 3.28 |
| axi-t 1/3 | 0.0147 | 0.0492 | 0.5 | 0.82 | 2.19 | 4.03 | 0.95 | 1.07 | 2.15 | 2.57 |
| axi-t 2/3 | 0.0288 | 0.0968 | 0.66 | 0.86 | 2.09 | 3.75 | 0.87 | 1.06 | 2.19 | 3.08 |
| axi-t 3/3 | 0.0431 | 0.1448 | 0.8 | 1 | 1.88 | 3.77 | 0.89 | 1.1 | 2.11 | 3.13 |
| axi-t 3/3 | 0.0431 | 0.1447 | 0.81 | 1.01 | 1.82 | 3.75 | 0.89 | 1.1 | 2.08 | 3.13 |
| axi-t 2/3 | 0.0288 | 0.0966 | 0.68 | 0.88 | 2 | 3.7 | 0.82 | 1.03 | 2.19 | 3.03 |
| axi-t 1/3 | 0.0146 | 0.0489 | 0.54 | 0.72 | 2.01 | 3.82 | 0.96 | 1.05 | 2.09 | 2.44 |

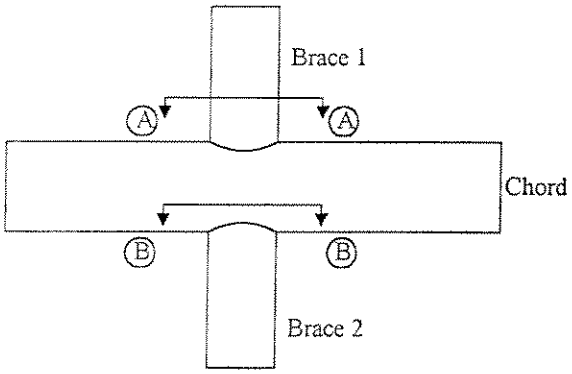
**Table 7: Measured SNCFs on chord of intersections of brace and chord for DT3 at preload level of 50%**

| DT3 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0287 | -0.0429 | 3.1 | 1.51 | 1.35 | -0.06 | -1.23 | -1.59 | -1.34 | -0.21 |
| ipb 2/3 | -0.0548 | -0.0819 | 2.87 | 1.43 | 1.12 | -0.12 | -1.22 | -1.51 | -1.15 | -0.18 |
| ipb 3/3 | -0.0819 | -0.1226 | 2.71 | 1.45 | 1.01 | -0.12 | -1.23 | -1.48 | -1.06 | -0.18 |
| ipb 3/3 | -0.0814 | -0.1218 | 2.72 | 1.46 | 1.01 | -0.14 | -1.24 | -1.48 | -1.06 | -0.19 |
| ipb 2/3 | -0.0549 | -0.0822 | 2.94 | 1.47 | 1.16 | -0.14 | -1.25 | -1.55 | -1.18 | -0.22 |
| ipb 1/3 | -0.0272 | -0.0407 | 3.21 | 1.57 | 1.44 | -0.16 | -1.27 | -1.61 | -1.38 | -0.23 |
| opb 1/3 | -0.0234 | -0.0491 | 0.11 | -0.4 | -1.25 | -2.2 | -0.02 | 0.38 | 0.95 | 2.05 |
| opb 2/3 | -0.0477 | -0.1002 | 0.07 | -0.39 | -1.28 | -2.23 | -0.01 | 0.38 | 0.95 | 2.05 |
| opb 3/3 | -0.072 | -0.1513 | 0.05 | -0.39 | -1.24 | -2.21 | -0.02 | 0.36 | 0.91 | 1.96 |
| opb 3/3 | -0.0722 | -0.1518 | 0.04 | -0.4 | -1.23 | -2.22 | -0.02 | 0.37 | 0.91 | 1.98 |
| opb 2/3 | -0.0479 | -0.1006 | 0.06 | -0.4 | -1.26 | -2.28 | 0 | 0.4 | 0.97 | 2.07 |
| opb 1/3 | -0.0236 | -0.0496 | 0.09 | -0.4 | -1.27 | -2.29 | -0.02 | 0.39 | 0.97 | 2.13 |
| axi-c 1/3 | -0.0146 | -0.0371 | 0.87 | 1.46 | 3.28 | 4.68 | 0.64 | 0.88 | 1.58 | 2.91 |
| axi-c 2/3 | -0.0291 | -0.0741 | 1.19 | 1.55 | 3.3 | 4.52 | 0.71 | 0.79 | 1.41 | 2.7 |
| axi-c 3/3 | -0.0436 | -0.1112 | 1.58 | 1.43 | 2.99 | 4.18 | 0.83 | 0.67 | 1.2 | 2.42 |
| axi-c 3/3 | -0.0436 | -0.1112 | 1.58 | 1.43 | 2.96 | 4.18 | 0.83 | 0.67 | 1.2 | 2.42 |
| axi-c 2/3 | -0.0291 | -0.0742 | 1.32 | 1.68 | 3.41 | 4.63 | 0.6 | 0.7 | 1.34 | 2.66 |
| axi-c 1/3 | -0.0145 | -0.0371 | 1.17 | 1.63 | 3.57 | 4.77 | 0.42 | 0.65 | 1.35 | 2.91 |
| axi-t 1/3 | 0.0147 | 0.0493 | 1.16 | 1.56 | 3.21 | 4.14 | 0.42 | 0.76 | 1.43 | 2.91 |
| axi-t 2/3 | 0.029 | 0.0972 | 1.08 | 1.35 | 3.02 | 3.89 | 0.55 | 0.81 | 1.55 | 3.03 |
| axi-t 3/3 | 0.0432 | 0.1449 | 1.04 | 1.34 | 2.66 | 3.43 | 0.58 | 0.85 | 1.52 | 2.79 |
| axi-t 3/3 | 0.0432 | 0.1451 | 1.04 | 1.34 | 2.68 | 3.4 | 0.57 | 0.84 | 1.49 | 2.8 |
| axi-t 2/3 | 0.0289 | 0.0971 | 1.09 | 1.47 | 3.07 | 3.88 | 0.5 | 0.79 | 1.55 | 3.13 |
| axi-t 1/3 | 0.0146 | 0.0492 | 1.17 | 1.59 | 3.37 | 4.08 | 0.36 | 0.59 | 1.19 | 2.82 |

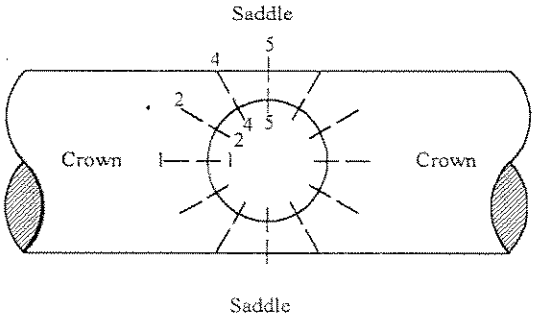
**Table 8: Measured SNCFs on brace of intersections of brace and chord for DT3 at preload level of 100 %**

| DT3 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0287 | -0.0429 | 2.16 | 1.86 | 1.19 | -0.08 | -1.97 | -2.42 | -1.85 | -0.11 |
| ipb 2/3 | -0.0548 | -0.0819 | 1.73 | 1.59 | 1.02 | -0.08 | -1.85 | -2.24 | -1.57 | -0.13 |
| ipb 3/3 | -0.0819 | -0.1226 | 1.52 | 1.39 | 0.9 | -0.11 | -1.76 | -2.11 | -1.42 | -0.17 |
| ipb 3/3 | -0.0814 | -0.1218 | 1.53 | 1.41 | 0.91 | -0.1 | -1.77 | -2.14 | -1.43 | -0.18 |
| ipb 2/3 | -0.0549 | -0.0822 | 1.78 | 1.68 | 1.03 | -0.08 | -1.9 | -2.31 | -1.63 | -0.17 |
| ipb 1/3 | -0.0272 | -0.0407 | 2.33 | 2.08 | 1.24 | -0.04 | -2.05 | -2.53 | -1.96 | -0.14 |
| opb 1/3 | -0.0234 | -0.0491 | 0.17 | -0.16 | -0.97 | -2.46 | -0.03 | 0.22 | 1.22 | 2.79 |
| opb 2/3 | -0.0477 | -0.1002 | 0.15 | -0.15 | -0.9 | -2.47 | -0.03 | 0.26 | 1.18 | 2.8 |
| opb 3/3 | -0.072 | -0.1513 | 0.13 | -0.16 | -0.89 | -2.49 | -0.04 | 0.21 | 1.14 | 2.75 |
| opb 3/3 | -0.0722 | -0.1518 | 0.12 | -0.13 | -0.88 | -2.48 | -0.02 | 0.22 | 1.12 | 2.76 |
| opb 2/3 | -0.0479 | -0.1006 | 0.15 | -0.12 | -0.9 | -2.5 | 0.03 | 0.28 | 1.17 | 2.81 |
| opb 1/3 | -0.0236 | -0.0496 | 0.21 | -0.08 | -0.94 | -2.45 | 0.03 | 0.29 | 1.19 | 2.85 |
| axi-c 1/3 | -0.0146 | -0.0371 | 1.04 | 1.29 | 2.65 | 4.31 | 0.65 | 0.79 | 2.06 | 3.18 |
| axi-c 2/3 | -0.0291 | -0.0741 | 1.47 | 1.44 | 2.58 | 4.21 | 0.73 | 0.66 | 1.71 | 2.93 |
| axi-c 3/3 | -0.0436 | -0.1112 | 1.57 | 1.42 | 2.33 | 3.97 | 0.84 | 0.67 | 1.54 | 2.71 |
| axi-c 3/3 | -0.0436 | -0.1112 | 1.54 | 1.45 | 2.33 | 3.93 | 0.84 | 0.67 | 1.52 | 2.69 |
| axi-c 2/3 | -0.0291 | -0.0742 | 1.67 | 1.58 | 2.69 | 4.29 | 0.52 | 0.56 | 1.62 | 2.9 |
| axi-c 1/3 | -0.0145 | -0.0371 | 1.27 | 1.77 | 3.02 | 4.42 | 0.18 | 0.34 | 1.69 | 3.06 |
| axi-t 1/3 | 0.0147 | 0.0493 | 1.24 | 1.43 | 2.56 | 3.73 | 0.13 | 0.52 | 1.67 | 3.12 |
| axi-t 2/3 | 0.029 | 0.0972 | 1.16 | 1.31 | 2.42 | 3.51 | 0.41 | 0.7 | 1.9 | 3.4 |
| axi-t 3/3 | 0.0432 | 0.1449 | 1.07 | 1.21 | 2.18 | 3.39 | 0.62 | 0.86 | 2.07 | 3.69 |
| axi-t 3/3 | 0.0432 | 0.1451 | 1.09 | 1.24 | 2.17 | 3.36 | 0.66 | 0.87 | 2.05 | 3.68 |
| axi-t 2/3 | 0.0289 | 0.0971 | 1.21 | 1.39 | 2.46 | 3.62 | 0.43 | 0.69 | 1.88 | 3.38 |
| axi-t 1/3 | 0.0146 | 0.0492 | 1.43 | 1.6 | 2.71 | 3.78 | 0.14 | 0.39 | 1.5 | 3.01 |

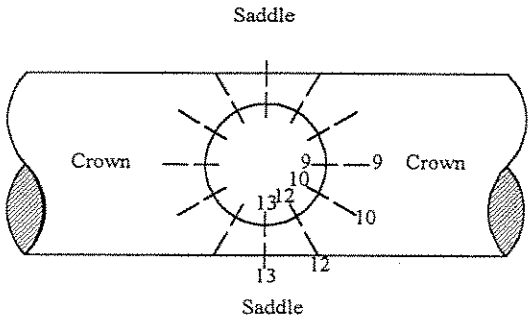
**Table 9: Measured SNCFs on chord of intersections of brace and chord for DT3 at preload level of 100 %**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

| DT4 | pl. cap | design | BC;1,br1 | BS;5,br1 | BC;9,br1 | BS;13,br1 | CC;1,br1 | CS;5,br1 | CC;9,br1 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0312 | -0.0543 | 3.39 | -0.4 | -2.06 | -0.66 | 2.16 | -0.84 | -3.76 | -1.56 |
| ipb 2/3 | -0.0603 | -0.1049 | 3.29 | -0.39 | -2.09 | -0.62 | 1.94 | -0.83 | -3.68 | -1.46 |
| ipb 3/3 | -0.0895 | -0.1557 | 3.18 | -0.37 | -2.07 | -0.56 | 1.82 | -0.8 | -3.61 | -1.4 |
| ipb 3/3 | -0.0917 | -0.1596 | 3.15 | -0.38 | -2.04 | -0.56 | 1.78 | -0.82 | -3.56 | -1.37 |
| ipb 2/3 | -0.0637 | -0.1108 | 3.34 | -0.41 | -2.12 | -0.61 | 1.99 | -0.85 | -3.74 | -1.44 |
| ipb 1/3 | -0.0325 | -0.0566 | 3.57 | -0.44 | -2.21 | -0.69 | 2.36 | -0.92 | -4 | -1.52 |
| opb 1/3 | -0.0106 | -0.037 | -0.14 | -4.34 | -0.18 | 3.39 | -0.27 | -8.45 | -0.47 | 7.4 |
| opb 2/3 | -0.0239 | -0.0836 | -0.17 | -3.64 | -0.2 | 3.03 | -0.35 | -7.11 | -0.57 | 4.79 |
| opb 3/3 | -0.0366 | -0.1281 | -0.2 | -3.4 | -0.26 | 3.01 | -0.41 | -6.7 | -0.6 | 3.86 |
| opb 3/3 | -0.0379 | -0.1326 | -0.21 | -3.34 | -0.21 | 2.95 | -0.36 | -6.64 | -0.58 | 3.79 |
| opb 2/3 | -0.0238 | -0.0834 | -0.23 | -3.82 | -0.15 | 3.2 | -0.3 | -7.54 | -0.56 | 5.09 |
| opb 1/3 | -0.0111 | -0.0388 | -0.1 | -4.52 | 0.05 | 3.42 | -0.16 | -8.96 | -0.33 | 7.65 |
| axi-c 1/3 | -0.0123 | -0.069 | -0.79 | 2.93 | 4.45 | 1.61 | -0.25 | 5.91 | 9.69 | 5.43 |
| axi-c 2/3 | -0.0238 | -0.1341 | -0.18 | 2.05 | 3.59 | 1.4 | 0.72 | 3.73 | 6.54 | 4.43 |
| axi-c 3/3 | -0.0357 | -0.2009 | 0.05 | 1.58 | 3.29 | 1.55 | 0.89 | 2.77 | 4.96 | 3.8 |
| axi-c 3/3 | -0.0357 | -0.2009 | 0.05 | 1.6 | 3.29 | 1.55 | 0.89 | 2.79 | 4.92 | 3.85 |
| axi-c 2/3 | -0.024 | -0.1347 | -0.15 | 1.92 | 3.64 | 1.59 | 0.67 | 3.7 | 6.45 | 4.83 |
| axi-c 1/3 | -0.0121 | -0.068 | -1.03 | 2.46 | 4.87 | 2.02 | -0.4 | 5.48 | 10.62 | 6.79 |
| axi-t 1/3 | 0.0127 | 0.0642 | -0.28 | 0.03 | 2.23 | 6.35 | -0.07 | 0.16 | 5.49 | 15.79 |
| axi-t 2/3 | 0.0243 | 0.1234 | 0.57 | 1.88 | 1.33 | 4.87 | 1.13 | 3.29 | 3.89 | 12 |
| axi-t 3/3 | 0.0361 | 0.1831 | 0.69 | 2.45 | 1.29 | 4 | 1.23 | 4.56 | 3.49 | 9.93 |
| axi-t 3/3 | 0.036 | 0.1828 | 0.69 | 2.52 | 1.28 | 3.98 | 1.23 | 4.56 | 3.5 | 9.81 |
| axi-t 2/3 | 0.0241 | 0.1221 | 0.57 | 1.88 | 1.41 | 4.95 | 1.1 | 3.21 | 3.94 | 12.13 |
| axi-t 1/3 | 0.0121 | 0.0615 | 0.3 | 0.1 | 1.73 | 6.75 | 0.9 | 0.43 | 4.91 | 16.58 |

**Table 10: Measured SNCFs on intersections of brace 1 and chord for DT4**

| DT4 | pl. cap | design | BC;1,br2 | BS;5,br2 | BC;9,br2 | BS;13,br2 | CC;1,br2 | CS;5,br2 | CC;9,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0312 | -0.0543 | 4.13 | -0.2 | -2.33 | -0.73 | 1.66 | -0.68 | -2.84 | -1.23 |
| ipb 2/3 | -0.0603 | -0.1049 | 4.1 | -0.24 | -2.41 | -0.7 | 1.54 | -0.67 | -2.79 | -1.18 |
| ipb 3/3 | -0.0895 | -0.1557 | 4.02 | -0.23 | -2.44 | -0.68 | 1.46 | -0.66 | -2.81 | -1.17 |
| ipb 3/3 | -0.0917 | -0.1596 | 3.97 | -0.23 | -2.4 | -0.65 | 1.42 | -0.65 | -2.76 | -1.15 |
| ipb 2/3 | -0.0637 | -0.1108 | 4.15 | -0.24 | -2.45 | -0.7 | 1.55 | -0.66 | -2.87 | -1.2 |
| ipb 1/3 | -0.0325 | -0.0566 | 4.32 | -0.28 | -2.5 | -0.7 | 1.82 | -0.63 | -2.99 | -1.28 |
| opb 1/3 | -0.0106 | -0.037 | -0.32 | -2.35 | 0.06 | 4.95 | 0.01 | -7.84 | 0.22 | 7.2 |
| opb 2/3 | -0.0239 | -0.0836 | -0.28 | -2.18 | 0.07 | 4.38 | -0.29 | -6.5 | -0.01 | 5 |
| opb 3/3 | -0.0366 | -0.1281 | -0.31 | -1.98 | 0.02 | 4.18 | -0.29 | -6.13 | -0.14 | 3.89 |
| opb 3/3 | -0.0379 | -0.1326 | -0.28 | -1.99 | 0.03 | 4.13 | -0.28 | -6.09 | -0.14 | 4 |
| opb 2/3 | -0.0238 | -0.0834 | -0.24 | -2.13 | 0.14 | 4.51 | -0.21 | -6.77 | 0.01 | 5.45 |
| opb 1/3 | -0.0111 | -0.0388 | -0.18 | -2.49 | 0.17 | 4.78 | 0.05 | -7.7 | 0.27 | 7.55 |
| axi-c 1/3 | -0.0123 | -0.069 | -2.88 | 3.39 | 8.4 | 1.63 | -2.8 | 8.8 | 9.6 | 3.17 |
| axi-c 2/3 | -0.0238 | -0.1341 | -0.72 | 2.02 | 6.03 | 1.91 | -0.18 | 5.27 | 5.7 | 3.76 |
| axi-c 3/3 | -0.0357 | -0.2009 | -0.02 | 1.51 | 4.89 | 2.1 | 0.67 | 3.72 | 4.06 | 3.71 |
| axi-c 3/3 | -0.0357 | -0.2009 | 0.02 | 1.53 | 4.84 | 2.07 | 0.61 | 3.75 | 4.12 | 3.72 |
| axi-c 2/3 | -0.024 | -0.1347 | -0.83 | 2.11 | 6.14 | 1.99 | -0.23 | 5.21 | 5.83 | 4.01 |
| axi-c 1/3 | -0.0121 | -0.068 | -3.35 | 3.35 | 9.43 | 1.68 | -3.51 | 8.94 | 10.78 | 3.55 |
| axi-t 1/3 | 0.0127 | 0.0642 | 0.06 | 1.73 | 2.2 | 5.88 | 0.38 | 5.08 | 4.13 | 9.73 |
| axi-t 2/3 | 0.0243 | 0.1234 | 0.99 | 1.86 | 1.41 | 5.47 | 1.26 | 5.22 | 2.95 | 9.01 |
| axi-t 3/3 | 0.0361 | 0.1831 | 1.08 | 1.81 | 1.37 | 5.05 | 1.43 | 4.92 | 2.65 | 8.32 |
| axi-t 3/3 | 0.036 | 0.1828 | 1.01 | 1.72 | 1.45 | 4.99 | 1.33 | 4.89 | 2.68 | 8.32 |
| axi-t 2/3 | 0.0241 | 0.1221 | 0.95 | 1.69 | 1.48 | 5.79 | 1.23 | 4.75 | 3.05 | 9.63 |
| axi-t 1/3 | 0.0121 | 0.0615 | 0.52 | 1.51 | 1.8 | 6.78 | 0.96 | 4.62 | 3.78 | 11.39 |

**Table 11: Measured SNCFs on intersections of brace 2 and chord for DT4**

| DT4 | pl. cap | design | BC;1,br1 | BS;5,br1 | BC;9,br1 | BS;13,br1 | CC;1,br1 | CS;5,br1 | CC;9,br1 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0286 | -0.0498 | 3.29 | -0.36 | -1.96 | -0.57 | 2.13 | -0.78 | -3.64 | -1.41 |
| ipb 2/3 | -0.0545 | -0.0948 | 3.29 | -0.41 | -2.07 | -0.55 | 1.95 | -0.83 | -3.66 | -1.35 |
| ipb 3/3 | -0.0801 | -0.1394 | 3.22 | -0.44 | -2.07 | -0.52 | 1.83 | -0.88 | -3.6 | -1.26 |
| ipb 3/3 | -0.0818 | -0.1422 | 3.25 | -0.4 | -2.08 | -0.57 | 1.88 | -0.83 | -3.65 | -1.35 |
| ipb 2/3 | -0.0563 | -0.0979 | 3.39 | -0.37 | -2.12 | -0.62 | 2.09 | -0.82 | -3.82 | -1.44 |
| ipb 1/3 | -0.0298 | -0.0519 | 3.54 | -0.28 | -2.19 | -0.74 | 2.51 | -0.66 | -4.05 | -1.74 |
| opb 1/3 | -0.0111 | -0.039 | -0.06 | -3.75 | -0.13 | 3.26 | -0.17 | -7.63 | -0.38 | 7.01 |
| opb 2/3 | -0.024 | -0.0839 | -0.15 | -3.58 | -0.21 | 3.25 | -0.29 | -7.07 | -0.53 | 4.85 |
| opb 3/3 | -0.0342 | -0.1197 | -0.17 | -3.5 | -0.2 | 3.22 | -0.35 | -6.91 | -0.57 | 4.04 |
| opb 3/3 | -0.0347 | -0.1216 | -0.2 | -3.56 | -0.18 | 3.25 | -0.38 | -7.05 | -0.54 | 4.2 |
| opb 2/3 | -0.0241 | -0.0844 | -0.2 | -3.93 | -0.2 | 3.54 | -0.36 | -7.83 | -0.51 | 5.33 |
| opb 1/3 | -0.0106 | -0.037 | -0.16 | -4.49 | -0.09 | 3.86 | -0.31 | -9.21 | -0.24 | 8.42 |
| axi-c 1/3 | -0.0119 | -0.0669 | -2.76 | 9.22 | 6.2 | -2.45 | -4.06 | 12.64 | 11.32 | -6.18 |
| axi-c 2/3 | -0.0239 | -0.1344 | -1.09 | 5.2 | 4.64 | -0.37 | -1.19 | 6.86 | 7.72 | -0.38 |
| axi-c 3/3 | -0.0358 | -0.2015 | -0.48 | 3.15 | 4.28 | 0.45 | -0.05 | 4.52 | 6.05 | 2.14 |
| axi-c 3/3 | -0.0358 | -0.2015 | -0.48 | 3.18 | 4.41 | 0.49 | 0.06 | 4.53 | 6.37 | 2.18 |
| axi-c 2/3 | -0.0238 | -0.1341 | -0.97 | 4.83 | 4.79 | -0.01 | -0.75 | 6.65 | 8.3 | 0.54 |
| axi-c 1/3 | -0.012 | -0.0674 | -3.03 | 9.49 | 6.75 | -2.33 | -3.89 | 12.93 | 12.7 | -5.89 |
| axi-t 1/3 | 0.0123 | 0.0624 | 0.92 | 1.91 | 1.02 | 5.37 | 1.73 | 2.77 | 3.4 | 13.2 |
| axi-t 2/3 | 0.0245 | 0.1246 | 0.89 | 2.73 | 1.01 | 4.36 | 1.66 | 4.78 | 3.06 | 10.65 |
| axi-t 3/3 | 0.036 | 0.1828 | 0.7 | 2.95 | 1.17 | 3.89 | 1.34 | 5.38 | 3.14 | 9.37 |
| axi-t 3/3 | 0.0361 | 0.1831 | 0.66 | 3.02 | 1.17 | 3.82 | 1.32 | 5.43 | 3.1 | 9.2 |
| axi-t 2/3 | 0.0247 | 0.1252 | 0.86 | 2.94 | 0.98 | 4.31 | 1.6 | 5.15 | 3.02 | 10.4 |
| axi-t 1/3 | 0.0124 | 0.0627 | 1.14 | 2.08 | 0.74 | 5.53 | 2.27 | 3.12 | 2.65 | 13.35 |

**Table 12: Measured SNCFs on intersections of brace 1 and chord for DT4 at preload level of 50%**

| DT4 | pl. cap | design | BC;1,br2 | BS;5,br2 | BC;9,br2 | BS;13,br2 | CC;1,br2 | CS;5,br2 | CC;9,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0286 | -0.0498 | 4.08 | -0.28 | -2.3 | -0.6 | 1.7 | -0.67 | -2.78 | -1.02 |
| ipb 2/3 | -0.0545 | -0.0948 | 4.21 | -0.3 | -2.45 | -0.63 | 1.58 | -0.75 | -2.87 | -1.04 |
| ipb 3/3 | -0.0801 | -0.1394 | 4.14 | -0.3 | -2.46 | -0.58 | 1.46 | -0.78 | -2.83 | -1 |
| ipb 3/3 | -0.0818 | -0.1422 | 4.17 | -0.29 | -2.48 | -0.61 | 1.5 | -0.75 | -2.86 | -1.06 |
| ipb 2/3 | -0.0563 | -0.0979 | 4.36 | -0.24 | -2.53 | -0.66 | 1.69 | -0.75 | -2.97 | -1.14 |
| ipb 1/3 | -0.0298 | -0.0519 | 4.58 | -0.29 | -2.62 | -0.74 | 2.02 | -0.61 | -3.14 | -1.29 |
| opb 1/3 | -0.0111 | -0.039 | -0.2 | -2.41 | 0.09 | 4.59 | -0.1 | -6.96 | 0.01 | 6.81 |
| opb 2/3 | -0.024 | -0.0839 | -0.28 | -2.07 | 0.02 | 4.62 | -0.26 | -6.52 | -0.02 | 5.2 |
| opb 3/3 | -0.0342 | -0.1197 | -0.28 | -2.08 | 0.02 | 4.52 | -0.34 | -6.36 | -0.1 | 4.24 |
| opb 3/3 | -0.0347 | -0.1216 | -0.27 | -2.15 | 0.03 | 4.55 | -0.34 | -6.47 | -0.07 | 4.42 |
| opb 2/3 | -0.0241 | -0.0844 | -0.32 | -2.32 | 0.09 | 4.79 | -0.27 | -6.99 | 0.02 | 5.64 |
| opb 1/3 | -0.0106 | -0.037 | -0.21 | -2.61 | 0.17 | 5.01 | -0.1 | -8.06 | 0.1 | 8.08 |
| axi-c 1/3 | -0.0119 | -0.0669 | -4.04 | 7.87 | 5.79 | -4.24 | -4.6 | 13.51 | 7.53 | -7.5 |
| axi-c 2/3 | -0.0239 | -0.1344 | -1.54 | 4.48 | 4.59 | -1.03 | -1.5 | 7.41 | 5.1 | -1.61 |
| axi-c 3/3 | -0.0358 | -0.2015 | -0.57 | 2.7 | 4.68 | 0.69 | -0.06 | 4.85 | 4.22 | 1.51 |
| axi-c 3/3 | -0.0358 | -0.2015 | -0.67 | 2.7 | 4.76 | 0.68 | -0.17 | 4.81 | 4.34 | 1.56 |
| axi-c 2/3 | -0.0238 | -0.1341 | -1.64 | 4.04 | 4.98 | -0.42 | -1.44 | 7.01 | 5.64 | -0.36 |
| axi-c 1/3 | -0.012 | -0.0674 | -4.73 | 7.3 | 6.87 | -3.79 | -5.19 | 13.5 | 8.89 | -6.33 |
| axi-t 1/3 | 0.0123 | 0.0624 | 0.48 | 2.02 | 1.67 | 5.77 | 0.89 | 5.22 | 3.53 | 9.61 |
| axi-t 2/3 | 0.0245 | 0.1246 | 0.94 | 1.73 | 1.23 | 5.39 | 1.38 | 4.84 | 2.73 | 9.03 |
| axi-t 3/3 | 0.036 | 0.1828 | 0.9 | 1.62 | 1.39 | 5.26 | 1.3 | 4.33 | 2.66 | 8.77 |
| axi-t 3/3 | 0.0361 | 0.1831 | 0.85 | 1.73 | 1.43 | 5.21 | 1.28 | 4.39 | 2.66 | 8.64 |
| axi-t 2/3 | 0.0247 | 0.1252 | 0.86 | 1.84 | 1.33 | 5.75 | 1.37 | 4.41 | 2.73 | 9.44 |
| axi-t 1/3 | 0.0124 | 0.0627 | 0.79 | 1.9 | 1.35 | 6.62 | 1.52 | 4.38 | 3.1 | 11.09 |

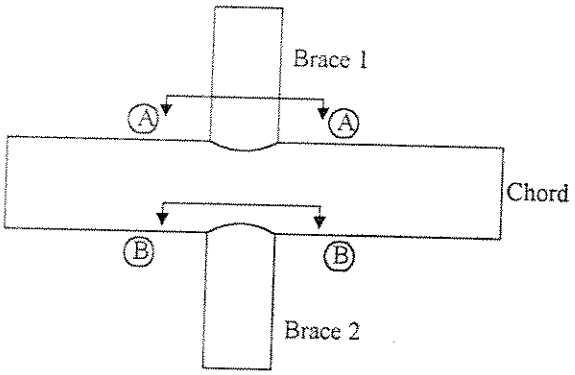
**Table 13: Measured SNCFs on intersections of brace 2 and chord for DT4 at preload level of 50%**

| DT4 | pl. cap | design | BC;1,br1 | BS;5,br1 | BC;9,br1 | BS;13,br1 | CC;1,br1 | CS;5,br1 | CC;9,br1 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0274 | -0.0477 | 2.81 | -0.28 | -1.63 | -0.58 | 1.85 | -0.44 | -3.12 | -1.33 |
| ipb 2.3 | -0.0578 | -0.1006 | 3.16 | -0.33 | -1.95 | -0.54 | 1.83 | -0.65 | -3.44 | -1.27 |
| ipb 3/3 | -0.0844 | -0.1468 | 3.13 | -0.36 | -1.97 | -0.5 | 1.72 | -0.7 | -3.44 | -1.21 |
| ipb 3/3 | -0.0811 | -0.1411 | 3.31 | -0.35 | -2.08 | -0.54 | 1.81 | -0.71 | -3.63 | -1.33 |
| ipb 2/3 | -0.055 | -0.0956 | 3.43 | -0.32 | -2.12 | -0.6 | 2.03 | -0.67 | -3.77 | -1.43 |
| ipb 1/3 | -0.0274 | -0.0477 | 3.53 | -0.25 | -2.18 | -0.71 | 2.47 | -0.49 | -4.02 | -1.74 |
| opb 1/3 | -0.0115 | -0.0404 | -0.25 | -4.04 | -0.09 | 3.51 | -0.35 | -8.19 | -0.46 | 7.68 |
| opb 2/3 | -0.0233 | -0.0815 | -0.24 | -3.73 | -0.15 | 3.4 | -0.38 | -7.44 | -0.53 | 5.5 |
| opb 3/3 | -0.0348 | -0.1218 | -0.22 | -3.58 | -0.17 | 3.31 | -0.41 | -7.08 | -0.52 | 4.41 |
| opb 3/3 | -0.0348 | -0.1218 | -0.21 | -3.56 | -0.19 | 3.28 | -0.39 | -7.06 | -0.52 | 4.33 |
| opb 2/3 | -0.0243 | -0.0852 | -0.24 | -3.76 | -0.19 | 3.47 | -0.35 | -7.62 | -0.54 | 5.42 |
| opb 1/3 | -0.0113 | -0.0395 | -0.22 | -4.39 | -0.13 | 3.73 | -0.32 | -8.83 | -0.35 | 8.07 |
| axi-c 1/3 | -0.012 | -0.0673 | -1.84 | 8.38 | 5.56 | -1.6 | -2.43 | 14.04 | 10.81 | -4.05 |
| axi-c 2/3 | -0.0239 | -0.1344 | -0.62 | 4.69 | 4.31 | 0.01 | -0.28 | 7.55 | 7.68 | 0.83 |
| axi-c 3/3 | -0.0357 | -0.2007 | -0.04 | 3.39 | 3.88 | 0.46 | 0.59 | 5.4 | 5.96 | 2.14 |
| axi-c 3/3 | -0.0357 | -0.2006 | -0.07 | 3.39 | 3.88 | 0.46 | 0.59 | 5.33 | 6.25 | 2.18 |
| axi-c 2/3 | -0.0238 | -0.1337 | -0.57 | 4.94 | 4.03 | -0.04 | -0.12 | 7.73 | 7.85 | 0.64 |
| axi-c 1/3 | -0.0119 | -0.0667 | -2.03 | 9.52 | 5.38 | -2.27 | -2.41 | 14.97 | 11.28 | -5.59 |
| axi-t 1/3 | 0.0127 | 0.0645 | 1.02 | 1.09 | 1.19 | 7.41 | 2.09 | 1.82 | 4.04 | 17.93 |
| axi-t 2/3 | 0.0248 | 0.1258 | 0.81 | 1.34 | 1.49 | 6.67 | 1.53 | 2.55 | 4.15 | 16.13 |
| axi-t 3/3 | 0.0364 | 0.1846 | 0.76 | 2.07 | 1.55 | 5.7 | 1.45 | 3.83 | 3.99 | 13.75 |
| axi-t 3/3 | 0.0364 | 0.1846 | 0.79 | 2.08 | 1.57 | 5.7 | 1.45 | 3.83 | 4.03 | 13.76 |
| axi-t 2/3 | 0.0248 | 0.1261 | 0.83 | 1.26 | 1.54 | 6.75 | 1.53 | 2.48 | 4.3 | 16.41 |
| axi-t 1/3 | 0.0128 | 0.0651 | 1.05 | -0.34 | 1.47 | 8.66 | 1.92 | 0.59 | 4.62 | 21.11 |

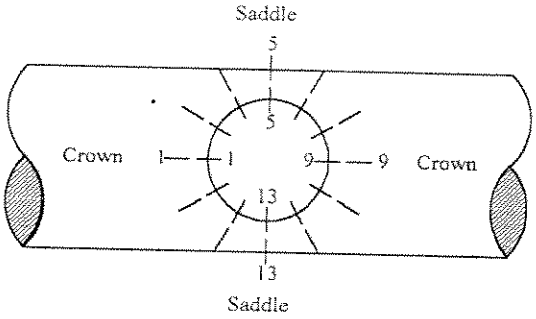
**Table 14: Measured SNCFs on intersections of brace 1 and chord for DT4 at preload level of 100 %**

| DT4 | pl. cap | design | BC;1,br2 | BS;5,br2 | BC;9,br2 | BS;13,br2 | CC;1,br2 | CS;5,br2 | CC;9,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0274 | -0.0477 | 3.64 | -0.17 | -2.04 | -0.53 | 1.55 | -0.56 | -2.48 | -0.91 |
| ipb 2/3 | -0.0578 | -0.1006 | 4.05 | -0.23 | -2.33 | -0.58 | 1.51 | -0.68 | -2.75 | -0.96 |
| ipb 3/3 | -0.0844 | -0.1468 | 4.04 | -0.28 | -2.37 | -0.57 | 1.4 | -0.69 | -2.74 | -0.98 |
| ipb 3/3 | -0.0811 | -0.1411 | 4.27 | -0.3 | -2.5 | -0.6 | 1.47 | -0.72 | -2.9 | -1.05 |
| ipb 2/3 | -0.055 | -0.0956 | 4.45 | -0.31 | -2.54 | -0.62 | 1.65 | -0.73 | -3.02 | -1.06 |
| ipb 1/3 | -0.0274 | -0.0477 | 4.62 | -0.31 | -2.62 | -0.62 | 2.04 | -0.72 | -3.21 | -1.15 |
| opb 1/3 | -0.0115 | -0.0404 | -0.28 | -2.13 | 0 | 4.61 | -0.04 | -7.05 | 0.04 | 6.74 |
| opb 2/3 | -0.0233 | -0.0815 | -0.27 | -2.23 | -0.01 | 4.66 | -0.23 | -6.59 | -0.08 | 5.26 |
| opb 3/3 | -0.0348 | -0.1218 | -0.23 | -2.12 | -0.05 | 4.55 | -0.28 | -6.33 | -0.14 | 4.15 |
| opb 3/3 | -0.0348 | -0.1218 | -0.23 | -2.12 | -0.08 | 4.53 | -0.28 | -6.34 | -0.14 | 4.16 |
| opb 2/3 | -0.0243 | -0.0852 | -0.25 | -2.15 | -0.05 | 4.68 | -0.22 | -6.67 | -0.08 | 5.21 |
| opb 1/3 | -0.0113 | -0.0395 | -0.29 | -2.19 | -0.11 | 4.98 | -0.02 | -7.61 | 0.11 | 7.35 |
| axi-c 1/3 | -0.012 | -0.0673 | -3.29 | 7.63 | 5.22 | -4.18 | -3.17 | 16.3 | 7.43 | -7.31 |
| axi-c 2/3 | -0.0239 | -0.1344 | -1.06 | 4.13 | 4.11 | -0.83 | -0.57 | 8.6 | 5.09 | -1.16 |
| axi-c 3/3 | -0.0357 | -0.2007 | -0.15 | 2.91 | 3.87 | 0.3 | 0.56 | 5.97 | 4.15 | 0.93 |
| axi-c 3/3 | -0.0357 | -0.2006 | -0.24 | 2.92 | 4 | 0.34 | 0.42 | 5.93 | 4.3 | 0.95 |
| axi-c 2/3 | -0.0238 | -0.1337 | -1.14 | 4.37 | 4.1 | -0.83 | -0.67 | 8.67 | 5.23 | -1.25 |
| axi-c 1/3 | -0.0119 | -0.0667 | -3.9 | 8.23 | 5.66 | -4.58 | -3.87 | 17.04 | 8.11 | -8.22 |
| axi-t 1/3 | 0.0127 | 0.0645 | 0.7 | 2.05 | 1.95 | 8.02 | 1.51 | 5.09 | 4.19 | 13.27 |
| axi-t 2/3 | 0.0248 | 0.1258 | 1.01 | 1.53 | 1.79 | 7.77 | 1.63 | 4.1 | 3.51 | 12.8 |
| axi-t 3/3 | 0.0364 | 0.1846 | 1.03 | 1.53 | 1.79 | 7.1 | 1.63 | 4.19 | 3.29 | 11.63 |
| axi-t 3/3 | 0.0364 | 0.1846 | 1 | 1.52 | 1.86 | 7.14 | 1.53 | 4.12 | 3.33 | 11.65 |
| axi-t 2/3 | 0.0248 | 0.1261 | 0.87 | 1.28 | 2.01 | 8.12 | 1.41 | 3.63 | 3.7 | 13.39 |
| axi-t 1/3 | 0.0128 | 0.0651 | 0.75 | 1.16 | 2.11 | 9.52 | 1.39 | 3.02 | 4.2 | 15.89 |

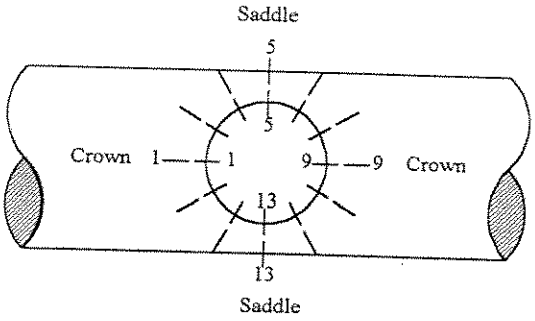
**Table 15: Measured SNCFs on intersections of brace 2 and chord for DT4 at preload level of 100 %**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

## SNCFs grouted Test Specimen: DT5.

| DT5 | pl. cap | design | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0486 | -0.0732 | 3.2 | -0.21 | -1.94 | -0.39 | 3.79 | -1.11 | -3.67 | -0.57 |
| ipb 2/3 | -0.0971 | -0.1462 | 3.01 | -0.25 | -1.86 | -0.35 | 2.64 | -0.97 | -3.35 | -0.57 |
| ipb 3/3 | -0.1425 | -0.2146 | 2.76 | -0.25 | -1.82 | -0.33 | 2.29 | -0.91 | -3.19 | -0.54 |
| ipb 3/3 | -0.1426 | -0.2147 | 2.77 | -0.25 | -1.82 | -0.32 | 2.3 | -0.92 | -3.19 | -0.52 |
| ipb 2/3 | -0.0978 | -0.1472 | 3.05 | -0.25 | -1.9 | -0.35 | 2.69 | -0.96 | -3.42 | -0.53 |
| ipb 1/3 | -0.0486 | -0.0733 | 3.34 | -0.22 | -2.04 | -0.38 | 3.98 | -1.16 | -3.82 | -0.55 |
| opb 1/3 | -0.0176 | -0.0571 | 0.01 | -6.29 | -0.1 | 6.06 | 5.91 | -15.39 | -0.25 | 8.88 |
| opb 2/3 | -0.0376 | -0.1215 | -0.03 | -4.82 | -0.07 | 4.25 | 3.93 | -11.37 | -0.49 | 4.78 |
| opb 3/3 | -0.0569 | -0.184 | -0.02 | -4.28 | -0.05 | 3.43 | 3.17 | -9.86 | -0.5 | 3.54 |
| opb 3/3 | -0.0578 | -0.187 | -0.03 | -4.35 | -0.06 | 3.52 | 3.27 | -9.95 | -0.5 | 3.81 |
| opb 2/3 | -0.0383 | -0.1239 | -0.03 | -4.92 | -0.09 | 4.33 | 4.06 | -11.3 | -0.43 | 5.17 |
| opb 1/3 | -0.0185 | -0.0598 | -0.02 | -6.2 | -0.12 | 6.39 | 5.82 | -14.91 | -0.19 | 9.56 |
| axi-c 1/3 | -0.0115 | -0.0617 | 1.31 | 7.65 | 3.74 | 7.86 | -0.36 | 16.97 | 8.4 | 12.15 |
| axi-c 2/3 | -0.0232 | -0.1241 | 1.16 | 4.53 | 3 | 5.24 | 1.06 | 10.58 | 5.41 | 8.45 |
| axi-c 3/3 | -0.0348 | -0.1861 | 1.15 | 3.27 | 2.38 | 3.83 | 1.59 | 7.67 | 3.84 | 6.39 |
| axi-c 3/3 | -0.0348 | -0.1861 | 1.14 | 3.29 | 2.38 | 3.79 | 1.69 | 7.57 | 3.85 | 6.42 |
| axi-c 2/3 | -0.0231 | -0.1234 | 1.24 | 4.61 | 2.78 | 5.24 | 1.66 | 10.5 | 5.35 | 8.56 |
| axi-c 1/3 | -0.0116 | -0.062 | 1.22 | 8.53 | 4.01 | 7.03 | -1 | 18.63 | 9.02 | 10.88 |
| axi-t 1/3 | 0.012 | 0.0513 | 0.93 | 8.16 | 1.45 | 5.06 | -3.19 | 17.34 | 4.34 | 8.03 |
| axi-t 2/3 | 0.0235 | 0.1006 | 0.76 | 6.13 | 1.11 | 4.63 | -1.45 | 12.41 | 3.34 | 6.97 |
| axi-t 3/3 | 0.0348 | 0.1492 | 0.75 | 5.15 | 1 | 4.08 | -0.65 | 10.45 | 2.97 | 6.23 |
| axi-t 3/3 | 0.0347 | 0.1488 | 0.71 | 5.22 | 1.02 | 3.99 | -0.73 | 10.72 | 2.98 | 6.11 |
| axi-t 2/3 | 0.0234 | 0.1003 | 0.61 | 6.11 | 1.22 | 4.71 | -1.77 | 12.73 | 3.25 | 7.08 |
| axi-t 1/3 | 0.012 | 0.0513 | 0.41 | 7.8 | 1.37 | 6.03 | -3.4 | 16.82 | 4.15 | 9.08 |

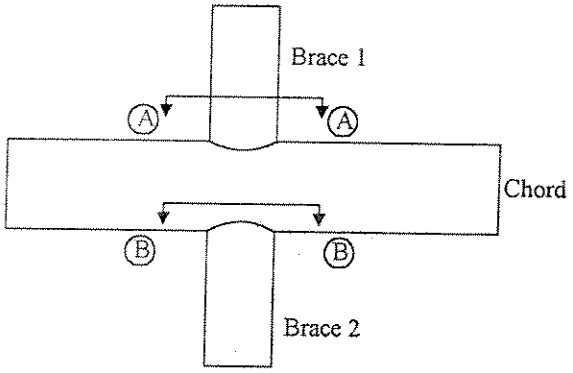
**Table 16: Measured SNCFs on intersections of brace 1,2 and chord for DT5**

| DT5 | pl. cap | design | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0467 | -0.0703 | 3.06 | -0.14 | -1.89 | -0.48 | 3.94 | -0.91 | -3.68 | -0.87 |
| ipb 2/3 | -0.0952 | -0.1434 | 2.98 | -0.18 | -1.85 | -0.49 | 2.65 | -0.76 | -3.41 | -0.83 |
| ipb 3/3 | -0.1414 | -0.2129 | 2.76 | -0.2 | -1.81 | -0.43 | 2.27 | -0.78 | -3.21 | -0.74 |
| ipb 3/3 | -0.1412 | -0.2127 | 2.79 | -0.2 | -1.82 | -0.45 | 2.29 | -0.8 | -3.23 | -0.73 |
| ipb 2/3 | -0.0941 | -0.1417 | 3.06 | -0.19 | -1.9 | -0.51 | 2.73 | -0.85 | -3.47 | -0.81 |
| ipb 1/3 | -0.0467 | -0.0703 | 3.23 | -0.14 | -1.99 | -0.57 | 4.18 | -1.05 | -3.9 | -0.9 |
| opb 1/3 | -0.0169 | -0.0547 | -0.1 | -6.59 | -0.07 | 6.75 | 6.32 | -16.07 | -0.17 | 10 |
| opb 2/3 | -0.0368 | -0.1189 | -0.07 | -5.01 | -0.08 | 4.63 | 4.18 | -11.82 | -0.39 | 5.21 |
| opb 3/3 | -0.0563 | -0.1822 | -0.04 | -4.44 | -0.05 | 3.56 | 3.34 | -10.19 | -0.47 | 3.71 |
| opb 3/3 | -0.0604 | -0.1953 | -0.04 | -4.58 | -0.02 | 3.74 | 3.46 | -10.59 | -0.41 | 4.15 |
| opb 2/3 | -0.04 | -0.1293 | -0.07 | -5.26 | -0.02 | 4.65 | 4.38 | -12.39 | -0.28 | 5.73 |
| opb 1/3 | -0.0209 | -0.0675 | -0.07 | -6.53 | 0 | 5.79 | 6.24 | -16.22 | -0.05 | 9.26 |
| axi-c 1/3 | -0.0116 | -0.0622 | -1.24 | 7.65 | 6.68 | 5.93 | -9.19 | 19.37 | 12.24 | 9.28 |
| axi-c 2/3 | -0.0231 | -0.1238 | -0.41 | 4.62 | 4.97 | 4.77 | -3.92 | 12.08 | 7.03 | 7.34 |
| axi-c 3/3 | -0.0348 | -0.1863 | 0.08 | 3.32 | 3.78 | 3.89 | -1.54 | 8.71 | 4.77 | 6.26 |
| axi-c 3/3 | -0.0348 | -0.1862 | 0.08 | 3.34 | 3.77 | 3.87 | -1.43 | 8.64 | 4.79 | 6.26 |
| axi-c 2/3 | -0.0231 | -0.1236 | -0.26 | 4.69 | 4.93 | 4.91 | -3.38 | 11.88 | 6.97 | 7.53 |
| axi-c 1/3 | -0.0115 | -0.0614 | -1.26 | 8.45 | 7.14 | 5.14 | -10.09 | 21.15 | 13.35 | 7.79 |
| axi-t 1/3 | 0.0118 | 0.0504 | 0.74 | 9.38 | 1.09 | 6.48 | -3.88 | 20.22 | 3.98 | 9.76 |
| axi-t 2/3 | 0.0233 | 0.0999 | 0.6 | 7.14 | 0.98 | 5.33 | -2.43 | 14.89 | 3.2 | 7.84 |
| axi-t 3/3 | 0.0347 | 0.1486 | 0.6 | 5.83 | 0.98 | 4.77 | -1.5 | 12.08 | 2.93 | 7.12 |
| axi-t 3/3 | 0.0347 | 0.1486 | 0.61 | 5.9 | 0.99 | 4.71 | -1.82 | 12.38 | 2.85 | 7.04 |
| axi-t 2/3 | 0.0232 | 0.0993 | 0.63 | 7.07 | 1.08 | 5.47 | -2.39 | 14.57 | 3.17 | 8.16 |
| axi-t 1/3 | 0.0118 | 0.0508 | 0.53 | 9.31 | 1.26 | 6.7 | -4.32 | 19.99 | 3.95 | 10.32 |

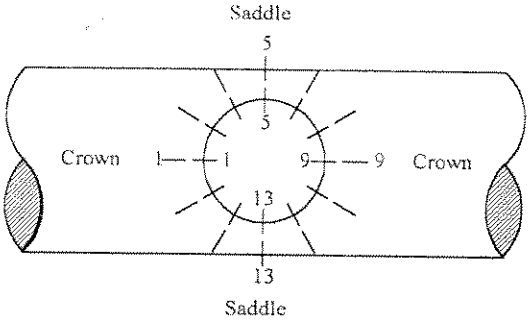
Table 17: Measured SNCFs on intersections of brace 1,2 and chord for DT5 at preload level of 50%

| DT5 | pl. cap | design | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0489 | -0.0737 | 3.09 | -0.2 | -1.95 | -0.29 | 4.47 | -1.28 | -3.74 | -0.54 |
| ipb 2/3 | -0.0968 | -0.1458 | 3.03 | -0.2 | -1.88 | -0.33 | 2.91 | -0.97 | -3.42 | -0.54 |
| ipb 3/3 | -0.1418 | -0.2136 | 2.84 | -0.2 | -1.84 | -0.26 | 2.45 | -0.89 | -3.25 | -0.46 |
| ipb 3/3 | -0.1421 | -0.2139 | 2.84 | -0.21 | -1.85 | -0.26 | 2.45 | -0.89 | -3.27 | -0.45 |
| ipb 2/3 | -0.0968 | -0.1458 | 3.09 | -0.22 | -1.93 | -0.28 | 3 | -1.01 | -3.52 | -0.45 |
| ipb 1/3 | -0.0496 | -0.0747 | 3.21 | -0.21 | -2.03 | -0.27 | 4.65 | -1.36 | -3.91 | -0.47 |
| opb 1/3 | -0.0186 | -0.0601 | -0.06 | -6.44 | -0.1 | 6.28 | 6.33 | -15.53 | -0.14 | 10.17 |
| opb 2/3 | -0.0181 | -0.0586 | -0.09 | -6.74 | -0.07 | 7.2 | 6.29 | -16.06 | -0.07 | 10.63 |
| opb 3/3 | -0.0378 | -0.1222 | -0.08 | -5.26 | -0.07 | 5.14 | 4.35 | -12.09 | -0.34 | 5.67 |
| opb 3/3 | -0.0579 | -0.1874 | -0.03 | -4.59 | -0.04 | 3.94 | 3.52 | -10.64 | -0.39 | 4.08 |
| opb 2/3 | -0.0376 | -0.1216 | -0.05 | -5.18 | -0.08 | 4.97 | 4.46 | -12.32 | -0.29 | 5.66 |
| opb 1/3 | -0.0178 | -0.0577 | -0.02 | -6.7 | -0.11 | 6.74 | 6.67 | -16.55 | -0.01 | 10.71 |
| axi-c 1/3 | -0.0116 | -0.0619 | 0.2 | 3.21 | 4.56 | 13.56 | 0.25 | 6.48 | 9.43 | 21.12 |
| axi-c 2/3 | -0.0232 | -0.1241 | 0.55 | 3.34 | 3.72 | 7.29 | 0.81 | 6.72 | 6.34 | 12.36 |
| axi-c 3/3 | -0.0349 | -0.1867 | 0.8 | 2.96 | 3.16 | 5.17 | 1.18 | 6.17 | 4.78 | 8.71 |
| axi-c 3/3 | -0.0349 | -0.1866 | 0.8 | 3 | 3.17 | 5.17 | 1.18 | 6.17 | 4.74 | 8.72 |
| axi-c 2/3 | -0.0232 | -0.124 | 0.67 | 3.54 | 3.75 | 7.21 | 1.02 | 7 | 6.4 | 12.33 |
| axi-c 1/3 | -0.0116 | -0.0619 | 0.02 | 4.74 | 5.42 | 12.3 | -1.17 | 9.93 | 10.95 | 19.33 |
| axi-t 1/3 | 0.0121 | 0.0519 | 0.64 | 9.54 | 0.95 | 6.8 | -5.01 | 20.85 | 3.66 | 10.08 |
| axi-t 2/3 | 0.0238 | 0.1021 | 0.55 | 6.92 | 0.95 | 5.77 | -2.72 | 14.49 | 3.13 | 8.58 |
| axi-t 3/3 | 0.0353 | 0.1512 | 0.58 | 6.06 | 0.87 | 4.81 | -1.92 | 12.55 | 2.75 | 7.07 |
| axi-t 3/3 | 0.0353 | 0.1512 | 0.58 | 6 | 0.91 | 4.81 | -1.92 | 12.49 | 2.77 | 7.15 |
| axi-t 2/3 | 0.0236 | 0.1012 | 0.58 | 7.21 | 0.97 | 5.32 | -3.19 | 15.45 | 2.99 | 8 |
| axi-t 1/3 | 0.0121 | 0.0519 | 0.53 | 9.96 | 1.05 | 5.97 | -5.69 | 22.21 | 3.48 | 9.11 |

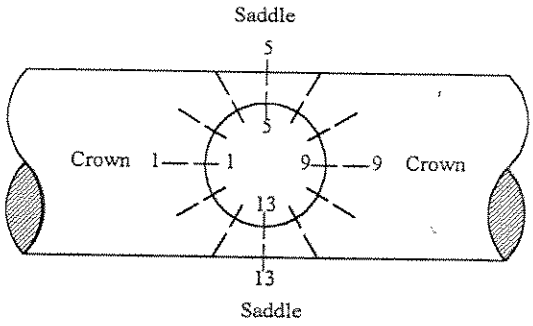
**Table 18: Measured SNCFs on intersections of brace 1,2 and chord for DT5 at preload level of 100 %**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

| DT6 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0283 | -0.0548 | 3.62 | 1.82 | 1.22 | 0.11 | -1.5 | -1.66 | -1.67 | 0.09 |
| ipb 2/3 | -0.0562 | -0.1089 | 3.39 | 1.84 | 1.04 | 0.07 | -1.48 | -1.64 | -1.51 | 0.01 |
| ipb 3/3 | -0.0825 | -0.1598 | 3.05 | 1.89 | 0.94 | 0.06 | -1.45 | -1.6 | -1.4 | -0.02 |
| ipb 3/3 | -0.0826 | -0.16 | 3.05 | 1.89 | 0.93 | 0.07 | -1.43 | -1.6 | -1.4 | -0.02 |
| ipb 2/3 | -0.0563 | -0.1091 | 3.42 | 1.87 | 1.03 | 0.1 | -1.47 | -1.66 | -1.54 | 0 |
| ipb 1/3 | -0.0281 | -0.0545 | 3.68 | 1.84 | 1.24 | 0.14 | -1.52 | -1.69 | -1.73 | 0.06 |
| opb 1/3 | -0.0156 | -0.0423 | 0.05 | -0.45 | -1.09 | -2.49 | -0.03 | 0.38 | 1.29 | 2.44 |
| opb 2/3 | -0.0325 | -0.0883 | 0.05 | -0.42 | -1.11 | -2.46 | -0.03 | 0.41 | 1.35 | 2.52 |
| opb 3/3 | -0.0499 | -0.1354 | 0.07 | -0.38 | -1.01 | -2.18 | -0.01 | 0.44 | 1.34 | 2.54 |
| opb 3/3 | -0.0501 | -0.1361 | 0.07 | -0.37 | -0.94 | -1.99 | -0.02 | 0.46 | 1.36 | 2.56 |
| opb 2/3 | -0.0327 | -0.0887 | 0.07 | -0.41 | -1.02 | -2.21 | -0.08 | 0.43 | 1.3 | 2.48 |
| opb 1/3 | -0.0152 | -0.0413 | 0.08 | -0.36 | -0.98 | -2.28 | -0.14 | 0.36 | 1.21 | 2.31 |
| axi-c 1/3 | -0.0097 | -0.0401 | 0.34 | 0.45 | 1.25 | 3.81 | 2.6 | 2.23 | 3.68 | 4.2 |
| axi-c 2/3 | -0.0195 | -0.0805 | 1.1 | 1.25 | 2.05 | 3.87 | 1.76 | 1.48 | 2.62 | 4.04 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.15 | 1.24 | 2 | 3.51 | 1.69 | 1.39 | 2.45 | 3.98 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.15 | 1.24 | 1.96 | 3.47 | 1.66 | 1.39 | 2.47 | 3.99 |
| axi-c 2/3 | -0.0195 | -0.0803 | 1.18 | 1.26 | 2.01 | 3.71 | 1.57 | 1.41 | 2.73 | 4.31 |
| axi-c 1/3 | -0.0097 | -0.0402 | 0.76 | 0.86 | 1.36 | 3.23 | 1.85 | 1.95 | 3.67 | 4.89 |
| axi-t 1/3 | 0.0115 | 0.0435 | 1.61 | 1.7 | 2.51 | 3.84 | 0.99 | 1.19 | 2.61 | 4.61 |
| axi-t 2/3 | 0.0223 | 0.0845 | 1.43 | 1.54 | 2.1 | 3.07 | 0.93 | 1.11 | 2.33 | 3.51 |
| axi-t 3/3 | 0.0332 | 0.1259 | 1.3 | 1.39 | 1.74 | 2.38 | 0.87 | 1.02 | 2.04 | 2.79 |
| axi-t 3/3 | 0.0332 | 0.1259 | 1.3 | 1.39 | 1.71 | 2.38 | 0.83 | 0.99 | 2.04 | 2.79 |
| axi-t 2/3 | 0.0224 | 0.0849 | 1.38 | 1.53 | 2.01 | 3.02 | 0.82 | 1.05 | 2.34 | 3.59 |
| axi-t 1/3 | 0.0113 | 0.043 | 1.59 | 1.64 | 2.33 | 3.97 | 0.81 | 1 | 2.55 | 4.47 |

**Table 19: Measured SNCFs on braces at intersections of brace and chord of DT6**

| DT6 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0283 | -0.0548 | 2.67 | 2.76 | 1.89 | 0.33 | -2.58 | -2.74 | -2.06 | 0.17 |
| ipb 2/3 | -0.0562 | -0.1089 | 1.57 | 2.13 | 1.58 | 0.18 | -2.39 | -2.63 | -1.82 | 0.06 |
| ipb 3/3 | -0.0825 | -0.1598 | 1.3 | 1.78 | 1.4 | 0.09 | -2.31 | -2.55 | -1.69 | 0 |
| ipb 3/3 | -0.0826 | -0.16 | 1.3 | 1.77 | 1.39 | 0.08 | -2.32 | -2.53 | -1.69 | 0 |
| ipb 2/3 | -0.0563 | -0.1091 | 1.56 | 2.16 | 1.6 | 0.2 | -2.43 | -2.66 | -1.84 | 0.05 |
| ipb 1/3 | -0.0281 | -0.0545 | 2.71 | 2.82 | 1.92 | 0.26 | -2.64 | -2.79 | -2.14 | 0.18 |
| opb 1/3 | -0.0156 | -0.0423 | 0.03 | -0.3 | -1.37 | -5.25 | -0.03 | 0.17 | 1.11 | 3.35 |
| opb 2/3 | -0.0325 | -0.0883 | 0.07 | -0.25 | -1.52 | -5.28 | -0.08 | 0.15 | 1.14 | 3.4 |
| opb 3/3 | -0.0499 | -0.1354 | 0.06 | -0.28 | -1.49 | -4.87 | -0.08 | 0.19 | 1.17 | 3.43 |
| opb 3/3 | -0.0501 | -0.1361 | 0.06 | -0.26 | -1.42 | -4.67 | -0.09 | 0.17 | 1.17 | 3.45 |
| opb 2/3 | -0.0327 | -0.0887 | 0.11 | -0.23 | -1.46 | -5.11 | -0.15 | 0.1 | 1.09 | 3.34 |
| opb 1/3 | -0.0152 | -0.0413 | 0.14 | -0.2 | -1.3 | -5.64 | -0.23 | -0.05 | 0.77 | 3.12 |
| axi-c 1/3 | -0.0097 | -0.0401 | -0.32 | -0.1 | 1.86 | 7.53 | 3.73 | 2.89 | 3.75 | 4.87 |
| axi-c 2/3 | -0.0195 | -0.0805 | 0.94 | 1.36 | 3.06 | 7.73 | 2 | 1.42 | 2.48 | 4.83 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.29 | 1.63 | 2.91 | 7.09 | 1.83 | 1.42 | 2.18 | 4.75 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.31 | 1.6 | 2.85 | 7.04 | 1.83 | 1.41 | 2.18 | 4.77 |
| axi-c 2/3 | -0.0195 | -0.0803 | 1.01 | 1.33 | 2.99 | 7.42 | 1.83 | 1.27 | 2.59 | 5.2 |
| axi-c 1/3 | -0.0097 | -0.0402 | 0.28 | 0.43 | 1.95 | 6.2 | 2.48 | 2.11 | 3.61 | 5.94 |
| axi-t 1/3 | 0.0115 | 0.0435 | 1.56 | 2.12 | 3.53 | 7.67 | 0.85 | 1.04 | 2.55 | 5.57 |
| axi-t 2/3 | 0.0223 | 0.0845 | 1.41 | 2.06 | 3.33 | 6.39 | 0.95 | 1.13 | 2.44 | 4.36 |
| axi-t 3/3 | 0.0332 | 0.1259 | 1.34 | 2 | 3.08 | 5.52 | 1.08 | 1.17 | 2.48 | 3.98 |
| axi-t 3/3 | 0.0332 | 0.1259 | 1.33 | 2 | 3.08 | 5.49 | 1.08 | 1.1 | 2.5 | 3.99 |
| axi-t 2/3 | 0.0224 | 0.0849 | 1.39 | 2.05 | 3.31 | 6.24 | 0.91 | 0.94 | 2.56 | 4.55 |
| axi-t 1/3 | 0.0113 | 0.043 | 1.54 | 2.01 | 3.57 | 7.76 | 0.71 | 0.57 | 2.52 | 5.57 |

**Table 20: Measured SNCFs on chord at intersections of brace and chord of DT6**

| DT6 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0001 | 0.0002 | -3.75 | 0.52 | -0.48 | -0.5 | -6.83 | -0.5 | 0 | 3.55 |
| ipb 2/3 | -0.0272 | -0.0527 | 3.66 | 1.75 | 1.22 | 0.11 | -1.47 | -1.68 | -1.76 | 0.04 |
| ipb 3/3 | -0.0552 | -0.1069 | 3.45 | 1.77 | 1.02 | 0.06 | -1.46 | -1.66 | -1.58 | -0.03 |
| ipb 3/3 | -0.0278 | -0.0539 | 3.16 | 1.77 | 0.82 | 0.02 | -1.4 | -1.6 | -1.33 | -0.06 |
| ipb 2/3 | -0.0546 | -0.1057 | 2.78 | 1.92 | 0.77 | 0 | -1.41 | -1.57 | -1.26 | -0.07 |
| ipb 1/3 | -0.0276 | -0.0534 | 3.25 | 1.78 | 0.83 | 0 | -1.45 | -1.62 | -1.34 | -0.06 |
| opb 1/3 | -0.0152 | -0.0413 | 0.03 | -0.42 | -0.96 | -2.34 | -0.03 | 0.49 | 1.39 | 2.57 |
| opb 2/3 | -0.033 | -0.0895 | 0.05 | -0.4 | -0.99 | -2.34 | -0.05 | 0.44 | 1.36 | 2.59 |
| opb 3/3 | -0.0505 | -0.137 | 0.05 | -0.38 | -0.95 | -2.22 | -0.04 | 0.44 | 1.37 | 2.6 |
| opb 3/3 | -0.0509 | -0.1383 | 0.05 | -0.38 | -0.94 | -2.2 | -0.04 | 0.43 | 1.38 | 2.61 |
| opb 2/3 | -0.0335 | -0.0911 | 0.05 | -0.37 | -0.97 | -2.31 | -0.07 | 0.4 | 1.37 | 2.59 |
| opb 1/3 | -0.0161 | -0.0437 | 0.03 | -0.39 | -0.98 | -2.37 | -0.08 | 0.38 | 1.37 | 2.61 |
| axi-c 1/3 | -0.0098 | -0.0403 | 0.8 | 1.12 | 1.95 | 4.5 | 1.78 | 1.68 | 2.76 | 3.83 |
| axi-c 2/3 | -0.0195 | -0.0804 | 1.38 | 1.66 | 2.52 | 4.33 | 1.19 | 1.08 | 2.2 | 4.01 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.47 | 1.56 | 2.34 | 3.9 | 1.17 | 1.13 | 2.28 | 4.11 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.47 | 1.56 | 2.37 | 3.9 | 1.15 | 1.11 | 2.35 | 4.1 |
| axi-c 2/3 | -0.0195 | -0.0806 | 1.51 | 1.68 | 2.59 | 4.18 | 1.05 | 1.03 | 2.37 | 4.21 |
| axi-c 1/3 | -0.0098 | -0.0403 | 1.32 | 1.58 | 2.43 | 4.06 | 1.04 | 1.16 | 2.75 | 4.51 |
| axi-t 1/3 | 0.0112 | 0.0423 | 0.97 | 0.93 | 1.84 | 3.85 | 1.33 | 1.47 | 3.07 | 4.56 |
| axi-t 2/3 | 0.0112 | 0.0423 | 0.97 | 0.93 | 1.84 | 3.85 | 1.33 | 1.47 | 3.07 | 4.56 |
| axi-t 3/3 | 0.0223 | 0.0845 | 1.05 | 1.13 | 1.85 | 3.43 | 1.16 | 1.28 | 2.7 | 3.86 |
| axi-t 3/3 | 0.0333 | 0.1261 | 1.03 | 1.18 | 1.69 | 2.73 | 1.03 | 1.18 | 2.39 | 3.15 |
| axi-t 2/3 | 0.0223 | 0.0844 | 0.98 | 1.22 | 1.85 | 3.32 | 1.13 | 1.32 | 2.77 | 3.96 |
| axi-t 1/3 | 0.0112 | 0.0423 | 0.93 | 1.1 | 1.7 | 3.6 | 1.28 | 1.55 | 3.39 | 4.89 |

**Table 21: Measured SNCFs on braces at intersections of brace and chord of DT6 at preload level of 50 %**

| DT6 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0001 | 0.0002 | 12.44 | 6.53 | -1.54 | -6.27 | 0 | 6.72 | -4.32 | 11.82 |
| ipb 2/3 | -0.0272 | -0.0527 | 2.69 | 2.69 | 1.88 | 0.36 | -2.59 | -2.78 | -2.23 | 0.14 |
| ipb 3/3 | -0.0552 | -0.1069 | 1.53 | 2.1 | 1.55 | 0.17 | -2.4 | -2.64 | -1.93 | 0.04 |
| ipb 3/3 | -0.0278 | -0.0539 | 0.36 | 1.52 | 1.22 | 0.03 | -2.13 | -2.48 | -1.61 | -0.01 |
| ipb 2/3 | -0.0546 | -0.1057 | 0.57 | 1.26 | 1.12 | -0.03 | -2.11 | -2.41 | -1.53 | -0.05 |
| ipb 1/3 | -0.0276 | -0.0534 | 0.38 | 1.59 | 1.28 | 0.05 | -2.2 | -2.52 | -1.62 | -0.05 |
| opb 1/3 | -0.0152 | -0.0413 | 0.01 | -0.13 | -1.41 | -4.96 | -0.11 | 0.13 | 1.22 | 3.48 |
| opb 2/3 | -0.033 | -0.0895 | 0.11 | -0.18 | -1.43 | -5.06 | -0.14 | 0.1 | 1.23 | 3.49 |
| opb 3/3 | -0.0505 | -0.137 | 0.11 | -0.17 | -1.45 | -4.88 | -0.11 | 0.14 | 1.25 | 3.52 |
| opb 3/3 | -0.0509 | -0.1383 | 0.11 | -0.17 | -1.44 | -4.85 | -0.1 | 0.13 | 1.26 | 3.54 |
| opb 2/3 | -0.0335 | -0.0911 | 0.09 | -0.18 | -1.42 | -5.02 | -0.14 | 0.07 | 1.24 | 3.53 |
| opb 1/3 | -0.0161 | -0.0437 | 0.07 | -0.12 | -1.47 | -5.1 | -0.17 | 0.02 | 1.21 | 3.53 |
| axi-c 1/3 | -0.0098 | -0.0403 | 0.5 | 0.77 | 2.76 | 8.9 | 2.18 | 1.62 | 2.72 | 4.26 |
| axi-c 2/3 | -0.0195 | -0.0804 | 1.38 | 1.83 | 3.73 | 8.64 | 0.91 | 0.67 | 2.03 | 4.7 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.66 | 2.02 | 3.38 | 7.8 | 1.28 | 0.86 | 2.02 | 4.87 |
| axi-c 3/3 | -0.0298 | -0.1229 | 1.66 | 2.02 | 3.43 | 7.81 | 1.36 | 0.93 | 2.09 | 4.87 |
| axi-c 2/3 | -0.0195 | -0.0806 | 1.55 | 1.97 | 3.81 | 8.35 | 0.78 | 0.69 | 2.23 | 5 |
| axi-c 1/3 | -0.0098 | -0.0403 | 1.46 | 1.63 | 3.52 | 7.93 | 0.84 | 0.94 | 2.75 | 5.2 |
| axi-t 1/3 | 0.0112 | 0.0423 | 0.66 | 0.96 | 2.7 | 7.79 | 1.44 | 1.32 | 3.19 | 5.6 |
| axi-t 2/3 | 0.0112 | 0.0423 | 0.66 | 0.96 | 2.7 | 7.79 | 1.44 | 1.32 | 3.19 | 5.6 |
| axi-t 3/3 | 0.0223 | 0.0845 | 0.86 | 1.32 | 3.02 | 6.91 | 1.33 | 1.23 | 2.92 | 4.77 |
| axi-t 3/3 | 0.0333 | 0.1261 | 0.93 | 1.5 | 2.86 | 5.85 | 1.24 | 1.3 | 2.84 | 3.99 |
| axi-t 2/3 | 0.0223 | 0.0844 | 0.75 | 1.22 | 2.82 | 6.77 | 1.26 | 1.38 | 3.07 | 4.84 |
| axi-t 1/3 | 0.0112 | 0.0423 | 0.51 | 0.85 | 2.38 | 7.12 | 1.3 | 1.44 | 3.49 | 5.95 |

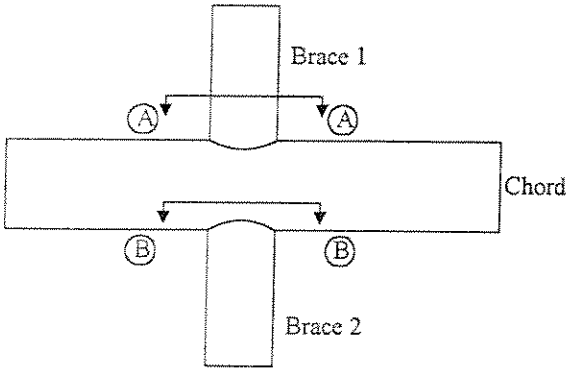
**Table 22: Measured SNCFs on chord at intersections of brace and chord of DT6 at preload level of 50 %**

| DT6 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.029 | -0.0561 | 3.47 | 1.8 | 1.16 | 0.01 | -1.49 | -1.62 | -1.76 | 0.1 |
| ipb 2/3 | -0.0581 | -0.1126 | 3.42 | 1.7 | 0.97 | -0.03 | -1.46 | -1.61 | -1.55 | 0.01 |
| ipb 3/3 | -0.0855 | -0.1656 | 3.1 | 1.82 | 0.87 | -0.03 | -1.43 | -1.57 | -1.43 | -0.03 |
| ipb 3/3 | -0.0855 | -0.1656 | 3.1 | 1.83 | 0.89 | -0.02 | -1.41 | -1.56 | -1.41 | -0.02 |
| ipb 2/3 | -0.0583 | -0.1129 | 3.43 | 1.71 | 1 | -0.02 | -1.43 | -1.59 | -1.55 | 0.02 |
| ipb 1/3 | -0.0304 | -0.0588 | 3.55 | 1.78 | 1.19 | -0.01 | -1.49 | -1.63 | -1.77 | 0.1 |
| opb 1/3 | -0.0169 | -0.0459 | 0.02 | -0.42 | -1.08 | -2.53 | -0.31 | 0.13 | 0.97 | 2.27 |
| opb 2/3 | -0.0344 | -0.0935 | 0.02 | -0.42 | -1.04 | -2.46 | -0.2 | 0.26 | 1.15 | 2.4 |
| opb 3/3 | -0.0513 | -0.1392 | 0.03 | -0.41 | -1 | -2.34 | -0.14 | 0.32 | 1.23 | 2.5 |
| opb 3/3 | -0.0521 | -0.1414 | 0.04 | -0.4 | -0.99 | -2.33 | -0.15 | 0.32 | 1.24 | 2.53 |
| opb 2/3 | -0.0355 | -0.0963 | 0.04 | -0.41 | -0.97 | -2.35 | -0.24 | 0.27 | 1.23 | 2.66 |
| opb 1/3 | -0.0172 | -0.0466 | 0.07 | -0.43 | -0.92 | -2.32 | -0.4 | 0.13 | 1.11 | 2.81 |
| axi-c 1/3 | -0.0098 | -0.0404 | 2.21 | 2.35 | 3.24 | 4.11 | 0.32 | 0.32 | 1.37 | 4.39 |
| axi-c 2/3 | -0.0196 | -0.0807 | 2.38 | 2.44 | 3.16 | 4.12 | 0.24 | 0.27 | 1.36 | 4.23 |
| axi-c 3/3 | -0.0298 | -0.1231 | 2.43 | 2.19 | 2.71 | 3.79 | 0.55 | 0.54 | 1.69 | 4.2 |
| axi-c 3/3 | -0.0299 | -0.1232 | 2.43 | 2.19 | 2.7 | 3.77 | 0.55 | 0.54 | 1.69 | 4.16 |
| axi-c 2/3 | -0.0196 | -0.0807 | 2.51 | 2.47 | 3.11 | 3.95 | 0.21 | 0.3 | 1.44 | 4.34 |
| axi-c 1/3 | -0.0098 | -0.0405 | 2.57 | 2.56 | 3.33 | 3.59 | -0.15 | 0.16 | 1.37 | 4.98 |
| axi-t 1/3 | 0.0113 | 0.0429 | 0.64 | 0.73 | 1.44 | 3.7 | 1.63 | 1.86 | 3.56 | 4.87 |
| axi-t 2/3 | 0.0221 | 0.0839 | 0.87 | 0.97 | 1.69 | 3.51 | 1.39 | 1.54 | 3.11 | 4.23 |
| axi-t 3/3 | 0.0333 | 0.126 | 0.93 | 1.08 | 1.64 | 2.95 | 1.18 | 1.33 | 2.62 | 3.43 |
| axi-t 3/3 | 0.0333 | 0.126 | 0.93 | 1.08 | 1.63 | 2.95 | 1.2 | 1.32 | 2.63 | 3.43 |
| axi-t 2/3 | 0.0222 | 0.0843 | 0.89 | 1.03 | 1.71 | 3.5 | 1.34 | 1.48 | 3.04 | 4.22 |
| axi-t 1/3 | 0.0111 | 0.0421 | 0.7 | 0.66 | 1.43 | 3.58 | 1.65 | 1.8 | 3.59 | 4.93 |

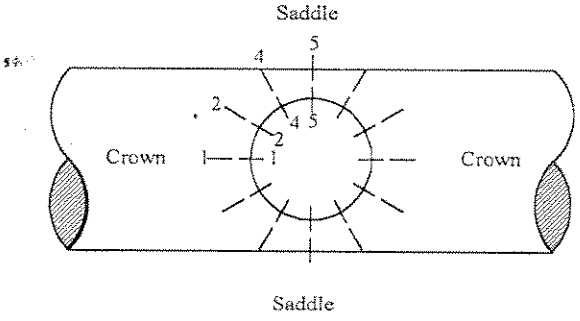
**Table 23: Measured SNCFs on braces at intersections of brace and chord of DT6 at preload level of 100%**

| DT6 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.029 | -0.0561 | 2.92 | 2.87 | 1.88 | 0.15 | -2.61 | -2.68 | -2.21 | 0.28 |
| ipb 2/3 | -0.0581 | -0.1126 | 1.58 | 2.26 | 1.56 | 0.05 | -2.38 | -2.57 | -1.85 | 0.12 |
| ipb 3/3 | -0.0855 | -0.1656 | 1.29 | 1.8 | 1.38 | -0.01 | -2.27 | -2.47 | -1.7 | 0.03 |
| ipb 3/3 | -0.0855 | -0.1656 | 1.29 | 1.81 | 1.37 | -0.01 | -2.27 | -2.46 | -1.67 | 0.04 |
| ipb 2/3 | -0.0583 | -0.1129 | 1.58 | 2.29 | 1.57 | 0.04 | -2.39 | -2.56 | -1.85 | 0.1 |
| ipb 1/3 | -0.0304 | -0.0588 | 2.84 | 2.89 | 1.91 | 0.11 | -2.64 | -2.7 | -2.18 | 0.22 |
| opb 1/3 | -0.0169 | -0.0459 | 0.05 | -0.22 | -1.51 | -5.42 | -0.66 | -0.36 | 0.75 | 3.03 |
| opb 2/3 | -0.0344 | -0.0935 | 0.04 | -0.21 | -1.47 | -5.3 | -0.39 | -0.12 | 0.98 | 3.31 |
| opb 3/3 | -0.0513 | -0.1392 | 0.03 | -0.23 | -1.45 | -5.11 | -0.3 | -0.05 | 1.11 | 3.44 |
| opb 3/3 | -0.0521 | -0.1414 | 0.02 | -0.23 | -1.44 | -5.08 | -0.3 | -0.05 | 1.12 | 3.46 |
| opb 2/3 | -0.0355 | -0.0963 | 0.04 | -0.19 | -1.36 | -5.15 | -0.44 | -0.18 | 1.07 | 3.7 |
| opb 1/3 | -0.0172 | -0.0466 | 0.03 | -0.17 | -1.11 | -4.95 | -0.8 | -0.44 | 1.01 | 4.03 |
| axi-c 1/3 | -0.0098 | -0.0404 | 2.65 | 3.25 | 4.96 | 8.37 | -1.01 | -0.76 | 1.12 | 5.35 |
| axi-c 2/3 | -0.0196 | -0.0807 | 2.96 | 3.36 | 4.84 | 8.34 | -0.95 | -0.6 | 1.08 | 5.1 |
| axi-c 3/3 | -0.0298 | -0.1231 | 2.95 | 3.01 | 4.09 | 7.72 | -0.07 | -0.05 | 1.33 | 5.13 |
| axi-c 3/3 | -0.0299 | -0.1232 | 2.95 | 3.01 | 4.06 | 7.66 | -0.03 | -0.05 | 1.27 | 5.13 |
| axi-c 2/3 | -0.0196 | -0.0807 | 3.11 | 3.39 | 4.68 | 7.97 | -1.01 | -0.67 | 1.05 | 5.4 |
| axi-c 1/3 | -0.0098 | -0.0405 | 3.22 | 3.83 | 5.25 | 7.13 | -1.71 | -1.09 | 0.96 | 6.22 |
| axi-t 1/3 | 0.0113 | 0.0429 | 0.07 | 0.38 | 2.13 | 7.31 | 2.14 | 1.82 | 3.72 | 5.87 |
| axi-t 2/3 | 0.0221 | 0.0839 | 0.55 | 0.89 | 2.57 | 7.01 | 1.64 | 1.53 | 3.35 | 5.11 |
| axi-t 3/3 | 0.0333 | 0.126 | 0.74 | 1.22 | 2.67 | 6.25 | 1.39 | 1.39 | 3.01 | 4.22 |
| axi-t 3/3 | 0.0333 | 0.126 | 0.74 | 1.2 | 2.67 | 6.25 | 1.41 | 1.43 | 3.04 | 4.24 |
| axi-t 2/3 | 0.0222 | 0.0843 | 0.52 | 0.89 | 2.64 | 7.02 | 1.55 | 1.47 | 3.31 | 5.15 |
| axi-t 1/3 | 0.0111 | 0.0421 | 0.19 | 0.24 | 2.11 | 7.36 | 2.05 | 1.97 | 3.81 | 6.11 |

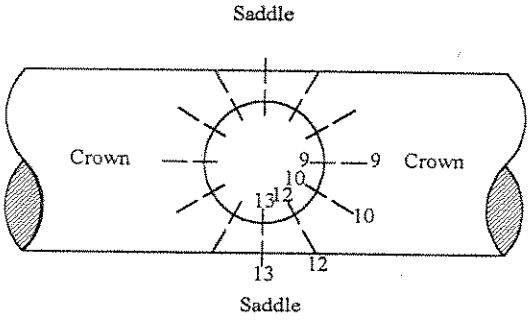
**Table 24: Measured SNCFs on chord at intersections of brace and chord of DT6 at preload level of 100%**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

| DT8 | pl. cap | design | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0329 | -0.0696 | 3.42 | -0.3 | -1.51 | -0.49 | 1.34 | -0.59 | -2.88 | -0.69 |
| ipb 2/3 | -0.0647 | -0.1367 | 3.16 | -0.26 | -1.53 | -0.49 | 1.16 | -0.57 | -2.8 | -0.77 |
| ipb 3/3 | -0.0965 | -0.2039 | 2.95 | -0.26 | -1.52 | -0.49 | 1.09 | -0.6 | -2.73 | -0.8 |
| ipb 3/3 | -0.0946 | -0.1999 | 2.97 | -0.26 | -1.54 | -0.48 | 1.05 | -0.61 | -2.75 | -0.82 |
| ipb 2/3 | -0.0624 | -0.1319 | 3.24 | -0.23 | -1.57 | -0.49 | 1.14 | -0.52 | -2.88 | -0.83 |
| ipb 1/3 | -0.0305 | -0.0644 | 3.6 | -0.23 | -1.61 | -0.5 | 1.36 | -0.46 | -3.03 | -0.8 |
| opb 1/3 | -0.0124 | -0.0605 | -0.09 | -6.26 | -0.12 | 5.57 | -0.61 | -13.63 | -0.34 | 8.63 |
| opb 2/3 | -0.0244 | -0.119 | -0.06 | -4.69 | -0.09 | 4.39 | -0.64 | -10.38 | -0.5 | 5.19 |
| opb 3/3 | -0.0346 | -0.1685 | -0.08 | -4.36 | -0.09 | 3.72 | -0.68 | -9.52 | -0.54 | 4.01 |
| opb 3/3 | -0.0344 | -0.1675 | -0.08 | -4.31 | -0.09 | 3.7 | -0.68 | -9.3 | -0.55 | 4.21 |
| opb 2/3 | -0.0236 | -0.1149 | -0.08 | -4.73 | -0.11 | 4.33 | -0.59 | -10.13 | -0.4 | 5.5 |
| opb 1/3 | -0.0118 | -0.0574 | -0.06 | -5.69 | -0.1 | 5.72 | -0.47 | -12.39 | -0.21 | 9.61 |
| axi-c 1/3 | -0.0079 | -0.0667 | -2.39 | 6.63 | 5.66 | 1.31 | -4.87 | 13.88 | 9.57 | 1.74 |
| axi-c 2/3 | -0.0153 | -0.1301 | -1.39 | 3.57 | 5.94 | 2.47 | -2.18 | 7.73 | 6.2 | 4.6 |
| axi-c 3/3 | -0.0233 | -0.1974 | -0.81 | 2.99 | 4.83 | 1.92 | -1.15 | 5.77 | 4.27 | 3.6 |
| axi-c 3/3 | -0.0233 | -0.1974 | -0.86 | 2.96 | 4.79 | 1.89 | -1.16 | 5.69 | 4.21 | 3.61 |
| axi-c 2/3 | -0.0153 | -0.1302 | -1.32 | 4.22 | 5.04 | 1.94 | -2.19 | 8.2 | 5.86 | 3.42 |
| axi-c 1/3 | -0.0078 | -0.066 | -2.5 | 8.24 | 4.83 | -0.31 | -4.57 | 15.6 | 8.32 | -1.04 |
| axi-t 1/3 | 0.0092 | 0.0628 | 0.59 | 0.61 | 0.35 | 7.22 | 1.67 | 0.49 | 1.81 | 12.54 |
| axi-t 2/3 | 0.0174 | 0.1183 | 0.57 | 2.21 | 0.51 | 6.16 | 1.86 | 2.65 | 1.67 | 10.86 |
| axi-t 3/3 | 0.0259 | 0.176 | 0.71 | 2.57 | 0.46 | 5.5 | 1.97 | 3.91 | 1.58 | 9.88 |
| axi-t 3/3 | 0.0258 | 0.1753 | 0.71 | 2.55 | 0.49 | 5.52 | 2.07 | 3.95 | 1.58 | 9.84 |
| axi-t 2/3 | 0.0172 | 0.1167 | 0.67 | 1.93 | 0.43 | 6.51 | 2.13 | 2.46 | 1.58 | 11.35 |
| axi-t 1/3 | 0.0088 | 0.0599 | 0.67 | 0.48 | 0.45 | 8.26 | 2.27 | 1.42 | 1.73 | 14.24 |

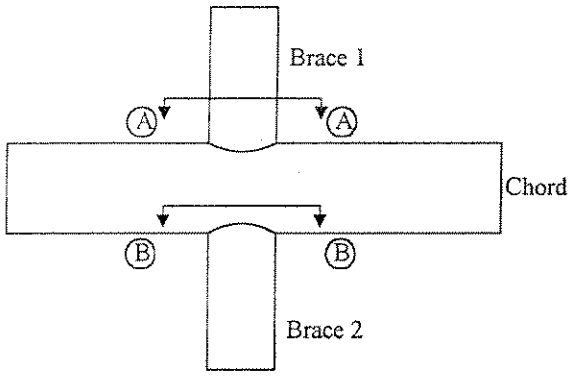
**Table 25: Measured SNCFs on intersections of brace 1,2 and chord for DT8**

| DT8 | pl. cap | design | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.031 | -0.0655 | 3.67 | -0.34 | -1.57 | -0.58 | 1.62 | -0.71 | -2.99 | -0.93 |
| ipb 2/3 | -0.064 | -0.1353 | 3.32 | -0.31 | -1.55 | -0.57 | 1.27 | -0.67 | -2.86 | -0.94 |
| ipb 3/3 | -0.095 | -0.2008 | 3.07 | -0.3 | -1.53 | -0.52 | 1.17 | -0.68 | -2.77 | -0.91 |
| ipb 3/3 | -0.0939 | -0.1985 | 3.07 | -0.29 | -1.53 | -0.52 | 1.12 | -0.68 | -2.77 | -0.92 |
| ipb 2/3 | -0.0617 | -0.1303 | 3.37 | -0.3 | -1.55 | -0.55 | 1.24 | -0.67 | -2.9 | -0.95 |
| ipb 1/3 | -0.0307 | -0.0649 | 3.81 | -0.28 | -1.61 | -0.58 | 1.62 | -0.65 | -3.12 | -0.98 |
| opb 1/3 | -0.0109 | -0.053 | -0.18 | -6.14 | -0.02 | 6.64 | -0.47 | -13.46 | -0.3 | 12.45 |
| opb 2/3 | -0.0226 | -0.1104 | -0.14 | -4.99 | -0.02 | 4.77 | -0.6 | -10.74 | -0.43 | 7.03 |
| opb 3/3 | -0.0331 | -0.1615 | -0.09 | -4.54 | -0.04 | 4.01 | -0.62 | -9.78 | -0.51 | 5.33 |
| opb 3/3 | -0.0339 | -0.1654 | -0.08 | -4.56 | -0.06 | 3.88 | -0.64 | -9.77 | -0.53 | 5.12 |
| opb 2/3 | -0.0239 | -0.1166 | -0.11 | -4.95 | -0.06 | 4.62 | -0.65 | -10.56 | -0.45 | 6.66 |
| opb 1/3 | -0.012 | -0.0586 | -0.08 | -6.04 | -0.08 | 6.3 | -0.48 | -13 | -0.35 | 11.42 |
| axi-c 1/3 | -0.0077 | -0.0656 | -0.5 | 8.17 | 4.39 | 5.77 | -0.06 | 19.06 | 8.15 | 10.55 |
| axi-c 2/3 | -0.0154 | -0.1306 | 0.08 | 4.17 | 3.58 | 4.49 | 1.47 | 10.57 | 4.67 | 8.76 |
| axi-c 3/3 | -0.0232 | -0.1968 | 0.24 | 3.06 | 2.99 | 3.39 | 1.44 | 7.63 | 3.31 | 6.91 |
| axi-c 3/3 | -0.0232 | -0.1967 | 0.22 | 3.06 | 2.99 | 3.39 | 1.44 | 7.66 | 3.33 | 6.88 |
| axi-c 2/3 | -0.0153 | -0.1301 | 0.17 | 4.27 | 3.34 | 4.47 | 1.67 | 10.98 | 4.63 | 8.62 |
| axi-c 1/3 | -0.0077 | -0.0657 | -0.06 | 8.35 | 3.71 | 5.47 | 0.89 | 20.43 | 7.4 | 9.77 |
| axi-t 1/3 | 0.0092 | 0.0628 | 0.81 | 5.76 | 0.56 | 9.42 | 2.9 | 12.97 | 1.8 | 16.25 |
| axi-t 2/3 | 0.0176 | 0.1198 | 0.72 | 5.42 | 0.42 | 6.97 | 2.36 | 12 | 1.61 | 12.07 |
| axi-t 3/3 | 0.0256 | 0.1741 | 0.65 | 4.63 | 0.6 | 6.04 | 2.08 | 10.38 | 1.83 | 10.6 |
| axi-t 3/3 | 0.0256 | 0.1741 | 0.69 | 4.86 | 0.45 | 5.92 | 1.97 | 10.48 | 1.82 | 10.55 |
| axi-t 2/3 | 0.0175 | 0.1192 | 0.72 | 5.35 | 0.38 | 7.12 | 2.07 | 11.35 | 1.84 | 12.6 |
| axi-t 1/3 | 0.0093 | 0.0634 | 0.63 | 5.78 | 0.4 | 9.27 | 2 | 11.97 | 2.19 | 16.68 |

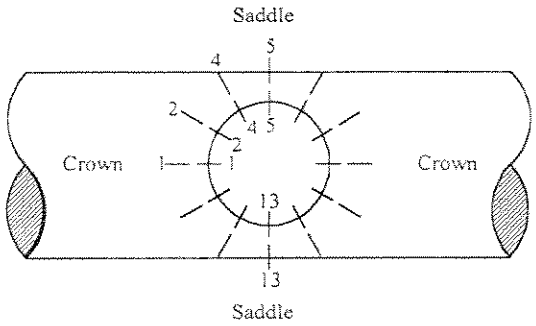
**Table 26: Measured SNCFs on intersections of brace 1,2 and chord for DT8 at preload level of 50%**

| DT8 | pl. cap | design | BC;1,br1 | BS;5,br2 | BC;9,br2 | BS;13,br1 | CC;1,br1 | CS;5,br2 | CC;9,br2 | CS;13,br1 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0328 | -0.0692 | 3.64 | -0.35 | -1.52 | -0.47 | 1.74 | -0.69 | -2.91 | -0.67 |
| ipb 2/3 | -0.0633 | -0.1338 | 3.35 | -0.33 | -1.52 | -0.46 | 1.35 | -0.68 | -2.83 | -0.74 |
| ipb 3/3 | -0.0957 | -0.2023 | 3.09 | -0.31 | -1.51 | -0.45 | 1.21 | -0.71 | -2.73 | -0.74 |
| ipb 3/3 | -0.0955 | -0.2018 | 3.11 | -0.31 | -1.51 | -0.45 | 1.21 | -0.73 | -2.74 | -0.74 |
| ipb 2/3 | -0.0633 | -0.1337 | 3.39 | -0.3 | -1.54 | -0.47 | 1.38 | -0.7 | -2.86 | -0.72 |
| ipb 1/3 | -0.0314 | -0.0664 | 3.83 | -0.34 | -1.6 | -0.47 | 1.89 | -0.72 | -3.08 | -0.64 |
| opb 1/3 | -0.0111 | -0.0542 | -0.03 | -6.34 | -0.09 | 8.62 | -0.23 | -13.27 | -0.18 | 15.52 |
| opb 2/3 | -0.0233 | -0.1135 | -0.06 | -5.17 | -0.1 | 5.65 | -0.44 | -10.98 | -0.41 | 8.42 |
| opb 3/3 | -0.0338 | -0.1649 | -0.08 | -4.71 | -0.07 | 4.52 | -0.47 | -10.11 | -0.48 | 6.26 |
| opb 3/3 | -0.034 | -0.1658 | -0.11 | -4.89 | -0.06 | 3.77 | -0.47 | -10.47 | -0.5 | 5.37 |
| opb 2/3 | -0.0236 | -0.115 | -0.1 | -5.32 | -0.03 | 4.79 | -0.46 | -11.46 | -0.46 | 7.31 |
| opb 1/3 | -0.0129 | -0.0628 | -0.16 | -6.18 | -0.03 | 6.37 | -0.32 | -13.42 | -0.26 | 12.01 |
| axi-c 1/3 | -0.0077 | -0.0655 | -1.88 | 9.03 | 3.67 | -2.19 | -3.54 | 18.62 | 6.41 | -5.39 |
| axi-c 2/3 | -0.0154 | -0.1306 | -1.52 | 6.67 | 3.91 | -1 | -2.95 | 11.03 | 5.21 | -2.28 |
| axi-c 3/3 | -0.0233 | -0.1976 | -0.95 | 4.7 | 4.14 | 0.54 | -1.72 | 7.74 | 4.11 | 0.68 |
| axi-c 3/3 | -0.0232 | -0.1971 | -0.98 | 4.55 | 4.18 | 0.7 | -1.82 | 7.3 | 4.19 | 1.04 |
| axi-c 2/3 | -0.0153 | -0.1297 | -1.53 | 6.74 | 3.85 | -0.99 | -3.12 | 10.73 | 5.35 | -2.22 |
| axi-c 1/3 | -0.0076 | -0.0646 | -2.73 | 13.64 | 4.06 | -8.28 | -6.32 | 21.14 | 6.9 | -15.89 |
| axi-t 1/3 | 0.0085 | 0.058 | 1 | 5.54 | 0.39 | 10.59 | 2.59 | 11.6 | 1.89 | 18.67 |
| axi-t 2/3 | 0.017 | 0.1157 | 0.77 | 4.78 | 0.43 | 8.25 | 2.13 | 10.19 | 1.94 | 14.54 |
| axi-t 3/3 | 0.0254 | 0.1725 | 0.76 | 4.5 | 0.43 | 7.03 | 2.1 | 9.82 | 1.88 | 12.33 |
| axi-t 3/3 | 0.0254 | 0.1728 | 0.81 | 4.51 | 0.4 | 6.96 | 2.15 | 9.84 | 1.88 | 12.19 |
| axi-t 2/3 | 0.0167 | 0.1139 | 0.98 | 4.91 | 0.29 | 8.1 | 2.34 | 10.45 | 1.82 | 14.03 |
| axi-t 1/3 | 0.0087 | 0.0593 | 1.19 | 5.08 | 0.04 | 9.53 | 3.05 | 10.74 | 1.52 | 16.89 |

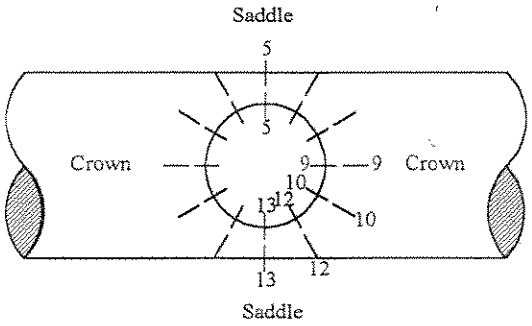
**Table 27: Measured SNCFs on intersections of brace 1,2 and chord for DT8 at preload level of 100 %**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

| DT9 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0382 | -0.083 | 3.45 | 1.84 | 0.78 | 0.05 | -1.51 | -1.39 | -1.23 | 0.04 |
| ipb 2/3 | -0.0737 | -0.1603 | 3 | 1.87 | 0.69 | 0.03 | -1.49 | -1.35 | -1.05 | 0.05 |
| ipb 3/3 | -0.1106 | -0.2403 | 2.78 | 1.82 | 0.65 | 0.02 | -1.51 | -1.33 | -0.95 | 0.05 |
| ipb 3/3 | -0.1115 | -0.2423 | 2.76 | 1.8 | 0.63 | 0.01 | -1.51 | -1.33 | -0.95 | 0.05 |
| ipb 2/3 | -0.0743 | -0.1616 | 3.04 | 1.88 | 0.7 | 0.02 | -1.53 | -1.36 | -1.07 | 0.06 |
| ipb 1/3 | -0.0384 | -0.0835 | 3.57 | 1.82 | 0.82 | 0.04 | -1.58 | -1.4 | -1.25 | 0.06 |
| opb 1/3 | -0.0162 | -0.0496 | 0.11 | -0.5 | -0.78 | -2.34 | 0.05 | 0.44 | 0.97 | 2.33 |
| opb 2/3 | -0.036 | -0.1102 | 0.07 | -0.42 | -0.74 | -1.73 | -0.05 | 0.42 | 0.95 | 2.34 |
| opb 3/3 | -0.0551 | -0.1684 | 0.07 | -0.38 | -0.69 | -1.49 | -0.03 | 0.39 | 0.94 | 2.33 |
| opb 3/3 | -0.0555 | -0.1696 | 0.07 | -0.4 | -0.68 | -1.45 | -0.02 | 0.39 | 0.96 | 2.33 |
| opb 2/3 | -0.036 | -0.11 | 0.06 | -0.43 | -0.69 | -1.64 | -0.04 | 0.38 | 0.94 | 2.38 |
| opb 1/3 | -0.0162 | -0.0496 | 0.11 | -0.5 | -0.72 | -2.09 | -0.11 | 0.31 | 0.83 | 2.47 |
| axi-c 1/3 | -0.0123 | -0.065 | 1.45 | 1.28 | 1.26 | 2.45 | 1.5 | 1.5 | 2.45 | 4.05 |
| axi-c 2/3 | -0.0245 | -0.1293 | 1.59 | 1.42 | 1.67 | 2.87 | 1.27 | 1.25 | 2.03 | 4.05 |
| axi-c 3/3 | -0.0368 | -0.1943 | 1.82 | 1.51 | 1.66 | 2.98 | 1.29 | 1.06 | 1.82 | 3.73 |
| axi-c 3/3 | -0.0368 | -0.1944 | 1.82 | 1.51 | 1.67 | 2.98 | 1.31 | 1.1 | 1.82 | 3.77 |
| axi-c 2/3 | -0.0245 | -0.1296 | 1.88 | 1.71 | 1.88 | 2.76 | 0.99 | 1.2 | 1.96 | 4.24 |
| axi-c 1/3 | -0.0123 | -0.0651 | 1.91 | 1.5 | 1.48 | 1.38 | 0.95 | 1.39 | 2.36 | 5.14 |
| axi-t 1/3 | 0.0125 | 0.0465 | 1.31 | 1.64 | 1.87 | 3.32 | 0.83 | 0.87 | 1.81 | 2.87 |
| axi-t 2/3 | 0.0245 | 0.0908 | 1.38 | 1.6 | 1.58 | 2.42 | 0.78 | 0.81 | 1.46 | 2.04 |
| axi-t 3/3 | 0.0364 | 0.135 | 1.35 | 1.48 | 1.28 | 1.79 | 0.72 | 0.71 | 1.22 | 1.49 |
| axi-t 3/3 | 0.0363 | 0.1348 | 1.3 | 1.47 | 1.28 | 1.78 | 0.74 | 0.74 | 1.2 | 1.49 |
| axi-t 2/3 | 0.0244 | 0.0906 | 1.31 | 1.55 | 1.54 | 2.38 | 0.75 | 0.85 | 1.46 | 2.07 |
| axi-t 1/3 | 0.0122 | 0.0453 | 1.35 | 1.67 | 1.87 | 2.96 | 0.83 | 1.11 | 1.89 | 3.18 |

**Table 28: Measured SNCFs on braces at intersections of brace and chord for DT9**

| DT9 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0382 | -0.083 | 0.49 | 2.07 | 1.23 | 0.17 | -2.65 | -2.98 | -1.79 | 0.2 |
| ipb 2/3 | -0.0737 | -0.1603 | 0.5 | 1.62 | 1.1 | 0.06 | -2.55 | -2.87 | -1.55 | 0.14 |
| ipb 3/3 | -0.1106 | -0.2403 | 0.51 | 1.41 | 1.02 | -0.02 | -2.51 | -2.8 | -1.43 | 0.06 |
| ipb 3/3 | -0.1115 | -0.2423 | 0.5 | 1.41 | 1.01 | -0.02 | -2.5 | -2.77 | -1.42 | 0.04 |
| ipb 2/3 | -0.0743 | -0.1616 | 0.5 | 1.67 | 1.14 | 0.08 | -2.58 | -2.89 | -1.57 | 0.12 |
| ipb 1/3 | -0.0384 | -0.0835 | 0.55 | 2.2 | 1.3 | 0.18 | -2.72 | -3.05 | -1.8 | 0.2 |
| opb 1/3 | -0.0162 | -0.0496 | 0.1 | -0.31 | -0.99 | -4.41 | -0.13 | 0.17 | 1.29 | 7.01 |
| opb 2/3 | -0.036 | -0.1102 | 0.1 | -0.25 | -1.17 | -3.79 | -0.19 | 0.07 | 1.32 | 7.03 |
| opb 3/3 | -0.0551 | -0.1684 | 0.06 | -0.25 | -1.22 | -3.6 | -0.17 | 0.09 | 1.35 | 6.96 |
| opb 3/3 | -0.0555 | -0.1696 | 0.04 | -0.24 | -1.2 | -3.58 | -0.15 | 0.11 | 1.35 | 6.98 |
| opb 2/3 | -0.036 | -0.11 | 0.08 | -0.23 | -1.12 | -3.79 | -0.22 | 0.06 | 1.32 | 7.09 |
| opb 1/3 | -0.0162 | -0.0496 | 0.12 | -0.18 | -0.82 | -4.09 | -0.38 | -0.08 | 1.1 | 7.36 |
| axi-c 1/3 | -0.0123 | -0.065 | 0.91 | 1.43 | 1.72 | 4.22 | 2.15 | 1.58 | 3.48 | 12.56 |
| axi-c 2/3 | -0.0245 | -0.1293 | 1.64 | 1.75 | 2.08 | 5.13 | 1.81 | 0.92 | 2.8 | 12.23 |
| axi-c 3/3 | -0.0368 | -0.1943 | 2.12 | 2.3 | 2.09 | 5.3 | 1.96 | 0.89 | 2.3 | 10.78 |
| axi-c 3/3 | -0.0368 | -0.1944 | 2.12 | 2.29 | 2.08 | 5.28 | 2.02 | 0.89 | 2.37 | 10.84 |
| axi-c 2/3 | -0.0245 | -0.1296 | 2.14 | 2.06 | 2.32 | 4.96 | 1.26 | 0.62 | 2.71 | 12.58 |
| axi-c 1/3 | -0.0123 | -0.0651 | 1.69 | 2.17 | 2 | 2.02 | 0.82 | 0.64 | 3.34 | 15.65 |
| axi-t 1/3 | 0.0125 | 0.0465 | 0.93 | 2.21 | 2.91 | 6.08 | 1.28 | 1 | 2.68 | 8.69 |
| axi-t 2/3 | 0.0245 | 0.0908 | 1.04 | 2.36 | 2.87 | 5.03 | 1.23 | 1.04 | 2.48 | 7.41 |
| axi-t 3/3 | 0.0364 | 0.135 | 1.08 | 2.39 | 2.76 | 4.6 | 1.21 | 1.11 | 2.33 | 6.55 |
| axi-t 3/3 | 0.0363 | 0.1348 | 1.07 | 2.36 | 2.78 | 4.66 | 1.23 | 1.1 | 2.32 | 6.47 |
| axi-t 2/3 | 0.0244 | 0.0906 | 1.02 | 2.34 | 2.87 | 5.05 | 1.2 | 1.06 | 2.45 | 7.41 |
| axi-t 1/3 | 0.0122 | 0.0453 | 1.13 | 2.53 | 2.72 | 5.41 | 1.2 | 0.96 | 2.69 | 9.25 |

**Table 29: Measured SNCFs on chord at intersections of brace and chord for DT9**

| DT9 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0395 | -0.0858 | 3.42 | 1.9 | 0.79 | 0.03 | -1.46 | -1.35 | -1.21 | 0.07 |
| ipb 2/3 | -0.0755 | -0.164 | 2.99 | 1.96 | 0.72 | -0.01 | -1.5 | -1.36 | -1.07 | 0.06 |
| ipb 3/3 | -0.1122 | -0.2439 | 2.77 | 1.89 | 0.68 | -0.02 | -1.51 | -1.34 | -0.97 | 0.05 |
| ipb 3/3 | -0.1121 | -0.2437 | 2.78 | 1.89 | 0.68 | -0.03 | -1.51 | -1.33 | -0.98 | 0.06 |
| ipb 2/3 | -0.0753 | -0.1636 | 3.07 | 2.01 | 0.74 | -0.02 | -1.52 | -1.37 | -1.09 | 0.09 |
| ipb 1/3 | -0.0397 | -0.0863 | 3.58 | 1.97 | 0.82 | -0.03 | -1.56 | -1.42 | -1.26 | 0.11 |
| opb 1/3 | -0.0166 | -0.0508 | 0.08 | -0.52 | -0.96 | -2.27 | 0.05 | 0.49 | 0.98 | 2.31 |
| opb 2/3 | -0.036 | -0.11 | 0.07 | -0.4 | -0.77 | -1.71 | 0.01 | 0.45 | 0.97 | 2.28 |
| opb 3/3 | -0.0546 | -0.1668 | 0.07 | -0.35 | -0.73 | -1.55 | -0.01 | 0.43 | 0.96 | 2.27 |
| opb 3/3 | -0.0547 | -0.1671 | 0.05 | -0.35 | -0.71 | -1.56 | -0.01 | 0.43 | 0.97 | 2.26 |
| opb 2/3 | -0.0353 | -0.1079 | 0.04 | -0.39 | -0.75 | -1.75 | -0.03 | 0.42 | 0.95 | 2.26 |
| opb 1/3 | -0.0158 | -0.0484 | -0.03 | -0.45 | -0.86 | -2.35 | -0.08 | 0.34 | 0.83 | 2.25 |
| axi-c 1/3 | -0.0124 | -0.0654 | 0.32 | 0.33 | 0.6 | 2.91 | 2.82 | 2.31 | 3.17 | 4.28 |
| axi-c 2/3 | -0.0246 | -0.1296 | 0.96 | 0.9 | 1.4 | 3.01 | 2.32 | 1.59 | 2.35 | 4.22 |
| axi-c 3/3 | -0.0368 | -0.1944 | 1.24 | 1.07 | 1.59 | 3.15 | 2.4 | 1.4 | 2.03 | 3.86 |
| axi-c 3/3 | -0.0368 | -0.1944 | 1.24 | 1.07 | 1.6 | 3.15 | 2.4 | 1.4 | 2.01 | 3.85 |
| axi-c 2/3 | -0.0246 | -0.1299 | 1.09 | 1.02 | 1.49 | 2.85 | 1.9 | 1.56 | 2.28 | 4.38 |
| axi-c 1/3 | -0.0123 | -0.065 | 0.9 | 0.51 | 0.55 | 1.32 | 1.9 | 2.04 | 3.34 | 5.68 |
| axi-t 1/3 | 0.0123 | 0.0456 | 1.33 | 1.51 | 1.94 | 3.75 | 1.05 | 1.15 | 1.98 | 3.28 |
| axi-t 2/3 | 0.0244 | 0.0907 | 1.19 | 1.36 | 1.49 | 2.32 | 0.95 | 1 | 1.65 | 2.14 |
| axi-t 3/3 | 0.0366 | 0.1357 | 1.18 | 1.29 | 1.29 | 1.74 | 0.9 | 0.88 | 1.42 | 1.56 |
| axi-t 3/3 | 0.0366 | 0.1357 | 1.15 | 1.29 | 1.27 | 1.73 | 0.9 | 0.88 | 1.4 | 1.57 |
| axi-t 2/3 | 0.0246 | 0.0913 | 1.18 | 1.35 | 1.5 | 2.27 | 0.9 | 1 | 1.66 | 2.24 |
| axi-t 1/3 | 0.0121 | 0.045 | 1.35 | 1.53 | 1.84 | 3.49 | 1.02 | 1.26 | 2.06 | 3.47 |

**Table 30: Measured SNCFs on braces at intersections of brace and chord for DT9 at preload level of 50%**

| DT9 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0395 | -0.0858 | 0.5 | 2.11 | 1.26 | 0.11 | -2.61 | -2.87 | -1.8 | 0.31 |
| ipb 2/3 | -0.0755 | -0.164 | 0.53 | 1.65 | 1.13 | -0.01 | -2.55 | -2.86 | -1.59 | 0.24 |
| ipb 3/3 | -0.1122 | -0.2439 | 0.52 | 1.44 | 1.05 | -0.07 | -2.52 | -2.78 | -1.46 | 0.13 |
| ipb 3/3 | -0.1121 | -0.2437 | 0.52 | 1.44 | 1.06 | -0.07 | -2.53 | -2.8 | -1.47 | 0.13 |
| ipb 2/3 | -0.0753 | -0.1636 | 0.54 | 1.71 | 1.17 | -0.01 | -2.61 | -2.93 | -1.63 | 0.25 |
| ipb 1/3 | -0.0397 | -0.0863 | 0.59 | 2.25 | 1.38 | 0.05 | -2.79 | -3.05 | -1.88 | 0.38 |
| opb 1/3 | -0.0166 | -0.0508 | -0.02 | -0.24 | -1.18 | -4.6 | 0.12 | 0.25 | 1.33 | 6.93 |
| opb 2/3 | -0.036 | -0.11 | 0.04 | -0.19 | -1.25 | -3.97 | -0.04 | 0.17 | 1.3 | 6.9 |
| opb 3/3 | -0.0546 | -0.1668 | 0.04 | -0.19 | -1.3 | -3.82 | -0.08 | 0.13 | 1.31 | 6.89 |
| opb 3/3 | -0.0547 | -0.1671 | 0.06 | -0.19 | -1.29 | -3.82 | -0.08 | 0.14 | 1.29 | 6.88 |
| opb 2/3 | -0.0353 | -0.1079 | 0.09 | -0.17 | -1.21 | -4.05 | -0.11 | 0.1 | 1.23 | 6.91 |
| opb 1/3 | -0.0158 | -0.0484 | 0.1 | -0.15 | -1.02 | -4.65 | -0.21 | 0.03 | 0.98 | 6.96 |
| axi-c 1/3 | -0.0124 | -0.0654 | -0.65 | -0.55 | 0.65 | 5.15 | 5.26 | 3.1 | 4.6 | 12.97 |
| axi-c 2/3 | -0.0246 | -0.1296 | 0.59 | 0.62 | 1.76 | 5.45 | 3.43 | 1.64 | 3.4 | 12.77 |
| axi-c 3/3 | -0.0368 | -0.1944 | 1.41 | 1.26 | 1.84 | 5.61 | 2.84 | 1.3 | 2.71 | 11.28 |
| axi-c 3/3 | -0.0368 | -0.1944 | 1.41 | 1.3 | 1.87 | 5.63 | 2.83 | 1.27 | 2.72 | 11.32 |
| axi-c 2/3 | -0.0246 | -0.1299 | 0.83 | 0.85 | 1.96 | 5.25 | 2.86 | 1.36 | 3.36 | 13.32 |
| axi-c 1/3 | -0.0123 | -0.065 | 0.19 | 0.23 | 0.75 | 2.24 | 3.14 | 2.05 | 4.98 | 17.31 |
| axi-t 1/3 | 0.0123 | 0.0456 | 1.01 | 1.63 | 2.58 | 7.06 | 1.19 | 1.12 | 3.05 | 9.73 |
| axi-t 2/3 | 0.0244 | 0.0907 | 0.89 | 1.75 | 2.73 | 5.38 | 1.32 | 1.19 | 2.78 | 7.85 |
| axi-t 3/3 | 0.0366 | 0.1357 | 0.96 | 1.95 | 2.65 | 4.68 | 1.3 | 1.3 | 2.71 | 6.74 |
| axi-t 3/3 | 0.0366 | 0.1357 | 0.95 | 1.97 | 2.64 | 4.67 | 1.28 | 1.33 | 2.71 | 6.71 |
| axi-t 2/3 | 0.0246 | 0.0913 | 0.89 | 1.8 | 2.65 | 5.23 | 1.25 | 1.23 | 2.82 | 8.05 |
| axi-t 1/3 | 0.0121 | 0.045 | 1.04 | 1.74 | 2.46 | 6.58 | 1.15 | 1.24 | 3.14 | 10.3 |

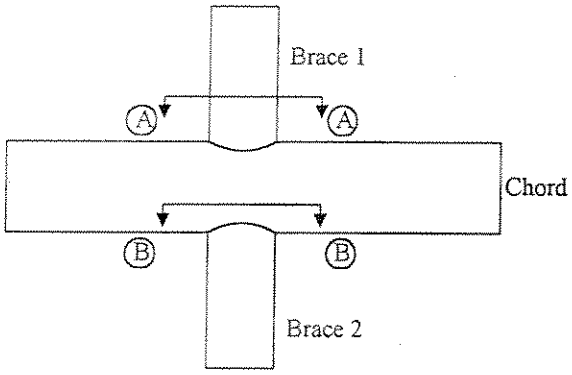
**Table 31: Measured SNCFs on chord at intersections of brace and chord for DT9 at preload level of 50%**

| DT9 | pl. cap | design | BC;1,br1 | BI;2,br1 | BI;4,br1 | BS;5,br1 | BC;9,br2 | BI;10,br2 | BI;12,br2 | BS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0383 | -0.0832 | 3.61 | 1.72 | 0.82 | -0.02 | -1.47 | -1.36 | -1.25 | 0.05 |
| ipb 2/3 | -0.0767 | -0.1668 | 3.18 | 1.87 | 0.74 | -0.03 | -1.5 | -1.37 | -1.1 | 0.05 |
| ipb 3/3 | -0.1132 | -0.2461 | 2.9 | 1.86 | 0.68 | -0.03 | -1.52 | -1.36 | -0.99 | 0.06 |
| ipb 3/3 | -0.1131 | -0.2459 | 2.89 | 1.87 | 0.67 | -0.03 | -1.52 | -1.37 | -0.99 | 0.07 |
| ipb 2/3 | -0.076 | -0.1653 | 3.23 | 1.95 | 0.73 | -0.01 | -1.54 | -1.43 | -1.11 | 0.07 |
| ipb 1/3 | -0.0387 | -0.0841 | 3.77 | 1.89 | 0.84 | -0.03 | -1.56 | -1.52 | -1.35 | 0.09 |
| opb 1/3 | -0.0164 | -0.0501 | 0.11 | -0.41 | -0.77 | -2.44 | 0.08 | 0.49 | 0.93 | 2.12 |
| opb 2/3 | -0.0361 | -0.1103 | 0.06 | -0.41 | -0.77 | -2.04 | 0 | 0.45 | 0.91 | 2.21 |
| opb 3/3 | -0.0557 | -0.1703 | 0.08 | -0.39 | -0.74 | -1.77 | -0.01 | 0.43 | 0.94 | 2.23 |
| opb 3/3 | -0.0562 | -0.1717 | 0.07 | -0.38 | -0.73 | -1.76 | -0.01 | 0.43 | 0.95 | 2.22 |
| opb 2/3 | -0.0365 | -0.1117 | 0.07 | -0.41 | -0.74 | -2.03 | -0.02 | 0.43 | 0.91 | 2.19 |
| opb 1/3 | -0.0168 | -0.0514 | 0.05 | -0.35 | -0.7 | -2.42 | 0 | 0.43 | 0.86 | 2.2 |
| axi-c 1/3 | -0.0122 | -0.0645 | 0 | 0.24 | 0.66 | 3.81 | 3.6 | 2.39 | 2.79 | 2.96 |
| axi-c 2/3 | -0.0246 | -0.1297 | 0.87 | 0.98 | 1.57 | 3.64 | 2.53 | 1.52 | 1.97 | 3.45 |
| axi-c 3/3 | -0.0367 | -0.1937 | 1.03 | 1.09 | 1.73 | 3.64 | 2.95 | 1.36 | 1.65 | 3.13 |
| axi-c 3/3 | -0.0367 | -0.1936 | 1.03 | 1.12 | 1.8 | 3.69 | 2.92 | 1.36 | 1.74 | 3.3 |
| axi-c 2/3 | -0.0245 | -0.1294 | 0.96 | 1.15 | 1.78 | 3.7 | 2.21 | 1.51 | 2.14 | 3.78 |
| axi-c 1/3 | -0.0123 | -0.065 | 0.46 | 0.51 | 1.02 | 3.14 | 2.61 | 2.14 | 3.09 | 4.6 |
| axi-t 1/3 | 0.0126 | 0.0468 | 1.19 | 1.24 | 1.62 | 3.68 | 1.02 | 1.25 | 2.19 | 3.96 |
| axi-t 2/3 | 0.0245 | 0.091 | 1.14 | 1.34 | 1.65 | 3.08 | 0.99 | 1.11 | 1.95 | 3.16 |
| axi-t 3/3 | 0.0366 | 0.1357 | 1.15 | 1.33 | 1.38 | 2.21 | 0.89 | 0.93 | 1.59 | 2.3 |
| axi-t 3/3 | 0.0366 | 0.1358 | 1.12 | 1.35 | 1.4 | 2.18 | 0.89 | 0.93 | 1.56 | 2.32 |
| axi-t 2/3 | 0.0246 | 0.0911 | 1.1 | 1.34 | 1.63 | 3.07 | 0.99 | 1.15 | 1.94 | 3.23 |
| axi-t 1/3 | 0.0123 | 0.0458 | 1.13 | 1.19 | 1.53 | 3.26 | 1.13 | 1.45 | 2.29 | 4.44 |

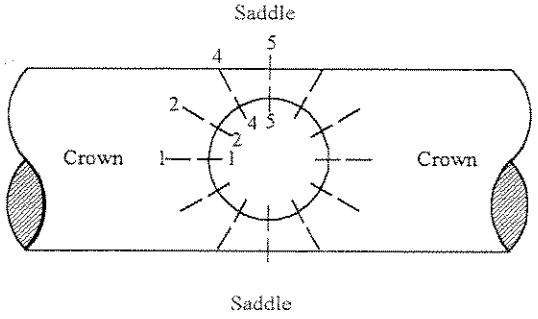
**Table 32: Measured SNCFs on braces at intersections of brace and chord for DT9 at preload level of 100%**

| DT9 | pl. cap | design | CC;1,br1 | CI;2,br1 | CI;4,br1 | CS;5,br1 | CC;9,br2 | CI;10,br2 | CI;12,br2 | CS;13,br2 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | -0.0383 | -0.0832 | 0.97 | 2.28 | 1.26 | 0.11 | -2.72 | -3.06 | -1.72 | 0.28 |
| ipb 2/3 | -0.0767 | -0.1668 | 0.74 | 1.76 | 1.07 | 0.03 | -2.65 | -2.99 | -1.53 | 0.22 |
| ipb 3/3 | -0.1132 | -0.2461 | 0.69 | 1.49 | 1 | -0.05 | -2.57 | -2.88 | -1.43 | 0.15 |
| ipb 3/3 | -0.1131 | -0.2459 | 0.69 | 1.48 | 1.01 | -0.05 | -2.57 | -2.88 | -1.43 | 0.15 |
| ipb 2/3 | -0.076 | -0.1653 | 0.77 | 1.8 | 1.14 | 0.02 | -2.68 | -3.05 | -1.58 | 0.23 |
| ipb 1/3 | -0.0387 | -0.0841 | 1.08 | 2.39 | 1.41 | 0.07 | -2.84 | -3.21 | -1.86 | 0.27 |
| opb 1/3 | -0.0164 | -0.0501 | 0.15 | 0.14 | -0.83 | -5.02 | 0.07 | 0.25 | 1.18 | 6.48 |
| opb 2/3 | -0.0361 | -0.1103 | 0.1 | -0.09 | -1.02 | -4.59 | -0.06 | 0.12 | 1.23 | 6.71 |
| opb 3/3 | -0.0557 | -0.1703 | 0.1 | -0.14 | -1.17 | -4.3 | -0.08 | 0.15 | 1.28 | 6.71 |
| opb 3/3 | -0.0562 | -0.1717 | 0.11 | -0.13 | -1.16 | -4.28 | -0.09 | 0.16 | 1.28 | 6.74 |
| opb 2/3 | -0.0365 | -0.1117 | 0.14 | -0.07 | -1 | -4.59 | -0.11 | 0.12 | 1.19 | 6.78 |
| opb 1/3 | -0.0168 | -0.0514 | 0.19 | 0.29 | -0.7 | -4.85 | -0.07 | 0.09 | 0.96 | 6.79 |
| axi-c 1/3 | -0.0122 | -0.0645 | -1.04 | -1.07 | 0.58 | 6.91 | 6.82 | 3.68 | 4 | 9 |
| axi-c 2/3 | -0.0246 | -0.1297 | 0.52 | 0.63 | 2.14 | 6.74 | 3.79 | 1.66 | 2.83 | 10.36 |
| axi-c 3/3 | -0.0367 | -0.1937 | 1.13 | 1.18 | 2.1 | 6.64 | 2.83 | 1.35 | 2.38 | 9.47 |
| axi-c 3/3 | -0.0367 | -0.1936 | 1.17 | 1.15 | 2.13 | 6.81 | 2.77 | 1.35 | 2.51 | 9.85 |
| axi-c 2/3 | -0.0245 | -0.1294 | 0.7 | 0.67 | 2.33 | 6.92 | 3.41 | 1.52 | 2.97 | 11.25 |
| axi-c 1/3 | -0.0123 | -0.065 | -0.23 | -0.46 | 1.09 | 5.85 | 4.74 | 2.71 | 4.52 | 13.5 |
| axi-t 1/3 | 0.0126 | 0.0468 | 0.72 | 0.96 | 2.3 | 6.66 | 1.22 | 1.17 | 3.25 | 11.78 |
| axi-t 2/3 | 0.0245 | 0.091 | 0.74 | 1.38 | 2.43 | 6.31 | 1.33 | 1.27 | 3.29 | 11.85 |
| axi-t 3/3 | 0.0366 | 0.1357 | 0.85 | 1.73 | 2.56 | 5.6 | 1.31 | 1.2 | 3.03 | 9.64 |
| axi-t 3/3 | 0.0366 | 0.1358 | 0.84 | 1.73 | 2.52 | 5.57 | 1.3 | 1.18 | 3.03 | 9.68 |
| axi-t 2/3 | 0.0246 | 0.0911 | 0.7 | 1.43 | 2.31 | 6.26 | 1.32 | 1.24 | 3.32 | 12.06 |
| axi-t 1/3 | 0.0123 | 0.0458 | 0.71 | 0.94 | 1.88 | 5.87 | 1.24 | 1.1 | 3.55 | 13.28 |

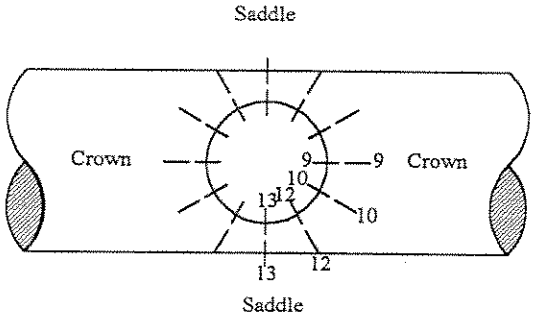
**Table 33: Measured SNCFs on chord at intersections of brace and chord for DT9 at preload level of 100%**




Elevation on DT Joint




View 'A' on brace 1




View 'B' on brace 2

| T1 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0416 | 0.0513 | -1.29 | -0.08 | 1.35 | 0.01 | -2.3 | -0.06 | 2.32 | 0.04 |
| ipb 2/3 | 0.0845 | 0.1042 | -1.37 | -0.03 | 1.37 | 0 | -2.32 | -0.01 | 2.31 | 0.04 |
| ipb 3/3 | 0.1265 | 0.1559 | -1.5 | 0.02 | 1.34 | 0.07 | -2.02 | 0.06 | 2.22 | 0.15 |
| ipb 3/3 | 0.1264 | 0.1557 | -1.49 | 0.02 | 1.35 | 0.06 | -2.02 | 0.04 | 2.21 | 0.13 |
| ipb 2/3 | 0.0844 | 0.104 | -1.36 | -0.03 | 1.4 | 0.01 | -2.37 | -0.05 | 2.32 | 0.03 |
| ipb 1/3 | 0.0418 | 0.0516 | -1.35 | -0.08 | 1.39 | 0.03 | -2.4 | -0.09 | 2.38 | 0.06 |
| opb 1/3 | 0.028 | 0.057 | 0.04 | -3.05 | 0.07 | 2.66 | 0.16 | -4.86 | 0.11 | 5.15 |
| opb 2/3 | 0.0594 | 0.1207 | 0.1 | -2.92 | 0.05 | 2.49 | 0.15 | -4.3 | 0.11 | 4.78 |
| opb 3/3 | 0.0895 | 0.1819 | 0.11 | -2.81 | 0.08 | 2.38 | 0.17 | -3.5 | 0.13 | 4.5 |
| opb 3/3 | 0.0907 | 0.1844 | 0.11 | -2.81 | 0.07 | 2.37 | 0.18 | -3.5 | 0.11 | 4.51 |
| opb 2/3 | 0.0607 | 0.1234 | 0.08 | -3 | 0.05 | 2.55 | 0.14 | -4.46 | 0.06 | 4.93 |
| opb 1/3 | 0.03 | 0.0609 | 0.05 | -3.13 | 0.03 | 2.74 | 0.07 | -5.12 | 0.09 | 5.35 |
| axi-c 1/3 | -0.0155 | -0.0445 | 0.89 | 1.15 | 1.09 | 5.89 | 5.73 | 0.85 | 5.14 | 10.41 |
| axi-c 2/3 | -0.031 | -0.0892 | 1.75 | 1.53 | 0.64 | 3.53 | 6.02 | 2.1 | 4.12 | 6.17 |
| axi-c 3/3 | -0.0464 | -0.1337 | 2.15 | 1.69 | 0.7 | 2.45 | 5.49 | 2.48 | 3.79 | 4.46 |
| axi-c 3/3 | -0.0464 | -0.1337 | 2.16 | 1.69 | 0.67 | 2.45 | 5.49 | 2.48 | 3.81 | 4.46 |
| axi-c 2/3 | -0.0311 | -0.0895 | 1.83 | 1.39 | 0.48 | 3.84 | 6.04 | 1.86 | 3.92 | 6.48 |
| axi-c 1/3 | -0.0155 | -0.0446 | 1.56 | 0.25 | 0.07 | 7.14 | 6.75 | -0.57 | 4.02 | 11.96 |
| axi-t 1/3 | 0.0157 | 0.0356 | 0.6 | 3.49 | 0.71 | 4.78 | 5.51 | 4.93 | 4.84 | 8.55 |
| axi-t 2/3 | 0.0313 | 0.0709 | 0.79 | 3.35 | 0.88 | 4.07 | 5.24 | 4.68 | 4.52 | 6.98 |
| axi-t 3/3 | 0.0467 | 0.1058 | 0.83 | 2.85 | 1.13 | 5.42 | 5.18 | 2.91 | 4.6 | 6.54 |
| axi-t 3/3 | 0.0467 | 0.1059 | 0.95 | 2.75 | 0.84 | 3.82 | 5.18 | 3.84 | 4.39 | 6.63 |
| axi-t 2/3 | 0.0315 | 0.0715 | 0.87 | 2.63 | 0.74 | 4.64 | 5.38 | 3.64 | 4.49 | 8.22 |
| axi-t 1/3 | 0.0159 | 0.036 | 0.75 | 1.46 | 0.72 | 6.4 | 5.55 | 1.87 | 4.87 | 12.05 |

**Table 34: Measured SNCFs on intersection of brace and chord for T1**

| T1 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0419 | 0.0517 | -1.31 | -0.03 | 1.36 | 0.03 | -2.39 | -0.02 | 2.28 | 0.06 |
| ipb 2/3 | 0.0845 | 0.1042 | -1.33 | -0.06 | 1.36 | 0.01 | -2.42 | -0.06 | 2.31 | 0 |
| ipb 3/3 | 0.1264 | 0.1557 | -1.33 | -0.08 | 1.38 | -0.01 | -2.43 | -0.08 | 2.29 | -0.02 |
| ipb 3/3 | 0.1265 | 0.1559 | -1.33 | -0.08 | 1.37 | -0.02 | -2.43 | -0.08 | 2.28 | -0.01 |
| ipb 2/3 | 0.085 | 0.1047 | -1.33 | -0.03 | 1.37 | 0 | -2.44 | -0.04 | 2.33 | 0.03 |
| ipb 1/3 | 0.042 | 0.0518 | -1.34 | -0.02 | 1.34 | 0 | -2.47 | -0.02 | 2.3 | 0.1 |
| opb 1/3 | 0.0286 | 0.0582 | 0.09 | -3.04 | 0 | 2.63 | 0.09 | -4.73 | -0.04 | 5.02 |
| opb 2/3 | 0.059 | 0.1199 | 0.09 | -2.98 | 0.01 | 2.53 | 0.08 | -4.58 | -0.1 | 4.77 |
| opb 3/3 | 0.0895 | 0.1819 | 0.13 | -3 | 0.02 | 2.45 | 0.11 | -4.04 | -0.09 | 4.65 |
| opb 3/3 | 0.0904 | 0.1838 | 0.13 | -3 | 0.02 | 2.46 | 0.12 | -4.1 | -0.09 | 4.71 |
| opb 2/3 | 0.0598 | 0.1215 | 0.11 | -3.02 | -0.01 | 2.54 | 0.11 | -4.89 | -0.14 | 5.07 |
| opb 1/3 | 0.0309 | 0.0628 | 0.18 | -2.98 | -0.11 | 2.66 | 0.28 | -5.02 | -0.23 | 5.24 |
| axi-c 1/3 | -0.0155 | -0.0446 | 0.97 | 1.35 | 0.58 | 7.12 | 6.74 | 1.1 | 5.33 | 13.3 |
| axi-c 2/3 | -0.0309 | -0.089 | 1.57 | 2.33 | 0.41 | 4.89 | 7.34 | 3.03 | 4.71 | 9.12 |
| axi-c 3/3 | -0.0464 | -0.1336 | 1.73 | 2.5 | 0.52 | 3.5 | 6.96 | 3.67 | 4.73 | 6.63 |
| axi-c 3/3 | -0.0464 | -0.1336 | 1.7 | 2.5 | 0.49 | 3.5 | 6.94 | 3.72 | 4.71 | 6.65 |
| axi-c 2/3 | -0.031 | -0.0892 | 1.58 | 2.04 | 0.3 | 5.37 | 7.28 | 2.61 | 4.67 | 9.89 |
| axi-c 1/3 | -0.0155 | -0.0445 | 1.45 | 0.1 | -0.18 | 8.61 | 7.76 | -1.1 | 4.27 | 16.5 |
| axi-t 1/3 | 0.016 | 0.0362 | 0.63 | 2.8 | 0.92 | 4.67 | 5.13 | 3.56 | 5.17 | 8.5 |
| axi-t 2/3 | 0.0313 | 0.071 | 0.89 | 2.88 | 0.81 | 3.82 | 5.24 | 3.78 | 4.72 | 6.64 |
| axi-t 3/3 | 0.0464 | 0.1051 | 0.93 | 2.54 | 0.92 | 3.59 | 5.14 | 3.3 | 4.62 | 6.11 |
| axi-t 3/3 | 0.0464 | 0.1051 | 0.94 | 2.54 | 0.92 | 3.59 | 5.18 | 3.3 | 4.62 | 6.08 |
| axi-t 2/3 | 0.0313 | 0.071 | 0.88 | 2.54 | 0.84 | 4.12 | 5.31 | 3.25 | 4.72 | 7.23 |
| axi-t 1/3 | 0.0158 | 0.0357 | 0.78 | 2.14 | 0.7 | 5.39 | 5.55 | 2.55 | 4.93 | 9.92 |

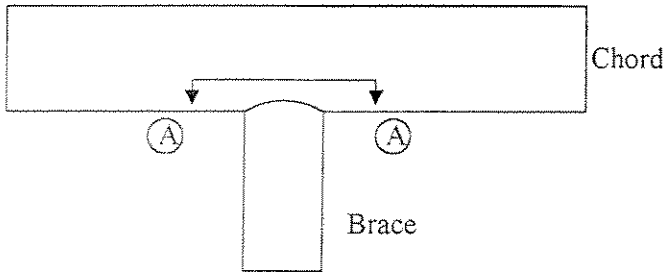
**Table 35: Measured SNCFs on intersection of brace and chord for T1 at preload level of 45%**

| T1 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0424 | 0.0522 | -1.32 | -0.07 | 1.39 | 0 | -2.19 | -0.11 | 2.21 | -0.03 |
| ipb 2/3 | 0.0849 | 0.1047 | -1.31 | -0.09 | 1.39 | -0.04 | -2.27 | -0.11 | 2.21 | -0.04 |
| ipb 3/3 | 0.1267 | 0.1562 | -1.31 | -0.09 | 1.39 | -0.04 | -2.34 | -0.13 | 2.23 | -0.05 |
| ipb 3/3 | 0.1267 | 0.1562 | -1.32 | -0.09 | 1.39 | -0.04 | -2.33 | -0.13 | 2.21 | -0.05 |
| ipb 2/3 | 0.0852 | 0.105 | -1.32 | -0.08 | 1.39 | -0.03 | -2.33 | -0.09 | 2.25 | -0.05 |
| ipb 1/3 | 0.0419 | 0.0517 | -1.33 | -0.05 | 1.41 | -0.02 | -2.3 | -0.05 | 2.27 | -0.03 |
| opb 1/3 | 0.0276 | 0.0561 | 0.16 | -2.89 | 0.05 | 2.53 | 0.11 | -4.48 | 0 | 4.63 |
| opb 2/3 | 0.0576 | 0.117 | 0.16 | -2.95 | 0.03 | 2.43 | 0.09 | -4.34 | -0.08 | 4.53 |
| opb 3/3 | 0.0882 | 0.1794 | 0.17 | -2.89 | 0.03 | 2.35 | 0.1 | -4.03 | -0.05 | 4.31 |
| opb 3/3 | 0.0903 | 0.1836 | 0.17 | -2.91 | 0.04 | 2.33 | 0.11 | -4.05 | -0.05 | 4.33 |
| opb 2/3 | 0.0601 | 0.1223 | 0.17 | -2.97 | 0.03 | 2.37 | 0.15 | -4.39 | -0.07 | 4.59 |
| opb 1/3 | 0.0295 | 0.06 | 0.21 | -2.92 | -0.02 | 2.45 | 0.22 | -4.46 | -0.19 | 4.66 |
| axi-c 1/3 | -0.0155 | -0.0446 | 2.21 | -0.88 | -0.35 | 6.53 | 7.33 | -2.63 | 2.43 | 11.59 |
| axi-c 2/3 | -0.0309 | -0.0891 | 2.05 | 1.31 | -0.23 | 4.75 | 7.34 | 0.92 | 2.87 | 8.39 |
| axi-c 3/3 | -0.0463 | -0.1334 | 1.89 | 2.49 | 0.08 | 3.74 | 7.2 | 3.05 | 3.48 | 6.44 |
| axi-c 3/3 | -0.0463 | -0.1334 | 1.93 | 2.52 | 0.09 | 3.71 | 7.19 | 3.05 | 3.48 | 6.41 |
| axi-c 2/3 | -0.0365 | -0.1051 | 2.02 | 1.88 | -0.21 | 4.33 | 7.36 | 1.93 | 3.13 | 7.69 |
| axi-c 1/3 | -0.0154 | -0.0442 | 2.57 | -0.88 | -0.63 | 6.76 | 7.93 | -3.06 | 2.28 | 12.19 |
| axi-t 1/3 | 0.0157 | 0.0357 | 1.6 | 2.02 | 0.48 | 2.88 | 5.91 | 2.35 | 3.76 | 4.92 |
| axi-t 2/3 | 0.0316 | 0.0716 | 1.23 | 2.37 | 1.05 | 2.86 | 5.22 | 2.76 | 4.38 | 4.46 |
| axi-t 3/3 | 0.0464 | 0.1051 | 1.09 | 2.22 | 1.18 | 2.74 | 4.98 | 2.72 | 4.61 | 4.38 |
| axi-t 3/3 | 0.0464 | 0.1051 | 1.08 | 2.17 | 1.11 | 2.68 | 4.9 | 2.75 | 4.6 | 4.35 |
| axi-t 2/3 | 0.0315 | 0.0714 | 1.15 | 2.05 | 0.93 | 2.96 | 5.1 | 2.52 | 4.5 | 4.86 |
| axi-t 1/3 | 0.0157 | 0.0356 | 1.24 | 1.22 | 0.79 | 3.87 | 5.42 | 1.43 | 4.34 | 6.5 |

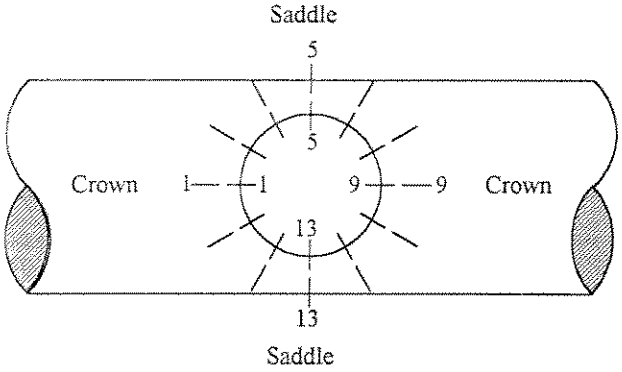
**Table 36: Measured SNCFs on intersection of brace and chord for T1 at preload level of 90 %**

| T1 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0428 | 0.0527 | -1.33 | -0.06 | 1.38 | 0.02 | -2.26 | -0.07 | 2.25 | 0.02 |
| ipb 2/3 | 0.0859 | 0.1059 | -1.32 | -0.08 | 1.39 | -0.01 | -2.32 | -0.09 | 2.27 | -0.01 |
| ipb 3/3 | 0.1271 | 0.1567 | -1.31 | -0.1 | 1.39 | -0.03 | -2.35 | -0.09 | 2.26 | -0.03 |
| ipb 3/3 | 0.1273 | 0.1569 | -1.3 | -0.1 | 1.4 | -0.03 | -2.33 | -0.09 | 2.26 | -0.03 |
| ipb 2/3 | 0.0855 | 0.1054 | -1.31 | -0.06 | 1.4 | -0.03 | -2.37 | -0.07 | 2.3 | -0.01 |
| ipb 1/3 | 0.0425 | 0.0524 | -1.32 | -0.07 | 1.41 | 0.01 | -2.37 | -0.02 | 2.37 | -0.01 |
| opb 1/3 | 0.0289 | 0.0587 | 0.09 | -2.87 | 0.02 | 2.5 | 0.06 | -4.51 | -0.08 | 4.77 |
| opb 2/3 | 0.0588 | 0.1195 | 0.14 | -2.84 | -0.01 | 2.43 | 0.07 | -4.44 | -0.1 | 4.71 |
| opb 3/3 | 0.091 | 0.185 | 0.15 | -2.82 | 0 | 2.32 | 0.08 | -4.15 | -0.09 | 4.46 |
| opb 3/3 | 0.0924 | 0.1879 | 0.16 | -2.85 | -0.01 | 2.34 | 0.11 | -4.15 | -0.09 | 4.46 |
| opb 2/3 | 0.0621 | 0.1262 | 0.16 | -2.83 | -0.03 | 2.38 | 0.14 | -4.4 | -0.12 | 4.67 |
| opb 1/3 | 0.0302 | 0.0614 | 0.19 | -2.96 | -0.11 | 2.59 | 0.27 | -4.59 | -0.26 | 4.78 |
| axi-c 1/3 | -0.0154 | -0.0443 | 1.28 | -1.32 | 0.51 | 6.67 | 6.14 | -3.4 | 3.87 | 11.91 |
| axi-c 2/3 | -0.0309 | -0.089 | 1.54 | 0.9 | 0.3 | 4.74 | 6.46 | 0.33 | 3.8 | 8.5 |
| axi-c 3/3 | -0.0463 | -0.1333 | 1.29 | 1.84 | 0.61 | 3.98 | 6.09 | 1.97 | 4.38 | 7.04 |
| axi-c 3/3 | -0.0463 | -0.1333 | 1.29 | 1.84 | 0.64 | 4 | 6.05 | 2.02 | 4.33 | 6.97 |
| axi-c 2/3 | -0.031 | -0.0893 | 1.44 | 0.82 | 0.35 | 4.93 | 6.38 | 0.31 | 3.95 | 8.72 |
| axi-c 1/3 | -0.0154 | -0.0443 | 1.45 | -1.61 | 0.31 | 7.21 | 6.59 | -3.89 | 3.87 | 13.1 |
| axi-t 1/3 | 0.0159 | 0.036 | 0.9 | 0.5 | 1.16 | 4.46 | 5.36 | 0.04 | 4.64 | 7.7 |
| axi-t 2/3 | 0.0311 | 0.0706 | 1.02 | 1.55 | 1.03 | 3.35 | 5.29 | 1.81 | 4.61 | 5.72 |
| axi-t 3/3 | 0.0464 | 0.1052 | 1.07 | 2.07 | 0.91 | 2.77 | 5.38 | 2.67 | 4.41 | 4.64 |
| axi-t 3/3 | 0.0464 | 0.1052 | 1.18 | 2.1 | 0.92 | 2.75 | 5.26 | 2.64 | 4.43 | 4.64 |
| axi-t 2/3 | 0.0315 | 0.0714 | 1.36 | 1.95 | 0.77 | 3.07 | 5.6 | 2.35 | 4.21 | 5.22 |
| axi-t 1/3 | 0.0157 | 0.0357 | 1.53 | 0.99 | 0.42 | 4.09 | 6.07 | 0.76 | 3.95 | 7.29 |

**Table 37: Measured SNCFs on intersection of brace and chord for T1 at preload level of 130 %**




Elevation on T Joint




View 'A' on brace

**SCNFs grouted Test Specimen: T3.**

| T3 | pl. cap | design | BC;1 | BI;2 | BI;4 | BS;5 | BC;9 | BI;10 | BI;12 | BS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0312 | 0.0467 | -1.23 | -1.02 | -1.04 | -0.09 | 1.38 | 1.34 | 0.92 | -0.11 |
| ipb 2/3 | 0.0624 | 0.0934 | -1.48 | -0.99 | -0.92 | -0.01 | 1.31 | 1.3 | 0.98 | -0.03 |
| ipb 3/3 | 0.0937 | 0.1403 | -1.53 | -1.02 | -0.84 | 0.02 | 1.29 | 1.28 | 0.95 | -0.01 |
| ipb 3/3 | 0.0938 | 0.1404 | -1.53 | -1.01 | -0.84 | 0.01 | 1.29 | 1.28 | 0.96 | -0.01 |
| ipb 2/3 | 0.0626 | 0.0937 | -1.48 | -0.98 | -0.93 | -0.03 | 1.32 | 1.3 | 0.98 | -0.03 |
| ipb 1/3 | 0.0314 | 0.047 | -1.26 | -1.02 | -1.07 | -0.12 | 1.38 | 1.3 | 0.97 | -0.09 |
| opb 1/3 | -0.0289 | -0.0607 | 0.13 | 0.58 | 1.02 | 1.89 | -0.4 | -0.84 | -1.95 | -2.69 |
| opb 2/3 | -0.0587 | -0.1234 | 0.06 | 0.52 | 0.86 | 1.48 | -0.22 | -0.66 | -1.69 | -2.29 |
| opb 3/3 | -0.0891 | -0.1873 | 0.02 | 0.52 | 0.85 | 1.31 | -0.18 | -0.57 | -1.51 | -2.1 |
| opb 3/3 | -0.0897 | -0.1886 | 0.02 | 0.53 | 0.84 | 1.32 | -0.18 | -0.56 | -1.5 | -2.11 |
| opb 2/3 | -0.0594 | -0.1249 | 0.07 | 0.53 | 0.87 | 1.51 | -0.23 | -0.64 | -1.66 | -2.33 |
| opb 1/3 | -0.0308 | -0.0648 | 0.13 | 0.58 | 1.01 | 1.9 | -0.34 | -0.79 | -1.94 | -2.69 |
| axi-c 1/3 | -0.0145 | -0.04 | 3.61 | 3.35 | 4.01 | 1.74 | 1.29 | 1.5 | 2.4 | 2.86 |
| axi-c 2/3 | -0.0291 | -0.08 | 3.19 | 2.62 | 3.27 | 1.68 | 2.22 | 2 | 2.53 | 2.19 |
| axi-c 3/3 | -0.0435 | -0.1199 | 3.26 | 2.63 | 3.22 | 1.9 | 2.27 | 1.86 | 2.27 | 1.54 |
| axi-c 3/3 | -0.0435 | -0.1199 | 3.26 | 2.63 | 3.2 | 1.9 | 2.27 | 1.87 | 2.25 | 1.54 |
| axi-c 2/3 | -0.0291 | -0.08 | 3.24 | 2.65 | 3.28 | 1.65 | 2.12 | 1.94 | 2.5 | 2.13 |
| axi-c 1/3 | -0.0145 | -0.04 | 3.88 | 3.48 | 4.06 | 1.56 | 1.02 | 1.39 | 2.4 | 2.93 |
| axi-t 1/3 | 0.0144 | 0.0371 | 2.69 | 3.11 | 4.4 | 2.04 | 2.43 | 2.63 | 3.82 | 2.45 |
| axi-t 2/3 | 0.0286 | 0.0737 | 2.61 | 2.81 | 3.73 | 1.41 | 2.2 | 2.59 | 3.73 | 2.17 |
| axi-t 3/3 | 0.0428 | 0.1103 | 2.72 | 2.79 | 3.56 | 1.3 | 2.09 | 2.61 | 3.88 | 2.33 |
| axi-t 3/3 | 0.0428 | 0.1102 | 2.55 | 2.65 | 3.36 | 1.18 | 1.96 | 2.6 | 3.73 | 2.19 |
| axi-t 2/3 | 0.0286 | 0.0736 | 2.52 | 2.77 | 3.61 | 1.26 | 2.04 | 2.65 | 3.74 | 2.17 |
| axi-t 1/3 | 0.0143 | 0.0368 | 2.35 | 2.96 | 4.2 | 2.16 | 2.24 | 2.53 | 3.55 | 1.99 |

**Table 38: Measured SNCFs on brace at intersection of brace and chord for T3**

| T3 | pl. cap | design | CC;1 | CI;2 | CI;4 | CS;5 | CC;9 | CI;10 | CI;12 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0312 | 0.0467 | -2.35 | -2.01 | -0.95 | -0.11 | 2.96 | 2.37 | 0.74 | -0.11 |
| ipb 2/3 | 0.0624 | 0.0934 | -2.22 | -1.8 | -0.79 | -0.02 | 2.86 | 2.4 | 0.81 | -0.02 |
| ipb 3/3 | 0.0937 | 0.1403 | -1.99 | -1.63 | -0.66 | 0.04 | 2.78 | 2.34 | 0.78 | 0.02 |
| ipb 3/3 | 0.0938 | 0.1404 | -2 | -1.63 | -0.66 | 0.05 | 2.77 | 2.32 | 0.76 | 0 |
| ipb 2/3 | 0.0626 | 0.0937 | -2.25 | -1.83 | -0.79 | 0 | 2.86 | 2.37 | 0.77 | -0.04 |
| ipb 1/3 | 0.0314 | 0.047 | -2.5 | -2.05 | -1.03 | -0.07 | 3.01 | 2.33 | 0.75 | -0.11 |
| opb 1/3 | -0.0289 | -0.0607 | 0.17 | 1.1 | 2.03 | 3.25 | -0.56 | -1.61 | -2.69 | -2.8 |
| opb 2/3 | -0.0587 | -0.1234 | 0.04 | 0.85 | 1.55 | 2.63 | -0.46 | -1.42 | -2.31 | -2.37 |
| opb 3/3 | -0.0891 | -0.1873 | -0.06 | 0.77 | 1.39 | 2.31 | -0.4 | -1.26 | -2.06 | -2.18 |
| opb 3/3 | -0.0897 | -0.1886 | -0.06 | 0.75 | 1.39 | 2.3 | -0.41 | -1.26 | -2.07 | -2.2 |
| opb 2/3 | -0.0594 | -0.1249 | 0.02 | 0.85 | 1.6 | 2.7 | -0.46 | -1.41 | -2.34 | -2.44 |
| opb 1/3 | -0.0308 | -0.0648 | 0.18 | 1.06 | 2 | 3.32 | -0.61 | -1.66 | -2.73 | -2.87 |
| axi-c 1/3 | -0.0145 | -0.04 | 10.78 | 7.67 | 4.22 | 0.08 | 6.83 | 3.77 | 2.47 | 1.54 |
| axi-c 2/3 | -0.0291 | -0.08 | 9.19 | 6.39 | 3.33 | 0.29 | 7.79 | 4.52 | 2.25 | 0.74 |
| axi-c 3/3 | -0.0435 | -0.1199 | 8.6 | 6.34 | 3.52 | 0.79 | 7.65 | 4.49 | 2.07 | 0.05 |
| axi-c 3/3 | -0.0435 | -0.1199 | 8.63 | 6.35 | 3.52 | 0.76 | 7.65 | 4.54 | 2.09 | 0.08 |
| axi-c 2/3 | -0.0291 | -0.08 | 9.4 | 6.48 | 3.41 | 0.21 | 7.85 | 4.57 | 2.2 | 0.8 |
| axi-c 1/3 | -0.0145 | -0.04 | 11.42 | 8.1 | 4.21 | -0.09 | 6.54 | 3.89 | 2.62 | 1.71 |
| axi-t 1/3 | 0.0144 | 0.0371 | 8.54 | 7.99 | 6.46 | 0.12 | 8.92 | 6.94 | 5.31 | 0.88 |
| axi-t 2/3 | 0.0286 | 0.0737 | 8.45 | 7.92 | 6.02 | -0.3 | 9.08 | 7.66 | 5.82 | 1.04 |
| axi-t 3/3 | 0.0428 | 0.1103 | 8.9 | 8.08 | 5.71 | -0.31 | 9.15 | 7.88 | 6.05 | 1.19 |
| axi-t 3/3 | 0.0428 | 0.1102 | 9 | 8.21 | 5.84 | -0.13 | 9.14 | 7.71 | 6.07 | 1.32 |
| axi-t 2/3 | 0.0286 | 0.0736 | 8.76 | 8.25 | 6.12 | -0.11 | 8.96 | 7.39 | 5.9 | 1.3 |
| axi-t 1/3 | 0.0143 | 0.0368 | 8.63 | 8.41 | 7.08 | 0.9 | 9.14 | 7.14 | 5.43 | 1.24 |

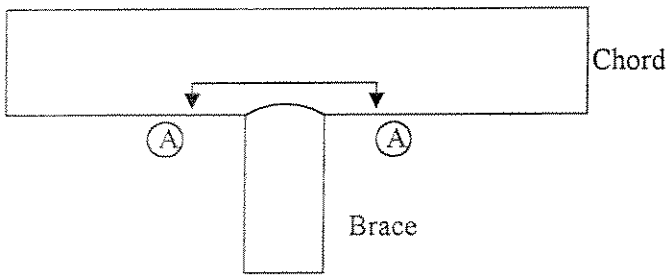
**Table 39: Measured SNCFs on chord at intersection of brace and chord for T3**

| T3 | pl. cap | design | BC;1 | BI;2 | BI;4 | BS;5 | BC;9 | BI;10 | BI;12 | BS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0315 | 0.0471 | -1.11 | -0.95 | -0.9 | -0.02 | 1.25 | 1.04 | 0.82 | -0.01 |
| ipb 2/3 | 0.0626 | 0.0938 | -1.19 | -0.92 | -0.9 | -0.02 | 1.24 | 1.13 | 0.9 | 0 |
| ipb 3/3 | 0.0941 | 0.1408 | -1.27 | -0.9 | -0.86 | -0.01 | 1.26 | 1.17 | 0.91 | 0.01 |
| ipb 3/3 | 0.094 | 0.1408 | -1.27 | -0.9 | -0.86 | -0.01 | 1.27 | 1.18 | 0.92 | 0.01 |
| ipb 2/3 | 0.0627 | 0.0938 | -1.2 | -0.94 | -0.92 | -0.03 | 1.26 | 1.14 | 0.93 | 0 |
| ipb 1/3 | 0.0312 | 0.0467 | -1.14 | -0.98 | -0.99 | -0.02 | 1.31 | 1.09 | 0.94 | 0.02 |
| opb 1/3 | -0.0288 | -0.0606 | 0.15 | 0.51 | 1.37 | 1.54 | -0.29 | -0.55 | -1.42 | -1.95 |
| opb 2/3 | -0.0591 | -0.1242 | 0.06 | 0.47 | 1.14 | 1.39 | -0.21 | -0.51 | -1.37 | -1.89 |
| opb 3/3 | -0.0886 | -0.1864 | 0.03 | 0.47 | 1.03 | 1.28 | -0.17 | -0.48 | -1.34 | -1.85 |
| opb 3/3 | -0.0892 | -0.1876 | 0.03 | 0.48 | 1.03 | 1.28 | -0.18 | -0.48 | -1.33 | -1.86 |
| opb 2/3 | -0.0594 | -0.1248 | 0.07 | 0.48 | 1.14 | 1.43 | -0.22 | -0.51 | -1.38 | -1.92 |
| opb 1/3 | -0.03 | -0.063 | 0.15 | 0.52 | 1.4 | 1.65 | -0.31 | -0.57 | -1.46 | -2.03 |
| axi-c 1/3 | -0.0145 | -0.0401 | 3.09 | 2.87 | 3 | 0.63 | 1.43 | 1.82 | 2.63 | 2.2 |
| axi-c 2/3 | -0.029 | -0.08 | 2.76 | 2.46 | 2.85 | 0.92 | 1.89 | 1.92 | 2.62 | 1.81 |
| axi-c 3/3 | -0.0436 | -0.1199 | 2.71 | 2.29 | 2.78 | 1.02 | 2.11 | 1.99 | 2.52 | 1.6 |
| axi-c 3/3 | -0.0436 | -0.1199 | 2.73 | 2.26 | 2.8 | 1.02 | 2.08 | 1.96 | 2.48 | 1.56 |
| axi-c 2/3 | -0.0291 | -0.0801 | 2.82 | 2.41 | 2.79 | 0.82 | 1.83 | 1.93 | 2.55 | 1.83 |
| axi-c 1/3 | -0.0146 | -0.0401 | 3.45 | 3.06 | 3.42 | 0.69 | 1.03 | 1.38 | 2.25 | 2.11 |
| axi-t 1/3 | 0.0145 | 0.0373 | 1.94 | 2.25 | 3.06 | 0.81 | 2.37 | 2.43 | 3.68 | 1.65 |
| axi-t 2/3 | 0.0287 | 0.074 | 2.34 | 2.5 | 3.11 | 0.68 | 1.94 | 2.28 | 3.62 | 1.83 |
| axi-t 3/3 | 0.043 | 0.1106 | 2.43 | 2.54 | 3.19 | 0.96 | 2.03 | 2.41 | 3.52 | 1.7 |
| axi-t 3/3 | 0.0429 | 0.1105 | 2.48 | 2.53 | 3.22 | 0.96 | 2.01 | 2.4 | 3.51 | 1.7 |
| axi-t 2/3 | 0.0286 | 0.0738 | 2.27 | 2.44 | 3.23 | 0.76 | 2.05 | 2.39 | 3.69 | 1.69 |
| axi-t 1/3 | 0.0144 | 0.0372 | 1.98 | 2.14 | 3.23 | 0.77 | 2.37 | 2.55 | 3.69 | 1.48 |

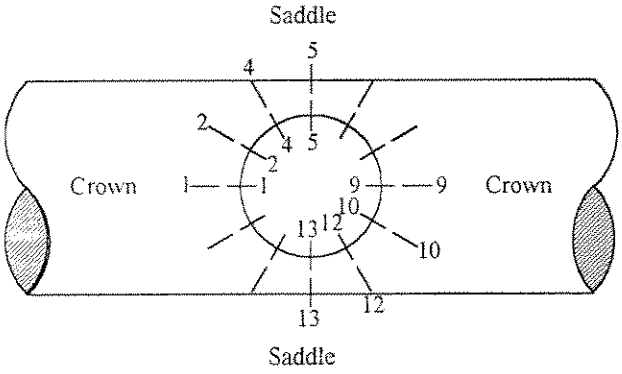
**Table 40: Measured SNCFs on brace at intersection of brace and chord for T3 at preload level of 50%**

| T3 | pl. cap | design | CC;1 | CI;2 | CI;4 | CS;5 | CC;9 | CI;10 | CI;12 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0315 | 0.0471 | -2.32 | -1.77 | -0.81 | 0.1 | 2.85 | 2.03 | 0.76 | -0.09 |
| ipb 2/3 | 0.0626 | 0.0938 | -2.37 | -1.76 | -0.71 | 0.08 | 2.86 | 2.14 | 0.76 | -0.05 |
| ipb 3/3 | 0.0941 | 0.1408 | -2.32 | -1.72 | -0.64 | 0.09 | 2.84 | 2.19 | 0.76 | -0.05 |
| ipb 3/3 | 0.094 | 0.1408 | -2.32 | -1.72 | -0.64 | 0.09 | 2.84 | 2.19 | 0.76 | -0.05 |
| ipb 2/3 | 0.0627 | 0.0938 | -2.41 | -1.8 | -0.73 | 0.06 | 2.91 | 2.18 | 0.79 | -0.06 |
| ipb 1/3 | 0.0312 | 0.0467 | -2.46 | -1.89 | -0.84 | 0.07 | 2.96 | 2.15 | 0.8 | -0.1 |
| opb 1/3 | -0.0288 | -0.0606 | 0.33 | 1.1 | 2.09 | 2.01 | -0.63 | -1.12 | -1.79 | -1.97 |
| opb 2/3 | -0.0591 | -0.1242 | 0.07 | 1.02 | 2.03 | 1.93 | -0.51 | -1.02 | -1.68 | -1.96 |
| opb 3/3 | -0.0886 | -0.1864 | -0.04 | 0.97 | 1.88 | 1.82 | -0.47 | -0.99 | -1.62 | -1.94 |
| opb 3/3 | -0.0892 | -0.1876 | -0.05 | 0.97 | 1.9 | 1.81 | -0.47 | -1 | -1.62 | -1.93 |
| opb 2/3 | -0.0594 | -0.1248 | 0.05 | 1.04 | 2.09 | 2.02 | -0.54 | -1.05 | -1.7 | -2.02 |
| opb 1/3 | -0.03 | -0.063 | 0.28 | 1.13 | 2.32 | 2.28 | -0.69 | -1.15 | -1.83 | -2.11 |
| axi-c 1/3 | -0.0145 | -0.0401 | 10.68 | 7.08 | 2.95 | -0.58 | 7.75 | 4.54 | 2.52 | 1.28 |
| axi-c 2/3 | -0.029 | -0.08 | 9.71 | 6.5 | 2.89 | -0.18 | 8.39 | 5.05 | 2.51 | 0.81 |
| axi-c 3/3 | -0.0436 | -0.1199 | 9.29 | 6.37 | 3.07 | -0.02 | 8.54 | 5.34 | 2.64 | 0.57 |
| axi-c 3/3 | -0.0436 | -0.1199 | 9.21 | 6.35 | 3.07 | -0.02 | 8.54 | 5.39 | 2.58 | 0.57 |
| axi-c 2/3 | -0.0291 | -0.0801 | 9.81 | 6.44 | 2.76 | -0.28 | 8.6 | 5.21 | 2.49 | 0.86 |
| axi-c 1/3 | -0.0146 | -0.0401 | 11.51 | 7.74 | 3.39 | -0.47 | 7.26 | 4.18 | 2.26 | 1.29 |
| axi-t 1/3 | 0.0145 | 0.0373 | 8.58 | 7.29 | 5.61 | -0.06 | 9.6 | 7.5 | 5.41 | 1.29 |
| axi-t 2/3 | 0.0287 | 0.074 | 9.27 | 7.88 | 5.54 | -0.12 | 9.02 | 7.31 | 5.56 | 1.4 |
| axi-t 3/3 | 0.043 | 0.1106 | 9.43 | 7.91 | 5.46 | 0.18 | 9.47 | 7.31 | 5.22 | 1.21 |
| axi-t 3/3 | 0.0429 | 0.1105 | 9.39 | 7.87 | 5.38 | 0.13 | 9.5 | 7.36 | 5.2 | 1.16 |
| axi-t 2/3 | 0.0286 | 0.0738 | 9.06 | 7.76 | 5.66 | -0.02 | 9.53 | 7.56 | 5.58 | 1.27 |
| axi-t 1/3 | 0.0144 | 0.0372 | 8.38 | 7.28 | 5.8 | 0.17 | 9.99 | 7.73 | 5.48 | 1.11 |

**Table 41: Measured SNCFs on chord at intersection of brace and chord for T3 at preload level of 50%**




Elevation on T Joint




View 'A' on brace

| T5 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0445 | 0.0672 | -1.55 | 0.05 | 1.84 | -0.1 | -3.29 | -0.2 | 4.11 | -0.14 |
| ipb 2/3 | 0.0871 | 0.1313 | -1.97 | 0.13 | 1.79 | -0.04 | -3.48 | -0.06 | 3.85 | -0.08 |
| ipb 3/3 | 0.1315 | 0.1984 | -2.18 | 0.2 | 1.74 | 0.05 | -2.77 | 0.09 | 3.59 | 0.08 |
| ipb 3/3 | 0.1323 | 0.1996 | -2.18 | 0.2 | 1.73 | 0.05 | -2.75 | 0.1 | 3.59 | 0.08 |
| ipb 2/3 | 0.0885 | 0.1335 | -1.96 | 0.13 | 1.77 | -0.04 | -3.49 | -0.05 | 3.87 | -0.06 |
| ipb 1/3 | 0.0442 | 0.0666 | -1.54 | 0.07 | 1.82 | -0.08 | -3.21 | -0.17 | 4.15 | -0.11 |
| opb 1/3 | -0.0216 | -0.0701 | -0.11 | 4.33 | -0.17 | -5.11 | -0.24 | 6.52 | -0.58 | -8.42 |
| opb 2/3 | -0.0418 | -0.1355 | -0.08 | 3.26 | -0.16 | -4.33 | -0.32 | 4.18 | -0.71 | -7.2 |
| opb 3/3 | -0.0624 | -0.2021 | -0.08 | 2.81 | -0.11 | -3.89 | -0.37 | 3.27 | -0.72 | -6.45 |
| opb 3/3 | -0.0615 | -0.1992 | -0.06 | 2.94 | -0.14 | -4.05 | -0.34 | 3.48 | -0.78 | -6.71 |
| opb 2/3 | -0.0425 | -0.1377 | -0.02 | 3.43 | -0.18 | -4.56 | -0.24 | 4.47 | -0.8 | -7.51 |
| opb 1/3 | -0.0207 | -0.0672 | 0.05 | 4.86 | -0.31 | -5.65 | 0.07 | 7.45 | -0.83 | -9.35 |
| axi-c 1/3 | -0.0175 | -0.0787 | 1.6 | 5.41 | 3.64 | 3.43 | 7.07 | 8.83 | 8.87 | 4.63 |
| axi-c 2/3 | -0.0348 | -0.1567 | 2.01 | 3.22 | 2.95 | 3.43 | 7.93 | 5.31 | 6.97 | 5.67 |
| axi-c 3/3 | -0.0522 | -0.2349 | 2.13 | 2.65 | 2.69 | 2.87 | 7.62 | 4.29 | 6.37 | 4.66 |
| axi-c 3/3 | -0.0522 | -0.2349 | 2.13 | 2.65 | 2.7 | 2.87 | 7.61 | 4.25 | 6.41 | 4.69 |
| axi-c 2/3 | -0.0349 | -0.157 | 2.05 | 3.06 | 2.91 | 3.68 | 8.07 | 4.86 | 7.04 | 6.31 |
| axi-c 1/3 | -0.0174 | -0.0783 | 1.91 | 4.61 | 3.46 | 5.02 | 7.96 | 6.98 | 8.92 | 7.88 |
| axi-t 1/3 | 0.0169 | 0.0556 | 1.98 | 2.26 | 1.08 | 7.27 | 6.94 | 3.07 | 5.97 | 11.06 |
| axi-t 2/3 | 0.0337 | 0.1112 | 1.57 | 3.1 | 1.51 | 5.16 | 5.91 | 4.31 | 6.99 | 7.62 |
| axi-t 3/3 | 0.0503 | 0.1658 | 1.63 | 2.86 | 1.39 | 4.49 | 5.92 | 4.03 | 6.77 | 6.58 |
| axi-t 3/3 | 0.0502 | 0.1655 | 1.59 | 2.78 | 1.36 | 4.52 | 5.94 | 3.93 | 6.78 | 6.71 |
| axi-t 2/3 | 0.0336 | 0.1108 | 1.53 | 2.89 | 1.44 | 5.37 | 5.98 | 4.02 | 6.95 | 8.08 |
| axi-t 1/3 | 0.0168 | 0.0553 | 1.33 | 3.2 | 1.88 | 7.11 | 5.89 | 4.24 | 7.84 | 10.69 |

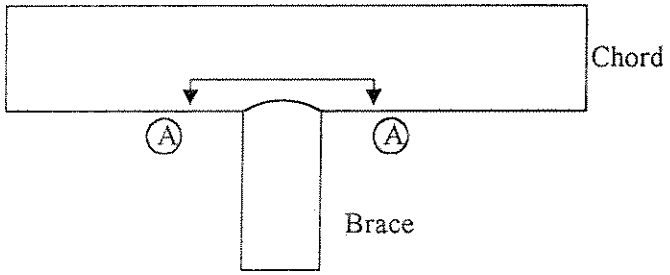
**Table 42: Measured SNCFs on intersection of brace and chord for T5**

| T5 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0434 | 0.0655 | -1.5 | 0.1 | 1.73 | -0.07 | -3.17 | -0.03 | 4.03 | -0.12 |
| ipb 2/3 | 0.0868 | 0.1309 | -1.75 | 0.16 | 1.75 | -0.09 | -3.38 | 0.02 | 3.84 | -0.14 |
| ipb 3/3 | 0.13 | 0.1961 | -2.03 | 0.21 | 1.74 | -0.01 | -2.9 | 0.13 | 3.62 | -0.02 |
| ipb 3/3 | 0.13 | 0.1961 | -2.02 | 0.23 | 1.74 | -0.03 | -2.9 | 0.16 | 3.62 | -0.05 |
| ipb 2/3 | 0.0869 | 0.1311 | -1.72 | 0.17 | 1.75 | -0.11 | -3.4 | 0.04 | 3.85 | -0.18 |
| ipb 1/3 | 0.0432 | 0.0652 | -1.48 | 0.17 | 1.74 | -0.13 | -3.19 | 0.08 | 4.05 | -0.12 |
| opb 1/3 | -0.0203 | -0.0657 | -0.11 | 4.39 | -0.14 | -5.05 | -0.25 | 6.41 | -0.32 | -8.31 |
| opb 2/3 | -0.0398 | -0.1289 | -0.09 | 3.31 | -0.11 | -4.4 | -0.33 | 4.35 | -0.48 | -7.26 |
| opb 3/3 | -0.059 | -0.191 | -0.1 | 2.89 | -0.1 | -4.01 | -0.37 | 3.48 | -0.53 | -6.59 |
| opb 3/3 | -0.0605 | -0.1961 | -0.09 | 3.01 | -0.11 | -4.11 | -0.35 | 3.79 | -0.55 | -6.73 |
| opb 2/3 | -0.0408 | -0.1322 | -0.07 | 3.5 | -0.13 | -4.62 | -0.23 | 4.91 | -0.47 | -7.51 |
| opb 1/3 | -0.0207 | -0.067 | -0.06 | 4.8 | -0.13 | -5.3 | -0.12 | 7.52 | -0.31 | -8.92 |
| axi-c 1/3 | -0.0175 | -0.0788 | 0.43 | 6.18 | 4.26 | 3.74 | 5.24 | 9.45 | 13.44 | 5.24 |
| axi-c 2/3 | -0.0348 | -0.1567 | 1.06 | 3.74 | 3.57 | 4.33 | 6.65 | 5.72 | 10.56 | 7.03 |
| axi-c 3/3 | -0.0522 | -0.2347 | 1.36 | 3.02 | 3.2 | 3.55 | 6.96 | 4.63 | 8.95 | 5.91 |
| axi-c 3/3 | -0.0522 | -0.2346 | 1.36 | 3.02 | 3.2 | 3.56 | 6.96 | 4.64 | 8.98 | 5.88 |
| axi-c 2/3 | -0.0347 | -0.1562 | 1.16 | 3.58 | 3.39 | 4.83 | 7.04 | 5.23 | 10.74 | 8.01 |
| axi-c 1/3 | -0.0174 | -0.0782 | 0.94 | 4.9 | 3.72 | 6.93 | 6.71 | 6.95 | 13.34 | 10.54 |
| axi-t 1/3 | 0.0168 | 0.0553 | 0.5 | 4.24 | 2.99 | 5.88 | 4.92 | 5.76 | 11.76 | 8.36 |
| axi-t 2/3 | 0.0333 | 0.1098 | 1.4 | 3.59 | 1.92 | 4.77 | 6.45 | 4.94 | 9.27 | 6.75 |
| axi-t 3/3 | 0.05 | 0.1646 | 1.44 | 3.18 | 1.93 | 4.09 | 6.32 | 4.39 | 8.88 | 5.79 |
| axi-t 3/3 | 0.05 | 0.1646 | 1.44 | 3.18 | 1.93 | 4.07 | 6.34 | 4.36 | 8.88 | 5.77 |
| axi-t 2/3 | 0.0332 | 0.1093 | 1.22 | 3.35 | 1.94 | 4.73 | 6.18 | 4.53 | 8.96 | 6.69 |
| axi-t 1/3 | 0.017 | 0.0562 | 0.73 | 3.95 | 2.67 | 6.25 | 5.4 | 5.16 | 10.96 | 8.98 |

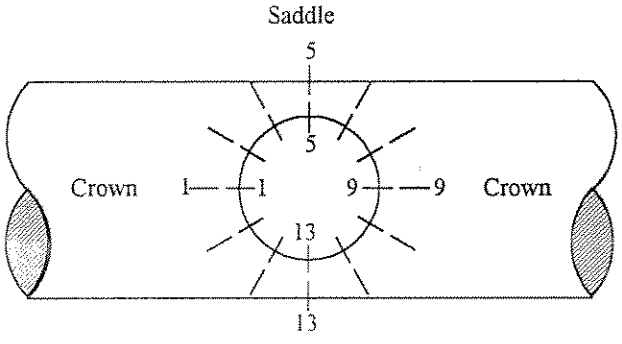
**Table 43: Measured SNCFs on intersection of brace and chord for T5 at preload level of 50%**

| T5 | pl. cap | design | BC;1 | BS;5 | BC;9 | BS;13 | CC;1 | CS;5 | CC;9 | CS;13 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.043 | 0.0649 | -1.53 | -0.11 | 1.86 | -0.21 | -2.93 | -0.29 | 3.48 | -0.27 |
| ipb 2/3 | 0.0867 | 0.1307 | -1.59 | -0.14 | 1.86 | -0.27 | -3.09 | -0.32 | 3.51 | -0.36 |
| ipb 3/3 | 0.1311 | 0.1978 | -1.76 | -0.1 | 1.84 | -0.24 | -3.28 | -0.29 | 3.45 | -0.32 |
| ipb 3/3 | 0.131 | 0.1976 | -1.75 | -0.1 | 1.84 | -0.23 | -3.26 | -0.29 | 3.46 | -0.29 |
| ipb 2/3 | 0.0856 | 0.1291 | -1.56 | -0.13 | 1.84 | -0.25 | -3.14 | -0.33 | 3.51 | -0.32 |
| ipb 1/3 | 0.0432 | 0.0652 | -1.48 | -0.11 | 1.81 | -0.18 | -2.99 | -0.31 | 3.48 | -0.15 |
| opb 1/3 | -0.0172 | -0.0557 | -0.4 | 4.66 | -0.06 | -4.36 | -0.22 | 6.85 | 0.1 | -6.91 |
| opb 2/3 | -0.0381 | -0.1234 | -0.39 | 4.53 | -0.1 | -4.29 | -0.3 | 6.38 | 0.01 | -6.84 |
| opb 3/3 | -0.0589 | -0.1908 | -0.31 | 3.81 | -0.09 | -3.92 | -0.32 | 5.1 | -0.17 | -6.36 |
| opb 3/3 | -0.059 | -0.191 | -0.29 | 3.84 | -0.1 | -3.98 | -0.29 | 5.15 | -0.19 | -6.44 |
| opb 2/3 | -0.0388 | -0.1256 | -0.36 | 4.54 | -0.12 | -4.29 | -0.2 | 6.46 | -0.01 | -6.93 |
| opb 1/3 | -0.0184 | -0.0595 | -0.31 | 4.64 | -0.1 | -4.48 | -0.08 | 6.77 | 0.08 | -7.05 |
| axi-c 1/3 | -0.0176 | -0.079 | 0.61 | 4.9 | 3.38 | 2.4 | 5.57 | 6.59 | 11.63 | 2.86 |
| axi-c 2/3 | -0.035 | -0.1574 | 1.49 | 3.72 | 2.45 | 4.62 | 7.14 | 4.73 | 9.94 | 6.4 |
| axi-c 3/3 | -0.0523 | -0.2353 | 1.75 | 3.8 | 2.5 | 4.85 | 7.82 | 4.94 | 9.7 | 6.86 |
| axi-c 3/3 | -0.0523 | -0.2353 | 1.75 | 3.8 | 2.5 | 4.85 | 7.82 | 4.96 | 9.73 | 6.88 |
| axi-c 2/3 | -0.0349 | -0.1571 | 1.57 | 3.05 | 2.28 | 5.56 | 7.37 | 3.7 | 9.67 | 7.91 |
| axi-c 1/3 | -0.0175 | -0.0788 | 1.27 | 2.11 | 2.62 | 5.58 | 6.72 | 2.1 | 10.24 | 7.98 |
| axi-t 1/3 | 0.0169 | 0.0557 | 1.44 | 1.18 | 2.3 | 4.64 | 6.44 | 1.32 | 8.62 | 6.68 |
| axi-t 2/3 | 0.0337 | 0.111 | 1.72 | 2.01 | 1.95 | 3.7 | 6.84 | 2.55 | 8.12 | 5.21 |
| axi-t 3/3 | 0.0502 | 0.1654 | 1.91 | 2.11 | 1.83 | 3.35 | 7.06 | 2.81 | 7.8 | 4.66 |
| axi-t 3/3 | 0.0501 | 0.1652 | 1.89 | 2.1 | 1.82 | 3.35 | 7.05 | 2.8 | 7.78 | 4.66 |
| axi-t 2/3 | 0.0334 | 0.1102 | 1.8 | 1.79 | 1.84 | 3.92 | 7.04 | 2.26 | 7.78 | 5.54 |
| axi-t 1/3 | 0.017 | 0.0562 | 1.46 | 1.41 | 2.16 | 4.72 | 6.59 | 1.44 | 8.39 | 6.79 |

**Table 44: Measured SNCFs on intersection of brace and chord for T5 at preload level of 100 %**




Elevation on T Joint




View 'A' on brace

SCNFs grouted Test Specimen: T9.

| T9 | pl. cap | design | BC;1 | BI;2 | BI;4 | BS;5 | BI;6 | BI;8 | BC;9 | BI;10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0326 | 0.0709 | -1.57 | -1.44 | -1.3 | -0.27 | 1.05 | 1.31 | 1.46 | 1.62 |
| ipb 2/3 | 0.0658 | 0.1432 | -1.94 | -1.39 | -1.14 | -0.17 | 1.03 | 1.34 | 1.45 | 1.64 |
| ipb 3/3 | 0.0985 | 0.2143 | -2.06 | -1.36 | -1.01 | -0.1 | 1.01 | 1.34 | 1.43 | 1.61 |
| ipb 3/3 | 0.0984 | 0.2139 | -2.07 | -1.37 | -1.01 | -0.1 | 1.01 | 1.34 | 1.42 | 1.61 |
| ipb 2/3 | 0.0658 | 0.1432 | -1.95 | -1.42 | -1.15 | -0.17 | 1.07 | 1.34 | 1.44 | 1.64 |
| ipb 1/3 | 0.0322 | 0.0701 | -1.55 | -1.42 | -1.24 | -0.18 | 1.09 | 1.3 | 1.41 | 1.62 |
| opb 1/3 | -0.0172 | -0.0525 | 0 | 0.48 | 1.65 | 3.5 | 1.93 | 1.42 | -0.19 | -1.14 |
| opb 2/3 | -0.0355 | -0.1086 | 0.14 | 0.48 | 0.97 | 2.03 | 1.13 | 0.82 | -0.26 | -0.92 |
| opb 3/3 | -0.0542 | -0.1658 | 0.15 | 0.47 | 0.83 | 1.58 | 0.88 | 0.59 | -0.26 | -0.81 |
| opb 3/3 | -0.0548 | -0.1676 | 0.14 | 0.48 | 0.83 | 1.59 | 0.9 | 0.58 | -0.27 | -0.83 |
| opb 2/3 | -0.0365 | -0.1117 | 0.26 | 0.63 | 0.99 | 2.1 | 1.06 | 0.61 | -0.39 | -1.03 |
| opb 1/3 | -0.0179 | -0.0546 | 0.52 | 1 | 1.95 | 3.6 | 1.64 | 0.56 | -0.72 | -1.54 |
| axi-c 1/3 | -0.0147 | -0.0837 | 2.69 | 3.11 | 4.28 | 3.78 | 2.68 | 2.68 | 2.88 | 3.13 |
| axi-c 2/3 | -0.0293 | -0.1668 | 2.55 | 2.92 | 3.94 | 3.2 | 2.35 | 2.56 | 2.69 | 2.81 |
| axi-c 3/3 | -0.0437 | -0.2491 | 2.31 | 2.57 | 3.53 | 3.03 | 2.26 | 2.49 | 2.73 | 2.6 |
| axi-c 3/3 | -0.0438 | -0.2492 | 2.28 | 2.58 | 3.5 | 3.01 | 2.26 | 2.49 | 2.73 | 2.59 |
| axi-c 2/3 | -0.0292 | -0.1663 | 2.63 | 3.05 | 3.93 | 3.15 | 2.31 | 2.54 | 2.68 | 2.81 |
| axi-c 1/3 | -0.0147 | -0.0836 | 3.16 | 3.58 | 4.46 | 3.23 | 2.21 | 1.75 | 2.18 | 2.95 |
| axi-t 1/3 | 0.0148 | 0.0788 | 2.6 | 2.92 | 3.27 | 2.27 | 2.73 | 1.46 | 1.51 | 2.22 |
| axi-t 2/3 | 0.0296 | 0.1572 | 2.63 | 2.94 | 2.91 | 1.95 | 2.59 | 1.45 | 1.37 | 1.89 |
| axi-t 3/3 | 0.0441 | 0.2346 | 2.58 | 2.74 | 2.62 | 1.76 | 2.41 | 1.49 | 1.37 | 1.91 |
| axi-t 3/3 | 0.0442 | 0.2348 | 2.6 | 2.76 | 2.6 | 1.79 | 2.41 | 1.49 | 1.37 | 1.93 |
| axi-t 2/3 | 0.0293 | 0.1559 | 2.69 | 2.92 | 2.82 | 1.9 | 2.55 | 1.46 | 1.38 | 2.04 |
| axi-t 1/3 | 0.0146 | 0.0778 | 2.36 | 2.5 | 2.69 | 1.87 | 2.6 | 1.63 | 1.8 | 2.62 |

**Table 45: Measured SNCFs on brace intersection of brace and chord for T9**

| T9 | pl. cap | design | BC;1 | BI;16 | BI;14 | BS;13 | BI;12 | BI;10 | BC;9 | BI;8 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0326 | 0.0709 | -1.57 | -1.37 | -1.02 | -0.02 | 1.32 | 1.62 | 1.46 | 1.31 |
| ipb 2/3 | 0.0658 | 0.1432 | -1.94 | -1.35 | -0.97 | -0.02 | 1.21 | 1.64 | 1.45 | 1.34 |
| ipb 3/3 | 0.0985 | 0.2143 | -2.06 | -1.31 | -0.86 | -0.01 | 1.13 | 1.61 | 1.43 | 1.34 |
| ipb 3/3 | 0.0984 | 0.2139 | -2.07 | -1.3 | -0.86 | -0.01 | 1.13 | 1.61 | 1.42 | 1.34 |
| ipb 2/3 | 0.0658 | 0.1432 | -1.95 | -1.34 | -1 | -0.03 | 1.23 | 1.64 | 1.44 | 1.34 |
| ipb 1/3 | 0.0322 | 0.0701 | -1.55 | -1.35 | -1.07 | -0.06 | 1.28 | 1.62 | 1.41 | 1.3 |
| opb 1/3 | -0.0172 | -0.0525 | 0 | -0.52 | -1.72 | -3.48 | -1.95 | -1.14 | -0.19 | 1.42 |
| opb 2/3 | -0.0355 | -0.1086 | 0.14 | -0.33 | -1.32 | -2.65 | -1.62 | -0.92 | -0.26 | 0.82 |
| opb 3/3 | -0.0542 | -0.1658 | 0.15 | -0.29 | -1.15 | -2.21 | -1.47 | -0.81 | -0.26 | 0.59 |
| opb 3/3 | -0.0548 | -0.1676 | 0.14 | -0.29 | -1.16 | -2.21 | -1.46 | -0.83 | -0.27 | 0.58 |
| opb 2/3 | -0.0365 | -0.1117 | 0.26 | -0.25 | -1.25 | -2.65 | -1.68 | -1.03 | -0.39 | 0.61 |
| opb 1/3 | -0.0179 | -0.0546 | 0.52 | -0.11 | -1.43 | -3.54 | -2.2 | -1.54 | -0.72 | 0.56 |
| axi-c 1/3 | -0.0147 | -0.0837 | 2.69 | 2.7 | 3.59 | 2.59 | 2.42 | 3.13 | 2.88 | 2.68 |
| axi-c 2/3 | -0.0293 | -0.1668 | 2.55 | 2.56 | 3.36 | 2.39 | 2.2 | 2.81 | 2.69 | 2.56 |
| axi-c 3/3 | -0.0437 | -0.2491 | 2.31 | 2.28 | 2.95 | 2.07 | 2.05 | 2.6 | 2.73 | 2.49 |
| axi-c 3/3 | -0.0438 | -0.2492 | 2.28 | 2.3 | 2.95 | 2.05 | 2.05 | 2.59 | 2.73 | 2.49 |
| axi-c 2/3 | -0.0292 | -0.1663 | 2.63 | 2.69 | 3.44 | 2.38 | 2.2 | 2.81 | 2.68 | 2.54 |
| axi-c 1/3 | -0.0147 | -0.0836 | 3.16 | 3.31 | 4.19 | 2.98 | 2.44 | 2.95 | 2.18 | 1.75 |
| axi-t 1/3 | 0.0148 | 0.0788 | 2.6 | 2.84 | 4 | 3.72 | 3.5 | 2.22 | 1.51 | 1.46 |
| axi-t 2/3 | 0.0296 | 0.1572 | 2.63 | 2.46 | 3.02 | 2.32 | 2.88 | 1.89 | 1.37 | 1.45 |
| axi-t 3/3 | 0.0441 | 0.2346 | 2.58 | 2.34 | 2.72 | 1.92 | 2.68 | 1.91 | 1.37 | 1.49 |
| axi-t 3/3 | 0.0442 | 0.2348 | 2.6 | 2.35 | 2.71 | 1.92 | 2.69 | 1.93 | 1.37 | 1.49 |
| axi-t 2/3 | 0.0293 | 0.1559 | 2.69 | 2.53 | 3.21 | 2.52 | 3.09 | 2.04 | 1.38 | 1.46 |
| axi-t 1/3 | 0.0146 | 0.0778 | 2.36 | 2.64 | 4.18 | 4.27 | 4.1 | 2.62 | 1.8 | 1.63 |

**Table 446: Measured SNCFs on brace intersection of brace and chord for T9**

| T9 | pl. cap | design | CC;1 | CI;2 | CI;4 | CS;5 | CI;6 | CI;8 | CC;9 | CI;10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0326 | 0.0709 | -2.6 | -2.47 | -1.68 | -0.35 | 1.45 | 2.64 | 2.84 | 2.3 |
| ipb 2/3 | 0.0658 | 0.1432 | -2.84 | -2.33 | -1.54 | -0.22 | 1.49 | 2.84 | 2.78 | 2.34 |
| ipb 3/3 | 0.0985 | 0.2143 | -2.31 | -2.11 | -1.35 | -0.1 | 1.5 | 2.86 | 2.63 | 2.28 |
| ipb 3/3 | 0.0984 | 0.2139 | -2.32 | -2.12 | -1.35 | -0.11 | 1.5 | 2.86 | 2.64 | 2.29 |
| ipb 2/3 | 0.0658 | 0.1432 | -2.92 | -2.36 | -1.55 | -0.21 | 1.55 | 2.88 | 2.78 | 2.36 |
| ipb 1/3 | 0.0322 | 0.0701 | -2.55 | -2.44 | -1.65 | -0.2 | 1.59 | 2.67 | 2.81 | 2.31 |
| opb 1/3 | -0.0172 | -0.0525 | -0.07 | 0.74 | 2.9 | 7.53 | 1.79 | 0.61 | -0.45 | -0.63 |
| opb 2/3 | -0.0355 | -0.1086 | 0 | 0.91 | 2.96 | 5.25 | 1.01 | 0.06 | -0.74 | -0.67 |
| opb 3/3 | -0.0542 | -0.1658 | -0.04 | 1.01 | 2.54 | 4.18 | 0.78 | 0 | -0.76 | -0.69 |
| opb 3/3 | -0.0548 | -0.1676 | -0.04 | 0.98 | 2.52 | 4.2 | 0.82 | 0.03 | -0.76 | -0.69 |
| opb 2/3 | -0.0365 | -0.1117 | 0.15 | 1.11 | 3.16 | 5.38 | 1 | -0.03 | -0.95 | -0.77 |
| opb 1/3 | -0.0179 | -0.0546 | 0.67 | 1.58 | 3.66 | 7.94 | 1.64 | -0.06 | -1.33 | -1.15 |
| axi-c 1/3 | -0.0147 | -0.0837 | 8.43 | 8.22 | 6.6 | 5.39 | 3.87 | 5.73 | 7.04 | 5.19 |
| axi-c 2/3 | -0.0293 | -0.1668 | 8.1 | 7.88 | 5.82 | 4.17 | 2.88 | 4.49 | 5.92 | 4.5 |
| axi-c 3/3 | -0.0437 | -0.2491 | 7.62 | 7.44 | 5.36 | 4.06 | 2.83 | 4.27 | 5.63 | 4.2 |
| axi-c 3/3 | -0.0438 | -0.2492 | 7.65 | 7.45 | 5.38 | 4.03 | 2.84 | 4.27 | 5.63 | 4.21 |
| axi-c 2/3 | -0.0292 | -0.1663 | 8.31 | 8.19 | 5.94 | 4.11 | 2.9 | 4.59 | 6.01 | 4.62 |
| axi-c 1/3 | -0.0147 | -0.0836 | 9.28 | 9.38 | 7.16 | 4.23 | 2.91 | 4.61 | 6.67 | 5.53 |
| axi-t 1/3 | 0.0148 | 0.0788 | 7.93 | 6.39 | 3.41 | 2.44 | 6.24 | 6.52 | 6.62 | 4.65 |
| axi-t 2/3 | 0.0296 | 0.1572 | 7.68 | 6.36 | 3.04 | 2.4 | 6.53 | 6.78 | 6.21 | 4.34 |
| axi-t 3/3 | 0.0441 | 0.2346 | 7.43 | 6.07 | 2.82 | 2.28 | 6.06 | 6.74 | 6.12 | 4.41 |
| axi-t 3/3 | 0.0442 | 0.2348 | 7.42 | 6.08 | 2.85 | 2.31 | 6.06 | 6.73 | 6.12 | 4.39 |
| axi-t 2/3 | 0.0293 | 0.1559 | 7.77 | 6.3 | 2.91 | 2.24 | 6.5 | 6.92 | 6.33 | 4.36 |
| axi-t 1/3 | 0.0146 | 0.0778 | 7.23 | 5.64 | 2.79 | 1.75 | 6.2 | 7.1 | 7.15 | 4.97 |

**Table 47: Measured SNCFs on chord intersection of brace and chord for T9**

| T9 | pl. cap | design | CC;1 | CI;16 | CI;14 | CS;13 | CI;12 | CI;10 | CC;9 | CI;8 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0326 | 0.0709 | -2.6 | -2.53 | -1.62 | 0.01 | 1.39 | 2.3 | 2.84 | 2.64 |
| ipb 2/3 | 0.0658 | 0.1432 | -2.84 | -2.38 | -1.35 | -0.01 | 1.15 | 2.34 | 2.78 | 2.84 |
| ipb 3/3 | 0.0985 | 0.2143 | -2.31 | -2.07 | -1.15 | 0.02 | 1.05 | 2.28 | 2.63 | 2.86 |
| ipb 3/3 | 0.0984 | 0.2139 | -2.32 | -2.07 | -1.12 | 0.03 | 1.05 | 2.29 | 2.64 | 2.86 |
| ipb 2/3 | 0.0658 | 0.1432 | -2.92 | -2.39 | -1.35 | -0.03 | 1.1 | 2.36 | 2.78 | 2.88 |
| ipb 1/3 | 0.0322 | 0.0701 | -2.55 | -2.51 | -1.45 | -0.01 | 1.34 | 2.31 | 2.81 | 2.67 |
| opb 1/3 | -0.0172 | -0.0525 | -0.07 | -0.68 | -2.54 | -7.45 | -2.32 | -0.63 | -0.45 | 0.61 |
| opb 2/3 | -0.0355 | -0.1086 | 0 | -0.62 | -2.28 | -5.63 | -1.83 | -0.67 | -0.74 | 0.06 |
| opb 3/3 | -0.0542 | -0.1658 | -0.04 | -0.66 | -2.22 | -4.81 | -1.71 | -0.69 | -0.76 | 0 |
| opb 3/3 | -0.0548 | -0.1676 | -0.04 | -0.64 | -2.22 | -4.82 | -1.7 | -0.69 | -0.76 | 0.03 |
| opb 2/3 | -0.0365 | -0.1117 | 0.15 | -0.46 | -2.18 | -5.71 | -1.86 | -0.77 | -0.95 | -0.03 |
| opb 1/3 | -0.0179 | -0.0546 | 0.67 | 0.05 | -2.08 | -7.55 | -2.45 | -1.15 | -1.33 | -0.06 |
| axi-c 1/3 | -0.0147 | -0.0837 | 8.43 | 7.83 | 4.32 | 2.73 | 4.11 | 5.19 | 7.04 | 5.73 |
| axi-c 2/3 | -0.0293 | -0.1668 | 8.1 | 7.45 | 3.92 | 2.52 | 3.76 | 4.5 | 5.92 | 4.49 |
| axi-c 3/3 | -0.0437 | -0.2491 | 7.62 | 6.85 | 3.46 | 2.05 | 3.44 | 4.2 | 5.63 | 4.27 |
| axi-c 3/3 | -0.0438 | -0.2492 | 7.65 | 6.88 | 3.55 | 2.05 | 3.43 | 4.21 | 5.63 | 4.27 |
| axi-c 2/3 | -0.0292 | -0.1663 | 8.31 | 7.68 | 4.13 | 2.51 | 3.96 | 4.62 | 6.01 | 4.59 |
| axi-c 1/3 | -0.0147 | -0.0836 | 9.28 | 8.6 | 5.15 | 3.66 | 4.87 | 5.53 | 6.67 | 4.61 |
| axi-t 1/3 | 0.0148 | 0.0788 | 7.93 | 8.42 | 6.74 | 5.95 | 4.78 | 4.65 | 6.62 | 6.52 |
| axi-t 2/3 | 0.0296 | 0.1572 | 7.68 | 7.83 | 5.33 | 3.59 | 3.97 | 4.34 | 6.21 | 6.78 |
| axi-t 3/3 | 0.0441 | 0.2346 | 7.43 | 7.46 | 4.99 | 2.99 | 3.86 | 4.41 | 6.12 | 6.74 |
| axi-t 3/3 | 0.0442 | 0.2348 | 7.42 | 7.47 | 5 | 2.98 | 3.85 | 4.39 | 6.12 | 6.73 |
| axi-t 2/3 | 0.0293 | 0.1559 | 7.77 | 8 | 5.72 | 3.78 | 4.2 | 4.36 | 6.33 | 6.92 |
| axi-t 1/3 | 0.0146 | 0.0778 | 7.23 | 8.04 | 7.25 | 7.05 | 5.24 | 4.97 | 7.15 | 7.1 |

**Table 48: Measured SNCFs on chord intersection of brace and chord for T9**

| T9 | pl. cap | design | BC;1 | BI;2 | BI;4 | BS;5 | BI;6 | BI;8 | BC;9 | BI;10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0333 | 0.0724 | -1.63 | -1.4 | -1.18 | -0.11 | 1.14 | 1.26 | 1.4 | 1.53 |
| ipb 2/3 | 0.0663 | 0.1442 | -1.89 | -1.39 | -1.09 | -0.08 | 1.09 | 1.32 | 1.4 | 1.58 |
| ipb 3/3 | 0.0992 | 0.2158 | -2.05 | -1.38 | -0.99 | -0.05 | 1.03 | 1.34 | 1.41 | 1.58 |
| ipb 3/3 | 0.0988 | 0.2148 | -2.06 | -1.39 | -1 | -0.05 | 1.03 | 1.35 | 1.42 | 1.59 |
| ipb 2/3 | 0.0662 | 0.1439 | -1.91 | -1.44 | -1.13 | -0.08 | 1.12 | 1.34 | 1.42 | 1.62 |
| ipb 1/3 | 0.032 | 0.0696 | -1.65 | -1.48 | -1.21 | -0.14 | 1.15 | 1.28 | 1.44 | 1.56 |
| opb 1/3 | -0.0163 | -0.0499 | 0.03 | 0.53 | 1.34 | 3.2 | 1.66 | 0.81 | -0.09 | -0.74 |
| opb 2/3 | -0.0346 | -0.1058 | 0.11 | 0.51 | 0.78 | 2 | 1.02 | 0.61 | -0.2 | -0.69 |
| opb 3/3 | -0.0533 | -0.1631 | 0.11 | 0.48 | 0.7 | 1.54 | 0.81 | 0.49 | -0.2 | -0.65 |
| opb 3/3 | -0.0545 | -0.1668 | 0.13 | 0.48 | 0.72 | 1.57 | 0.83 | 0.49 | -0.19 | -0.68 |
| opb 2/3 | -0.0363 | -0.111 | 0.25 | 0.62 | 0.87 | 2.03 | 0.97 | 0.45 | -0.26 | -0.82 |
| opb 1/3 | -0.0173 | -0.0528 | 0.48 | 0.93 | 1.65 | 3.37 | 1.39 | 0.22 | -0.54 | -1.18 |
| axi-c 1/3 | -0.0147 | -0.0836 | 2.9 | 3 | 4.37 | 4.13 | 3.31 | 2.27 | 2.36 | 2.77 |
| axi-c 2/3 | -0.0292 | -0.1663 | 2.72 | 2.8 | 3.95 | 3.41 | 2.91 | 2.08 | 2.51 | 2.82 |
| axi-c 3/3 | -0.0437 | -0.249 | 2.44 | 2.43 | 3.38 | 2.99 | 2.72 | 2.31 | 2.95 | 2.87 |
| axi-c 3/3 | -0.0437 | -0.249 | 2.44 | 2.43 | 3.35 | 2.97 | 2.69 | 2.31 | 2.95 | 2.88 |
| axi-c 2/3 | -0.0292 | -0.1661 | 2.78 | 2.9 | 4.02 | 3.32 | 2.91 | 2.04 | 2.43 | 2.8 |
| axi-c 1/3 | -0.0146 | -0.0832 | 3.37 | 3.36 | 4.34 | 3.3 | 2.68 | 1.78 | 1.74 | 2.53 |
| axi-t 1/3 | 0.0151 | 0.0801 | 2.19 | 2.4 | 2.69 | 1.9 | 2.52 | 1.58 | 1.75 | 2.59 |
| axi-t 2/3 | 0.0297 | 0.158 | 2.36 | 2.67 | 2.51 | 1.73 | 2.48 | 1.56 | 1.55 | 2.27 |
| axi-t 3/3 | 0.0444 | 0.2359 | 2.61 | 2.82 | 2.6 | 1.79 | 2.47 | 1.62 | 1.44 | 2.05 |
| axi-t 3/3 | 0.0443 | 0.2358 | 2.71 | 2.92 | 2.68 | 1.78 | 2.39 | 1.54 | 1.35 | 1.96 |
| axi-t 2/3 | 0.0296 | 0.1575 | 2.7 | 2.99 | 2.72 | 1.73 | 2.38 | 1.37 | 1.33 | 1.96 |
| axi-t 1/3 | 0.0149 | 0.0792 | 2.65 | 2.72 | 2.78 | 1.74 | 2.12 | 1.23 | 1.42 | 2.39 |

**Table 49: Measured SNCFs on brace intersection of brace and chord for T9 at preload level of 50%**

| T9 | pl. cap | design | BC;1 | BI;16 | BI;14 | BS;13 | BI;12 | BI;10 | BC;9 | BI;8 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0333 | 0.0724 | -1.63 | -1.4 | -0.97 | 0.05 | 1.32 | 1.53 | 1.4 | 1.26 |
| ipb 2/3 | 0.0663 | 0.1442 | -1.89 | -1.35 | -0.94 | 0.03 | 1.22 | 1.58 | 1.4 | 1.32 |
| ipb 3/3 | 0.0992 | 0.2158 | -2.05 | -1.31 | -0.84 | 0.04 | 1.15 | 1.58 | 1.41 | 1.34 |
| ipb 3/3 | 0.0988 | 0.2148 | -2.06 | -1.31 | -0.85 | 0.04 | 1.15 | 1.59 | 1.42 | 1.35 |
| ipb 2/3 | 0.0662 | 0.1439 | -1.91 | -1.37 | -0.95 | 0.05 | 1.25 | 1.62 | 1.42 | 1.34 |
| ipb 1/3 | 0.032 | 0.0696 | -1.65 | -1.38 | -1.02 | 0.12 | 1.35 | 1.56 | 1.44 | 1.28 |
| opb 1/3 | -0.0163 | -0.0499 | 0.03 | -0.58 | -1.67 | -3.33 | -1.81 | -0.74 | -0.09 | 0.81 |
| opb 2/3 | -0.0346 | -0.1058 | 0.11 | -0.39 | -1.27 | -2.46 | -1.52 | -0.69 | -0.2 | 0.61 |
| opb 3/3 | -0.0533 | -0.1631 | 0.11 | -0.32 | -1.11 | -2.06 | -1.36 | -0.65 | -0.2 | 0.49 |
| opb 3/3 | -0.0545 | -0.1668 | 0.13 | -0.32 | -1.09 | -2.06 | -1.33 | -0.68 | -0.19 | 0.49 |
| opb 2/3 | -0.0363 | -0.111 | 0.25 | -0.33 | -1.19 | -2.45 | -1.52 | -0.82 | -0.26 | 0.45 |
| opb 1/3 | -0.0173 | -0.0528 | 0.48 | -0.2 | -1.39 | -3.29 | -2.11 | -1.18 | -0.54 | 0.22 |
| axi-c 1/3 | -0.0147 | -0.0836 | 2.9 | 2.85 | 3.64 | 2.94 | 3.23 | 2.77 | 2.36 | 2.27 |
| axi-c 2/3 | -0.0292 | -0.1663 | 2.72 | 2.59 | 3.49 | 2.6 | 3.03 | 2.82 | 2.51 | 2.08 |
| axi-c 3/3 | -0.0437 | -0.249 | 2.44 | 2.21 | 3 | 2.09 | 2.83 | 2.87 | 2.95 | 2.31 |
| axi-c 3/3 | -0.0437 | -0.249 | 2.44 | 2.18 | 3 | 2.08 | 2.81 | 2.88 | 2.95 | 2.31 |
| axi-c 2/3 | -0.0292 | -0.1661 | 2.78 | 2.63 | 3.59 | 2.63 | 3.14 | 2.8 | 2.43 | 2.04 |
| axi-c 1/3 | -0.0146 | -0.0832 | 3.37 | 3.28 | 4.23 | 3.49 | 3.24 | 2.53 | 1.74 | 1.78 |
| axi-t 1/3 | 0.0151 | 0.0801 | 2.19 | 2.76 | 4.05 | 4.05 | 3.98 | 2.59 | 1.75 | 1.58 |
| axi-t 2/3 | 0.0297 | 0.158 | 2.36 | 2.53 | 3.21 | 2.67 | 3.22 | 2.27 | 1.55 | 1.56 |
| axi-t 3/3 | 0.0444 | 0.2359 | 2.61 | 2.5 | 2.88 | 2.17 | 2.87 | 2.05 | 1.44 | 1.62 |
| axi-t 3/3 | 0.0443 | 0.2358 | 2.71 | 2.61 | 2.91 | 2.22 | 2.81 | 1.96 | 1.35 | 1.54 |
| axi-t 2/3 | 0.0296 | 0.1575 | 2.7 | 2.86 | 3.38 | 2.72 | 3.02 | 1.96 | 1.33 | 1.37 |
| axi-t 1/3 | 0.0149 | 0.0792 | 2.65 | 3.13 | 4.6 | 4.62 | 3.95 | 2.39 | 1.42 | 1.23 |

**Table 50: Measured SNCFs on brace intersection of brace and chord for T9 at preload level of 50%**

| T9 | pl. cap | design | CC;1 | CI;2 | CI;4 | CS;5 | CI;6 | CI;8 | CC;9 | CI;10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0333 | 0.0724 | -2.74 | -2.41 | -1.5 | -0.07 | 1.63 | 2.53 | 2.78 | 2.19 |
| ipb 2/3 | 0.0663 | 0.1442 | -2.87 | -2.34 | -1.41 | -0.05 | 1.6 | 2.8 | 2.73 | 2.32 |
| ipb 3/3 | 0.0992 | 0.2158 | -2.42 | -2.17 | -1.3 | 0.02 | 1.53 | 2.87 | 2.64 | 2.28 |
| ipb 3/3 | 0.0988 | 0.2148 | -2.43 | -2.18 | -1.3 | 0 | 1.52 | 2.89 | 2.66 | 2.3 |
| ipb 2/3 | 0.0662 | 0.1439 | -2.94 | -2.42 | -1.48 | -0.08 | 1.63 | 2.88 | 2.81 | 2.39 |
| ipb 1/3 | 0.032 | 0.0696 | -2.75 | -2.49 | -1.57 | -0.19 | 1.69 | 2.62 | 2.88 | 2.33 |
| opb 1/3 | -0.0163 | -0.0499 | -0.11 | 0.83 | 3.07 | 7.48 | 1.28 | 0.27 | -0.44 | -0.47 |
| opb 2/3 | -0.0346 | -0.1058 | -0.09 | 1.04 | 3.07 | 5.31 | 0.8 | 0.08 | -0.64 | -0.58 |
| opb 3/3 | -0.0533 | -0.1631 | -0.09 | 1.16 | 2.6 | 4.27 | 0.63 | 0.01 | -0.68 | -0.62 |
| opb 3/3 | -0.0545 | -0.1668 | -0.09 | 1.18 | 2.57 | 4.28 | 0.66 | 0.03 | -0.65 | -0.61 |
| opb 2/3 | -0.0363 | -0.111 | 0.12 | 1.31 | 3.15 | 5.34 | 0.76 | -0.06 | -0.78 | -0.65 |
| opb 1/3 | -0.0173 | -0.0528 | 0.61 | 1.74 | 3.75 | 7.76 | 0.98 | -0.39 | -1.14 | -0.92 |
| axi-c 1/3 | -0.0147 | -0.0836 | 9.08 | 7.97 | 6.53 | 5.66 | 4.67 | 6.25 | 8.74 | 6.58 |
| axi-c 2/3 | -0.0292 | -0.1663 | 8.97 | 8.2 | 6.27 | 4.31 | 3.95 | 5.82 | 8.07 | 6.01 |
| axi-c 3/3 | -0.0437 | -0.249 | 8.43 | 7.88 | 5.77 | 3.78 | 4 | 5.72 | 7.56 | 5.54 |
| axi-c 3/3 | -0.0437 | -0.249 | 8.43 | 7.86 | 5.75 | 3.78 | 3.97 | 5.71 | 7.58 | 5.57 |
| axi-c 2/3 | -0.0292 | -0.1661 | 9 | 8.36 | 6.37 | 4.07 | 4.03 | 6.02 | 8.32 | 6.37 |
| axi-c 1/3 | -0.0146 | -0.0832 | 9.55 | 8.9 | 7.18 | 4.08 | 3.5 | 5.13 | 7.9 | 7.07 |
| axi-t 1/3 | 0.0151 | 0.0801 | 7.02 | 5.63 | 2.89 | 2.74 | 5.98 | 7.09 | 7.46 | 5.1 |
| axi-t 2/3 | 0.0297 | 0.158 | 7.29 | 6.09 | 2.67 | 2.35 | 6.35 | 7.46 | 7.12 | 4.87 |
| axi-t 3/3 | 0.0444 | 0.2359 | 7.64 | 6.48 | 3.03 | 2.3 | 6.14 | 7.48 | 7.02 | 4.94 |
| axi-t 3/3 | 0.0443 | 0.2358 | 7.83 | 6.69 | 3.13 | 2.31 | 5.98 | 7.31 | 6.85 | 4.84 |
| axi-t 2/3 | 0.0296 | 0.1575 | 7.92 | 6.7 | 2.88 | 2.38 | 6.23 | 7.1 | 6.73 | 4.44 |
| axi-t 1/3 | 0.0149 | 0.0792 | 7.78 | 6.34 | 2.82 | 2.47 | 5.83 | 6.77 | 6.93 | 4.67 |

**Table 51: Measured SNCFs on chord intersection of brace and chord for T9 at preload level of 50%**

| T9 | pl. cap | design | CC;1 | CI;16 | CI;14 | CS;13 | CI;12 | CI;10 | CC;9 | CI;8 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0333 | 0.0724 | -2.74 | -2.57 | -1.35 | 0.06 | 1.29 | 2.19 | 2.78 | 2.53 |
| ipb 2/3 | 0.0663 | 0.1442 | -2.87 | -2.37 | -1.23 | 0.06 | 1.11 | 2.32 | 2.73 | 2.8 |
| ipb 3/3 | 0.0992 | 0.2158 | -2.42 | -2.1 | -1.1 | 0.09 | 1.01 | 2.28 | 2.64 | 2.87 |
| ipb 3/3 | 0.0988 | 0.2148 | -2.43 | -2.12 | -1.08 | 0.11 | 1.02 | 2.3 | 2.66 | 2.89 |
| ipb 2/3 | 0.0662 | 0.1439 | -2.94 | -2.4 | -1.2 | 0.08 | 1.11 | 2.39 | 2.81 | 2.88 |
| ipb 1/3 | 0.032 | 0.0696 | -2.75 | -2.57 | -1.3 | 0.2 | 1.41 | 2.33 | 2.88 | 2.62 |
| opb 1/3 | -0.0163 | -0.0499 | -0.11 | -0.94 | -2.71 | -7.06 | -2.28 | -0.47 | -0.44 | 0.27 |
| opb 2/3 | -0.0346 | -0.1058 | -0.09 | -0.84 | -2.4 | -5.31 | -1.71 | -0.58 | -0.64 | 0.08 |
| opb 3/3 | -0.0533 | -0.1631 | -0.09 | -0.84 | -2.32 | -4.59 | -1.58 | -0.62 | -0.68 | 0.01 |
| opb 3/3 | -0.0545 | -0.1668 | -0.09 | -0.82 | -2.34 | -4.58 | -1.56 | -0.61 | -0.65 | 0.03 |
| opb 2/3 | -0.0363 | -0.111 | 0.12 | -0.71 | -2.32 | -5.36 | -1.67 | -0.65 | -0.78 | -0.06 |
| opb 1/3 | -0.0173 | -0.0528 | 0.61 | -0.32 | -2.5 | -7.09 | -2.36 | -0.92 | -1.14 | -0.39 |
| axi-c 1/3 | -0.0147 | -0.0836 | 9.08 | 8.24 | 4.38 | 3.1 | 4.96 | 6.58 | 8.74 | 6.25 |
| axi-c 2/3 | -0.0292 | -0.1663 | 8.97 | 7.9 | 4.1 | 2.4 | 4.75 | 6.01 | 8.07 | 5.82 |
| axi-c 3/3 | -0.0437 | -0.249 | 8.43 | 7.22 | 3.69 | 1.68 | 4.46 | 5.54 | 7.56 | 5.72 |
| axi-c 3/3 | -0.0437 | -0.249 | 8.43 | 7.22 | 3.69 | 1.65 | 4.48 | 5.57 | 7.58 | 5.71 |
| axi-c 2/3 | -0.0292 | -0.1661 | 9 | 8.01 | 4.2 | 2.35 | 5.22 | 6.37 | 8.32 | 6.02 |
| axi-c 1/3 | -0.0146 | -0.0832 | 9.55 | 8.76 | 5.08 | 4.12 | 6.12 | 7.07 | 7.9 | 5.13 |
| axi-t 1/3 | 0.0151 | 0.0801 | 7.02 | 8.19 | 6.6 | 6.78 | 4.92 | 5.1 | 7.46 | 7.09 |
| axi-t 2/3 | 0.0297 | 0.158 | 7.29 | 8.11 | 5.95 | 4.15 | 4.1 | 4.87 | 7.12 | 7.46 |
| axi-t 3/3 | 0.0444 | 0.2359 | 7.64 | 8.16 | 5.47 | 3.28 | 3.88 | 4.94 | 7.02 | 7.48 |
| axi-t 3/3 | 0.0443 | 0.2358 | 7.83 | 8.32 | 5.63 | 3.28 | 3.86 | 4.84 | 6.85 | 7.31 |
| axi-t 2/3 | 0.0296 | 0.1575 | 7.92 | 8.83 | 6.39 | 4.13 | 3.82 | 4.44 | 6.73 | 7.1 |
| axi-t 1/3 | 0.0149 | 0.0792 | 7.78 | 9.09 | 7.94 | 7.66 | 4.95 | 4.67 | 6.93 | 6.77 |

**Table 52: Measured SNCFs on chord intersection of brace and chord for T9 at preload level of 50%**

| T9 | pl. cap | design | BC;1 | BI;2 | BI;4 | BS;5 | BI;6 | BI;8 | BC;9 | BI;10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0317 | 0.069 | -1.52 | -1.32 | -1.01 | -0.05 | 0.91 | 1.01 | 1.42 | 1.53 |
| ipb 2/3 | 0.0648 | 0.141 | -1.75 | -1.34 | -0.98 | -0.07 | 0.98 | 1.11 | 1.44 | 1.53 |
| ipb 3/3 | 0.0979 | 0.2129 | -1.92 | -1.33 | -0.89 | -0.05 | 0.93 | 1.21 | 1.45 | 1.54 |
| ipb 3/3 | 0.0975 | 0.2121 | -1.92 | -1.33 | -0.89 | -0.06 | 0.92 | 1.24 | 1.45 | 1.55 |
| ipb 2/3 | 0.0653 | 0.1421 | -1.64 | -1.33 | -0.98 | -0.08 | 0.97 | 1.11 | 1.38 | 1.51 |
| ipb 1/3 | 0.0312 | 0.0678 | -1.48 | -1.3 | -0.97 | -0.06 | 0.87 | 1.08 | 1.38 | 1.42 |
| opb 1/3 | -0.0173 | -0.053 | -0.09 | 0.54 | 0.53 | 1.12 | 0.53 | 0.59 | 0.04 | -0.56 |
| opb 2/3 | -0.0359 | -0.1098 | 0.07 | 0.59 | 0.34 | 0.9 | 0.41 | 0.62 | -0.08 | -0.65 |
| opb 3/3 | -0.055 | -0.1682 | 0.09 | 0.56 | 0.35 | 0.76 | 0.38 | 0.54 | -0.15 | -0.68 |
| opb 3/3 | -0.0551 | -0.1686 | 0.09 | 0.57 | 0.35 | 0.78 | 0.37 | 0.54 | -0.14 | -0.69 |
| opb 2/3 | -0.0364 | -0.1115 | 0.16 | 0.7 | 0.37 | 0.92 | 0.31 | 0.46 | -0.18 | -0.78 |
| opb 1/3 | -0.0179 | -0.0546 | 0.35 | 0.94 | 0.72 | 1.25 | 0.2 | 0.16 | -0.36 | -0.97 |
| axi-c 1/3 | -0.0146 | -0.083 | 3.55 | 3.49 | 3.46 | 1.97 | 1.84 | 1.43 | 1.3 | 1.52 |
| axi-c 2/3 | -0.0292 | -0.1663 | 3.09 | 2.97 | 3.15 | 1.93 | 2 | 1.74 | 1.86 | 1.99 |
| axi-c 3/3 | -0.0437 | -0.2491 | 2.88 | 2.64 | 2.84 | 1.94 | 2.14 | 2.08 | 2.36 | 2.33 |
| axi-c 3/3 | -0.0437 | -0.2491 | 2.88 | 2.64 | 2.84 | 1.94 | 2.14 | 2.06 | 2.36 | 2.37 |
| axi-c 2/3 | -0.0291 | -0.1659 | 3.09 | 2.99 | 3.19 | 1.91 | 2.06 | 1.68 | 1.86 | 2.07 |
| axi-c 1/3 | -0.0146 | -0.0834 | 3.94 | 3.59 | 3.65 | 1.68 | 1.71 | 1.18 | 1.05 | 1.52 |
| axi-t 1/3 | 0.0151 | 0.0805 | 3.07 | 3.04 | 2.95 | 1.36 | 1.76 | 1.15 | 1.35 | 1.75 |
| axi-t 2/3 | 0.0297 | 0.1582 | 2.97 | 2.96 | 2.94 | 1.61 | 2.04 | 1.2 | 1.53 | 1.85 |
| axi-t 3/3 | 0.0445 | 0.2366 | 2.67 | 2.7 | 2.72 | 1.67 | 2.16 | 1.41 | 1.71 | 2.12 |
| axi-t 3/3 | 0.0446 | 0.2369 | 2.69 | 2.67 | 2.73 | 1.66 | 2.15 | 1.44 | 1.69 | 2.12 |
| axi-t 2/3 | 0.0298 | 0.1585 | 2.77 | 2.69 | 2.82 | 1.45 | 2.02 | 1.29 | 1.64 | 1.88 |
| axi-t 1/3 | 0.015 | 0.0799 | 2.61 | 2.43 | 2.56 | 0.98 | 1.82 | 1.34 | 1.84 | 2.09 |

**Table 53: Measured SNCFs on brace intersection of brace and chord for T9 at preload level of 100 %**

| T9 | pl. cap | design | BC;1 | BI;16 | BI;14 | BS;13 | BI;12 | BI;10 | BC;9 | BI;8 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0317 | 0.069 | -1.52 | -1.23 | -0.79 | 0.05 | 1.12 | 1.53 | 1.42 | 1.01 |
| ipb 2/3 | 0.0648 | 0.141 | -1.75 | -1.19 | -0.8 | 0 | 1.05 | 1.53 | 1.44 | 1.11 |
| ipb 3/3 | 0.0979 | 0.2129 | -1.92 | -1.15 | -0.76 | 0 | 1.01 | 1.54 | 1.45 | 1.21 |
| ipb 3/3 | 0.0975 | 0.2121 | -1.92 | -1.14 | -0.77 | -0.01 | 1.02 | 1.55 | 1.45 | 1.24 |
| ipb 2/3 | 0.0653 | 0.1421 | -1.64 | -1.18 | -0.83 | -0.02 | 1.08 | 1.51 | 1.38 | 1.11 |
| ipb 1/3 | 0.0312 | 0.0678 | -1.48 | -1.18 | -0.82 | 0.02 | 1.07 | 1.42 | 1.38 | 1.08 |
| opb 1/3 | -0.0173 | -0.053 | -0.09 | -0.44 | -0.84 | -1.68 | -0.95 | -0.56 | 0.04 | 0.59 |
| opb 2/3 | -0.0359 | -0.1098 | 0.07 | -0.39 | -0.88 | -1.61 | -1.02 | -0.65 | -0.08 | 0.62 |
| opb 3/3 | -0.055 | -0.1682 | 0.09 | -0.36 | -0.84 | -1.51 | -1.02 | -0.68 | -0.15 | 0.54 |
| opb 3/3 | -0.0551 | -0.1686 | 0.09 | -0.37 | -0.85 | -1.53 | -1.02 | -0.69 | -0.14 | 0.54 |
| opb 2/3 | -0.0364 | -0.1115 | 0.16 | -0.3 | -0.84 | -1.63 | -1.1 | -0.78 | -0.18 | 0.46 |
| opb 1/3 | -0.0179 | -0.0546 | 0.35 | -0.14 | -0.69 | -1.82 | -1.2 | -0.97 | -0.36 | 0.16 |
| axi-c 1/3 | -0.0146 | -0.083 | 3.55 | 3.11 | 3.49 | 1.25 | 2.25 | 1.52 | 1.3 | 1.43 |
| axi-c 2/3 | -0.0292 | -0.1663 | 3.09 | 2.65 | 3.06 | 1.4 | 2.44 | 1.99 | 1.86 | 1.74 |
| axi-c 3/3 | -0.0437 | -0.2491 | 2.88 | 2.28 | 2.74 | 1.38 | 2.44 | 2.33 | 2.36 | 2.08 |
| axi-c 3/3 | -0.0437 | -0.2491 | 2.88 | 2.28 | 2.74 | 1.38 | 2.44 | 2.37 | 2.36 | 2.06 |
| axi-c 2/3 | -0.0291 | -0.1659 | 3.09 | 2.64 | 3.11 | 1.5 | 2.54 | 2.07 | 1.86 | 1.68 |
| axi-c 1/3 | -0.0146 | -0.0834 | 3.94 | 3.44 | 3.7 | 1.5 | 2.34 | 1.52 | 1.05 | 1.18 |
| axi-t 1/3 | 0.0151 | 0.0805 | 3.07 | 2.73 | 2.97 | 1.58 | 2.23 | 1.75 | 1.35 | 1.15 |
| axi-t 2/3 | 0.0297 | 0.1582 | 2.97 | 2.62 | 2.72 | 1.55 | 2.21 | 1.85 | 1.53 | 1.2 |
| axi-t 3/3 | 0.0445 | 0.2366 | 2.67 | 2.35 | 2.53 | 1.58 | 2.28 | 2.12 | 1.71 | 1.41 |
| axi-t 3/3 | 0.0446 | 0.2369 | 2.69 | 2.33 | 2.53 | 1.58 | 2.28 | 2.12 | 1.69 | 1.44 |
| axi-t 2/3 | 0.0298 | 0.1585 | 2.77 | 2.37 | 2.65 | 1.48 | 2.17 | 1.88 | 1.64 | 1.29 |
| axi-t 1/3 | 0.015 | 0.0799 | 2.61 | 2.27 | 2.72 | 1.54 | 2.41 | 2.09 | 1.84 | 1.34 |

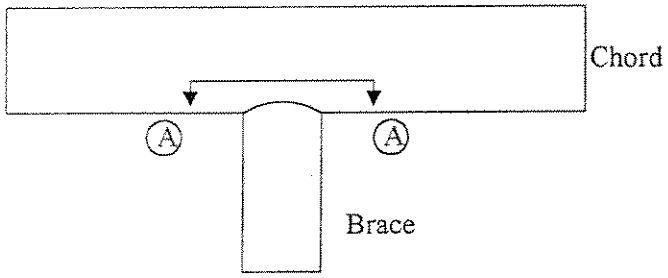
**Table 54: Measured SNCFs on brace intersection of brace and chord for T9 at preload level of 100 %**

| T9 | pl. cap | design | CC;1 | CI;2 | CI;4 | CS;5 | CI;6 | CI;8 | CC;9 | CI;10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0317 | 0.069 | -2.54 | -2.2 | -1.22 | -0.04 | 1.21 | 2.13 | 2.68 | 2.13 |
| ipb 2/3 | 0.0648 | 0.141 | -2.49 | -2.21 | -1.28 | -0.01 | 1.39 | 2.4 | 2.66 | 2.21 |
| ipb 3/3 | 0.0979 | 0.2129 | -2.13 | -2.09 | -1.2 | 0.02 | 1.37 | 2.54 | 2.62 | 2.16 |
| ipb 3/3 | 0.0975 | 0.2121 | -2.17 | -2.11 | -1.2 | 0.01 | 1.37 | 2.54 | 2.63 | 2.19 |
| ipb 2/3 | 0.0653 | 0.1421 | -2.53 | -2.24 | -1.29 | -0.05 | 1.41 | 2.31 | 2.6 | 2.13 |
| ipb 1/3 | 0.0312 | 0.0678 | -2.38 | -2.12 | -1.26 | -0.07 | 1.2 | 2.05 | 2.49 | 2.11 |
| opb 1/3 | -0.0173 | -0.053 | -0.35 | 0.96 | 2.36 | 2.38 | 0.69 | -0.05 | -0.2 | -0.76 |
| opb 2/3 | -0.0359 | -0.1098 | -0.27 | 1.09 | 2.63 | 2.06 | 0.5 | -0.19 | -0.51 | -0.72 |
| opb 3/3 | -0.055 | -0.1682 | -0.25 | 1.15 | 2.43 | 1.98 | 0.42 | -0.21 | -0.67 | -0.74 |
| opb 3/3 | -0.0551 | -0.1686 | -0.24 | 1.17 | 2.44 | 1.99 | 0.43 | -0.22 | -0.7 | -0.72 |
| opb 2/3 | -0.0364 | -0.1115 | -0.08 | 1.35 | 2.75 | 2.18 | 0.4 | -0.36 | -0.77 | -0.83 |
| opb 1/3 | -0.0179 | -0.0546 | 0.37 | 1.66 | 2.95 | 2.68 | 0.28 | -0.7 | -1.06 | -1.18 |
| axi-c 1/3 | -0.0146 | -0.083 | 10.17 | 9.41 | 6.39 | 3.54 | 3.76 | 5.38 | 7.27 | 5.54 |
| axi-c 2/3 | -0.0292 | -0.1663 | 9.39 | 8.54 | 5.85 | 3.07 | 3.78 | 5.42 | 7.3 | 5.62 |
| axi-c 3/3 | -0.0437 | -0.2491 | 8.46 | 7.86 | 5.35 | 2.81 | 3.84 | 5.4 | 7 | 5.28 |
| axi-c 3/3 | -0.0437 | -0.2491 | 8.49 | 7.83 | 5.34 | 2.82 | 3.84 | 5.42 | 7 | 5.29 |
| axi-c 2/3 | -0.0291 | -0.1659 | 9.33 | 8.45 | 5.89 | 2.97 | 3.93 | 5.64 | 7.54 | 5.88 |
| axi-c 1/3 | -0.0146 | -0.0834 | 10.39 | 9.54 | 6.78 | 3.05 | 3.23 | 4.84 | 6.82 | 5.68 |
| axi-t 1/3 | 0.0151 | 0.0805 | 8.9 | 7 | 3.52 | 1.94 | 4.67 | 6.17 | 7.12 | 4.58 |
| axi-t 2/3 | 0.0297 | 0.1582 | 8.63 | 6.98 | 3.37 | 2.07 | 5.15 | 6.65 | 7.45 | 4.7 |
| axi-t 3/3 | 0.0445 | 0.2366 | 8.01 | 6.61 | 3.2 | 1.97 | 5.08 | 6.98 | 7.72 | 5.2 |
| axi-t 3/3 | 0.0446 | 0.2369 | 7.99 | 6.59 | 3.19 | 1.97 | 5.08 | 6.97 | 7.7 | 5.21 |
| axi-t 2/3 | 0.0298 | 0.1585 | 8.13 | 6.43 | 3.13 | 2.04 | 5.27 | 6.68 | 7.53 | 4.61 |
| axi-t 1/3 | 0.015 | 0.0799 | 7.77 | 5.93 | 2.76 | 1.76 | 4.98 | 6.38 | 7.65 | 4.86 |

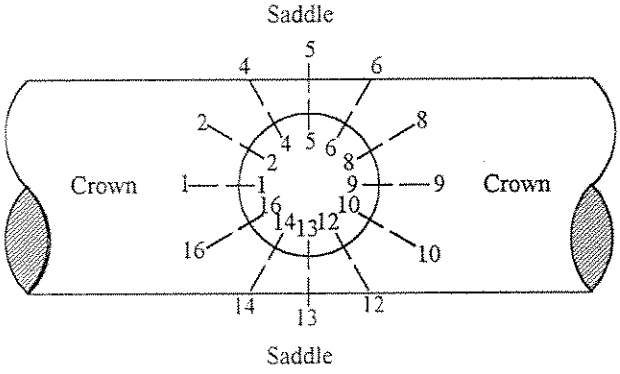
**Table 55: Measured SNCFs on chord intersection of brace and chord for T9 at preload level of 100 %**

| T9 | pl. cap | design | CC;1 | CI;16 | CI;14 | CS;13 | CI;12 | CI;10 | CC;9 | CI;8 |
|---|---|---|---|---|---|---|---|---|---|---|
| ipb 1/3 | 0.0317 | 0.069 | -2.54 | -2.46 | -1.26 | 0.01 | 1.3 | 2.13 | 2.68 | 2.13 |
| ipb 2/3 | 0.0648 | 0.141 | -2.49 | -2.34 | -1.12 | 0.09 | 1.08 | 2.21 | 2.66 | 2.4 |
| ipb 3/3 | 0.0979 | 0.2129 | -2.13 | -2.12 | -1.02 | 0.13 | 0.92 | 2.16 | 2.62 | 2.54 |
| ipb 3/3 | 0.0975 | 0.2121 | -2.17 | -2.13 | -1.03 | 0.16 | 0.91 | 2.19 | 2.63 | 2.54 |
| ipb 2/3 | 0.0653 | 0.1421 | -2.53 | -2.3 | -1.15 | 0.12 | 1.03 | 2.13 | 2.6 | 2.31 |
| ipb 1/3 | 0.0312 | 0.0678 | -2.38 | -2.34 | -1.33 | 0.12 | 1.19 | 2.11 | 2.49 | 2.05 |
| opb 1/3 | -0.0173 | -0.053 | -0.35 | -1.28 | -2.03 | -3.8 | -1.34 | -0.76 | -0.2 | -0.05 |
| opb 2/3 | -0.0359 | -0.1098 | -0.27 | -1.16 | -2.1 | -3.74 | -1.18 | -0.72 | -0.51 | -0.19 |
| opb 3/3 | -0.055 | -0.1682 | -0.25 | -1.01 | -2.02 | -3.56 | -1.17 | -0.74 | -0.67 | -0.21 |
| opb 3/3 | -0.0551 | -0.1686 | -0.24 | -1 | -2.02 | -3.59 | -1.19 | -0.72 | -0.7 | -0.22 |
| opb 2/3 | -0.0364 | -0.1115 | -0.08 | -0.89 | -2.01 | -3.78 | -1.19 | -0.83 | -0.77 | -0.36 |
| opb 1/3 | -0.0179 | -0.0546 | 0.37 | -0.64 | -1.92 | -3.99 | -1.49 | -1.18 | -1.06 | -0.7 |
| axi-c 1/3 | -0.0146 | -0.083 | 10.17 | 9.04 | 4.56 | 0.65 | 4.1 | 5.54 | 7.27 | 5.38 |
| axi-c 2/3 | -0.0292 | -0.1663 | 9.39 | 7.98 | 3.85 | 0.93 | 4.3 | 5.62 | 7.3 | 5.42 |
| axi-c 3/3 | -0.0437 | -0.2491 | 8.46 | 7.24 | 3.56 | 0.91 | 4.19 | 5.28 | 7 | 5.4 |
| axi-c 3/3 | -0.0437 | -0.2491 | 8.49 | 7.26 | 3.56 | 0.91 | 4.16 | 5.29 | 7 | 5.42 |
| axi-c 2/3 | -0.0291 | -0.1659 | 9.33 | 8.01 | 4.16 | 1.11 | 4.62 | 5.88 | 7.54 | 5.64 |
| axi-c 1/3 | -0.0146 | -0.0834 | 10.39 | 9.43 | 4.69 | 1.39 | 4.82 | 5.68 | 6.82 | 4.84 |
| axi-t 1/3 | 0.0151 | 0.0805 | 8.9 | 9.32 | 5.87 | 2.21 | 2.64 | 4.58 | 7.12 | 6.17 |
| axi-t 2/3 | 0.0297 | 0.1582 | 8.63 | 8.96 | 5.69 | 2.17 | 2.69 | 4.7 | 7.45 | 6.65 |
| axi-t 3/3 | 0.0445 | 0.2366 | 8.01 | 8.17 | 5.04 | 2.09 | 2.81 | 5.2 | 7.72 | 6.98 |
| axi-t 3/3 | 0.0446 | 0.2369 | 7.99 | 8.13 | 5.05 | 2.07 | 2.81 | 5.21 | 7.7 | 6.97 |
| axi-t 2/3 | 0.0298 | 0.1585 | 8.13 | 8.42 | 5.76 | 2.28 | 2.78 | 4.61 | 7.53 | 6.68 |
| axi-t 1/3 | 0.015 | 0.0799 | 7.77 | 8.22 | 5.9 | 2.52 | 3.14 | 4.86 | 7.65 | 6.38 |

**Table 56: Measured SNCFs on chord intersection of brace and chord for T9 at preload level of 100 %**




Elevation on T Joint




View 'A' on brace

Ungrouted/Grouted SNCF Plots.

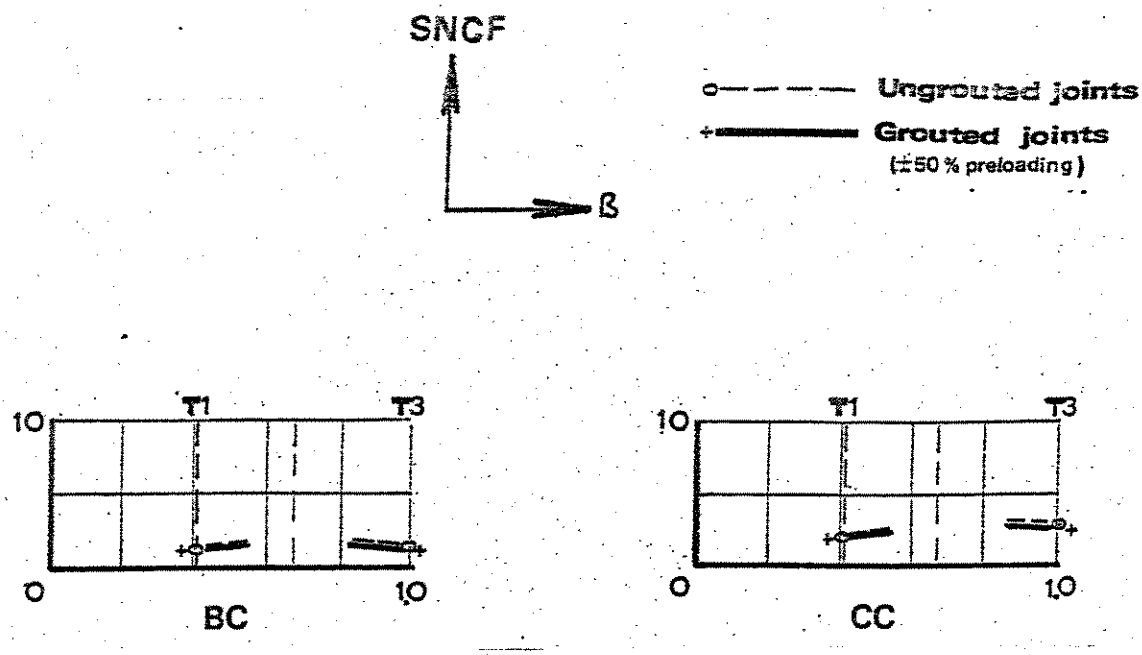



Figure 1: SNCFs for T-joints with $\gamma$= 12.7 for in-plane bending at crown

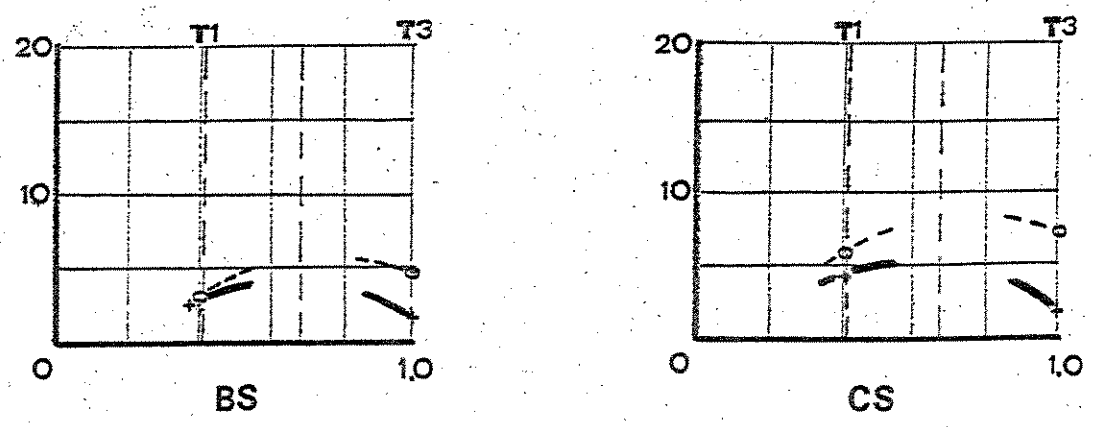



Figure 2: SNCFs for T-joints with $\gamma$= 12.7 for out-plane bending at saddle

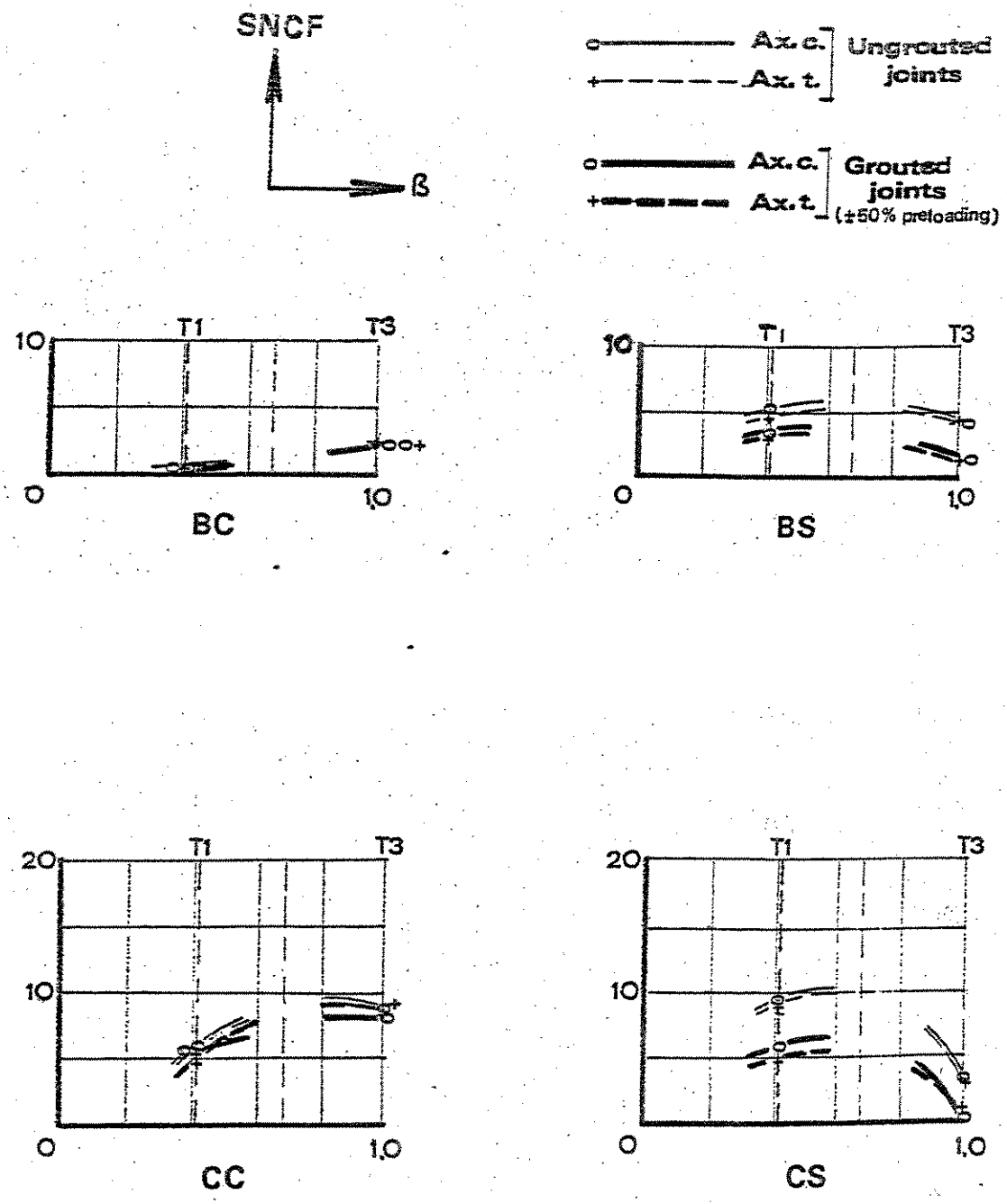



**Figure 3:** SNCFs for T-joints with $\gamma$=12.7 for axial loads at the crown and saddle.

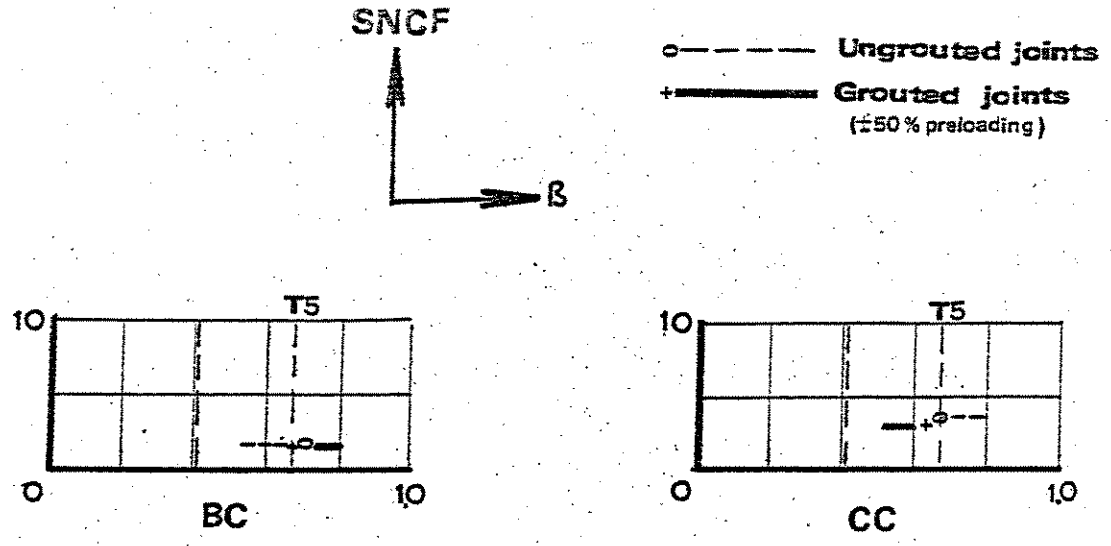



Figure 4: SNCFs for T-joints with $\gamma$=20.3 for in-plane bending at crown.

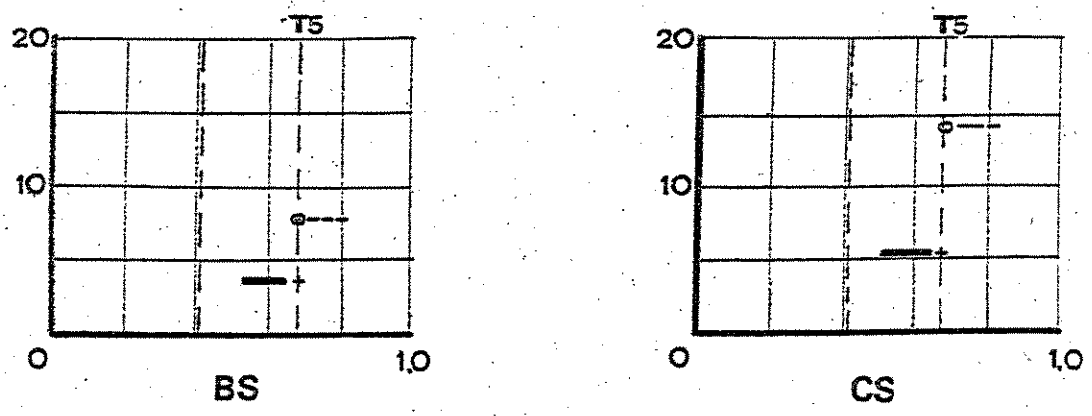



Figure 5: SNCFs for T-joints with $\gamma$=20.3 for out-of-plane bending at saddle.

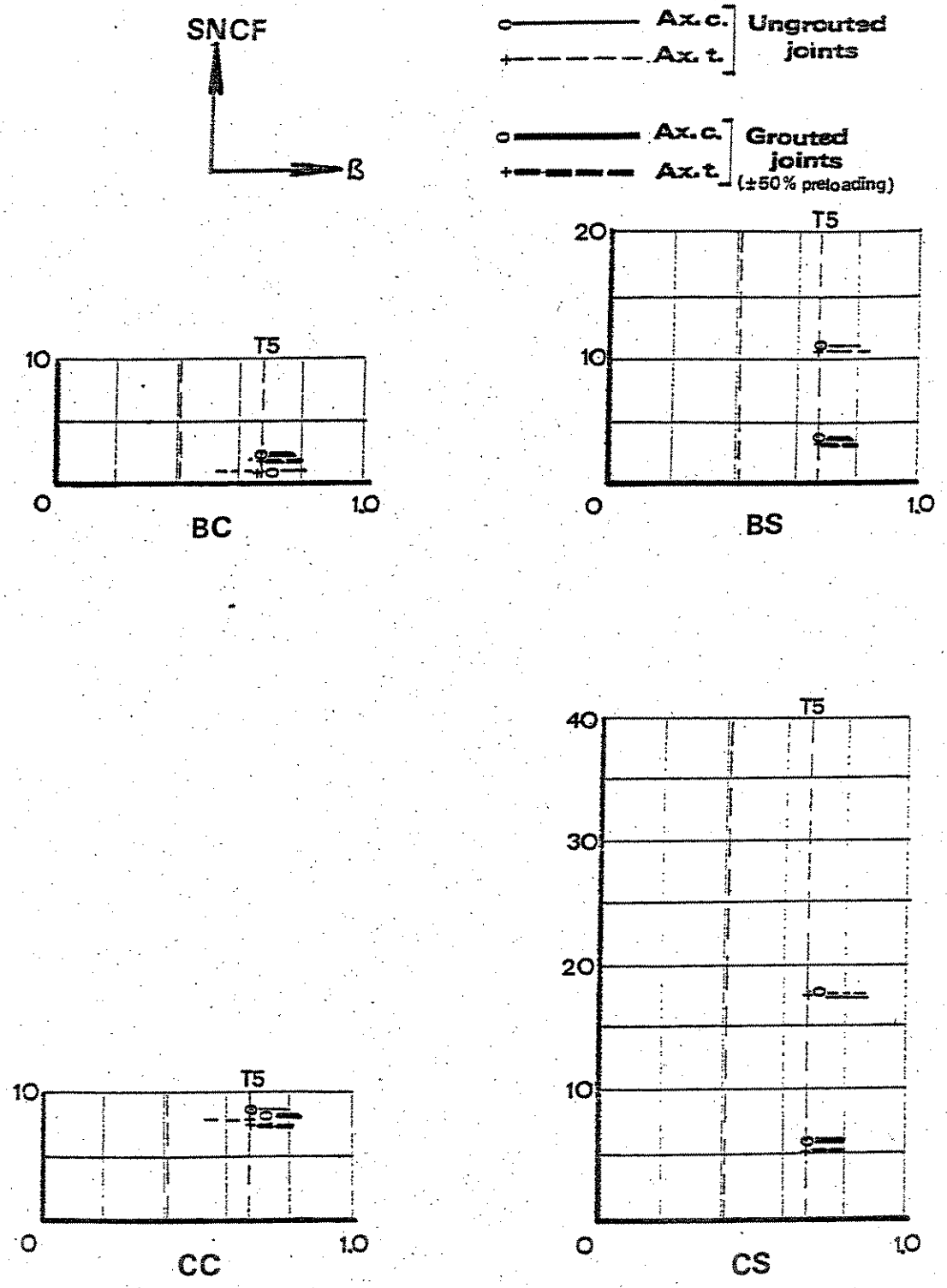



**Figure 6:** SNCFs for T-joints with $\gamma$=20.3 for axial loads at crown and saddle.

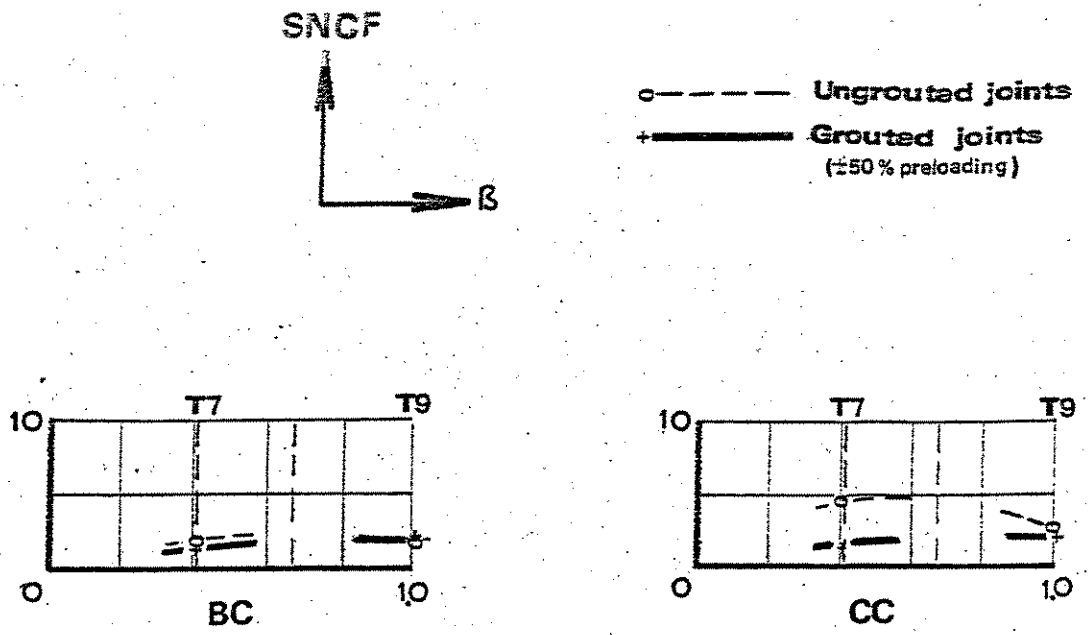



**Figure 7:** SNCFs for T-joints with $\gamma$= 25.7 for in-plane bending at crown.

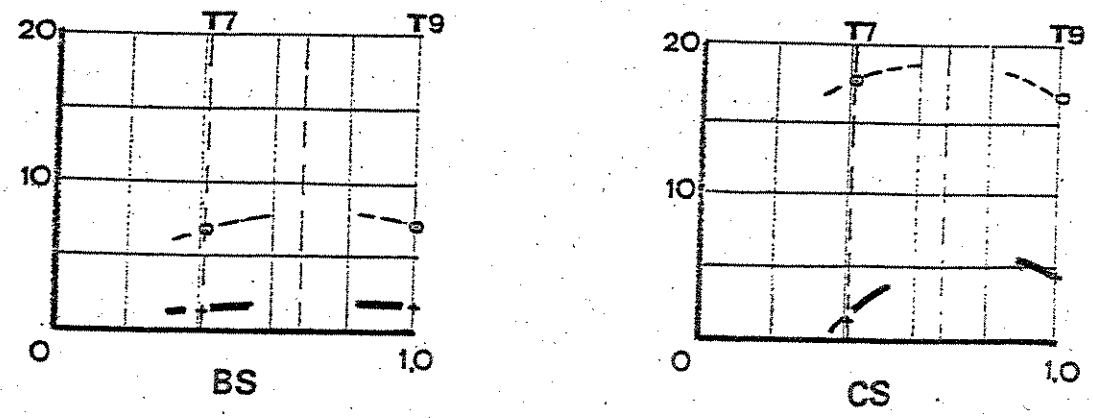



**Figure 8:** SNCFs for T-joints with $\gamma$= 25.7 for out-of-plane bending at saddle.

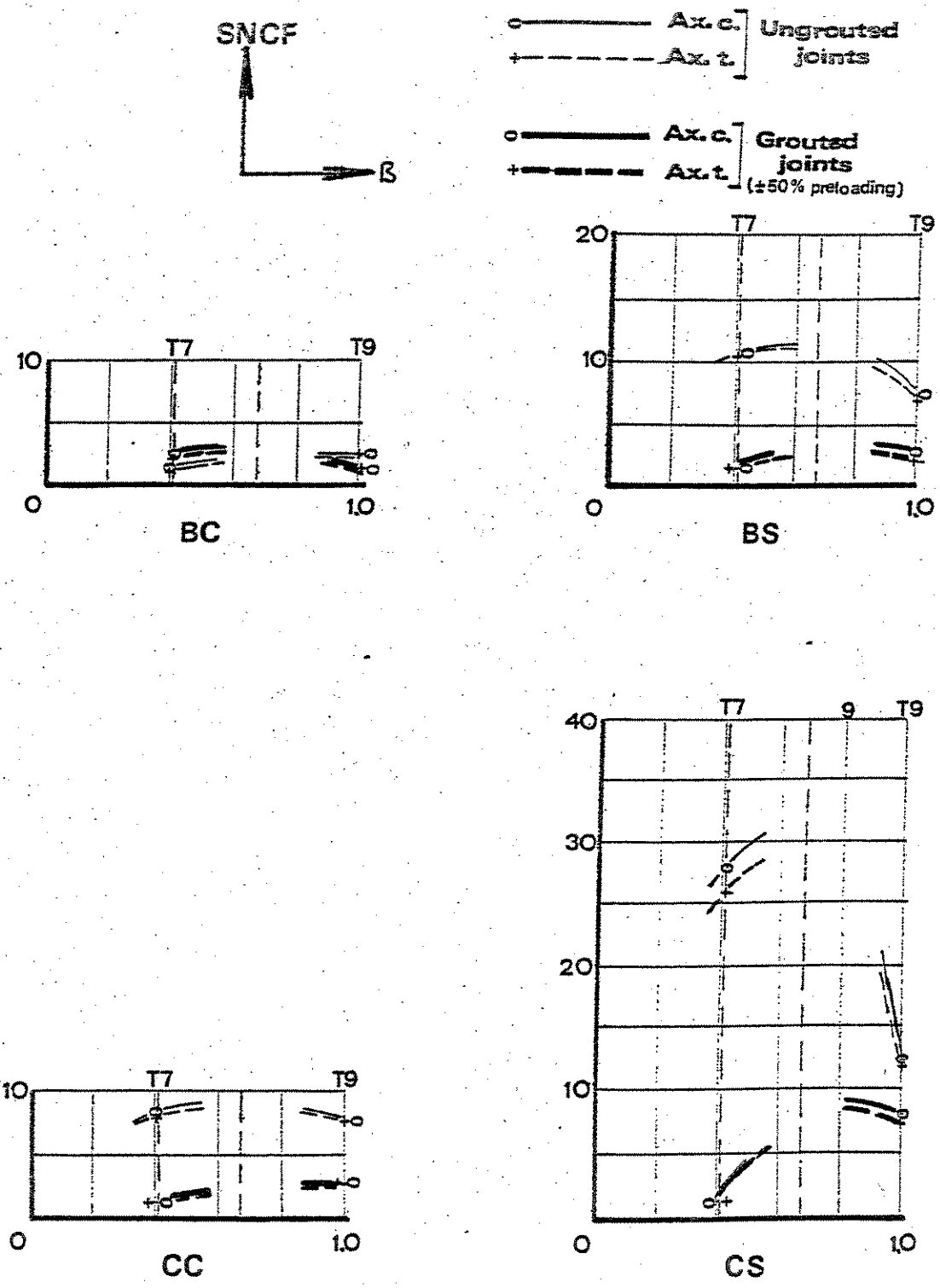



Figure 9: SNCFs for T-joints with $\gamma = 25.7$ for axial loads at crown and saddle.

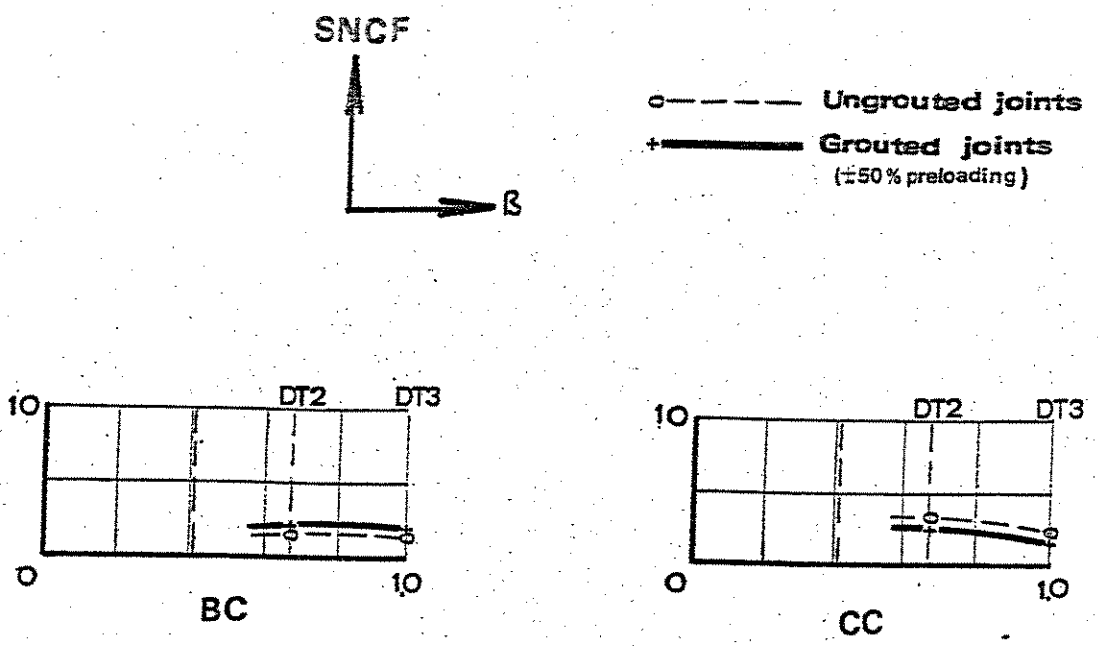



**Figure 10: SNCFs for DT-joints with $\gamma$= 12.7 for in-plane bending at crown.**

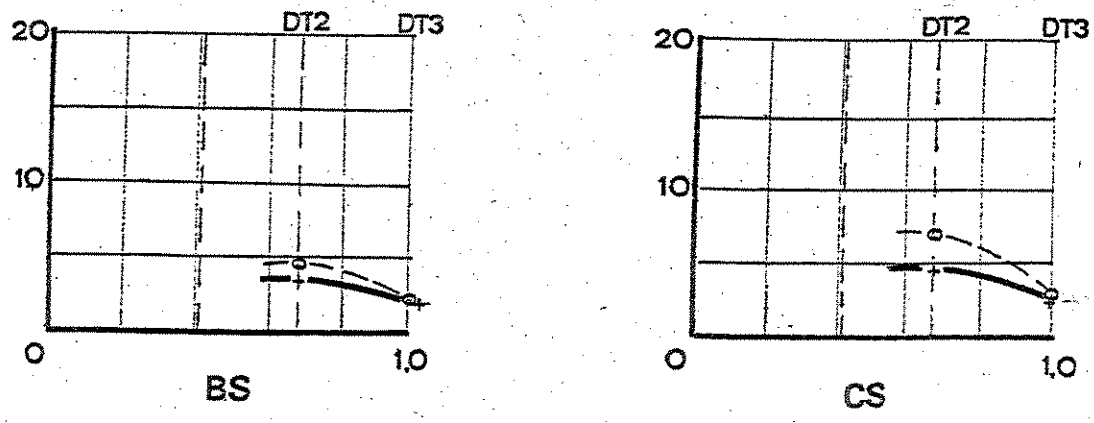



**Figure 11: SNCFs for DT-joints with $\gamma$=12.7 for out-of-plane bending at saddle.**

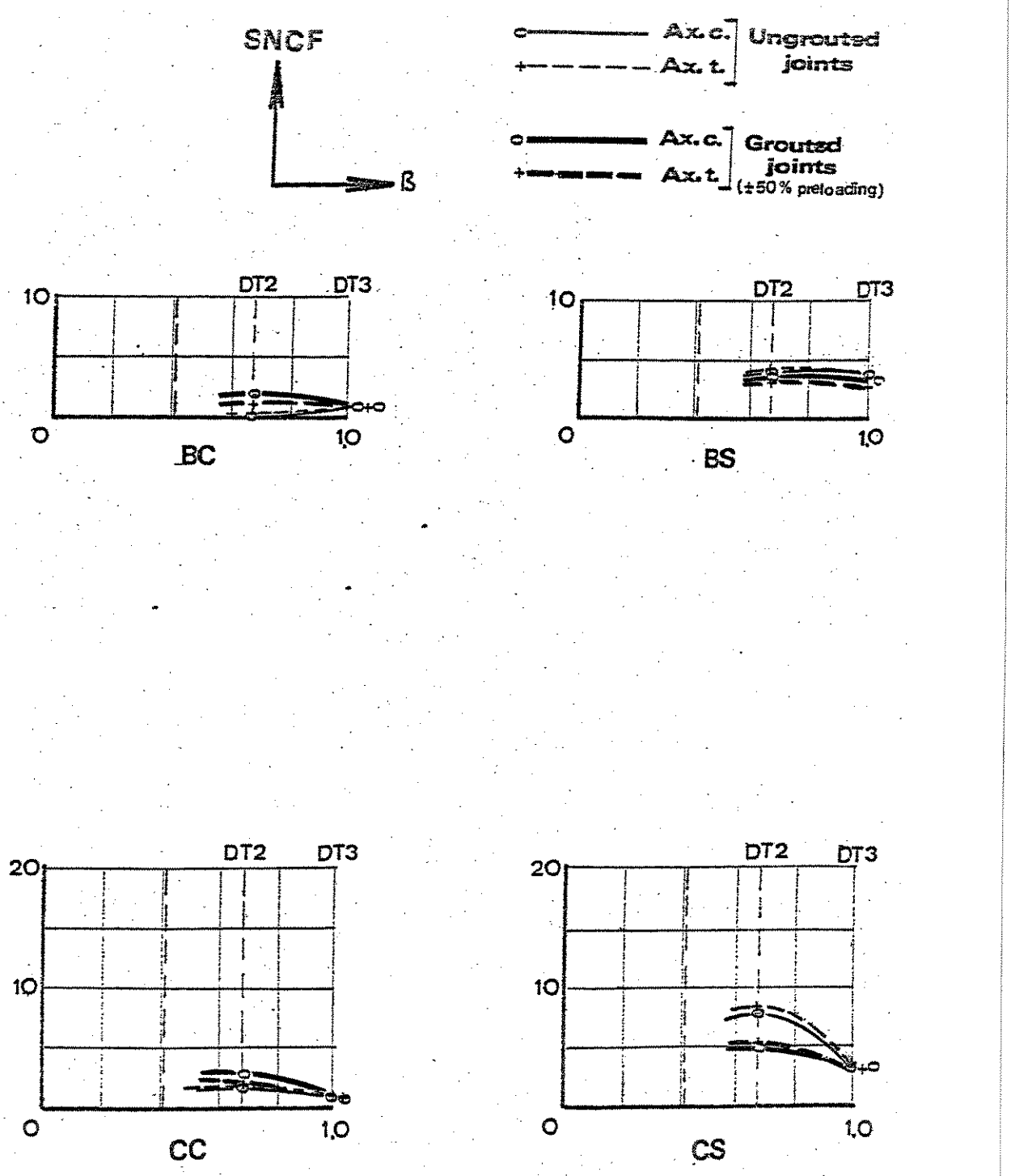



**Figure 12:** SNCFs for DT-joints with $\gamma$=12.7 for axial loads at crown and saddle.

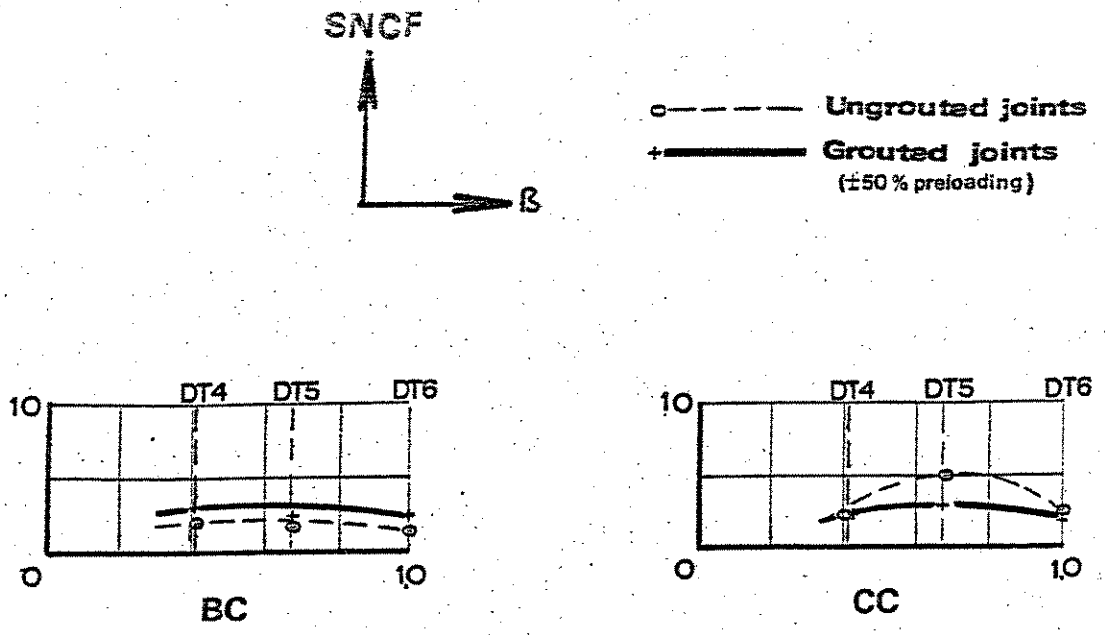



**Figure 13:** SNCFs for DT-joints with $\gamma$=20.3 for in-plane bending at crown

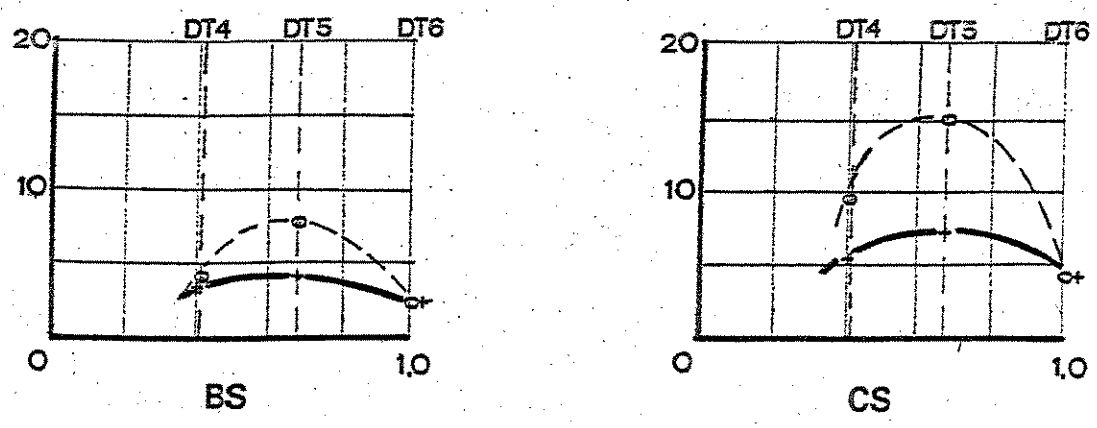



**Figure 14:** SNCFs for DT-joints with $\gamma$=20.3 for out-of-plane bending at saddle.

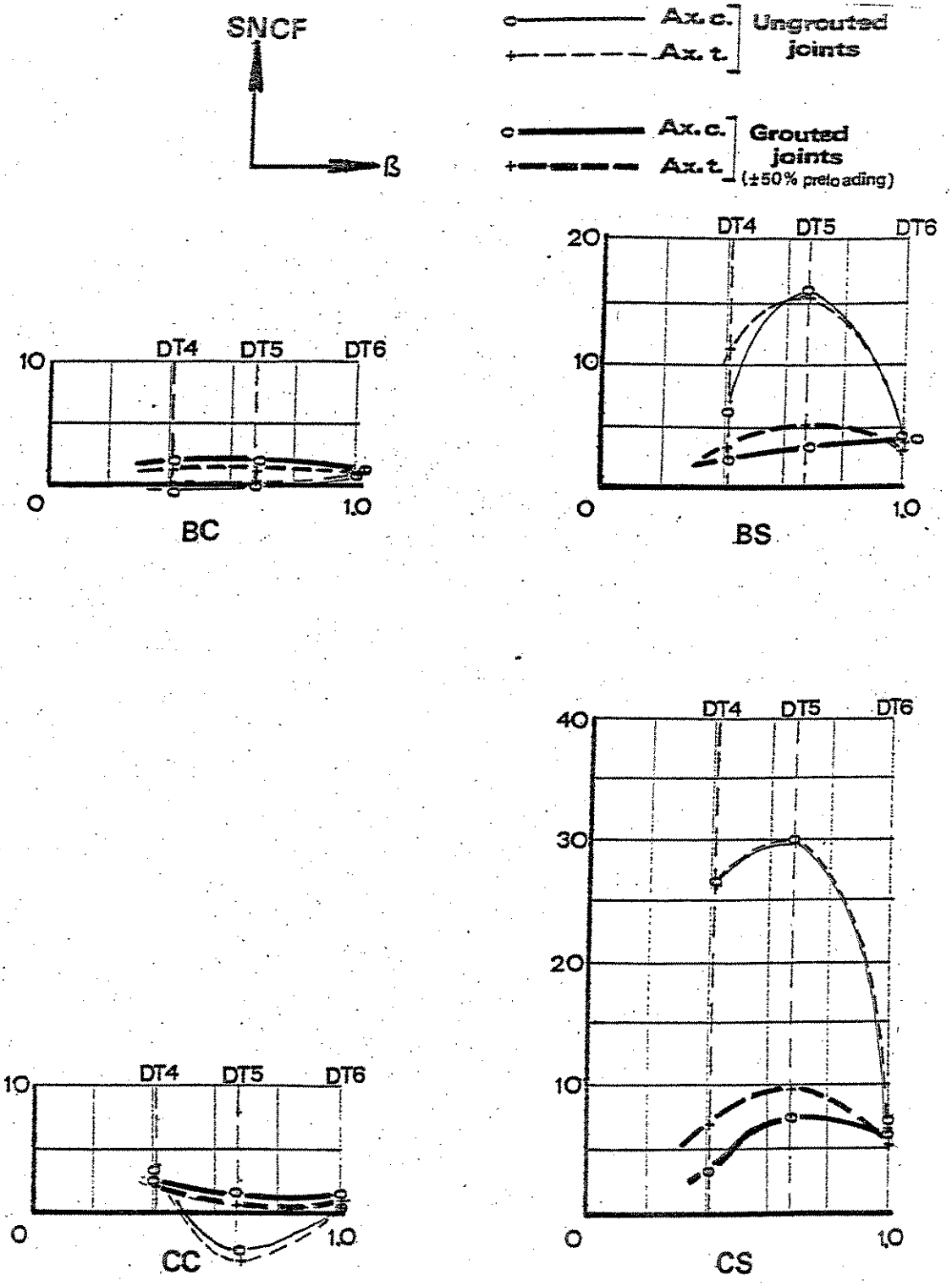



Figure 15: SNCFs for DT-joints with $\gamma = 20.3$ for axial loads at crown and saddle.

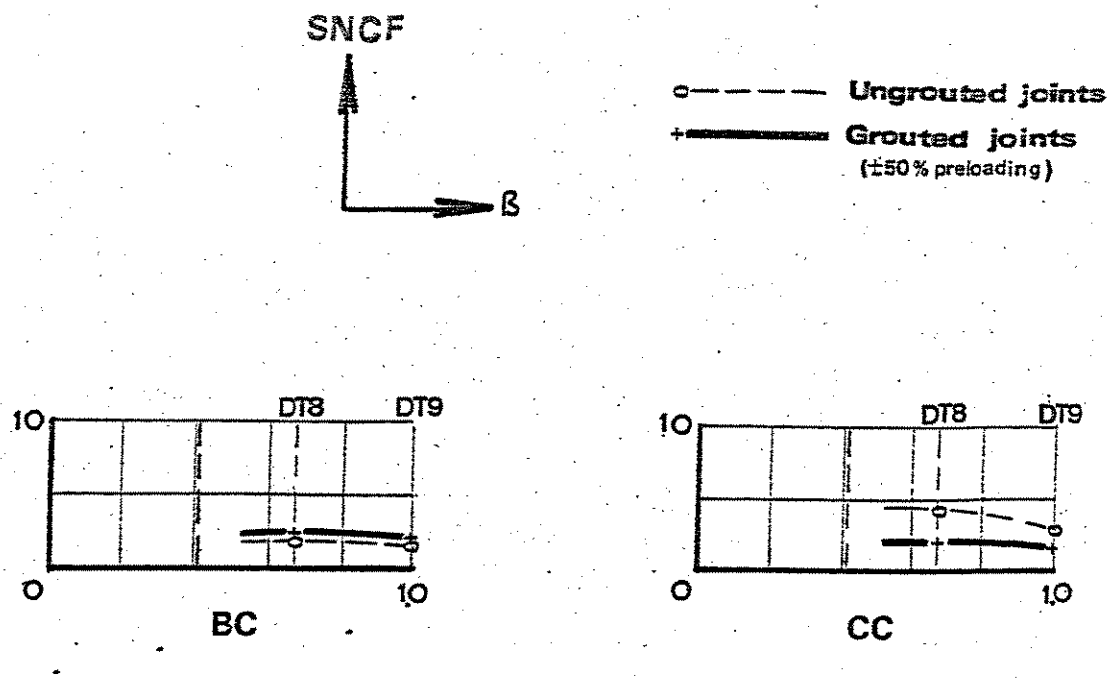



**Figure 16:** SNCFs for DT-joints with $\gamma$=25.7 for in-plane bending at crown.

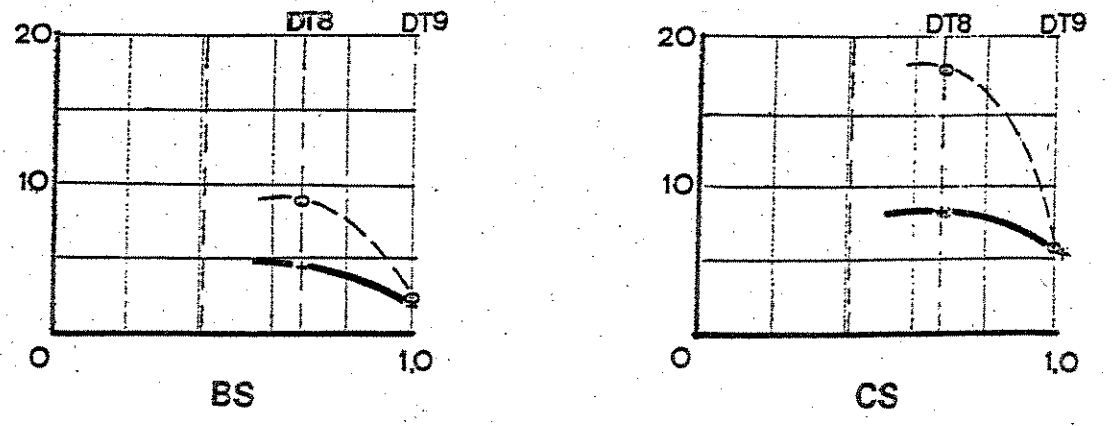



**Figure 17:** SNCFs for DT-joints with $\gamma$= 25.7 for out-of-plane bending at saddle.

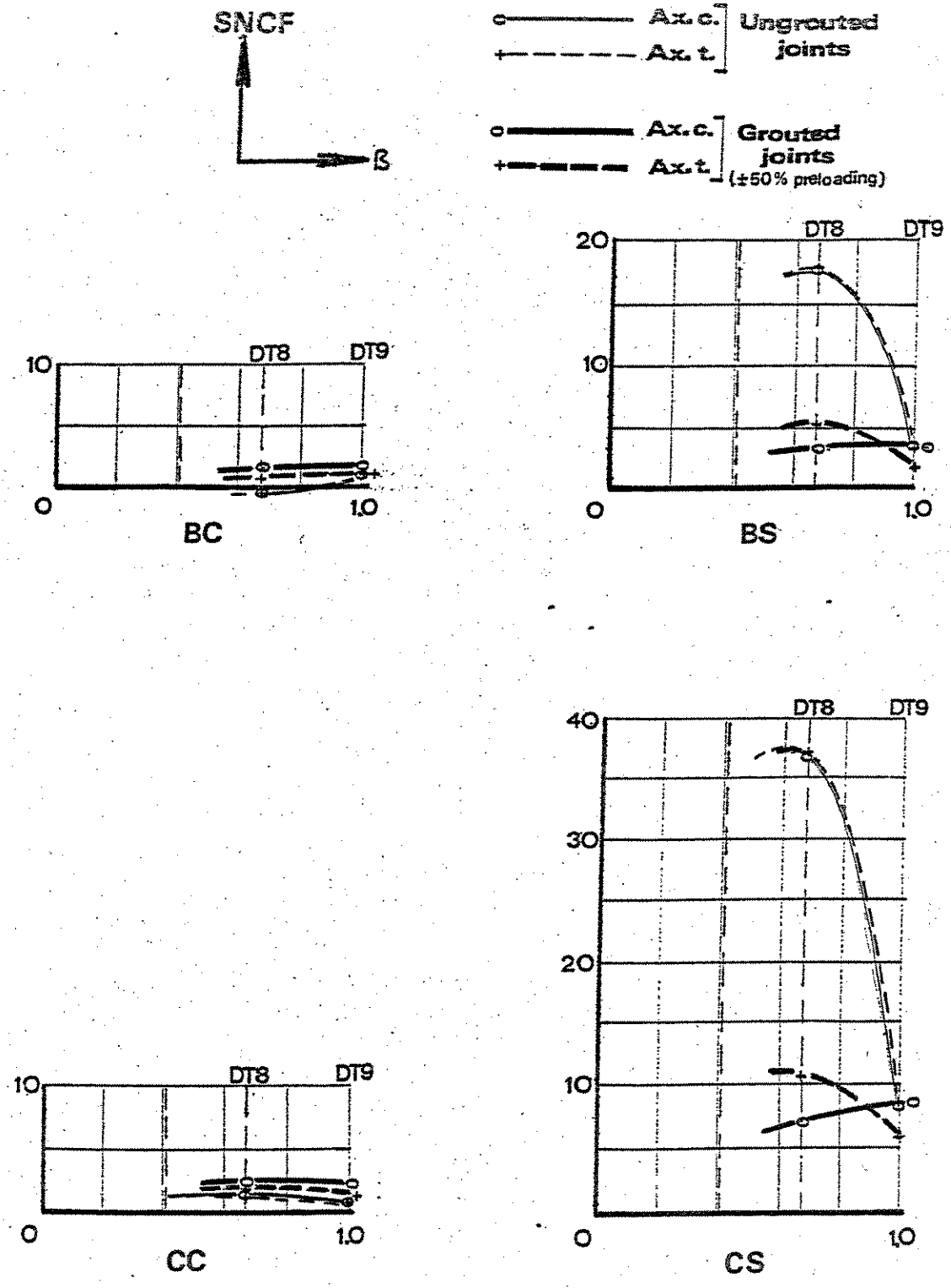



**Figure 18:** SNCFs for DT-joints with $\gamma = 25.7$ for axial loads at crown and saddle.

# Local Joint Deformation

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MSL

**Nonmenclature.**

| | |
|---|---|
| IPB | As welded joint subjected to in-plane bending. |
| OPB | As welded joint subjected to out-of-plane bending. |
| IPB-gr | Grouted joint subjected to in-plane bending. |
| OPB-gr | Grouted joint subjected to out-of-plane bending. |
| Compr | As welded joint subjected to compression loading. |
| Tension | As welded joint subjected to brace tension bending. |
| Comp-gr | Grouted joint subjected to compression bending. |
| Tension-gr | Grouted joint subjected to tension bending. |

**Local Joint deformation of DT2.**

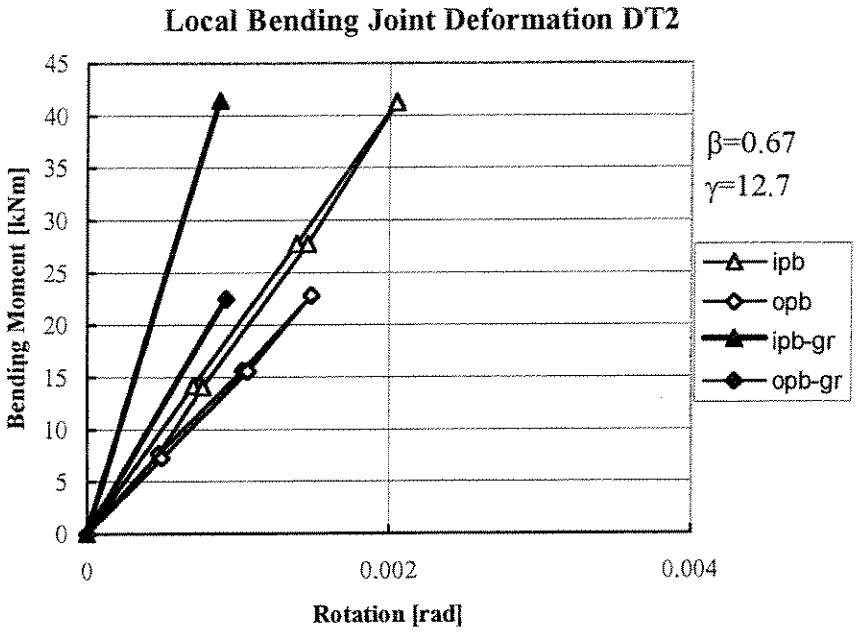


**Figure 1: Local bending joint deformation of specimen DT2**

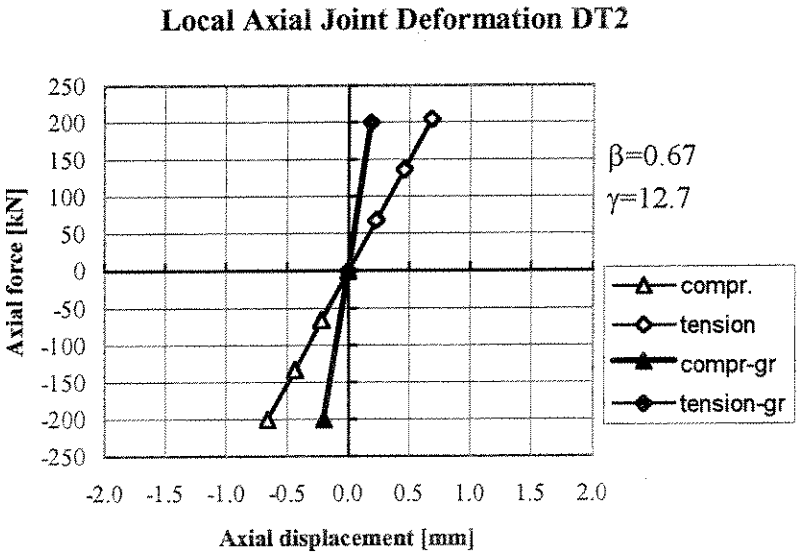


**Figure 2: Local axial joint deformation of specimen DT2**

**Local Joint deformation of DT3.**

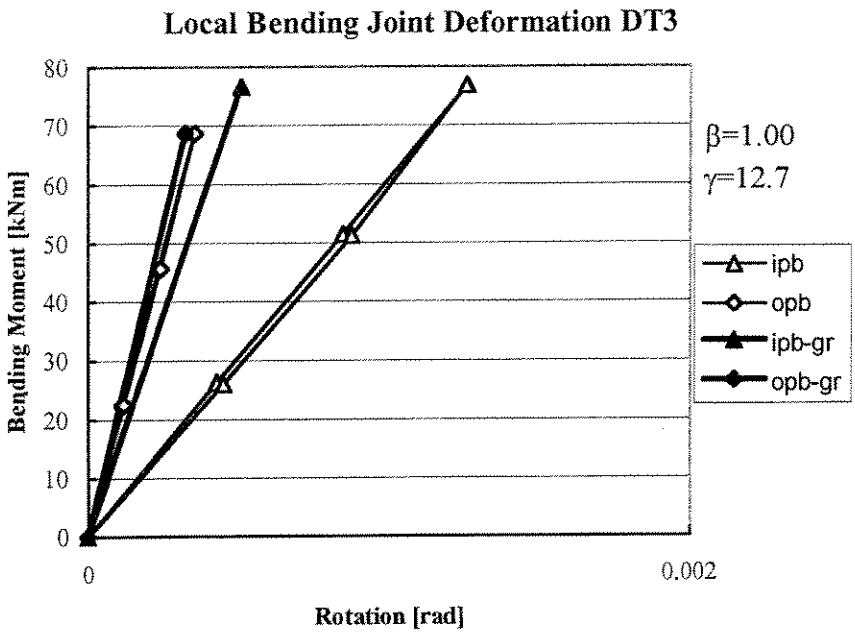


**Figure 3: Local bending joint deformation of specimen DT3**

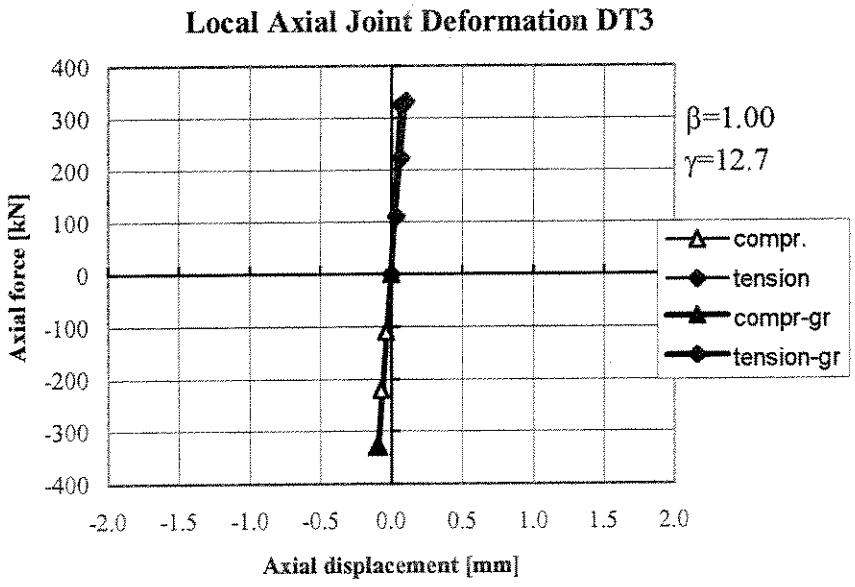


**Figure 4: Local axial joint deformation of specimen DT3**

**Local Joint deformation of DT4.**

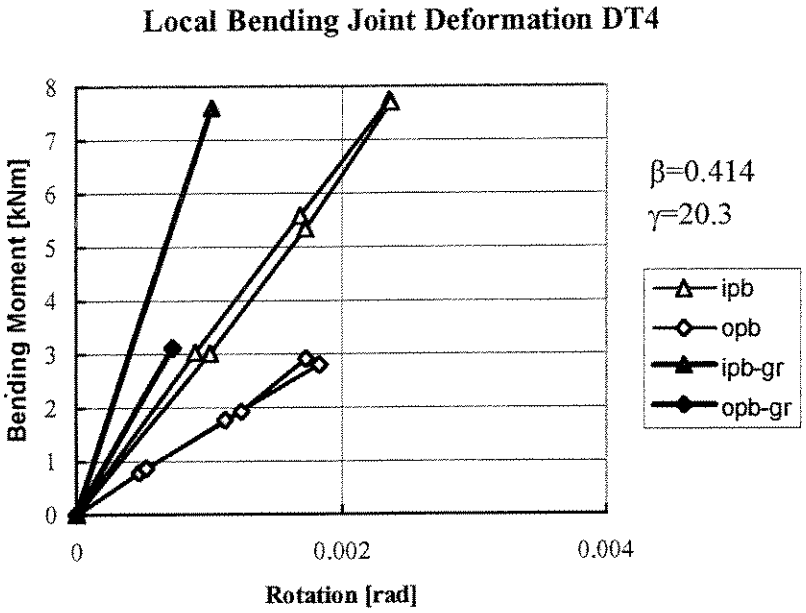


**Figure 5: Local bending joint deformation of specimen DT4**

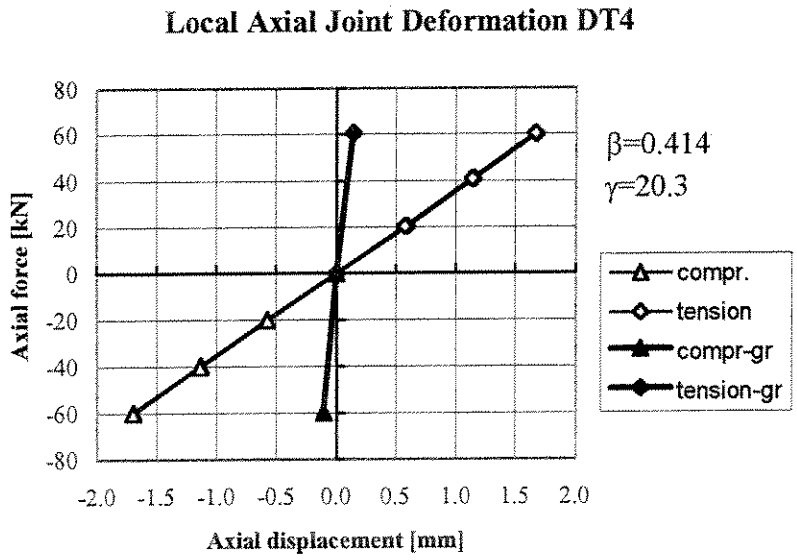


**Figure 6: Local axial joint deformation of specimen DT4**

**Local Joint deformation of DT5.**

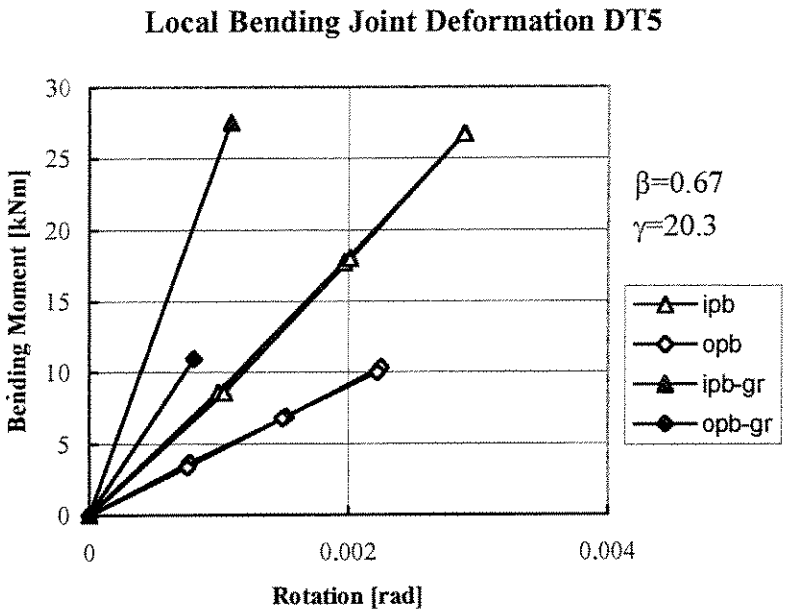


**Figure 7: Local bending joint deformation of specimen DT5**

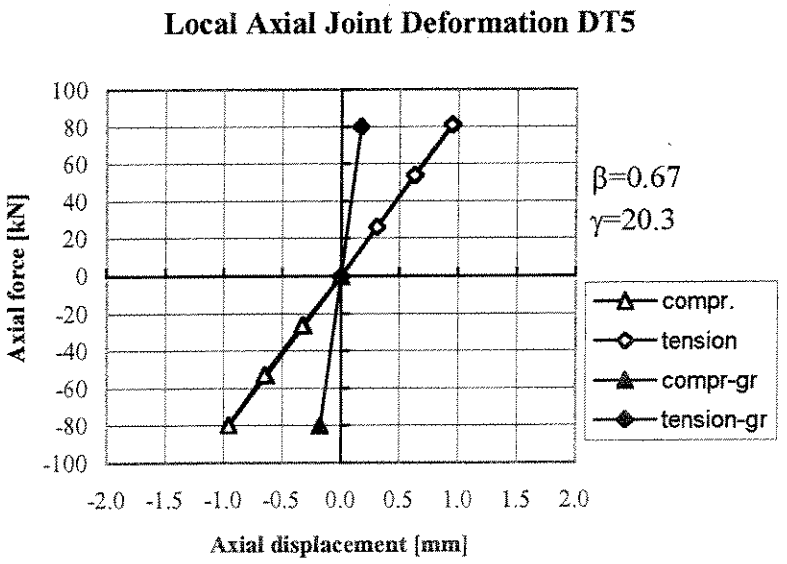


**Figure 8: Local axial joint deformation of specimen DT5**

**Local Joint deformation of DT6.**

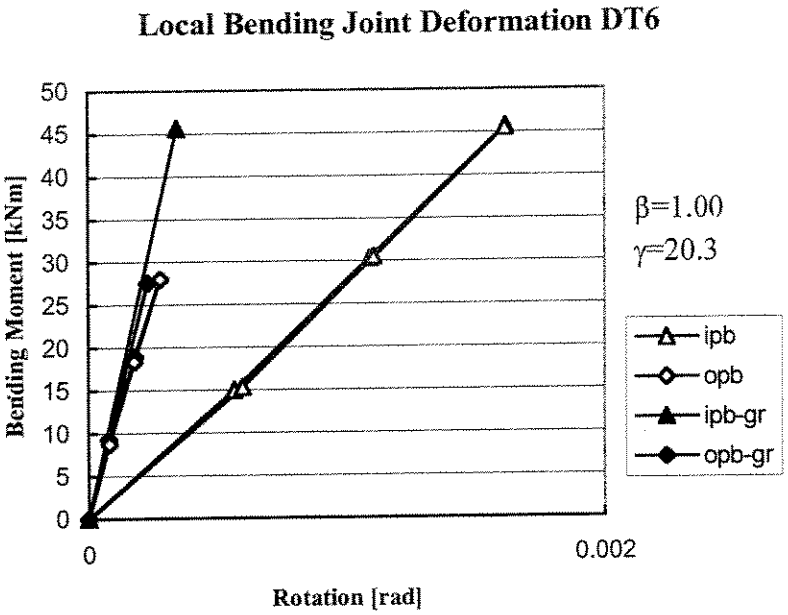


**Figure 9: Local bending joint deformation of specimen DT6**

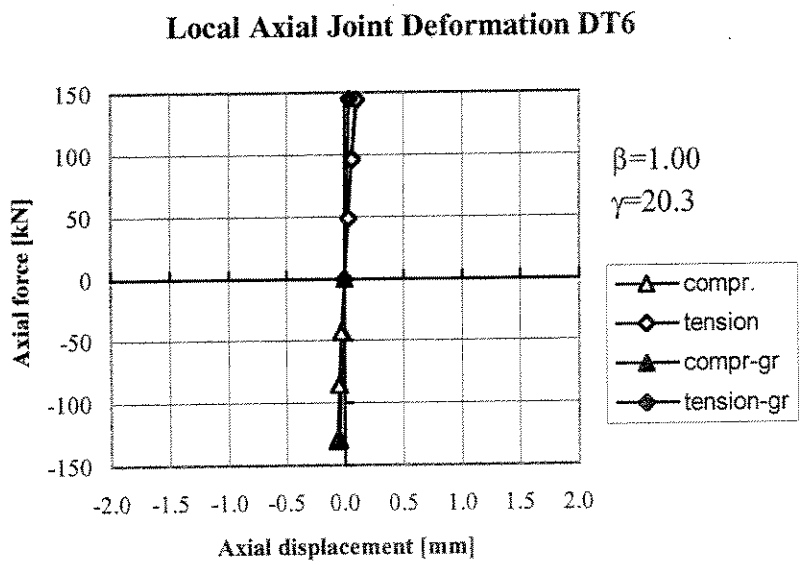


**Figure 10: Local axial joint deformation of specimen DT6**

**Local Joint deformation of DT8.**

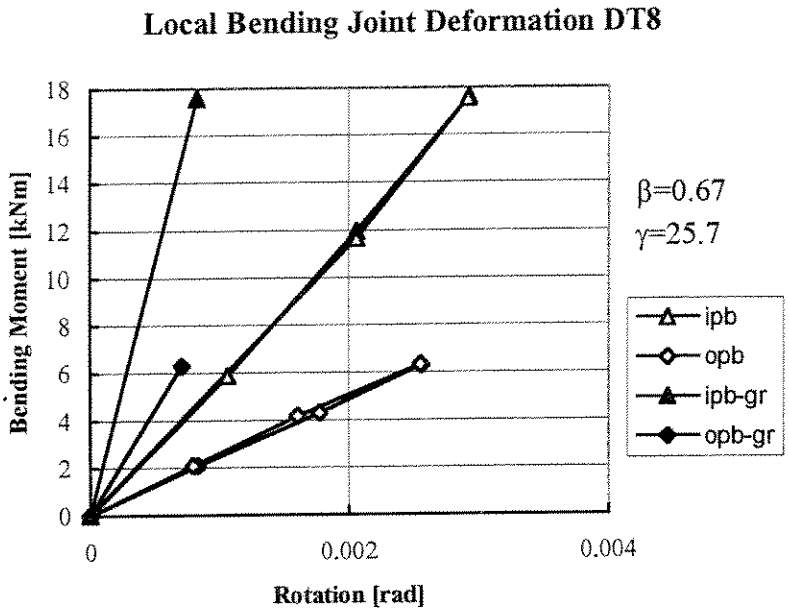


**Figure 11: Local bending joint deformation of specimen DT8**

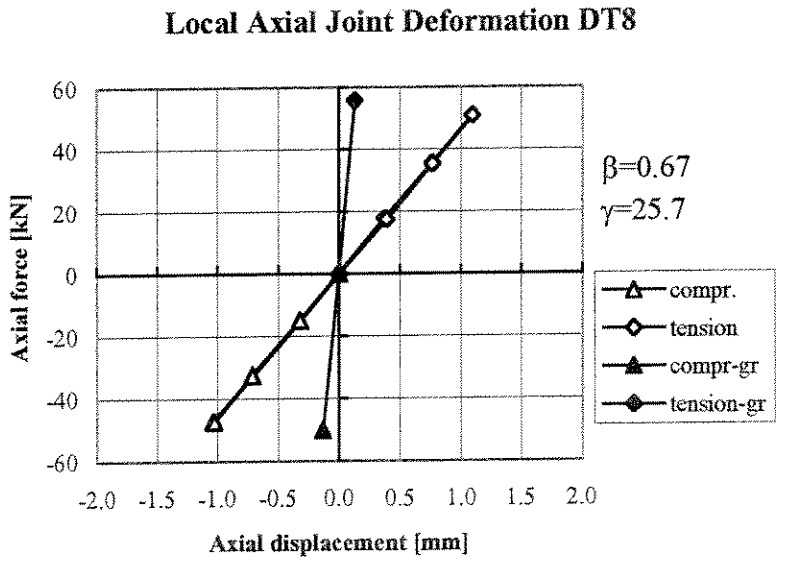


**Figure 12: Local axial joint deformation of specimen DT8**

**Local Joint deformation of DT9.**

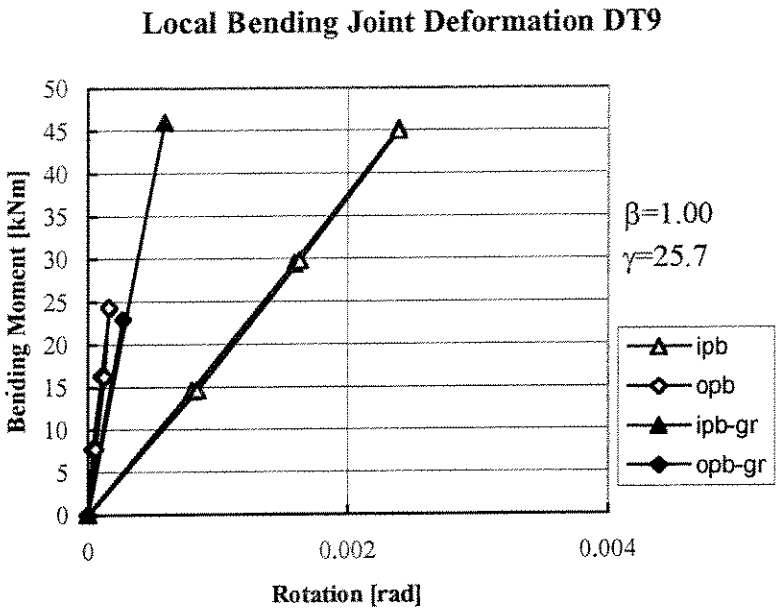


**Figure 13: Local bending joint deformation of specimen DT9**

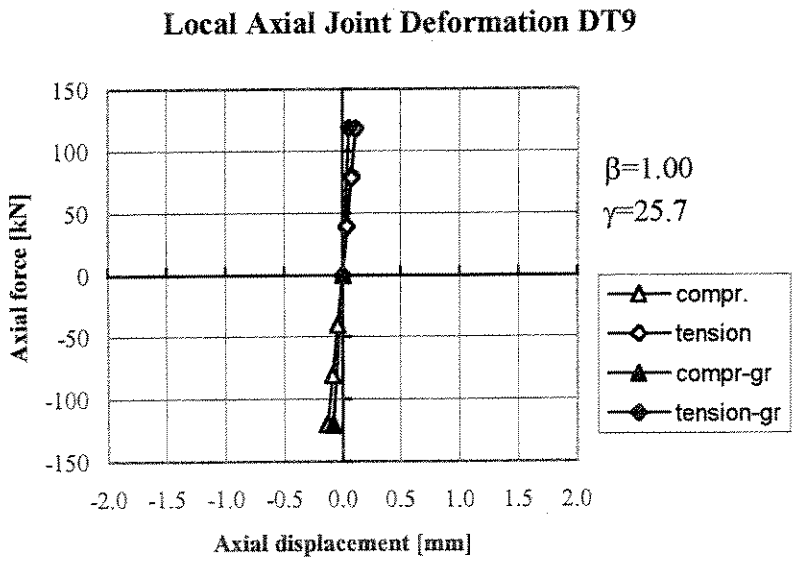


**Figure 14: Local axial joint deformation of specimen DT9**

**Local Joint deformation of T1.**

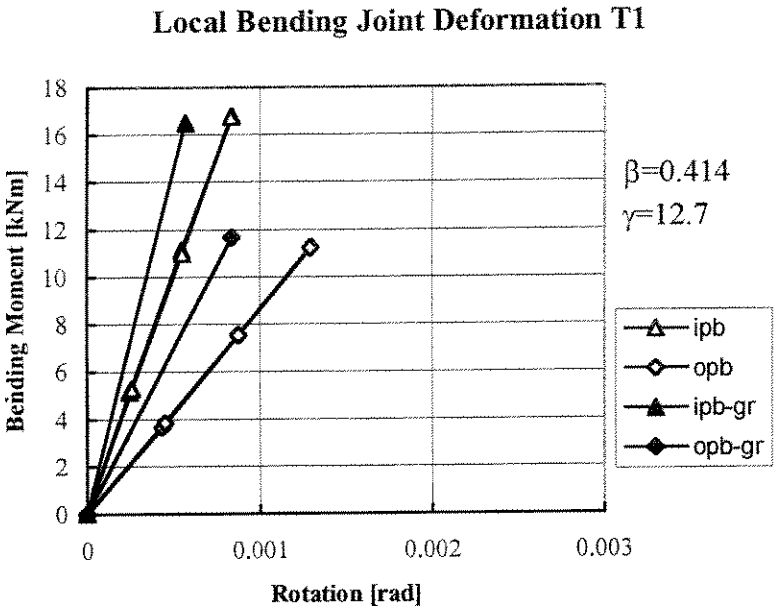


**Figure 15: Local bending joint deformation of specimen T1**

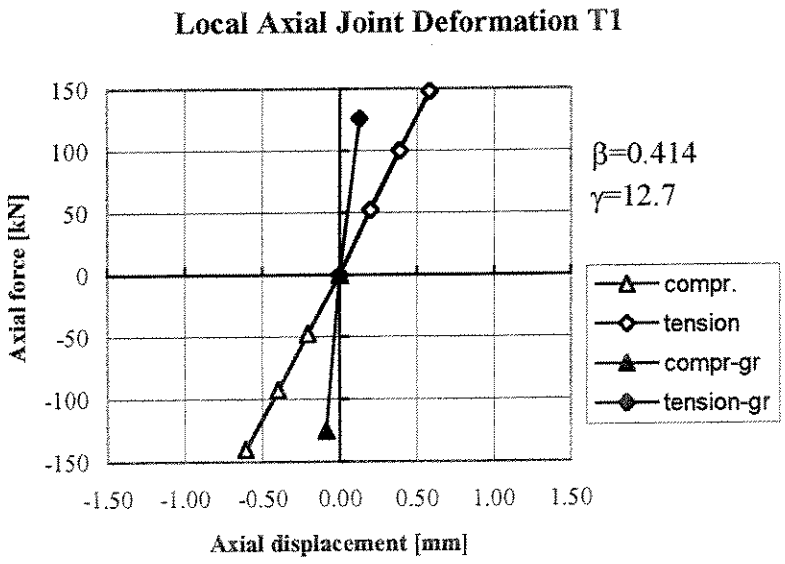


**Figure 16: Local axial joint deformation of specimen T1**

**Local Joint deformation of T3.**

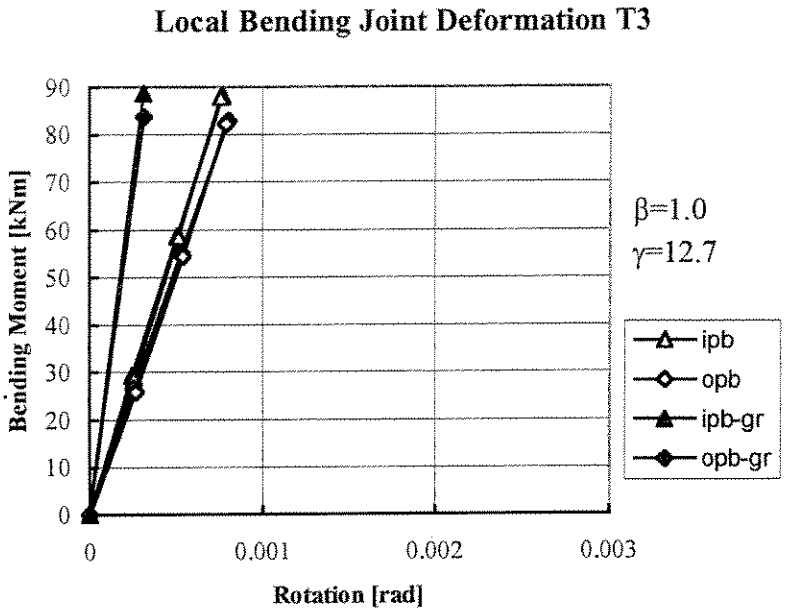


**Figure 17: Local bending joint deformation of specimen T3**

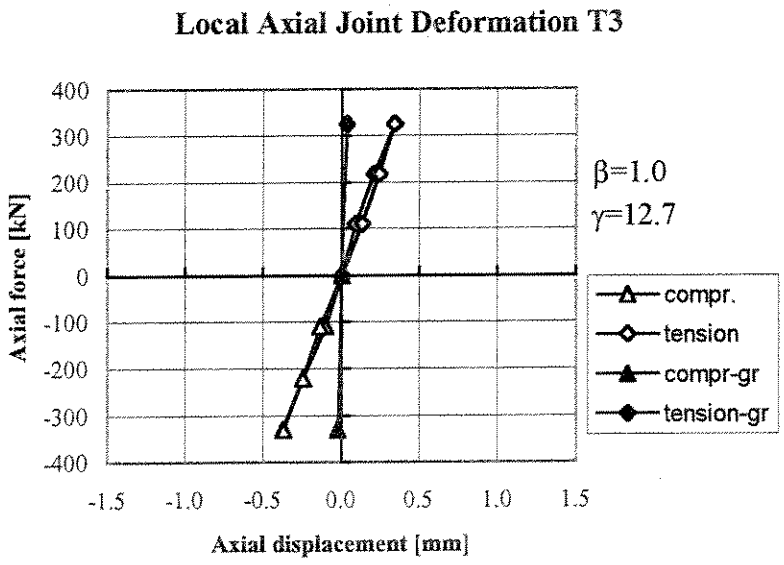


**Figure 18: Local axial joint deformation of specimen T3**

**Local Joint deformation of T5.**

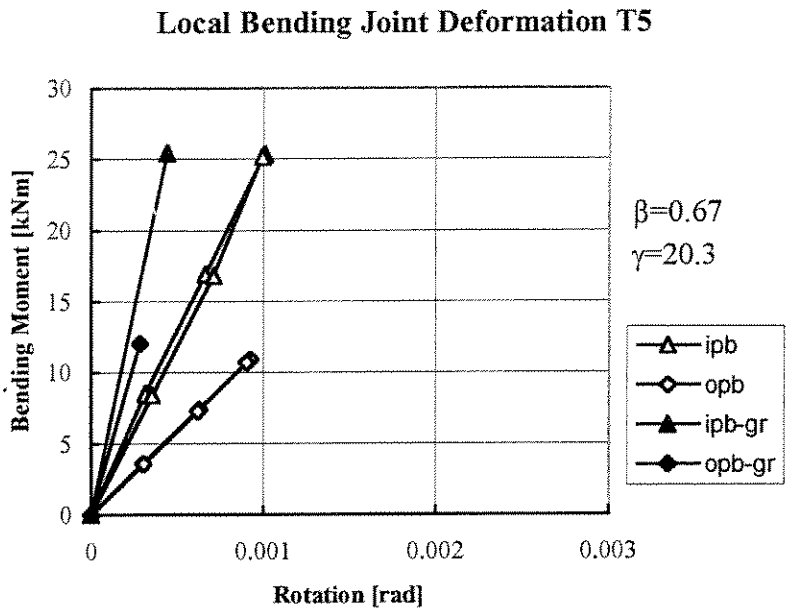


**Figure 19: Local bending joint deformation of specimen T5**

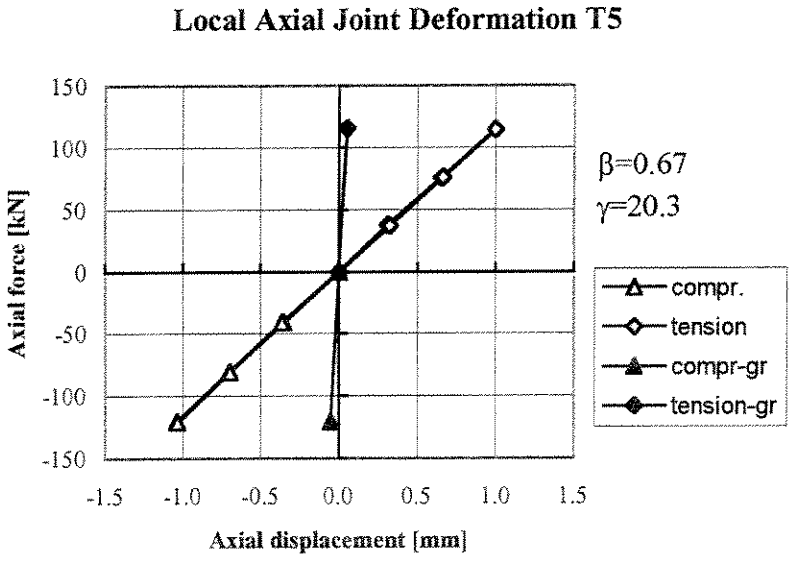


**Figure 20: Local axial joint deformation of specimen T5**

**Local Joint deformation of T7.**

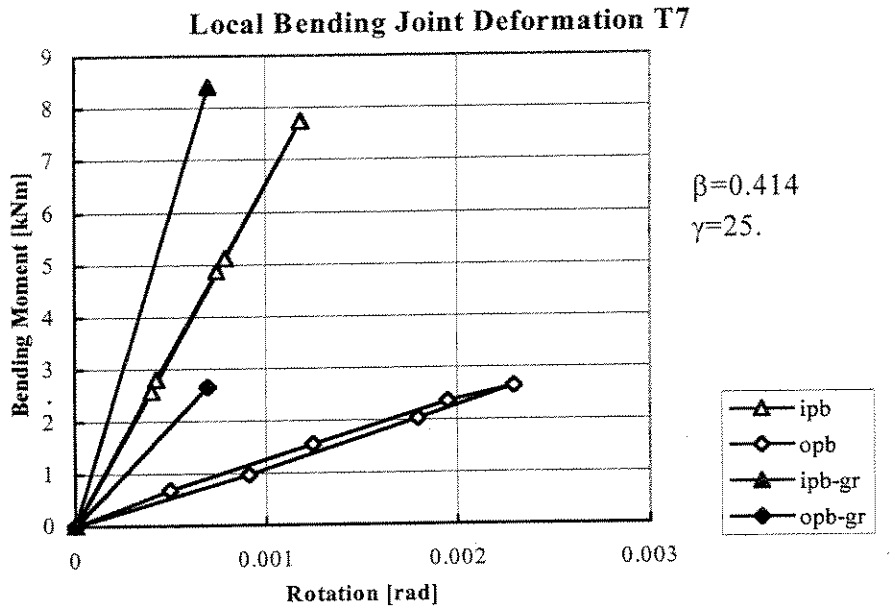


**Figure 21: Local bending joint deformation of specimen T7**

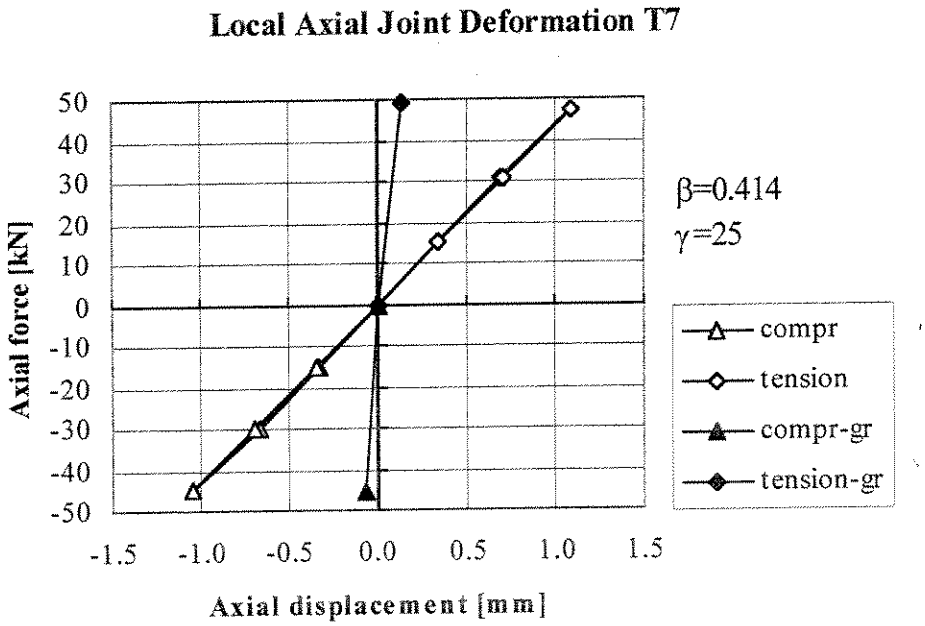


**Figure 22: Local axial joint deformation of specimen T7**

**Local Joint deformation of T9.**

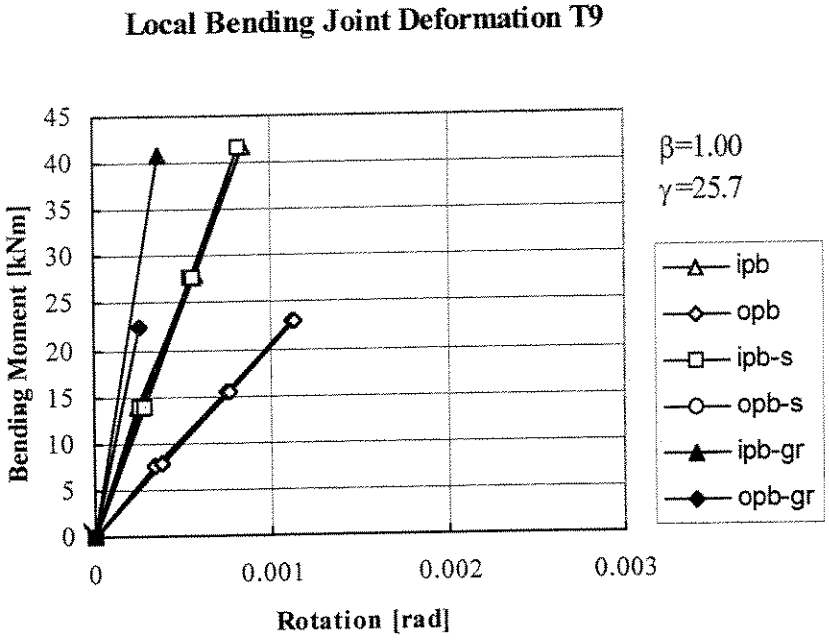


**Figure 23: Local bending joint deformation of specimen**

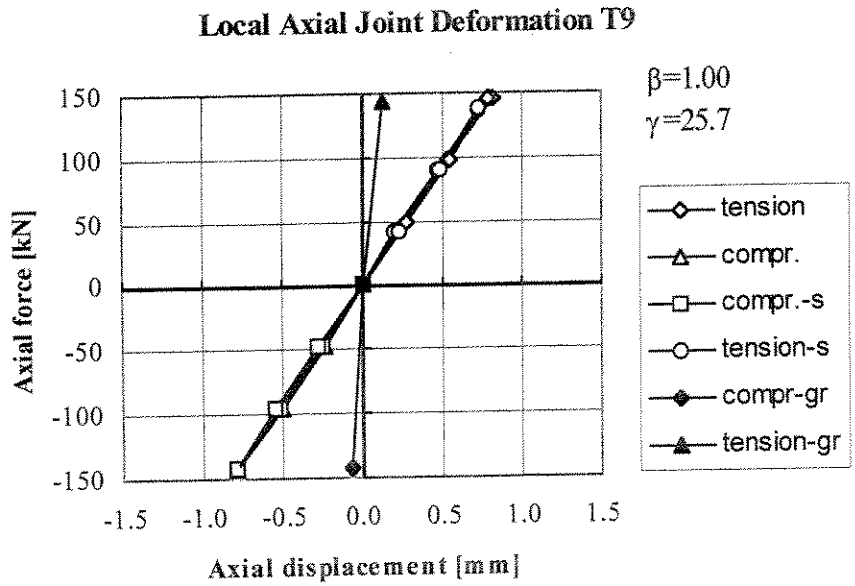


**Figure 24: Local axial joint deformation of specimen T9**

# APPENDIX D

## Ultimate Strength Test Results and Failure Photographs

# Ultimate Strength Test Results

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**T-Joints.**

The brace rotation and joint rotation are presented as functions of the applied bending moments. The out of plane loading conditions also led to a rotation of the chord at the supprt. This rotation was not eliminated from the brace global rotation. The local joint rotation was measured from the section of chord diametrically opposite the brace. The results are presented below.

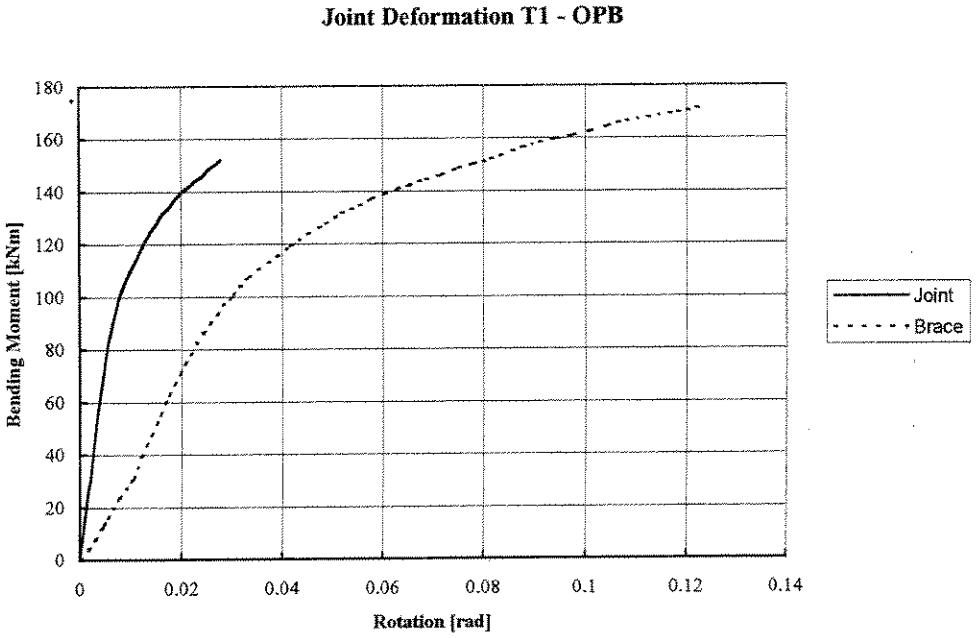


**Figure 1: Bending-rotation behaviour of T1**

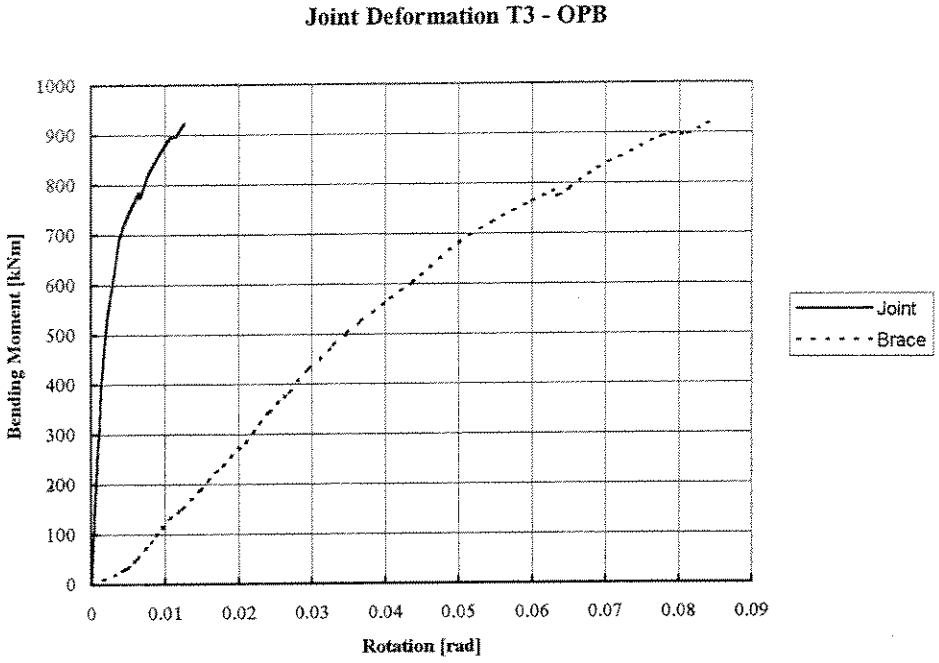


**Figure 2: Bending-rotation behaviour of T3**

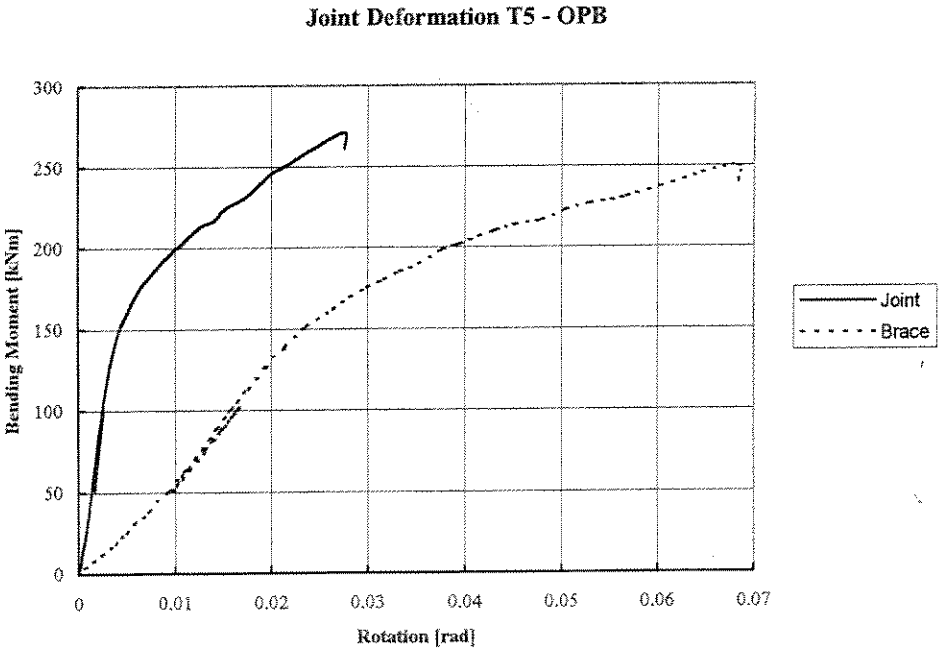


**Figure 3: Bending-rotation behaviour of T5**

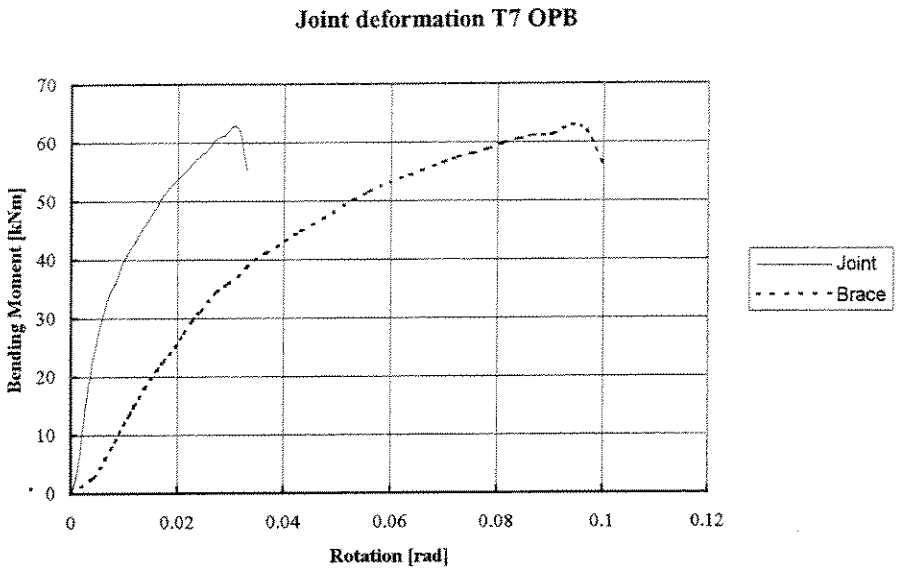


**Figure 4: Bending-rotation behaviour of T7**

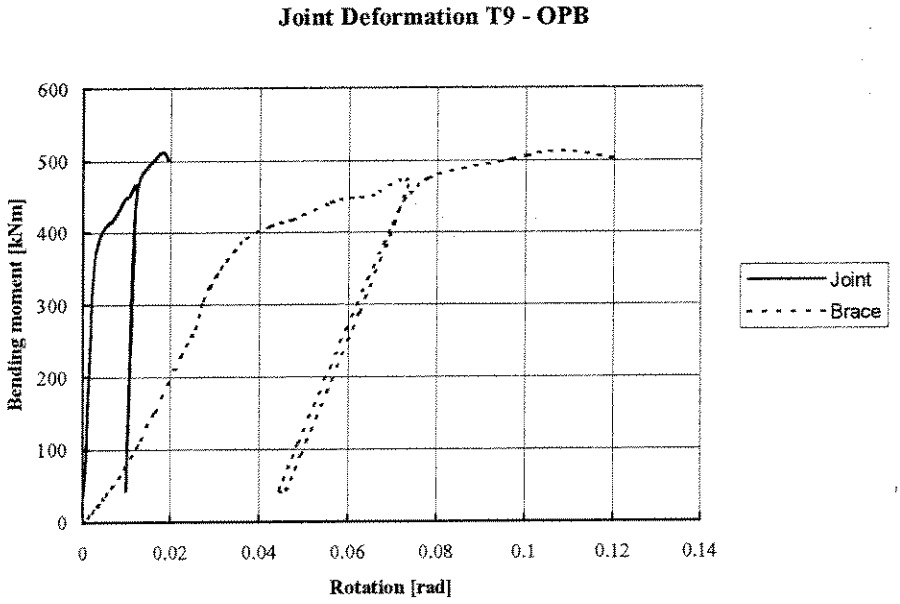


**Figure 5: Bending-rotation behaviour of T9**

**DT-Joints.**

The brace rotation and joint rotation are presented as functions of the applied bending moment. The joint rotation was measured relative to the two brace rotations.

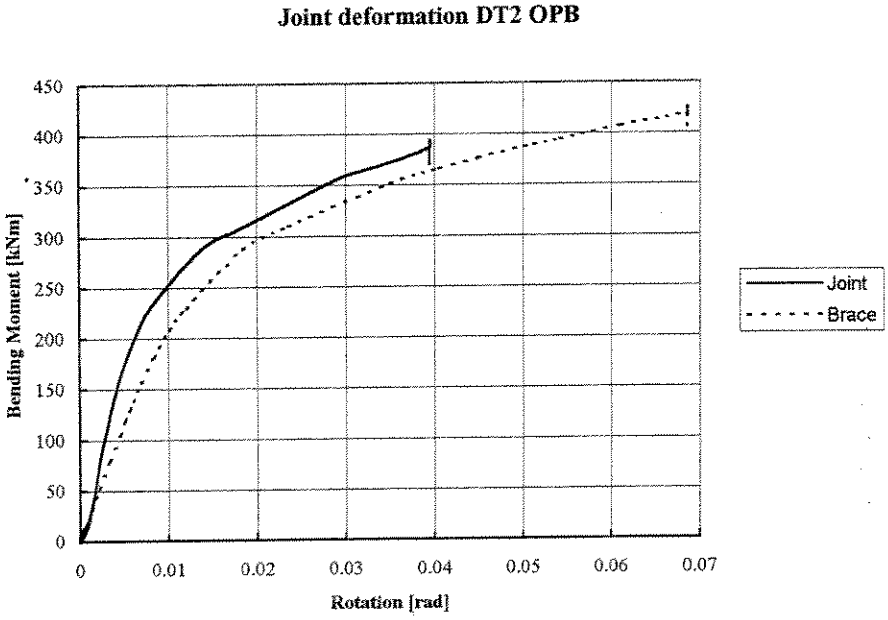


**Figure 6: Bending-rotation behaviour of DT2**

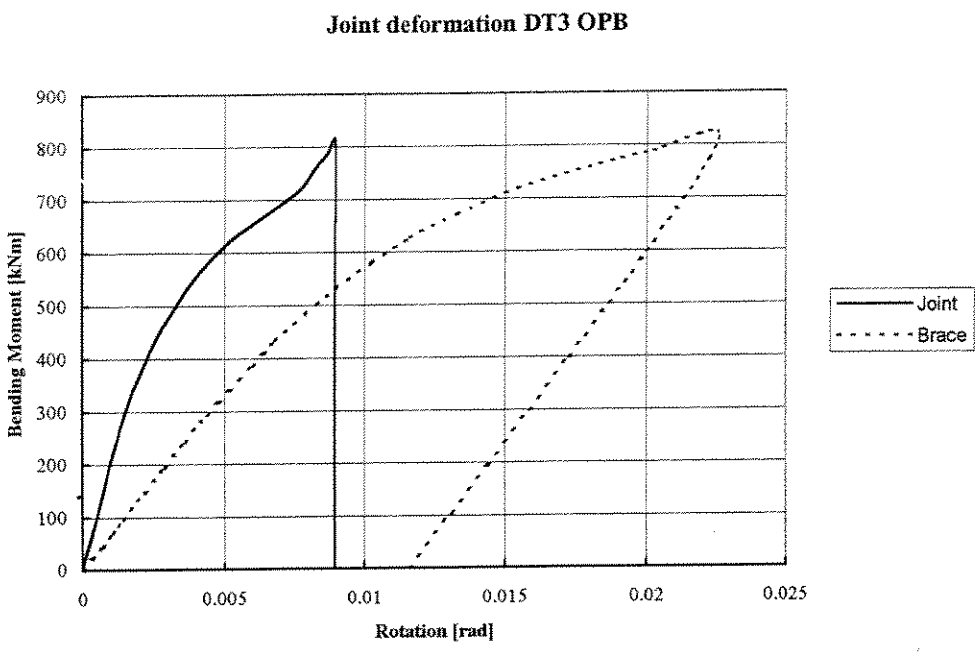


**Figure 7: Bending-rotation behaviour of DT3**

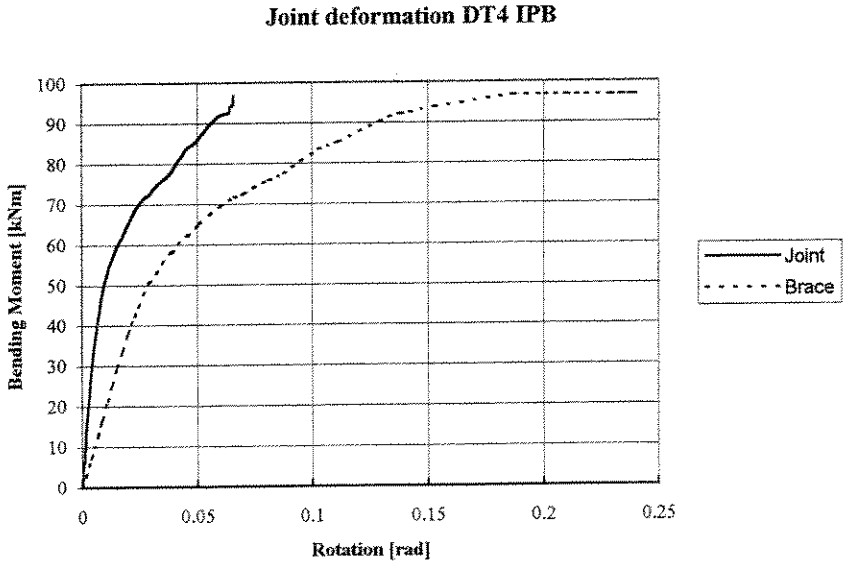


**Figure 8: Bending-rotation behaviour of DT4**

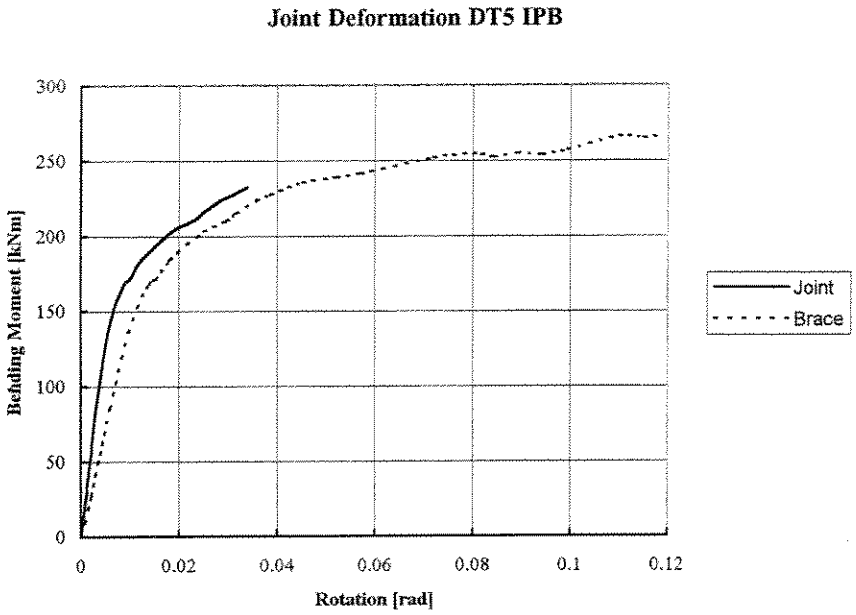


**Figure 9: Bending-rotation behaviour of DT5**

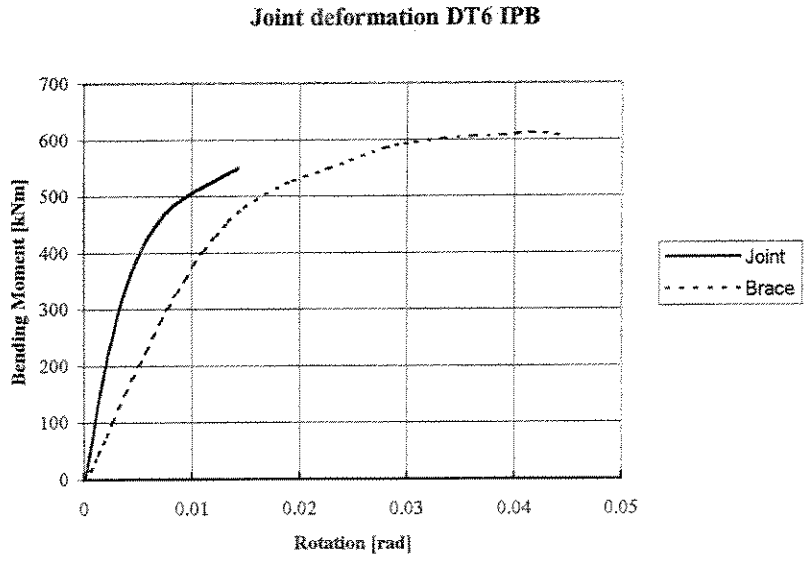


**Figure 10: Bending-rotation behaviour of DT6**

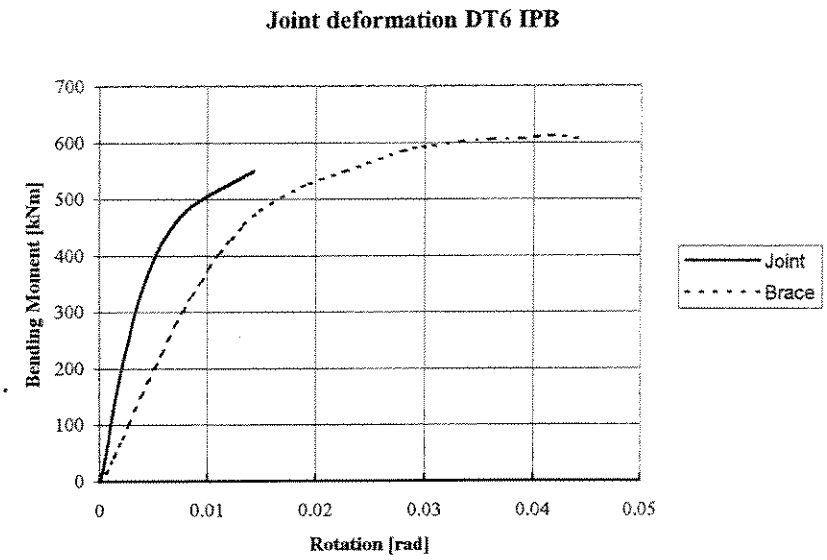


**Figure 11: Bending-rotation behaviour of DT8**

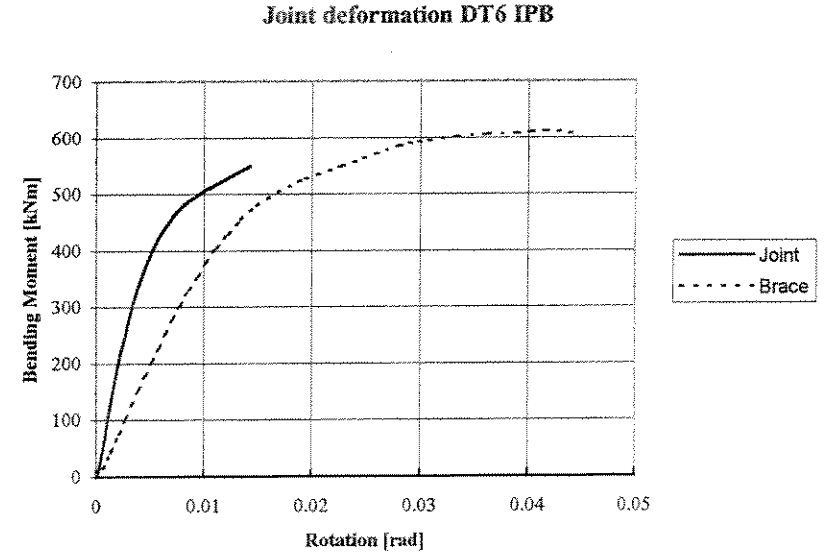


**Figure 12: Bending-rotation behaviour of DT9**

# Photographs of Failures for Ultimate Tests

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**T-Joints.**

The failure modes of T1, T5, T7 and T9 are presented below. Specimen T3 did not fail due to the limited test rig capacity.

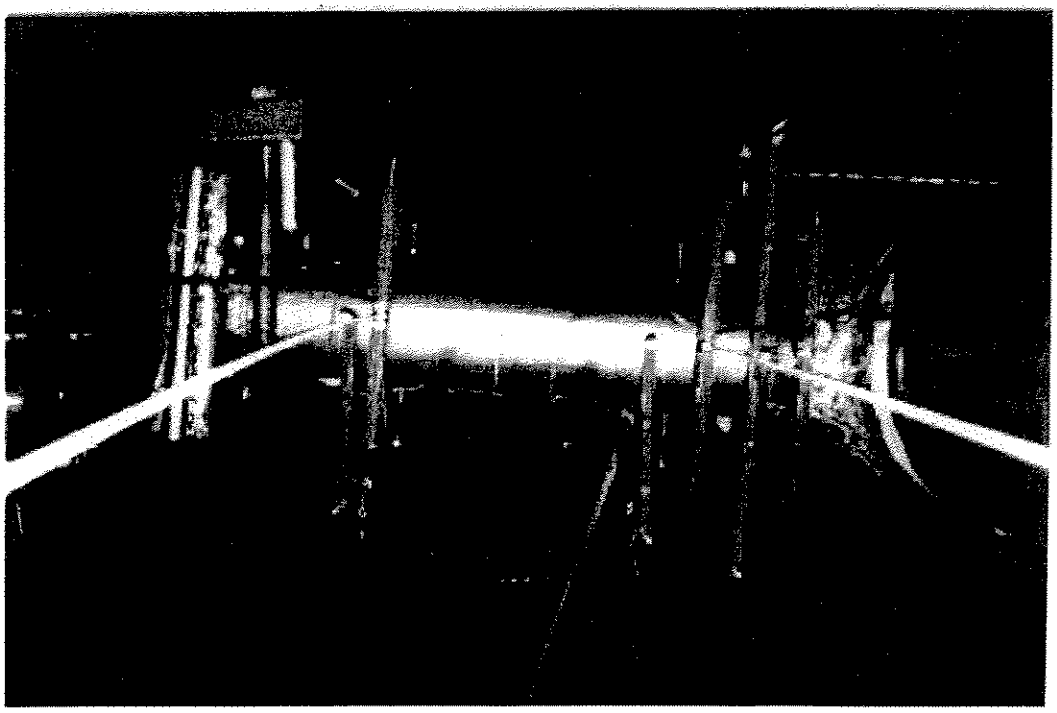

**Figure 1: Failure mode of specimen T1 (OPB Ultimate test)**



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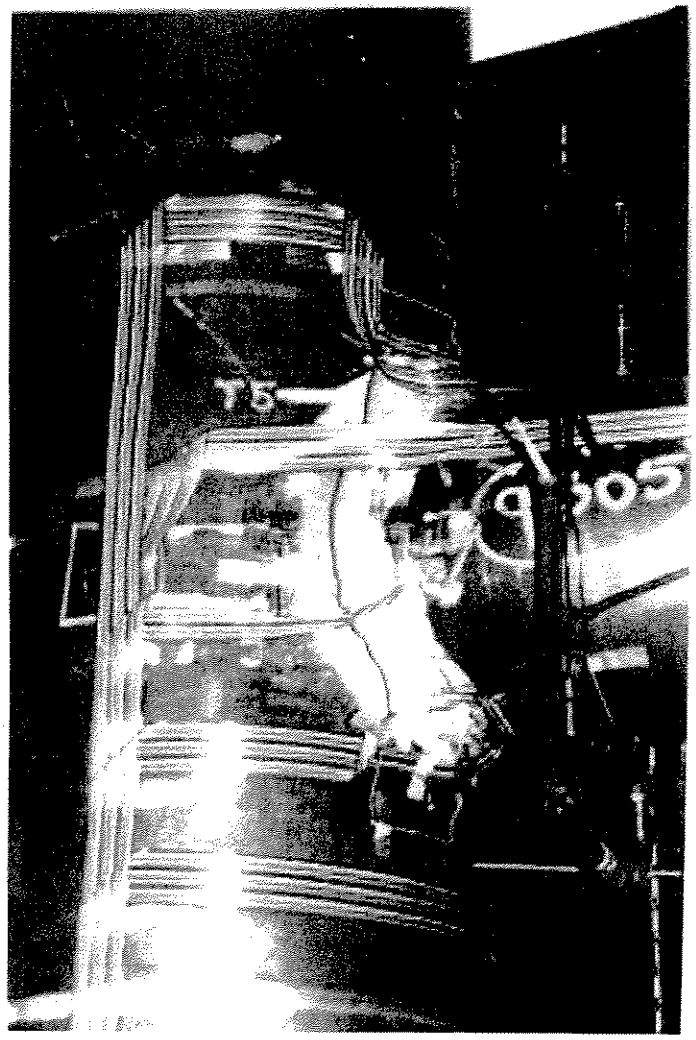


**Figure 2: Failure mode of specimen T5 (OPB Ultimate test)**



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**Figure 3: Failure mode of specimen T7 (OPB Ultimate test)**



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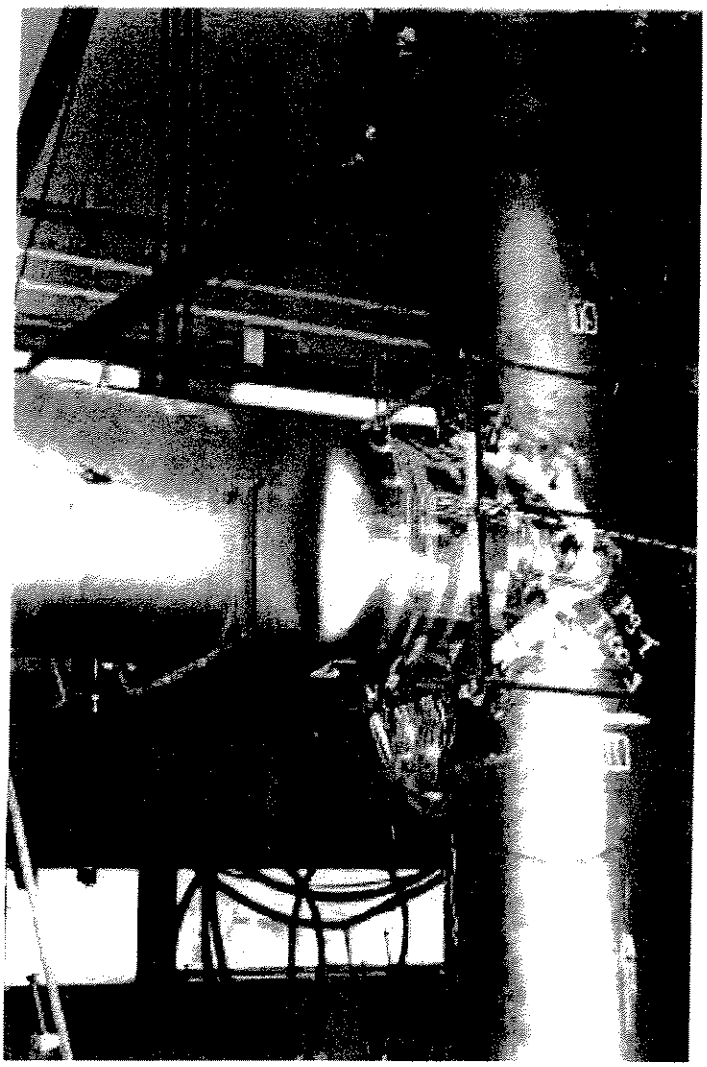

**Figure 4: Failure mode of specimen T9 (OPB Ultimate test)**



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**DT-joints.**

The failure modes of DT2, DT4, DT5, DT6, DT8 and DT9 are presented below. Specimen DT3 did not fail due to the limited test rig capacity.

**Figure 5: Failure mode of specimen DT2 (OPB Ultimate test)**



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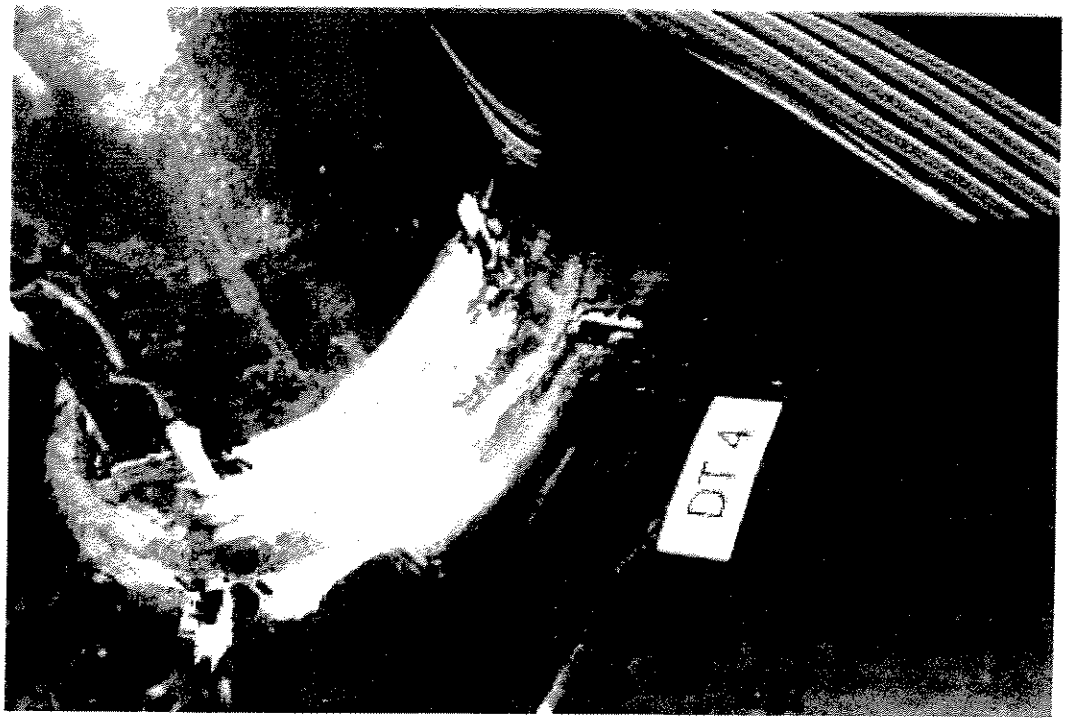


**Figure 6: Failure mode of specimen DT4 (IPB Ultimate test)**



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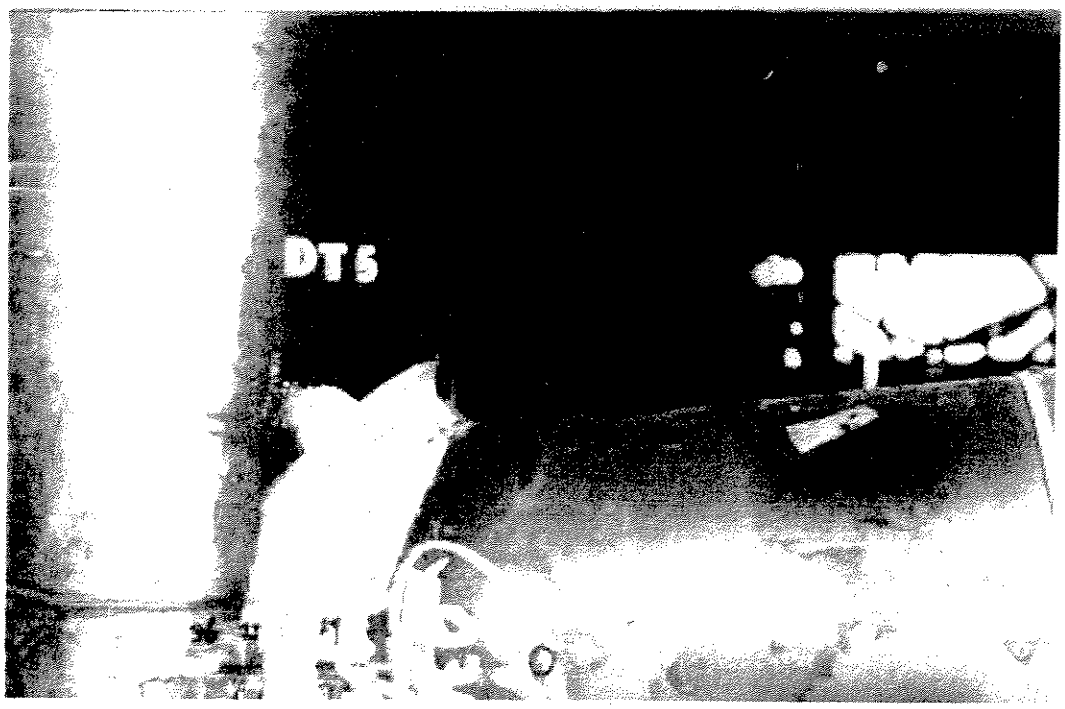


**Figure 7: Failure mode of specimen DT5 (IPB Ultimate test)**



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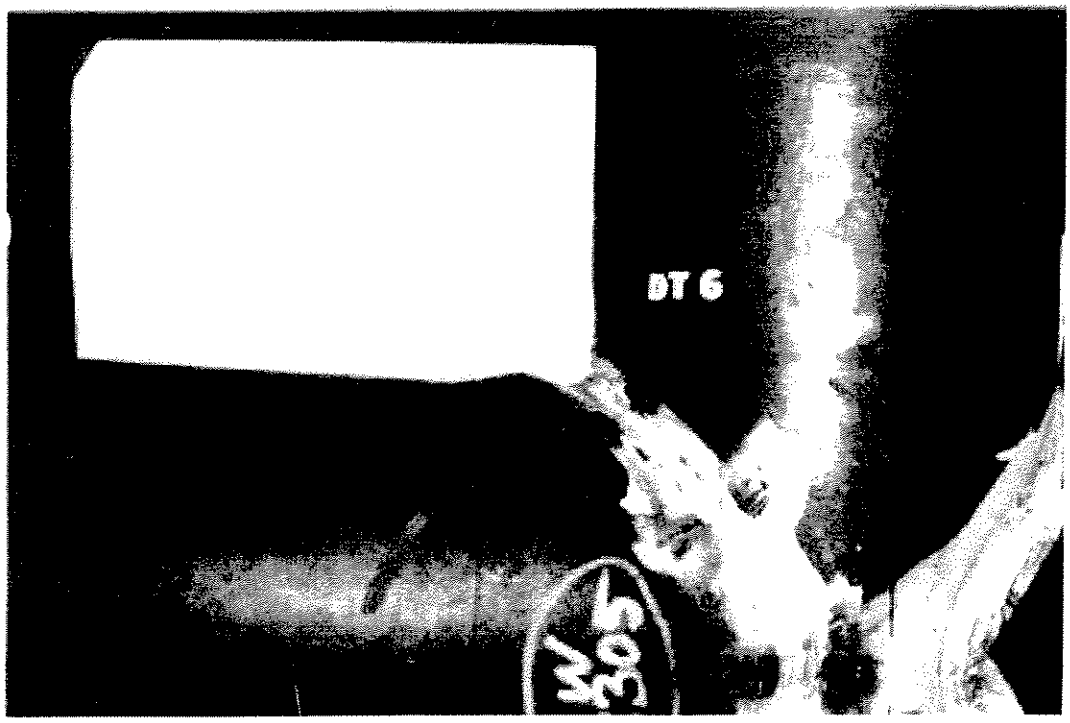


**Figure 8: Failure mode of specimen DT6 (IPB Ultimate test)**



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**Figure 9: Failure mode of specimen DT8 (OPB Ultimate test)**



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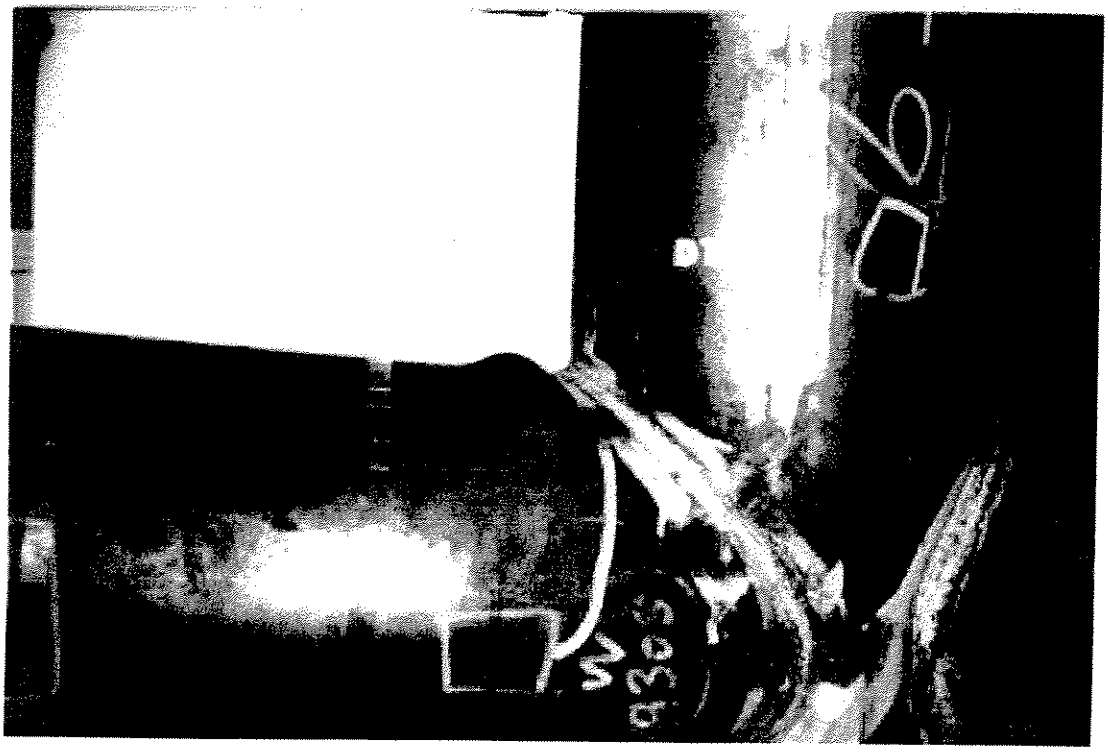

**Figure 10: Failure mode of specimen DT9 (IPB Ultimate test)**



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# APPENDIX E

## Development of Reduction Factors

# Development of Measured Grouted SNCF/Measured As-welded SNCF Reduction Factors

## DEVELOPMENT OF REDUCTION FACTORS

### 1 INTRODUCTION

This part of the appendix presents the development of formulations, using measured as-welded SCFs and measured grouted SCFs, to predict the SCF Reduction Factor (RF) for each joint and load type for both the chord and brace side of the weld. The definition of RF from which the formulations are derived is:

$$RF = \frac{\text{Measured value of SCF for grouted joint}}{\text{Measured value of SCF for as-welded joint}}$$

It may be noted that the RFs so derived reduce many of the inaccuracies normally associated with SCF measured values. SCF inaccuracies, for example, may arise from errors in the positioning of strain gauges or slight eccentricities in the loading arrangements. These effects will largely cancel when ratios of the SCFs, as in the case of RFs, are taken.

### 2 DATA

The baseline data are, of course, the measured SCF values of the as-welded and grouted joints. These data are discussed in Section 7 of the main text and also in Appendix C. It is noted here that the grouted SCFs used in this appendix relate to the values obtained following the 50% preload cycle.

The resulting RFs, found by applying the above definition, are summarised in Table 1. The table shows the RF for each joint and load type, and differentiates between the saddle and crown position for axially loaded joints. For the sake of completeness, the RFs for the brace side of the weld are also given. In addition to the measured RF values, the values predicted by the formulations given below are also shown in the table. As can be observed, good agreement between the observed and predicted values is indicated across the board except for the axially loaded DT joints at the crown position (this is discussed further below).

The data in Table 1 are presented in a series of figures (Figures 1 to 24), each figure relating to a single joint type (DT or T), load type (compression, tension, IPB or OPB) and, the SCF location (saddle or crown). Figures 1 to 12 relate to data on the chord side of the weld and Figures 13 to 24 to the brace side. Each figure contains three diagrams:

- plot of RF vs. $\beta$
- plot of RF vs. $\gamma$
- a 3-D representation of RF vs $\beta$ and $\gamma$.

The first two plots may have up to three lines, each line corresponding to a constant $\gamma$ or $\beta$ parameter. To visualise better these two diagrams, 3-D bar charts are given. Note, however, the bar chart axes are not true to scale (the 'skyscrapers' fall on a 3 x 3 regular matrix associated with the discrete values of $\beta$ and $\gamma$).

## 3 FITTING OF RF-SURFACES

The objective now is to find suitable functions

$RF = f(\beta, \gamma)$

for the various joint and load types. The functions should capture the shapes of the RF - $\beta$ - $\gamma$ surfaces, as illustrated in Figures 1 to 24, yet be reasonably simple.

An examination of the surface shapes suggests that RFs are not simple functions of $\beta$ and $\gamma$. Some surfaces exhibit a very strong twisted shape, especially for axially loaded T joints, and all surfaces do to some extent. This means that certain types of functions, such as those that increase monotonically (e.g. $RF = a\beta^b \gamma^c$ or $RF = a_0 + a_1\beta^b + a_2\gamma^c$), prove unsuitable. Figure 25 illustrates the simplest twisted surface: a twisted plane bounded by four RF values at the corners of the defined region. The equation on this figure is of the form:

$$RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma$$

To allow for deviations of additional RF points away from this twisted plane, the two second order terms of $\beta$ and $\gamma$ are added to give the following basic equation:

$$RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2$$

where $a_0$ to $a_5$ are constants to be fitted.

The above equation has 6 unknown constants whereas for T joints, only 5 data exist (for a given load type). Preliminary fitting trails and the behaviour of DT joints favoured the dropping of the $a_5\gamma^2$ term.

The constants were fitted using a multivariate technique based on minimising the sum of the squares of percentage (not absolute) differences between measured and predicted RF values. In general, it was found that the solution obtained during a fitting cycle was dependent on assumed starting values of the constants, to the extent that sometimes divergent behaviour was observed. Application of the equation shown on Figure 25 resolved all difficulties in selecting suitable starting constants.

During the course of fitting trials, the constants were successively rounded off starting with the higher order terms and ending with rounding off the lead constant ($a_0$) after the final fitting. The goodness of fit was monitored during the fitting process by observing the Coefficient of Variation (COV) of predicted RF to measured RF values and the maximum/minimum errors between the data points and fitted surfaces.

## 3.1 Chord Side RF Values

The results of the fitting process are summarised in Table 2.

The predicted RF values across the full range of $\beta$ and $\gamma$ are shown in Figures 26 to 37. These figures also show the measured RF values (some of the predicted values have been set to zero to enable low measured RF values to be observed). As can be seen, the predicted RF - $\beta$ - $\gamma$ surfaces are sensibly smooth and, on the whole, capture the measured values well. In one instance (DT joint in compression at the saddle position, Figure 26), the function predicts negative RF values on extrapolation to the high $\gamma$, very low $\beta$ region. It is therefore necessary to set a lower limit on RF. The following lower limit is suggested:

$$RF \geq 0.10$$

Inspection of Table 2 shows that the poorest fit relates to axially loaded DT joints at the crown position for the tension case, see Figure 29. The high RF values obtained at the crown position for both tension and compression load cases were capped to prevent a poor fit. The RFs were capped to values consistent with the results obtained for both DT and T joint specimens. The resultant fits give good prediction for grouted SCFs. The maximum error on the non-conservative side is 15.3%. The next 'poorest' fit (for DT joint in tension at the saddle position) gives a non-conservative error of only 6.7%. Examining the measured RF data in Figures 2 and especially 4, the problem seems to be associated with a deep well in the mid $\beta$ and $\gamma$ range, which the polynomial cannot easily model. The fitting process has given a fitted function that is generally non-conservative away from the mid $\beta$ and $\gamma$ region. Since this may be unacceptable, new fits were undertaken by ignoring the central data point. The resulting recommended functions for the DT crown cases are shown in Table 3 along with all other functions. The COV and error band for the DT crown compression case are 0.016 and 2.2/-2.7 respectively; and 0.106 and 15.3/-14.6 for the tension case. The revised RF - $\beta$ - $\gamma$ comparison plots are shown in Figures 38 and 39.

One final comment is worth making. This concerns the relatively high RF values for $\beta = 1$ DT joints under axial or OPB loads. For these cases, load transference across the chord is dominated by membrane action (which is why the RF values approach unity) and this membrane action quickly decays as $\beta$ is reduced from unity. In the fitting process, no attempt has been made to reflect more accurately the rapid decay (indeed, there are no data on which to base a suitable decay function). However, it is noted that the selected RF function will overestimate the RF value at $\beta$ values approaching unity. The selected RF function is, therefore, conservative.

## 3.2 Brace Side RF Values

A similar fitting exercise was carried out for the brace RF values as was performed for the chord side. The recommended functions for predicting brace side RF values are given in Table 4. The comparisons of predicted and measured RF values are illustrated in Figures 40 to 51.

The fitting of the RF-$\beta$-$\gamma$ surfaces usually proceeded without difficulty. However, again, the crown positions of axially loaded DT joints needed specific consideration. An examination of the data shown in Figures 14 and 16 show that extremely high brace side RF values may exist for joints of intermediate $\beta$. The high RF values arise from very low measured as-welded SCF values coupled with the above definition of RF. It was considered that a fitted surface to the

RF values as they stand would be suspect, and in any case highly dependent on the accuracy of the measured as-welded SCFs. In these cases, therefore, it was decided to treat the high RF values as being somewhat spurious and to replace both the high values at $\gamma = 12$ and 20 by a RF value of unity. Having made these replacements, functions were fitted and these are compared with the original data in Figures 41 and 43 for the compression and tension cases respectively.

The high measured RF values are approximately an order greater than corresponding predicted RF values and, therefore, the latter are potentially very non-conservative. Indeed they would be if applied to measured as-welded SCFs for estimating grouted SCFs. The predicted RFs are quite conservative, however, when used in conjunction with calculated as-welded SCFs from the Efthymiou set of parametric equations, see Tables 5 to 8.

## 4. Concluding Remarks

Tables 5 to 8 present a comparison of predicted and measured as-welded and grouted SCFs for the two joint types at all locations. Of note are the predicted grouted SCFs derived using predicted RFs, from joint parameters, with measured as-welded SCFs and Efthymiou predicted as-welded SCFs. The results demonstrate that for a number of joint configurations, the crown SCF becomes critical, in the grouted condition, and even supercedes the highest as-welded SCF.

| Specimen Ident. | D (mm) | d (mm) | T (mm) | t (mm) | L (mm) | θ (°) | β | γ | τ | α | Condition | Chord RFs | | | | | | Brace RFs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | IPB | OPB | Comp. | | Tens. | | IPB | OPB | Comp. | | Tens. | |
| | | | | | | | | | | | | | | Ax-s | Ax-c | Ax-s | Ax-c | | | Ax-s | Ax-c | Ax-s | Ax-c |
| T1 | 406.78 | 167.81 | 16.39 | 16.32 | 2440 | 90.0 | 0.413 | 12.409 | 0.996 | 12.00 | Measured | 0.97 | 0.72 | 0.55 | 1.01 | 0.54 | 0.91 | 1.01 | 0.89 | 0.56 | 4.43 | 0.62 | 3.89 |
| | | | | | | | | | | | Predicted | 1.00 | 0.71 | 0.55 | 0.98 | 0.53 | 0.91 | 1.07 | 0.89 | 0.53 | 4.53 | 0.65 | 3.82 |
| T3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.000 | 12.409 | 0.982 | 12.00 | Measured | 0.92 | 0.27 | 0.09 | 1.04 | 0.25 | 1.11 | 1.10 | 0.33 | 0.30 | 1.16 | 0.31 | 1.08 |
| | | | | | | | | | | | Predicted | 0.94 | 0.27 | 0.09 | 1.05 | 0.25 | 1.13 | 1.12 | 0.33 | 0.28 | 1.19 | 0.30 | 1.11 |
| T5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 0.964 | 11.99 | Measured | 0.90 | 0.37 | 0.30 | 0.93 | 0.29 | 0.95 | 1.24 | 0.45 | 0.30 | 2.07 | 0.34 | 1.67 |
| | | | | | | | | | | | Predicted | 0.87 | 0.37 | 0.30 | 0.93 | 0.28 | 0.95 | 1.26 | 0.45 | 0.34 | 2.07 | 0.35 | 1.65 |
| T7 | 406.96 | 168.41 | 7.86 | 8.31 | 2440 | 90.0 | 0.414 | 25.888 | 1.057 | 11.99 | Measured | 0.69 | 0.48 | 0.21 | 0.58 | 0.47 | 0.71 | 1.22 | 0.74 | 0.26 | 1.39 | 0.48 | 1.13 |
| | | | | | | | | | | | Predicted | 0.68 | 0.48 | 0.21 | 0.59 | 0.45 | 0.69 | 1.21 | 0.74 | 0.27 | 1.37 | 0.49 | 1.08 |
| T9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 1.000 | 11.99 | Measured | 0.95 | 0.27 | 0.22 | 1.03 | 0.24 | 0.98 | 1.24 | 0.26 | 0.36 | 1.24 | 0.29 | 0.94 |
| | | | | | | | | | | | Predicted | 0.94 | 0.27 | 0.23 | 1.05 | 0.25 | 0.99 | 1.26 | 0.26 | 0.42 | 1.19 | 0.30 | 0.97 |
| | | | | | | | | | | | | | | | | | | | | | | | |
| DT2 | 406.78 | 273.09 | 16.39 | 15.76 | 2440 | 90.0 | 0.671 | 12.409 | 0.962 | 12.00 | Measured | 0.79 | 0.66 | 0.39 | 1.57 | 0.39 | 0.95 | 1.38 | 0.74 | 0.34 | 33.40 | 0.41 | 10.43 |
| | | | | | | | | | | | Predicted | 0.74 | 0.65 | 0.36 | 1.61 | 0.38 | 0.97 | 1.36 | 0.72 | 0.35 | 4.34 | 0.42 | 1.47 |
| DT3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 0.982 | 12.00 | Measured | 0.67 | 0.97 | 0.95 | 1.86 | 1.02 | 1.29 | 1.61 | 0.96 | 0.90 | 1.24 | 0.79 | 1.11 |
| | | | | | | | | | | | Predicted | 0.68 | 0.99 | 0.92 | 1.91 | 1.02 | 1.40 | 1.65 | 1.02 | 0.94 | 1.34 | 0.90 | 1.15 |
| DT4 | 407.05 | 168.57 | 10.19 | 9.95 | 2440 | 90.0 | 0.414 | 19.973 | 0.976 | 11.99 | Measured | 0.57 | 0.55 | 0.12 | 0.71 | 0.27 | 0.57 | 1.35 | 0.85 | 0.16 | 2.23 | 0.31 | 1.00 |
| | | | | | | | | | | | Predicted | 0.57 | 0.55 | 0.12 | 0.74 | 0.28 | 0.56 | 1.34 | 0.83 | 0.15 | 2.39 | 0.31 | 1.06 |
| DT5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 0.964 | 11.99 | Measured | 0.54 | 0.47 | 0.25 | 0.48 | 0.32 | 0.16 | 1.40 | 0.54 | 0.23 | 27.57 | 0.34 | 16.00 |
| | | | | | | | | | | | Predicted | 0.59 | 0.51 | 0.28 | 1.67 | 0.31 | 1.22 | 1.41 | 0.57 | 0.25 | 4.24 | 0.34 | 1.20 |
| DT6 | 407.05 | 407.60 | 10.19 | 9.61 | 2440 | 90.0 | 1.001 | 19.973 | 0.943 | 11.99 | Measured | 0.62 | 0.97 | 0.89 | 2.92 | 0.81 | 2.10 | 1.76 | 1.00 | 0.92 | 1.42 | 0.79 | 1.09 |
| | | | | | | | | | | | Predicted | 0.60 | 0.95 | 0.96 | 2.90 | 0.83 | 1.78 | 1.65 | 0.94 | 0.94 | 1.62 | 0.67 | 0.95 |
| DT8 | 406.96 | 273.21 | 7.86 | 7.88 | 2440 | 90.0 | 0.671 | 25.888 | 1.003 | 11.99 | Measured | 0.49 | 0.42 | 0.20 | 1.68 | 0.28 | 1.46 | 1.44 | 0.49 | 0.18 | 3.83 | 0.30 | 1.40 |
| | | | | | | | | | | | Predicted | 0.48 | 0.40 | 0.21 | 1.73 | 0.26 | 1.42 | 1.45 | 0.46 | 0.17 | 4.17 | 0.28 | 1.23 |
| DT9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 1.000 | 11.99 | Measured | 0.53 | 0.93 | 1.00 | 3.53 | 0.69 | 1.81 | 1.56 | 0.85 | 0.94 | 1.75 | 0.47 | 0.98 |
| | | | | | | | | | | | Predicted | 0.54 | 0.92 | 0.99 | 3.67 | 0.68 | 2.07 | 1.65 | 0.88 | 0.94 | 1.88 | 0.49 | 1.03 |

Predicted RF values given by formulations in Tables 3 and 4.

**Table 1 : Summary of Reduction Factors**

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Joint type** | **Load (Position)** | **$a_0$** | **$a_1$** | **$a_2$** | **$a_3$** | **$a_4$** | **$a_5$** | **COV** | **Max/min Error (%)** |
| DT | COMP | 1.963 | -3.471 | -0.082 | 0.0534 | 2.670 | 0.0008 | 0.019 | 2.0/-3.7 |
| | (Saddle) | 1.505 | -3.125 | -0.047 | 0.0498 | 2.507 | **0** | 0.051 | 4.4/-8.9 |
| | | **1.46** | **-3.1** | **-0.045** | **0.05** | **2.5** | **0** | 0.062 | 6.6/-11.2 |
| | COMP | 4.0337 | -3.959 | -0.238 | 0.6073 | 0.2103 | 0.0001 | 0.015 | 2.6/-2.0 |
| | (Crown) | **4.1** | **-4.0** | **-0.24** | **0.37** | **0.2** | **0** | 0.016 | 2.2/-2.7 |
| | TENS | 0.418 | -1.312 | 0.016 | -0.0491 | 2.285 | 0.0002 | 0.006 | 0.6/-1.2 |
| | (Saddle) | 0.307 | -1.238 | 0.025 | -0.0490 | 2.239 | **0** | 0.013 | 1.1/-2.0 |
| | | **0.43** | **-1.6** | **0.025** | **-0.05** | **2.5** | **0** | 0.038 | 6.7/-2.6 |
| | TENS | -0.948 | 3.091 | 0.003 | 0.052 | -1.445 | 0.0001 | 0.105 | 14.9/-16.5 |
| | (Crown) | **-0.92** | **3.2** | **0** | **0.05** | **-1.5** | **0** | 0.106 | 15.3/-14.6 |
| | IPB | 1.623 | -0.611 | -0.065 | 0.0322 | -0.003 | 0.0006 | 0.044 | 5.6/-6.7 |
| | (Crown) | 1.328 | -0.365 | -0.042 | 0.0318 | -0.153 | **0** | 0.048 | 4.6/-10.3 |
| | | **1.28** | **-0.33** | **-0.040** | **0.03** | **-0.15** | **0** | 0.049 | 5.8/-10.0 |
| | OPB | 2.709 | -4.212 | -0.081 | 0.0452 | 2.801 | 0.0009 | 0.024 | 4.0/-2.5 |
| | (Saddle) | 2.255 | -3.844 | -0.046 | 0.0430 | 2.600 | **0** | 0.037 | 3.7/-8.0 |
| | | **2.25** | **-3.8** | **-0.045** | **0.04** | **2.6** | **0** | 0.039 | 4.4/-8.2 |
| T | COMP | 2.300 | -3.518 | -0.081 | 0.1228 | 0.783 | | 0 | 0/0 |
| | (Saddle) | **1.37** | **-1.1** | **-0.05** | **0.06** | **-0.3** | | 0.02 | -0.2/-4.5 |
| | COMP | -0.023 | 4.769 | -0.020 | -0.032 | -3.071 | | 0 | 0/0 |
| | (Crown) | **1.35** | **0.2** | **-0.05** | **-0.05** | **-0.5** | | 0.018 | 2.6/-1.9 |
| | TENS | 2.052 | -4.447 | -0.029 | 0.0570 | 2.295 | | 0 | 0/0 |
| | (Saddle) | **1.35** | **-2.3** | **-0.01** | **0.01** | **1.2** | | 0.032 | 3.2/-1.0 |
| | TENS | -0.365 | 4.492 | 0.013 | -0.068 | -2.335 | | 0 | 0/0 |
| | (Crown) | **0.75** | **1.1** | **-0.02** | **0.01** | **-0.6** | | 0.016 | 2.5/-1.4 |
| | IPB | 1.305 | -0.028 | -0.037 | 0.0393 | -0.385 | | 0 | 0/0 |
| | (Crown) | **1.54** | **-0.6** | **-0.04** | **0.04** | **0** | | 0.024 | 2.8/-3.2 |
| | OPB | 1.789 | -2.423 | -0.030 | 0.030 | 0.904 | | 0 | 0/0 |
| | (Saddle) | **1.77** | **-2.4** | **-0.03** | **0.03** | **0.9** | | 0.005 | 1.0/0 |

Notes:

1) Values in bold were fixed during fitting run
2) Error = (RF measured - RF predicted) / RF measured; therefore -ve error is conservative.

**Table 2: Summary of RF Results from Fitting Process for Chord Side**

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2$ but $RF \geq 0.10$ | | | | | | |
|---|---|---|---|---|---|---|
| **Joint Type** | **Load (Position)** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ |
| **DT** | COMP (Saddle) | 1.46 | -3.1 | -0.045 | 0.05 | 2.5 |
| | COMP (Crown)* | 4.10 | -4.0 | -0.240 | 0.37 | 0.2 |
| | TENS (Saddle) | 0.43 | -1.6 | 0.025 | -0.05 | 2.5 |
| | TENS (Crown)* | -0.92 | 3.2 | 0 | 0.05 | -1.5 |
| | IPB (Crown) | 1.28 | -0.33 | -0.040 | 0.03 | -0.15 |
| | OPB (Saddle) | 2.25 | -3.8 | -0.045 | 0.04 | 2.6 |
| **T** | COMP (Saddle) | 1.37 | -1.1 | -0.05 | 0.06 | -0.3 |
| | COMP (Crown) | 1.35 | 0.2 | -0.05 | 0.05 | -0.5 |
| | TENS (Saddle) | 1.35 | -2.3 | -0.01 | 0.01 | 1.2 |
| | TENS (Crown) | 0.75 | 1.1 | -0.02 | 0.01 | -0.6 |
| | IPB (Crown) | 1.54 | -0.6 | -0.04 | 0.04 | 0 |
| | OPB (Saddle) | 1.77 | -2.4 | -0.03 | 0.03 | 0.9 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | |

* Unduly conservative RF may be predicted at crown position for axially loaded DT joints.

**Table 3: Recommended Formulations for Reduction Factors on Chord Side**

| $RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2$ but $RF \geq 0.10$ | | | | | | |
|---|---|---|---|---|---|---|
| **Joint Type** | **Load (Position)** | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ |
| **DT** | COMP (Saddle) | 1.64 | -3.7 | -0.04 | 0.04 | 3.0 |
| | COMP (Crown)* | -3.0 | 22.7 | -0.06 | 0.10 | -19.0 |
| | TENS (Saddle) | 0.07 | -0.30 | 0.03 | -0.06 | 1.5 |
| | TENS (Crown)* | -0.54 | 1.9 | +0.09 | -0.1 | -0.1 |
| | IPB (Crown) | 1.05 | -0.21 | 0.02 | -0.02 | 0.8 |
| | OPB (Saddle) | 3.04 | -5.5 | -0.04 | 0.03 | 3.6 |
| **T** | COMP (Saddle) | 1.36 | -1.6 | -0.04 | 0.05 | 0.4 |
| | COMP (Crown) | 11.84 | -10.6 | -0.40 | +0.04 | -0.05 |
| | TENS (Saddle) | 1.6 | -2.4 | -0.02 | 0.02 | 1.1 |
| | TENS (Crown) | 10.33 | -10 | -0.34 | 0.33 | 0.9 |
| | IPB (Crown) | 0.5 | 1.5 | 0.01 | 0 | -1.0 |
| | OPB (Saddle) | 2.09 | -3.2 | -0.015 | 0.01 | 1.5 |
| Ranges of validity: $0.4 \leq \beta \leq 1.0$, $12 \leq \gamma \leq 26$, $\tau \approx 1.0$, $\theta = 90°$ | | | | | | |

* Non-conservative RF may be predicted at crown position for axially loaded DT joints.

**Table 4: Recommended Formulations for Reduction Factors on Brace Side**

| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 4 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 0.30 | 6.47 | 1.33 | 3.60 | 4.43 | 0.56 | 4.53 | 0.53 | 1.36 | 3.41 |
| Ten. | 0.29 | 5.95 | 1.12 | 3.68 | 3.89 | 0.62 | 3.82 | 0.65 | 1.10 | 3.87 |
| OPB | | 3.70 | | 3.28 | | 0.89 | | 0.89 | | 3.28 |
| IPB | 1.61 | | 1.62 | | 1.01 | | 1.07 | | 1.73 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 1.14 | 12.55 | 1.58 | 3.32 | 1.39 | 0.26 | 1.37 | 0.27 | 1.57 | 3.35 |
| Ten. | 1.16 | 12.44 | 1.31 | 5.93 | 1.13 | 0.48 | 1.08 | 0.49 | 1.25 | 6.12 |
| OPB | | 7.96 | | 5.88 | | 0.74 | | 0.74 | | 5.90 |
| IPB | 1.99 | | 2.42 | | 1.22 | | 1.21 | | 2.41 | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 4 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 1.32 | 13.16 | 2.74 | 3.95 | 2.07 | 0.30 | 2.07 | 0.34 | 2.74 | 4.44 |
| Ten. | 1.21 | 13.00 | 2.03 | 4.36 | 1.67 | 0.34 | 1.65 | 0.35 | 2.01 | 4.59 |
| OPB | | 9.26 | | 4.21 | | 0.45 | | 0.45 | | 4.18 |
| IPB | 1.82 | | 2.26 | | 1.24 | | 1.26 | | 2.29 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 4 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 2.48 | 5.15 | 2.89 | 1.56 | 1.16 | 0.30 | 1.19 | 0.28 | 2.96 | 1.46 |
| Ten. | 2.50 | 5.21 | 2.69 | 1.60 | 1.08 | 0.31 | 1.11 | 0.30 | 2.76 | 1.56 |
| OPB | | 5.77 | | 1.88 | | 0.33 | | 0.33 | | 1.89 |
| IPB | 1.38 | | 1.52 | | 1.10 | | 1.12 | | 1.55 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 2.62 | 8.53 | 3.24 | 3.03 | 1.24 | 0.36 | 1.19 | 0.42 | 3.11 | 3.57 |
| Ten. | 2.58 | 8.26 | 2.43 | 2.39 | 0.94 | 0.29 | 0.97 | 0.30 | 2.51 | 2.48 |
| OPB | | 8.44 | | 2.17 | | 0.26 | | 0.26 | | 2.20 |
| IPB | 1.68 | | 2.09 | | 1.24 | | 1.26 | | 2.11 | |

Table 5: Comparison of Brace T-Joint Measured and Predicted As-welded and Grouted SCFs.

| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 6.95 | 11.23 | 7.00 | 6.20 | 1.01 | 0.55 | 0.98 | 0.55 | 6.83 | 6.19 |
| Ten. | 6.42 | 10.43 | 5.87 | 5.64 | 0.91 | 0.54 | 0.91 | 0.53 | 5.81 | 5.53 |
| OPB | | 7.30 | | 5.26 | | 0.72 | | 0.71 | | 5.20 |
| IPB | 2.93 | | 2.83 | | 0.97 | | 1.00 | | 2.93 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 10.20 | 33.31 | 5.93 | 6.84 | 0.58 | 0.21 | 0.59 | 0.21 | 6.00 | 7.06 |
| Ten. | 9.59 | 31.09 | 6.77 | 14.50 | 0.71 | 0.47 | 0.69 | 0.45 | 6.63 | 14.05 |
| OPB | | 21.17 | | 10.21 | | 0.48 | | 0.48 | | 10.07 |
| IPB | 5.69 | | 3.95 | | 0.69 | | 0.68 | | 3.90 | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 10.30 | 21.35 | 9.56 | 6.32 | 0.93 | 0.30 | 0.93 | 0.30 | 9.59 | 6.45 |
| Ten. | 9.62 | 21.16 | 9.13 | 6.10 | 0.95 | 0.29 | 0.95 | 0.28 | 9.17 | 5.94 |
| OPB | | 16.86 | | 6.18 | | 0.37 | | 0.37 | | 6.19 |
| IPB | 4.36 | | 3.91 | | 0.90 | | 0.87 | | 3.81 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 10.27 | 3.54 | 10.68 | 0.34 | 1.04 | 0.09 | 1.05 | 0.09 | 10.79 | 0.33 |
| Ten. | 10.21 | 3.26 | 11.34 | 0.80 | 1.11 | 0.25 | 1.13 | 0.25 | 11.50 | 0.82 |
| OPB | | 8.41 | | 2.26 | | 0.27 | | 0.27 | | 2.27 |
| IPB | 3.37 | | 3.10 | | 0.92 | | 0.94 | | 3.17 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 9.30 | 14.53 | 9.60 | 3.26 | 1.03 | 0.22 | 1.05 | 0.23 | 9.77 | 3.33 |
| Ten. | 8.99 | 13.94 | 8.81 | 3.35 | 0.98 | 0.24 | 0.99 | 0.25 | 8.91 | 3.49 |
| OPB | | 19.38 | | 5.32 | | 0.27 | | 0.27 | | 5.23 |
| IPB | 3.22 | | 3.05 | | 0.95 | | 0.94 | | 3.02 | |

Table 6: Comparison of Chord T-Joint Measured and Predicted As-welded and Grouted SCFs.

| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 4 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 1.07 | 13.27 | 2.39 | 2.11 | 2.23 | 0.16 | 2.39 | 0.15 | 2.56 | 2.05 |
| Ten. | 1.23 | 13.50 | 1.24 | 4.13 | 1.00 | 0.31 | 1.06 | 0.31 | 1.31 | 4.13 |
| OPB | | 4.74 | | 4.02 | | 0.85 | | 0.83 | | 3.93 |
| IPB | 2.64 | | 3.58 | | 1.35 | | 1.34 | | 3.53 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 4 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 0.06 | 10.96 | 2.00 | 3.74 | 33.40 | 0.34 | 4.34 | 0.35 | 0.26 | 3.79 |
| Ten. | 0.08 | 11.11 | 0.88 | 4.51 | 10.43 | 0.41 | 1.47 | 0.42 | 0.12 | 4.64 |
| OPB | | 5.44 | | 4.03 | | 0.74 | | 0.72 | | 3.93 |
| IPB | 1.81 | | 2.50 | | 1.38 | | 1.36 | | 2.46 | |
| **19.973** | | | | | | | | | | |
| Comp. | 0.08 | 19.01 | 2.32 | 4.33 | 27.57 | 0.23 | 4.24 | 0.25 | 0.36 | 4.68 |
| Ten. | 0.06 | 18.60 | 0.96 | 6.36 | 16.00 | 0.34 | 1.20 | 0.34 | 0.07 | 6.32 |
| OPB | | 9.07 | | 4.90 | | 0.54 | | 0.57 | | 5.20 |
| IPB | 1.97 | | 2.76 | | 1.40 | | 1.41 | | 2.77 | |
| **25.888** | | | | | | | | | | |
| Comp. | 0.50 | 21.53 | 1.93 | 3.88 | 3.83 | 0.18 | 4.17 | 0.17 | 2.10 | 3.63 |
| Ten. | 0.52 | 21.70 | 0.72 | 6.43 | 1.40 | 0.30 | 1.23 | 0.28 | 0.64 | 6.04 |
| OPB | | 10.46 | | 5.10 | | 0.49 | | 0.46 | | 4.77 |
| IPB | 1.92 | | 2.76 | | 1.44 | | 1.45 | | 2.78 | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 4 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 0.86 | 4.31 | 1.07 | 3.89 | 1.24 | 0.90 | 1.34 | 0.94 | 1.15 | 4.05 |
| Ten. | 0.86 | 4.24 | 0.96 | 3.34 | 1.11 | 0.79 | 1.15 | 0.90 | 1.00 | 3.80 |
| OPB | | 2.53 | | 2.44 | | 0.96 | | 1.02 | | 2.57 |
| IPB | 1.43 | | 2.29 | | 1.61 | | 1.65 | | 2.36 | |
| **19.973** | | | | | | | | | | |
| Comp. | 1.12 | 5.24 | 1.58 | 4.80 | 1.42 | 0.92 | 1.62 | 0.94 | 1.80 | 4.95 |
| Ten. | 1.18 | 5.00 | 1.28 | 3.95 | 1.09 | 0.79 | 0.95 | 0.67 | 1.11 | 3.37 |
| OPB | | 2.89 | | 2.89 | | 1.00 | | 0.94 | | 2.73 |
| IPB | 1.62 | | 2.84 | | 1.76 | | 1.65 | | 2.68 | |
| **25.888** | | | | | | | | | | |
| Comp. | 1.25 | 4.45 | 2.18 | 4.20 | 1.75 | 0.94 | 1.88 | 0.94 | 2.34 | 4.18 |
| Ten. | 1.26 | 4.25 | 1.24 | 1.98 | 0.98 | 0.47 | 1.03 | 0.49 | 1.30 | 2.10 |
| OPB | | 2.71 | | 2.29 | | 0.85 | | 0.88 | | 2.39 |
| IPB | 1.64 | | 2.57 | | 1.56 | | 1.65 | | 2.71 | |

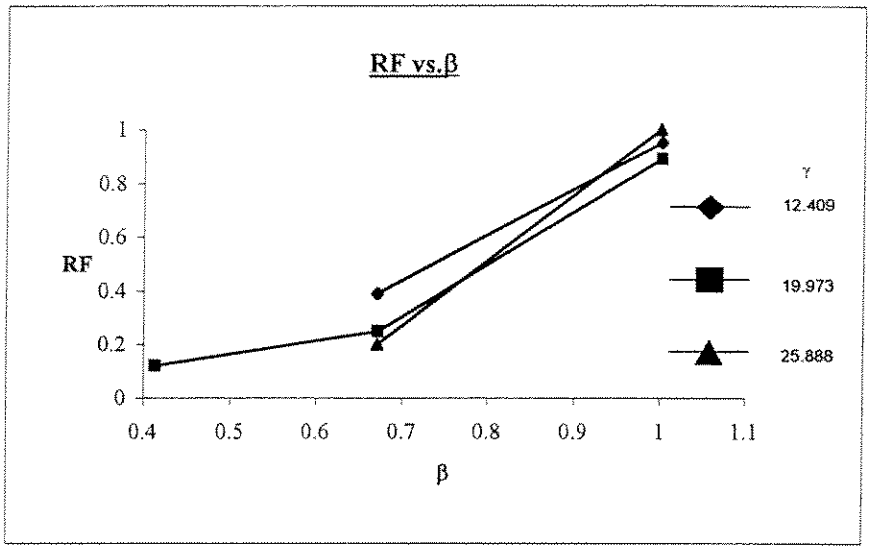
Table 7: Comparison of Brace DT-Joint Measured and Predicted As-welded and Grouted SCFs.

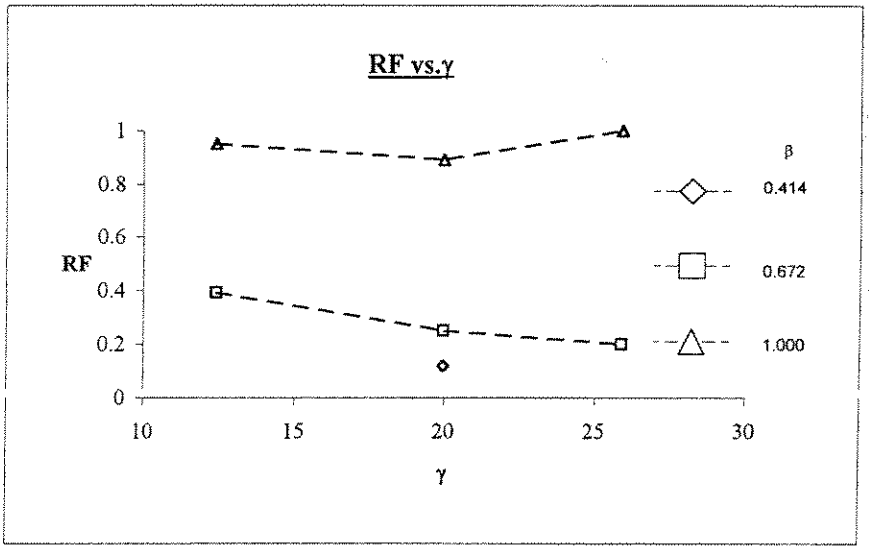
| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 4.38 | 31.52 | 3.12 | 3.91 | 0.71 | 0.12 | 0.74 | 0.12 | 3.26 | 3.77 |
| Ten. | 4.44 | 31.37 | 2.52 | 8.33 | 0.57 | 0.27 | 0.56 | 0.28 | 2.49 | 8.84 |
| OPB | | 11.81 | | 6.55 | | 0.55 | | 0.55 | | 6.55 |
| IPB | 5.14 | | 2.94 | | 0.57 | | 0.57 | | 2.91 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 2.08 | 15.73 | 3.26 | 6.08 | 2.47 | 0.15 | 1.61 | 0.36 | 3.34 | 5.73 |
| Ten. | 2.11 | 15.92 | 2.02 | 6.20 | 0.91 | 0.15 | 0.97 | 0.38 | 2.05 | 6.00 |
| OPB | | 8.08 | | 5.32 | | 0.43 | | 0.65 | | 5.21 |
| IPB | 3.98 | | 3.16 | | 0.63 | | 0.74 | | 2.97 | |
| **19.973** | | | | | | | | | | |
| Comp. | 4.12 | 35.92 | 1.98 | 8.96 | 0.48 | 0.25 | 1.67 | 0.28 | 6.89 | 9.99 |
| Ten. | 4.54 | 35.72 | 0.74 | 11.59 | 0.16 | 0.32 | 1.22 | 0.31 | 5.55 | 11.15 |
| OPB | | 18.20 | | 8.59 | | 0.47 | | 0.51 | | 9.26 |
| IPB | 6.06 | | 3.30 | | 0.54 | | 0.59 | | 3.60 | |
| **25.888** | | | | | | | | | | |
| Comp. | 1.70 | 43.92 | 2.86 | 8.72 | 1.68 | 0.20 | 1.73 | 0.21 | 2.94 | 9.25 |
| Ten. | 1.58 | 44.39 | 2.32 | 12.60 | 1.46 | 0.28 | 1.42 | 0.26 | 2.25 | 11.59 |
| OPB | | 21.59 | | 9.00 | | 0.42 | | 0.40 | | 8.67 |
| IPB | 4.79 | | 2.35 | | 0.49 | | 0.48 | | 2.28 | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measured as-welded SCF | | Measured grouted SCF | | Measured RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 0.78 | 4.07 | 1.45 | 3.86 | 1.86 | 0.95 | 1.91 | 0.92 | 1.49 | 3.75 |
| Ten. | 0.79 | 4.06 | 1.02 | 4.14 | 1.29 | 1.02 | 1.40 | 1.02 | 1.11 | 4.14 |
| OPB | | 3.10 | | 3.01 | | 0.97 | | 0.99 | | 3.06 |
| IPB | 2.88 | | 1.93 | | 0.67 | | 0.68 | | 1.95 | |
| **19.973** | | | | | | | | | | |
| Comp. | 0.61 | 8.53 | 1.79 | 7.61 | 2.92 | 0.89 | 2.90 | 0.96 | 1.78 | 8.22 |
| Ten. | 0.62 | 7.94 | 1.31 | 6.46 | 2.10 | 0.81 | 1.78 | 0.83 | 1.11 | 6.62 |
| OPB | | 5.18 | | 5.04 | | 0.97 | | 0.95 | | 4.94 |
| IPB | 3.10 | | 1.93 | | 0.62 | | 0.60 | | 1.86 | |
| **25.888** | | | | | | | | | | |
| Comp. | 0.72 | 10.16 | 2.54 | 10.15 | 3.53 | 1.00 | 3.67 | 0.99 | 2.64 | 10.06 |
| Ten. | 0.74 | 9.98 | 1.34 | 6.84 | 1.81 | 0.69 | 2.07 | 0.68 | 1.54 | 6.82 |
| OPB | | 6.90 | | 6.42 | | 0.93 | | 0.92 | | 6.35 |
| IPB | 3.47 | | 1.82 | | 0.53 | | 0.54 | | 1.88 | |

Table 8: Comparison of Chord DT-Joint Measured and Predicted As-welded and Grouted SCFs.



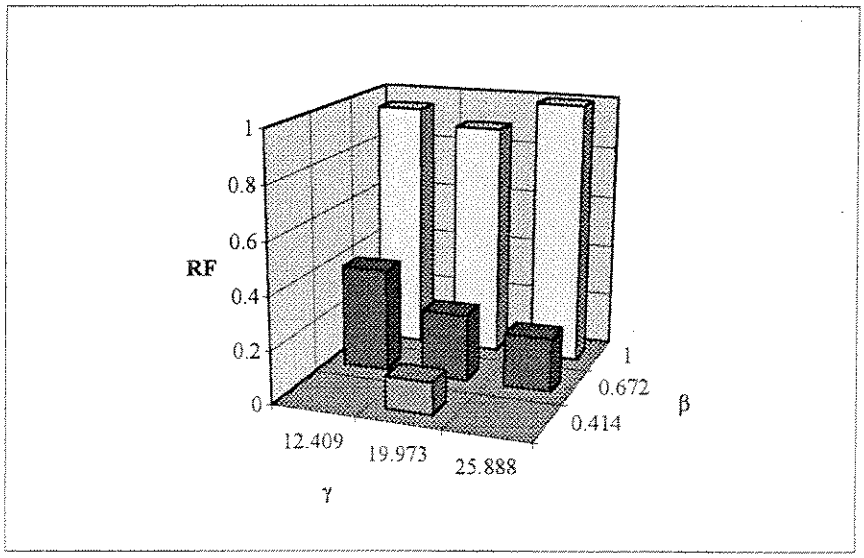
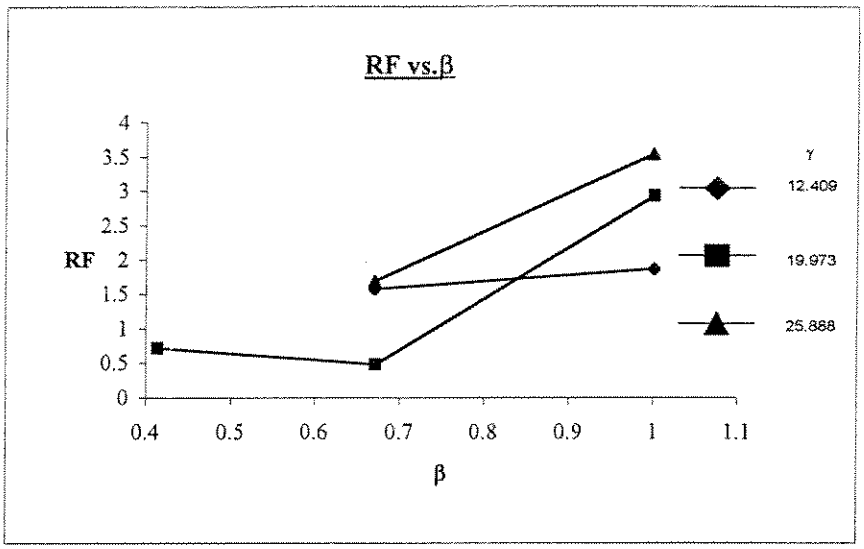
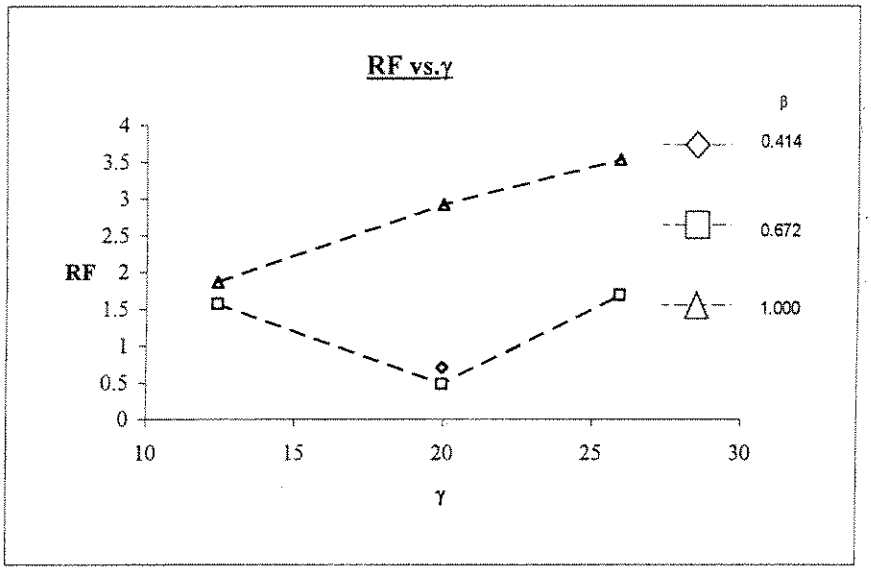




Fig. 1: DT Joints Under Compression, Chord Saddle



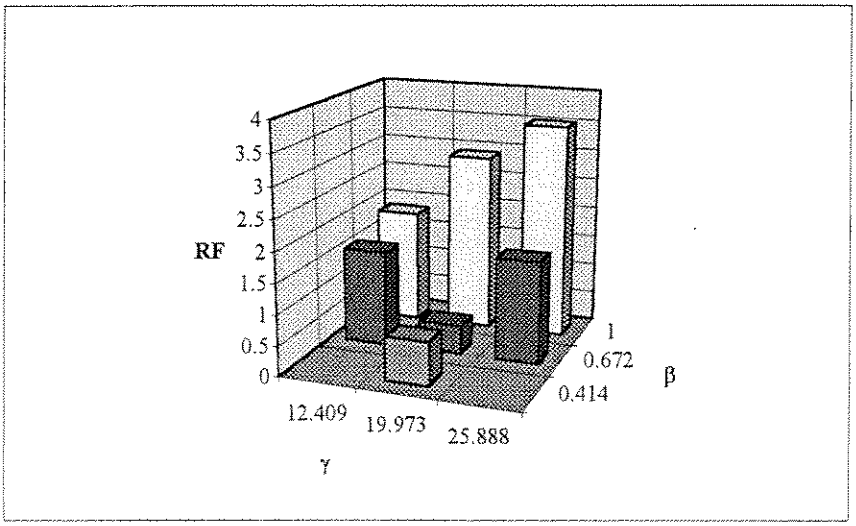
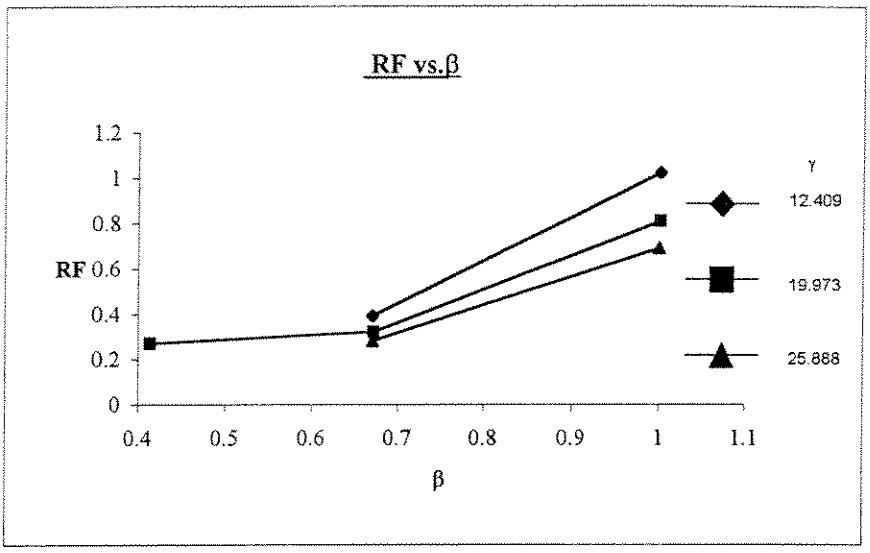
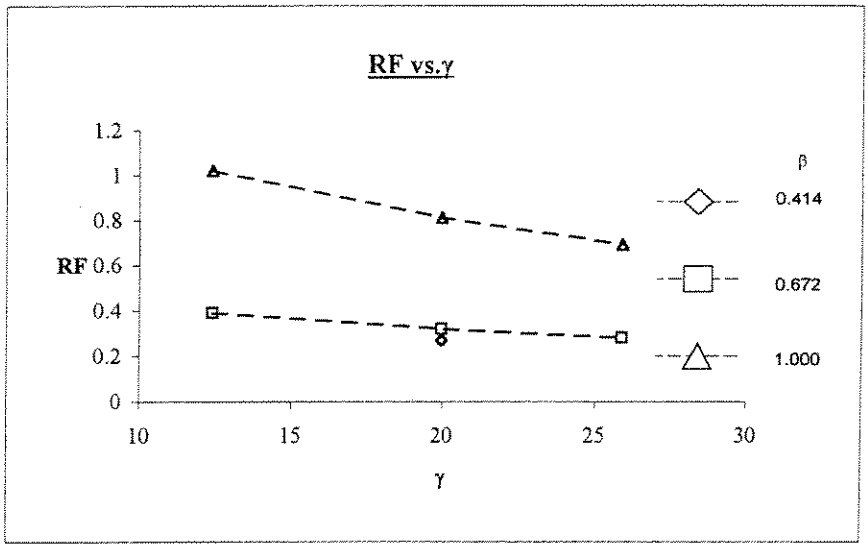




Fig. 2: DT Joints Under Compression, Chord Crown



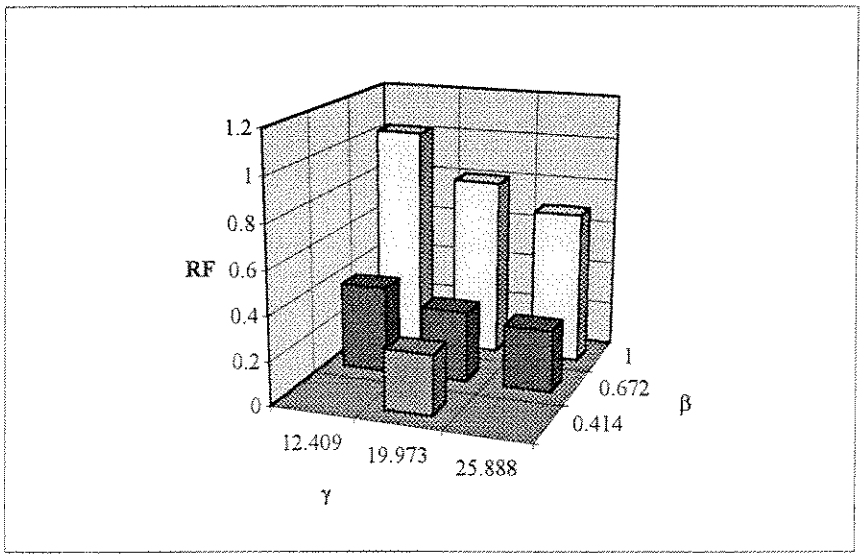
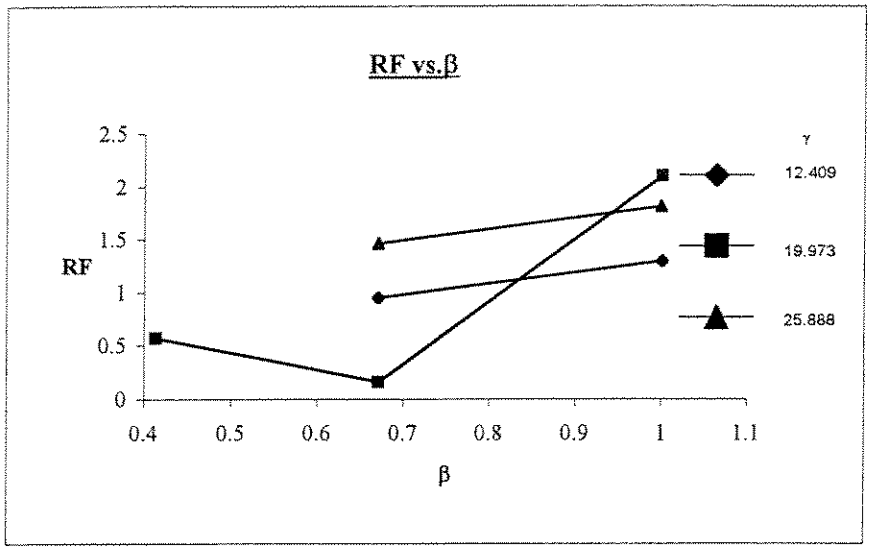
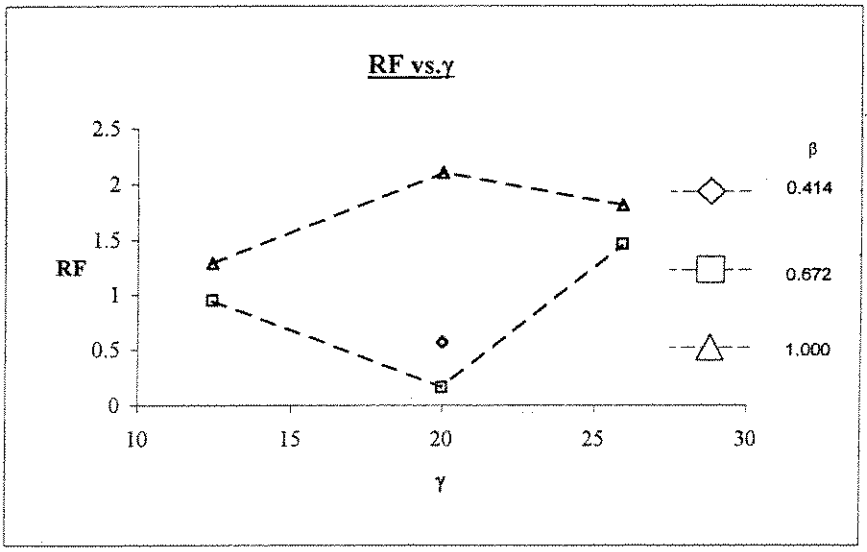




Fig. 3: DT Joints Under Tension, Chord Saddle



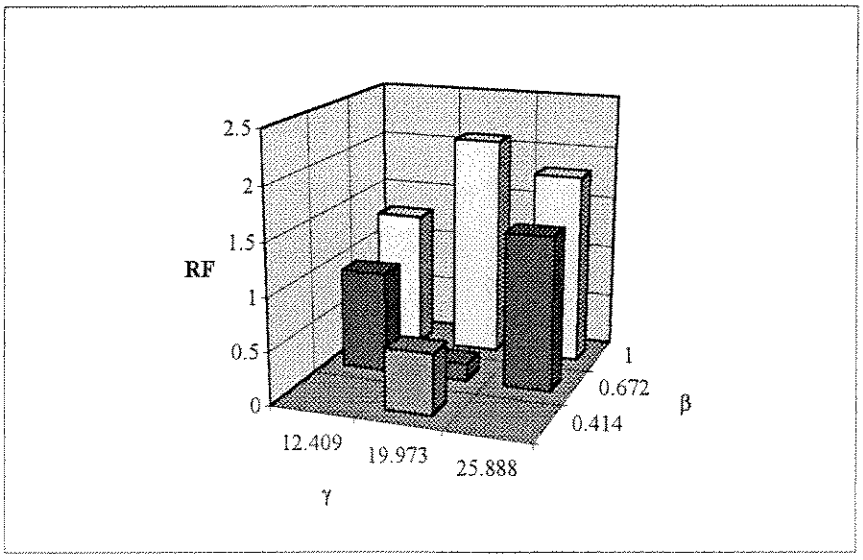
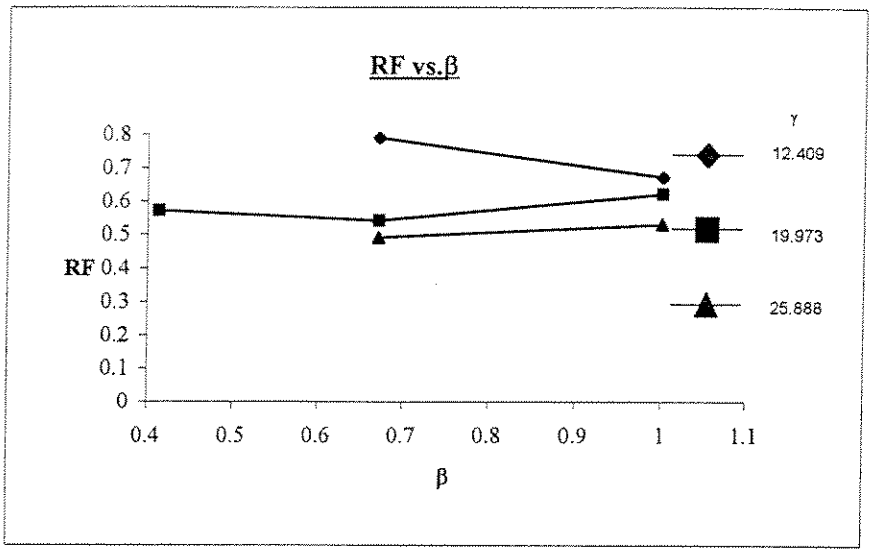
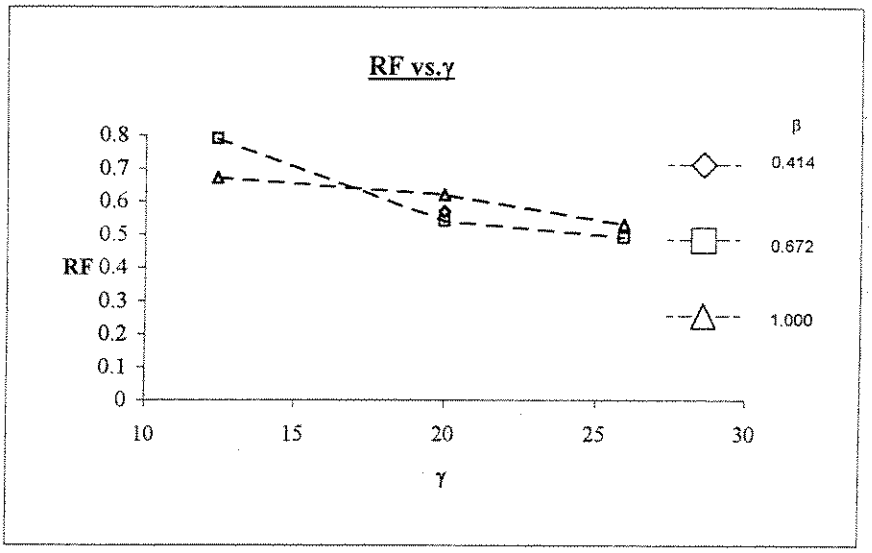




Fig. 4: DT Joints Under Tension, Chord Crown



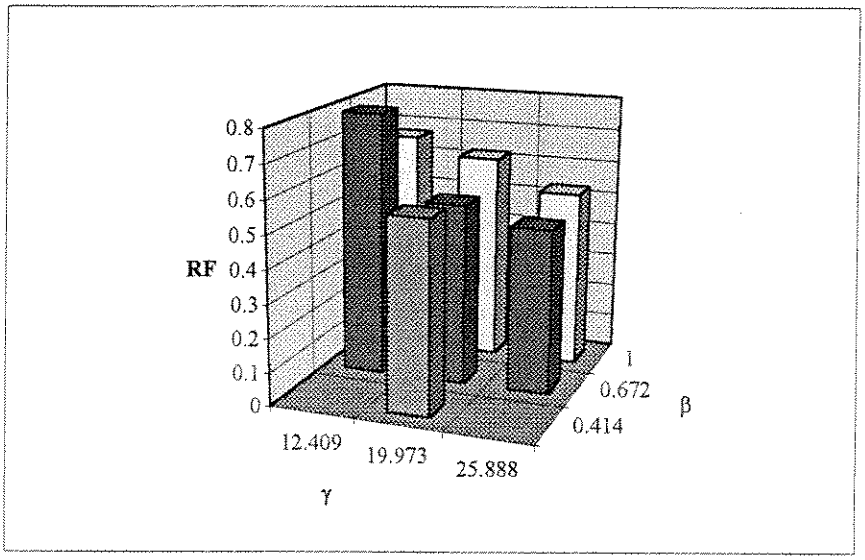
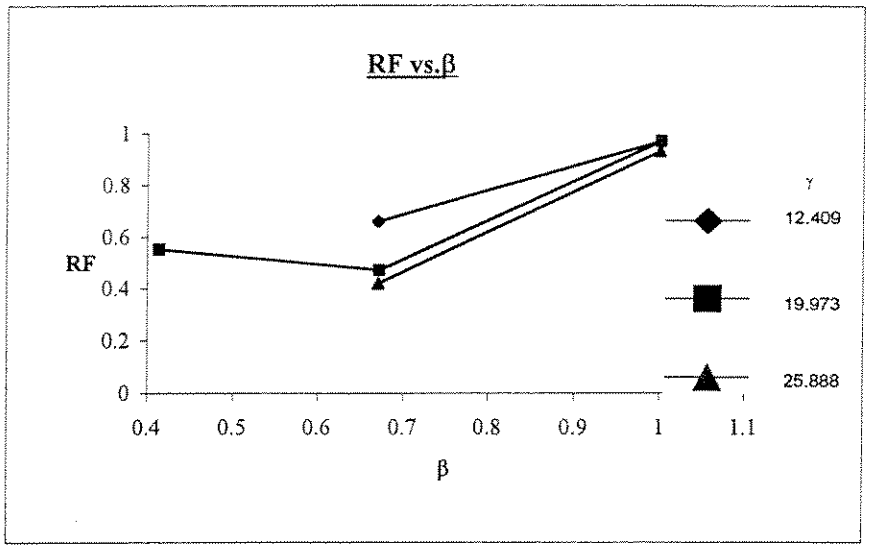
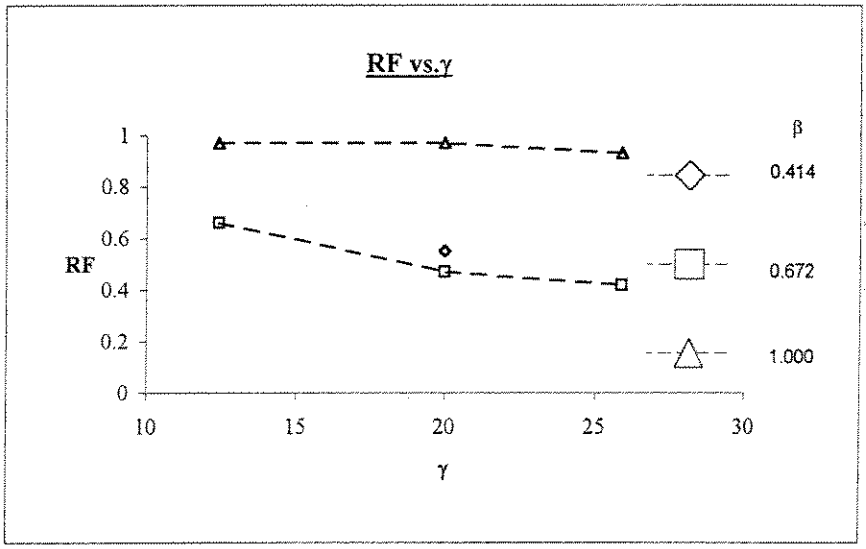




Fig. 5: DT Joints Under IPB, Chord Crown



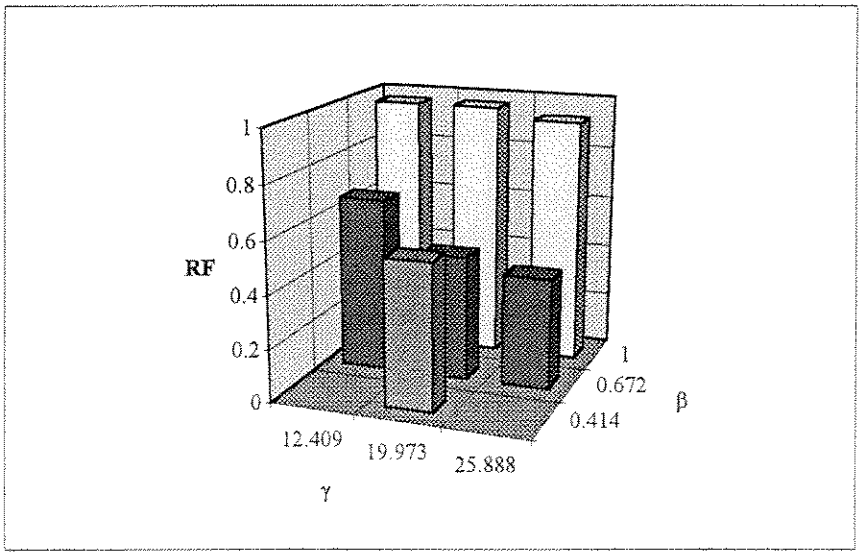
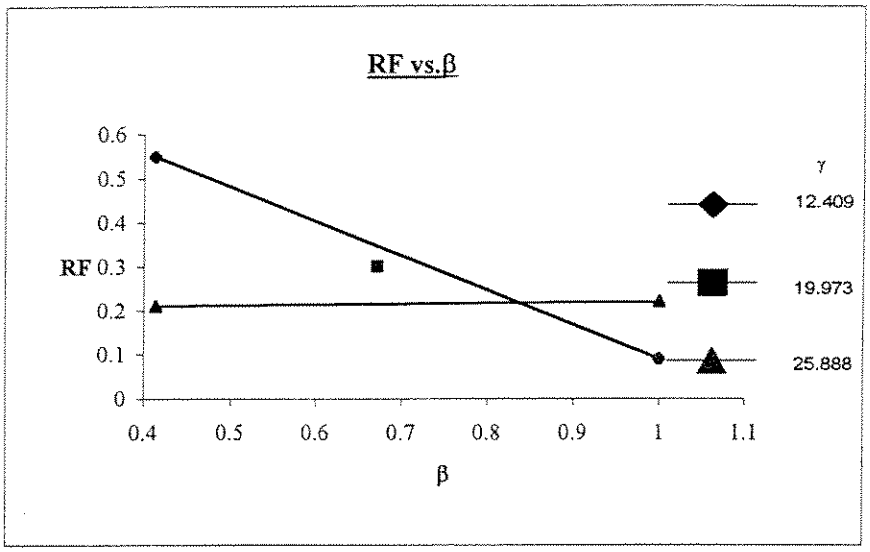
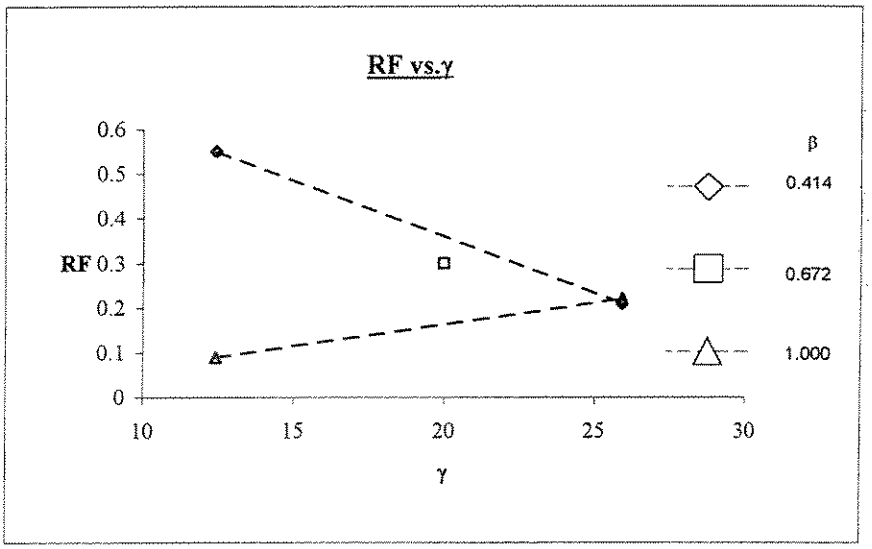




Fig. 6: DT Joints Under OPB, Chord Saddle



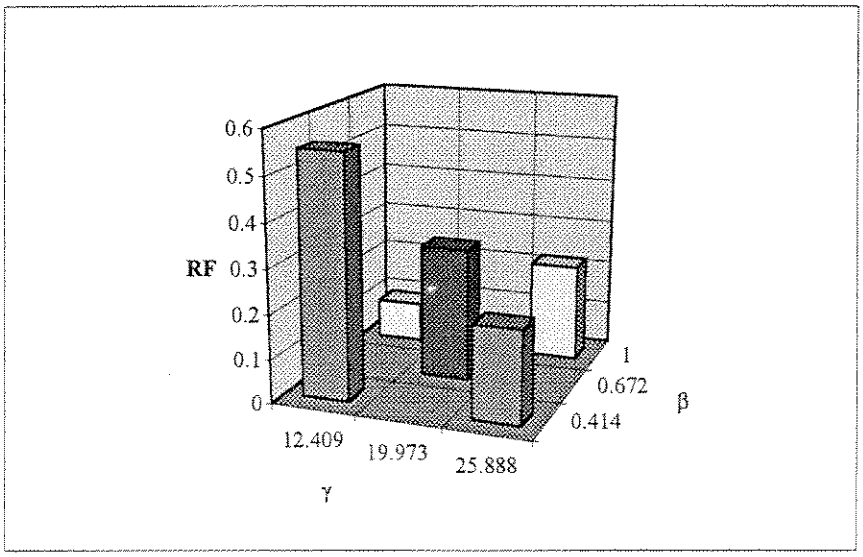
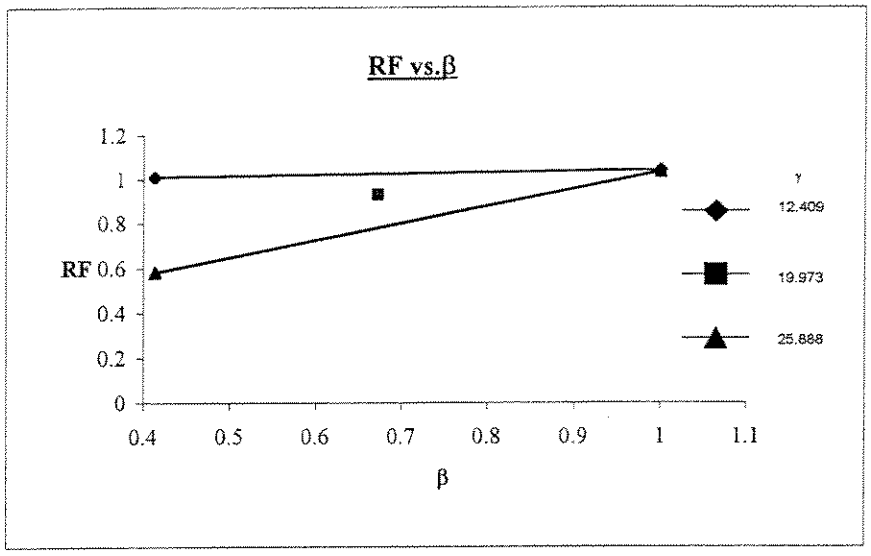
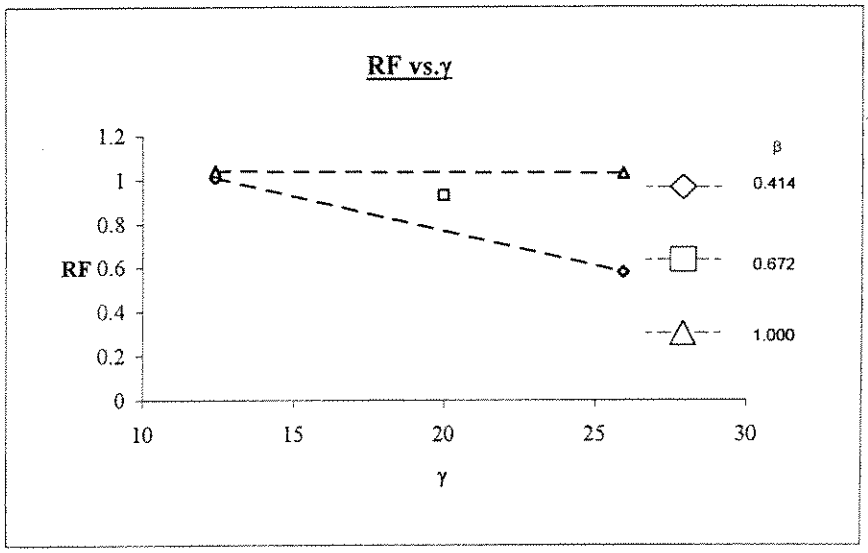




Fig. 7: T Joints Under Compression, Chord Saddle



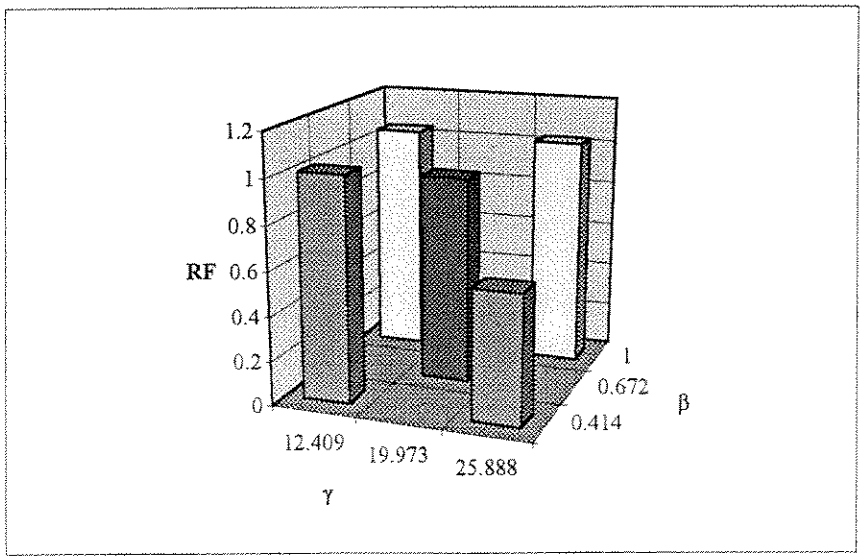
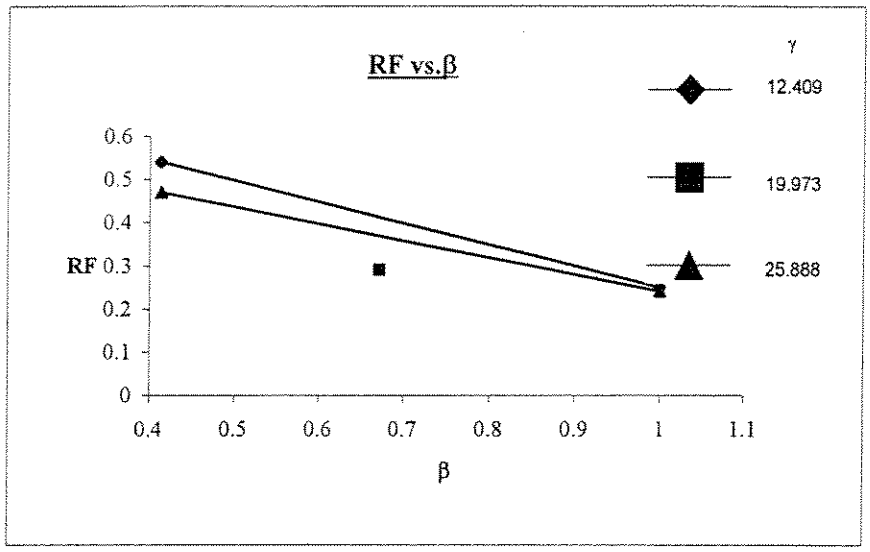
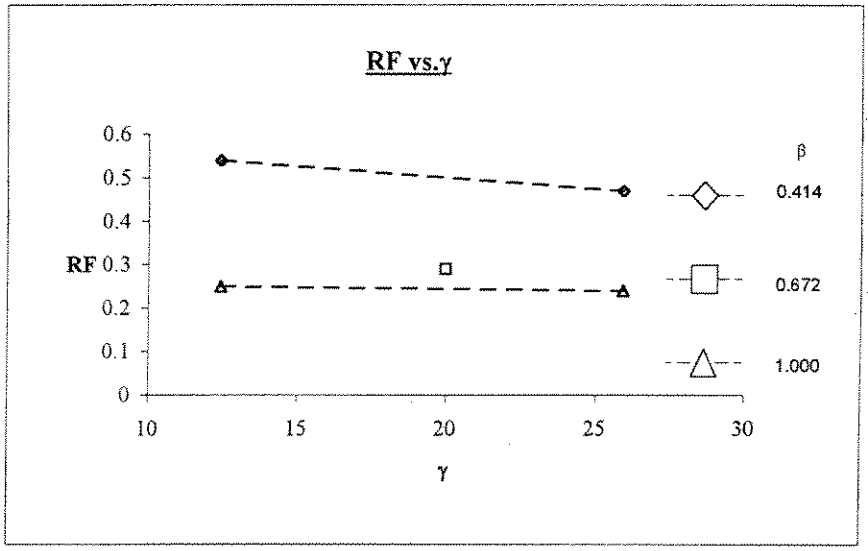




Fig. 8: T Joints Under Compression, Chord Crown



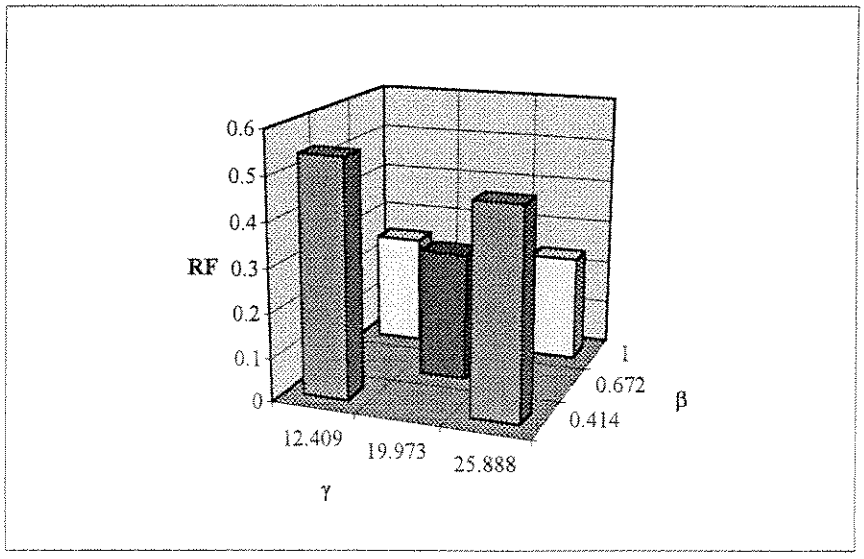
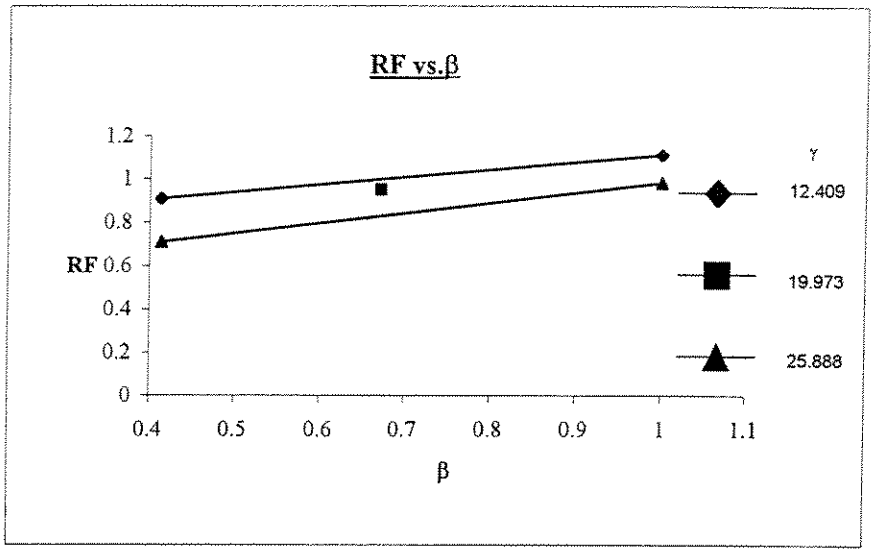
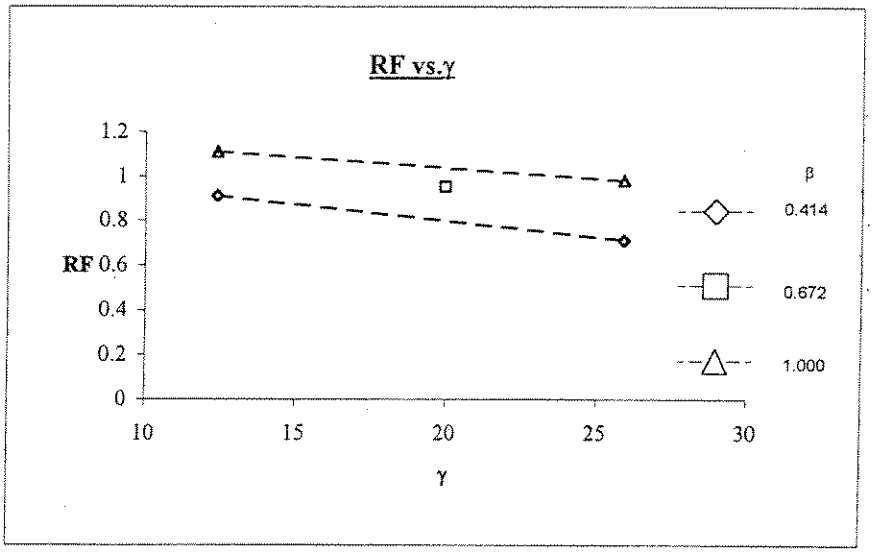




Fig. 9: T Joints Under Tension, Chord Saddle



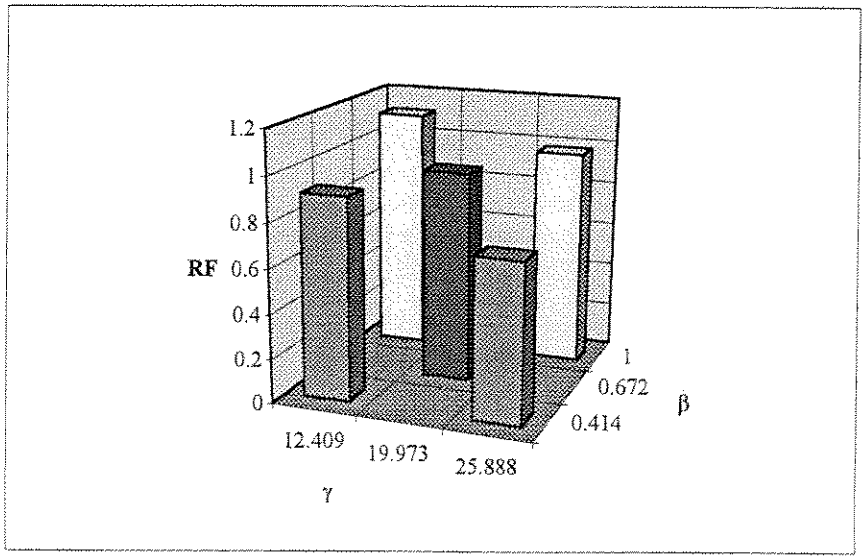
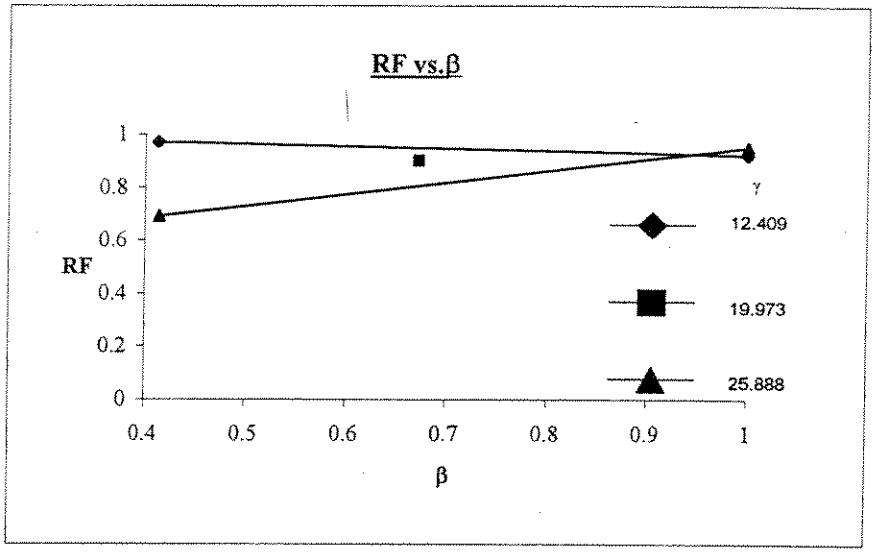
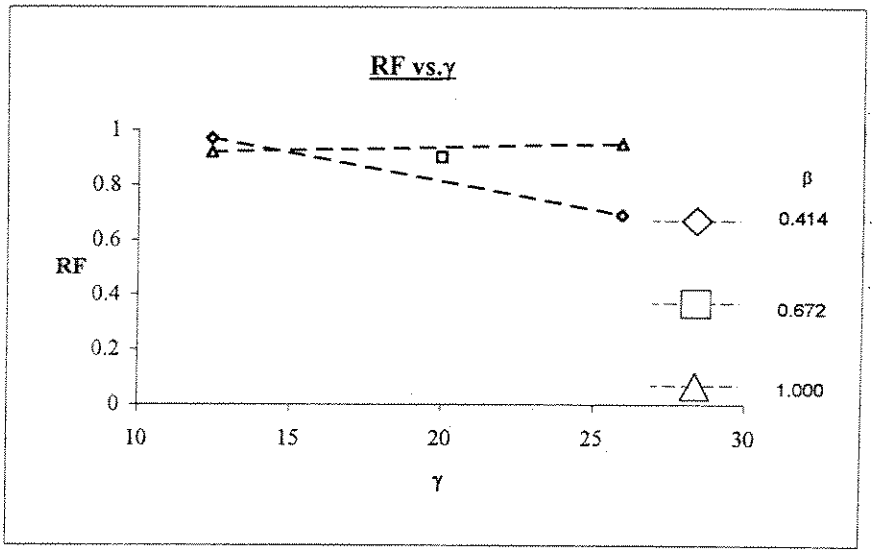




Fig. 10: T Joints Under Tension, Chord Crown



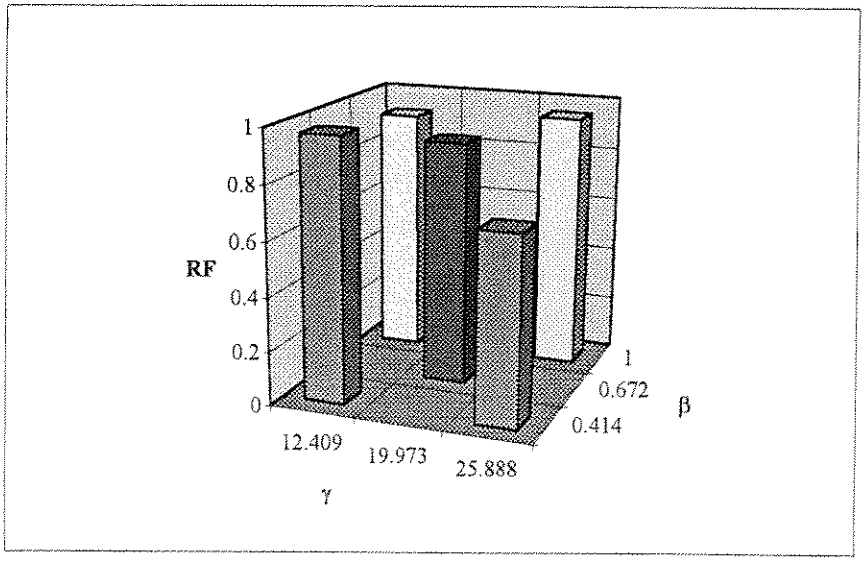
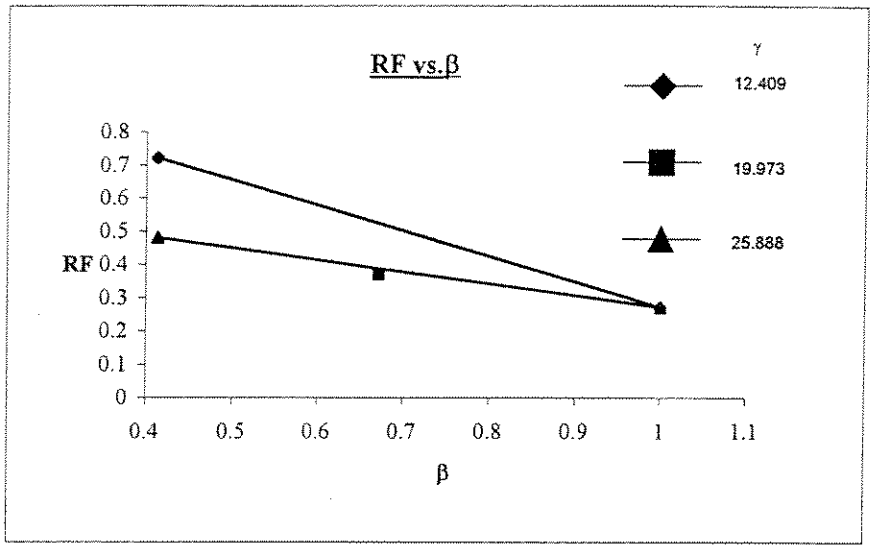
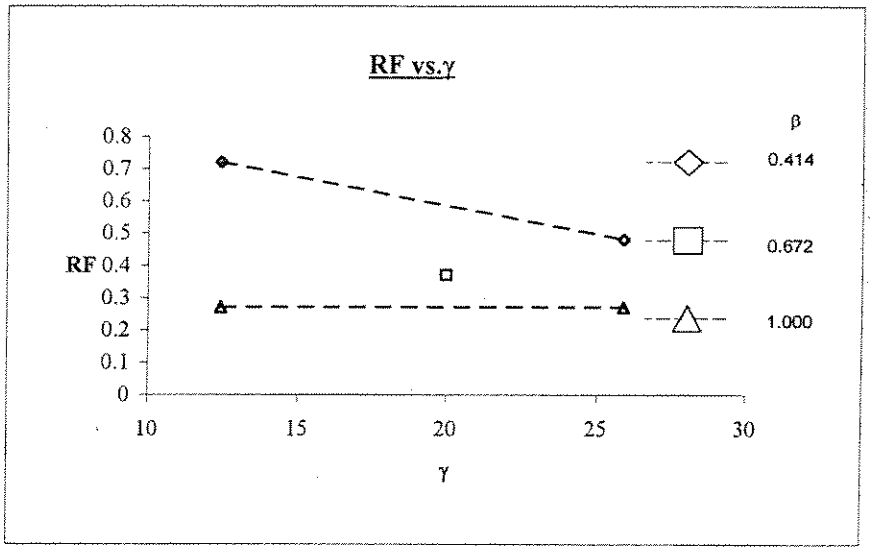




Fig. 11: T Joints Under IPB, Chord Crown



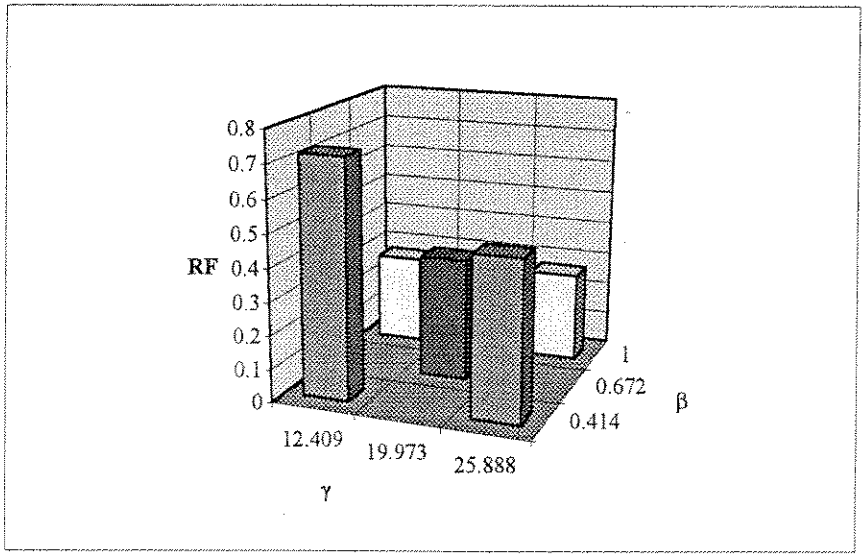
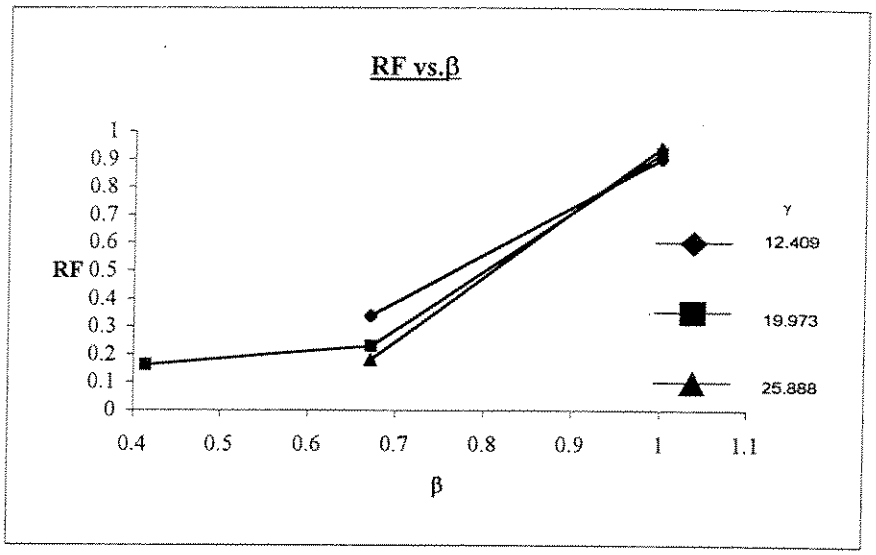
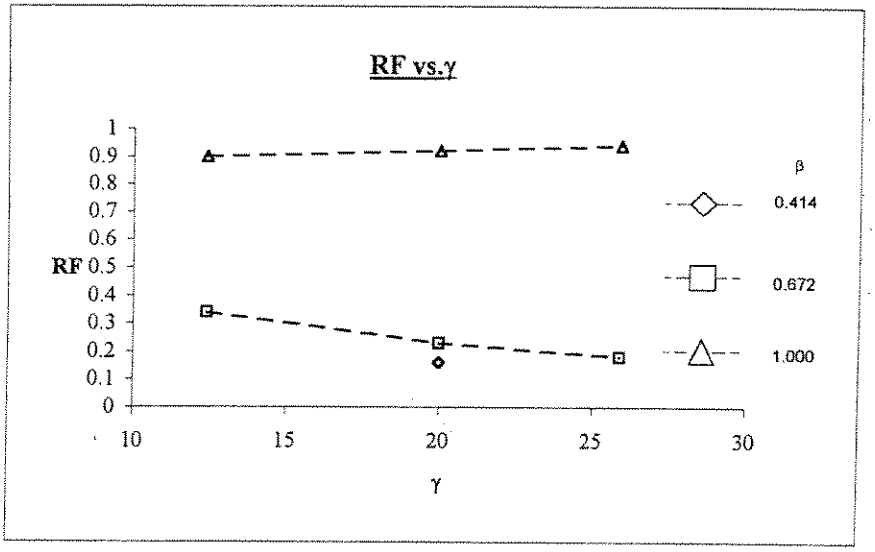




Fig. 12: T Joints Under OPB, Chord Saddle



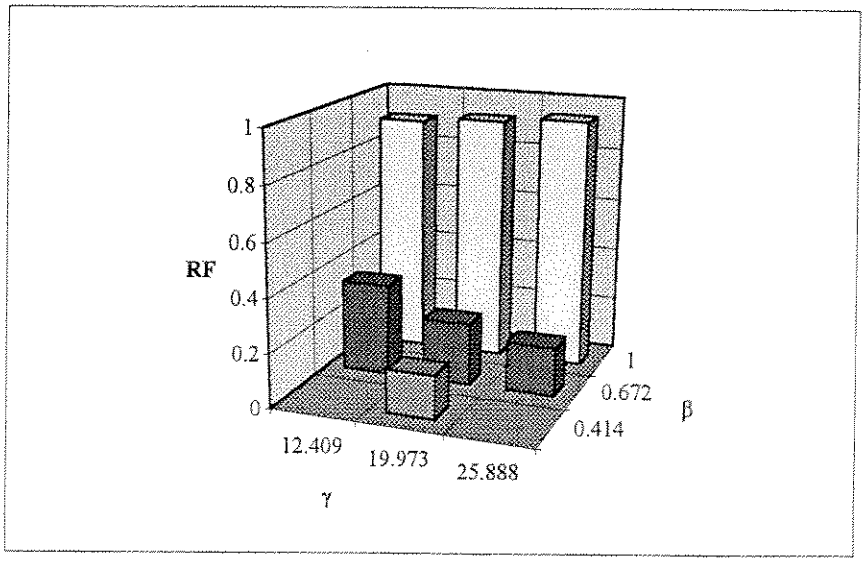
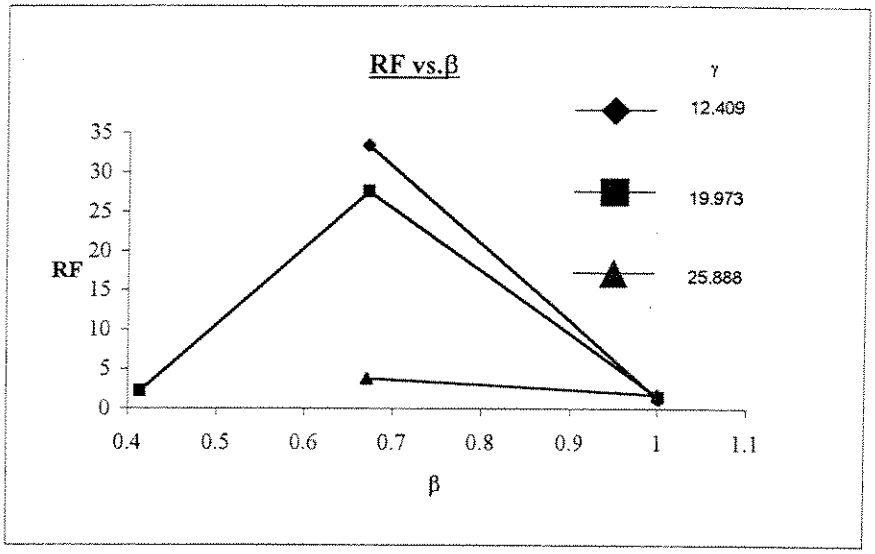
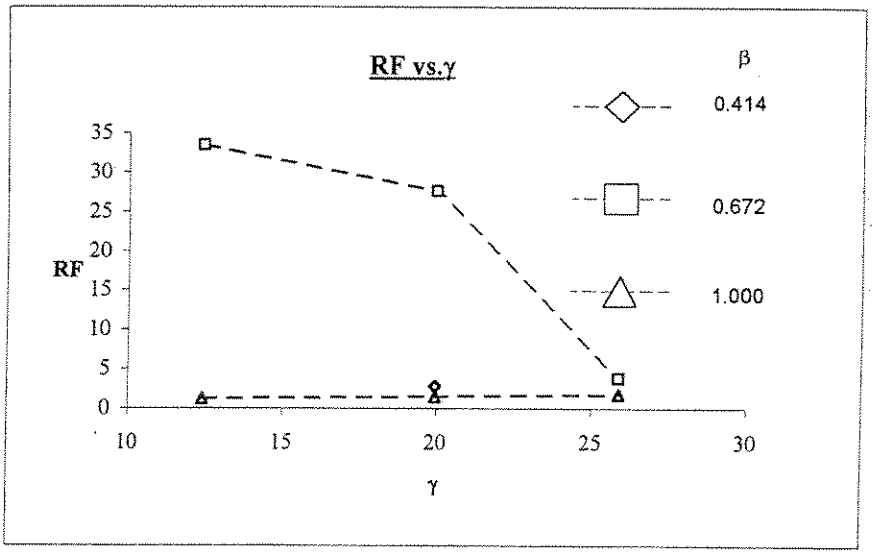




Fig. 13: DT Joints Under Compression, Brace Saddle



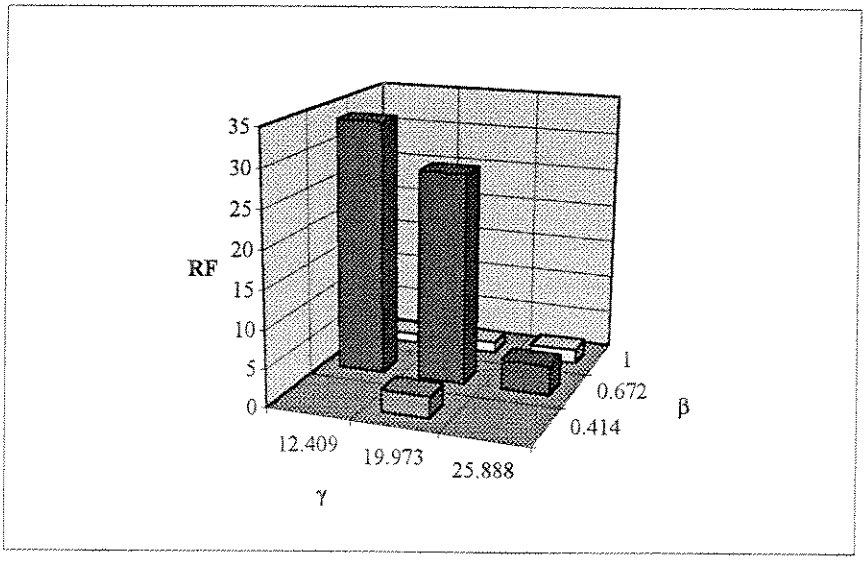
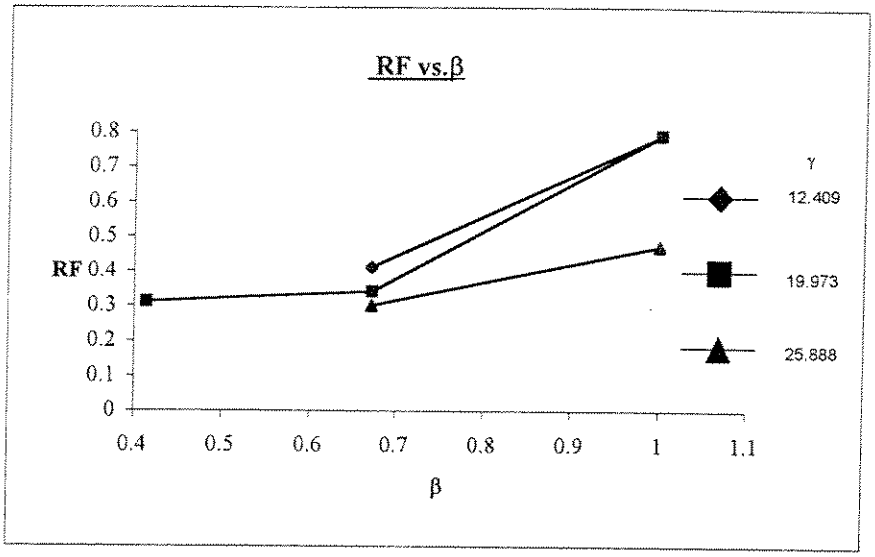
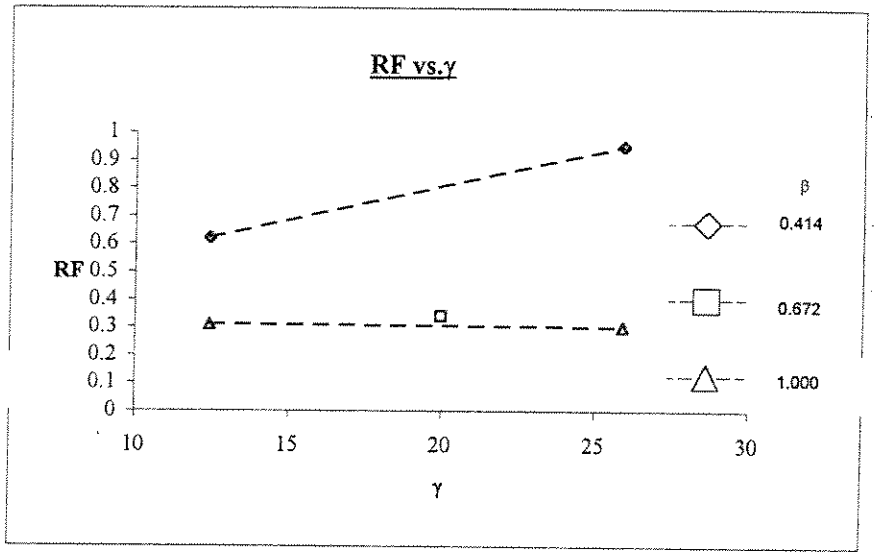




Fig. 14: DT Joints Under Compression, Brace Crown



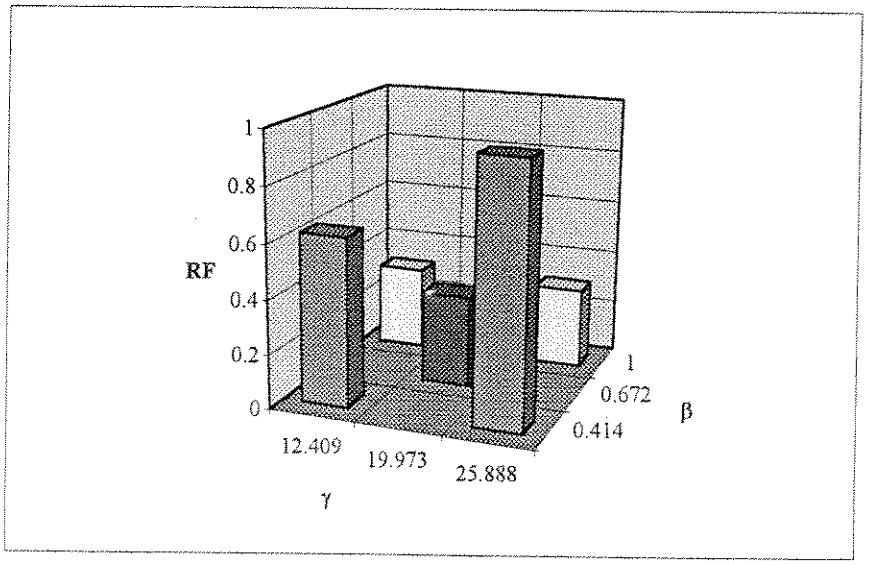
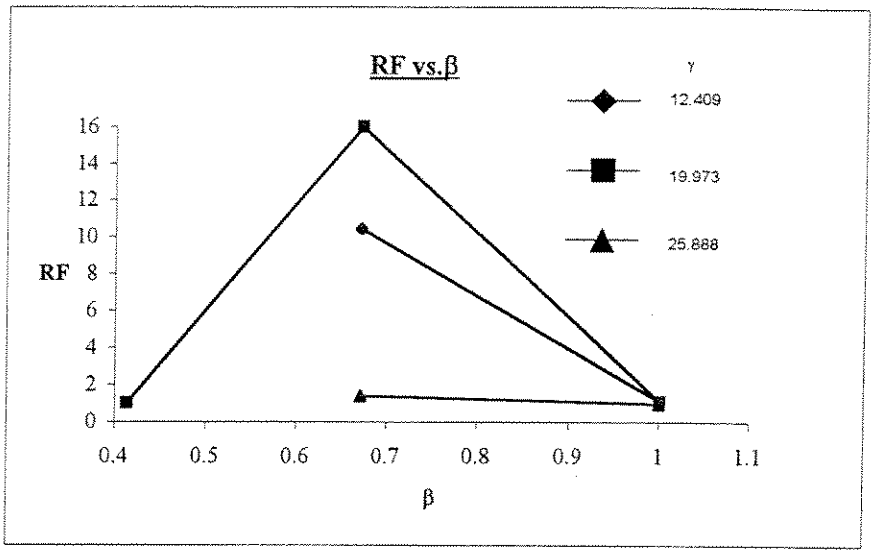
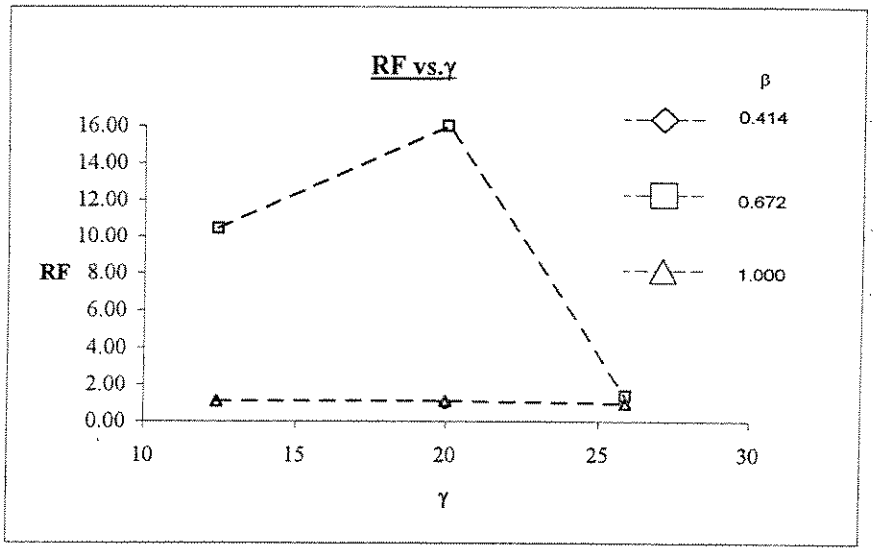




Fig. 15: DT Joints Under Tension, Brace Saddle



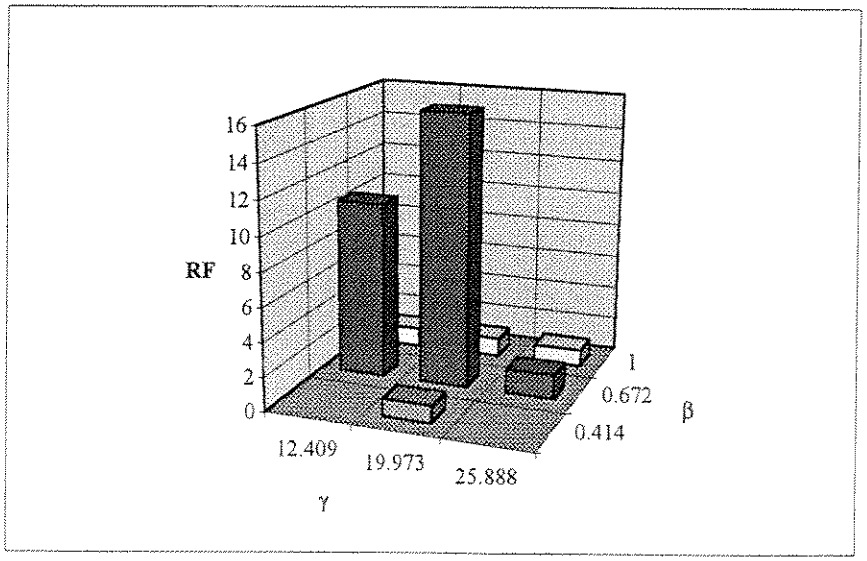
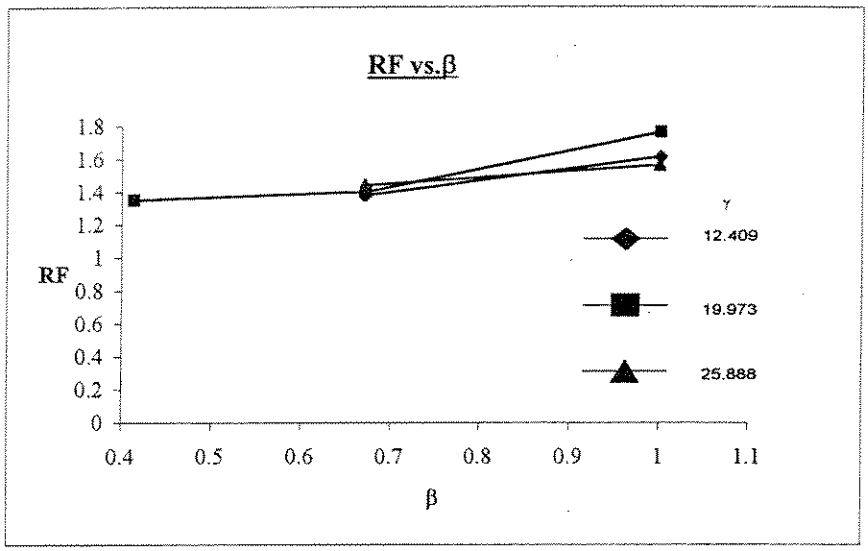
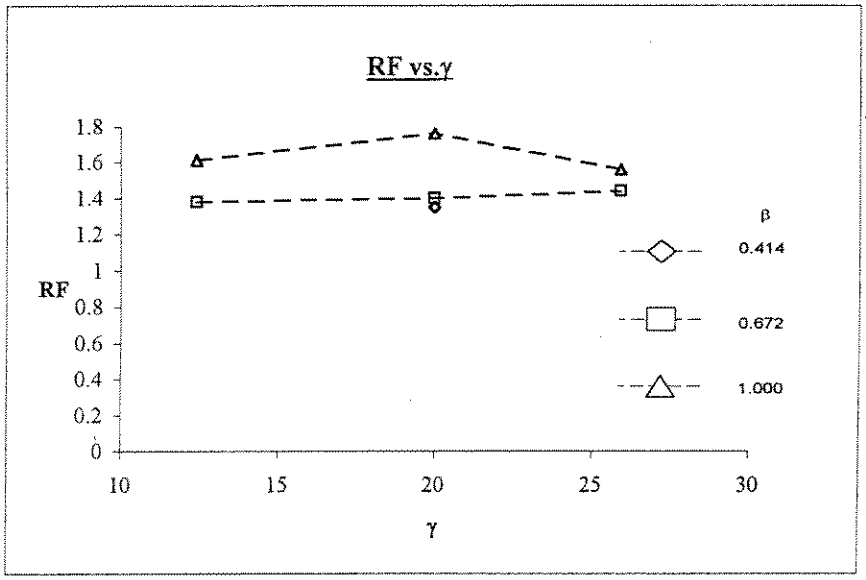




Fig. 16: DT Joints Under Tension, Brace Crown



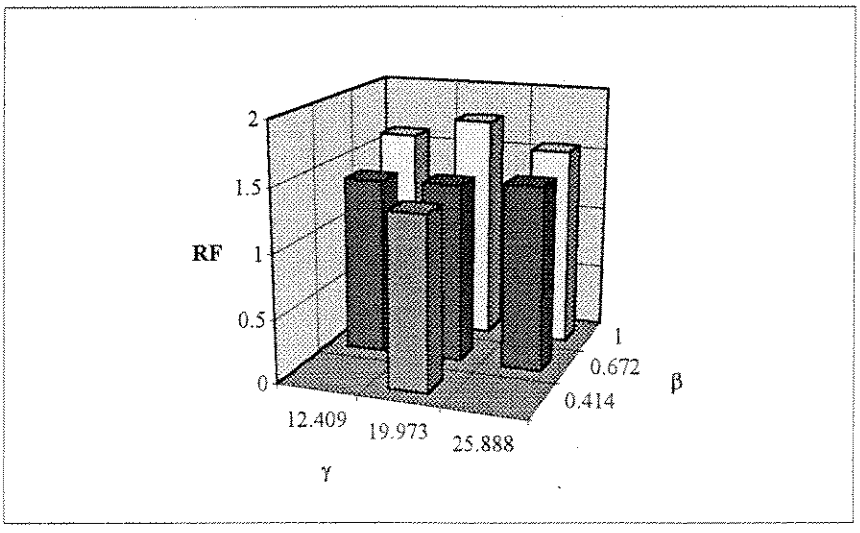
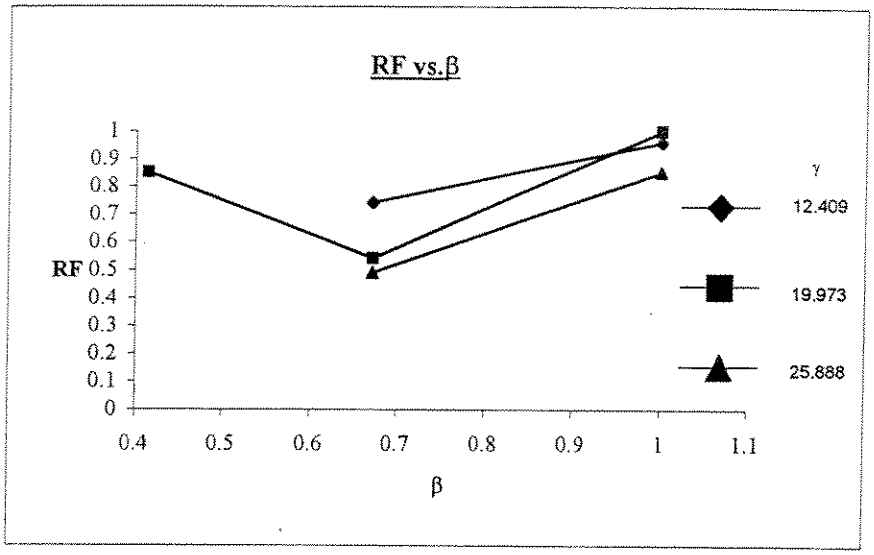
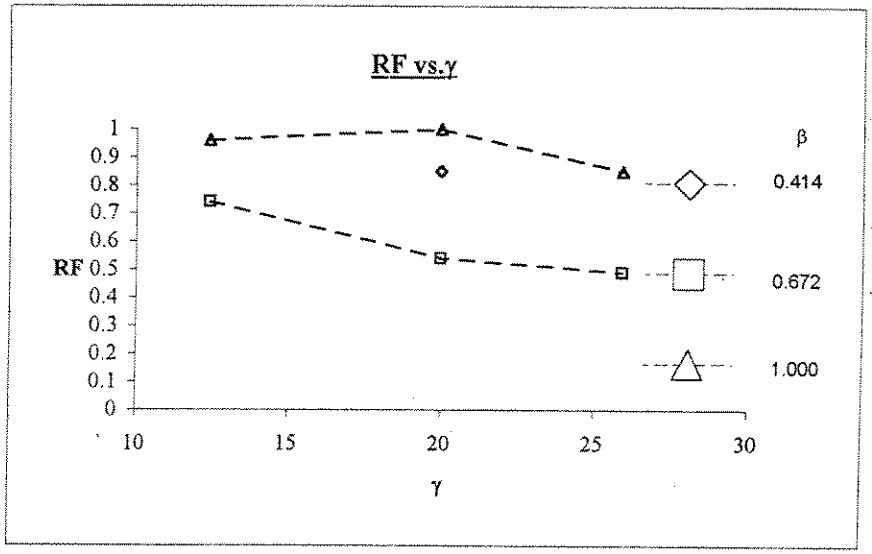




Fig. 17: DT Joints Under IPB, Brace-Crown



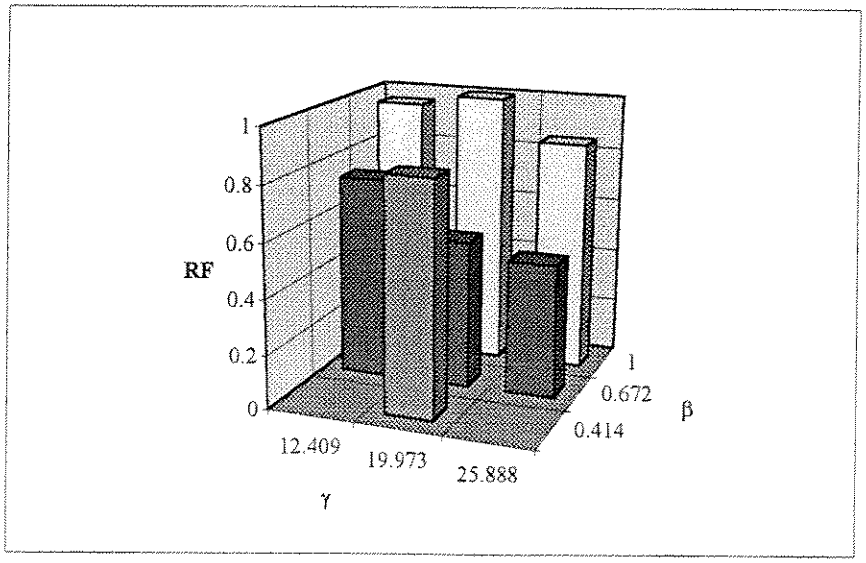
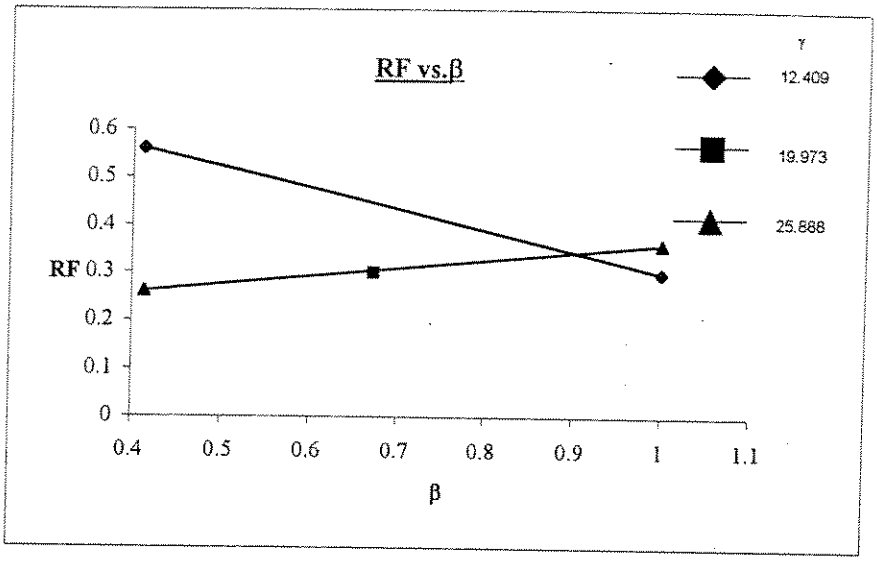
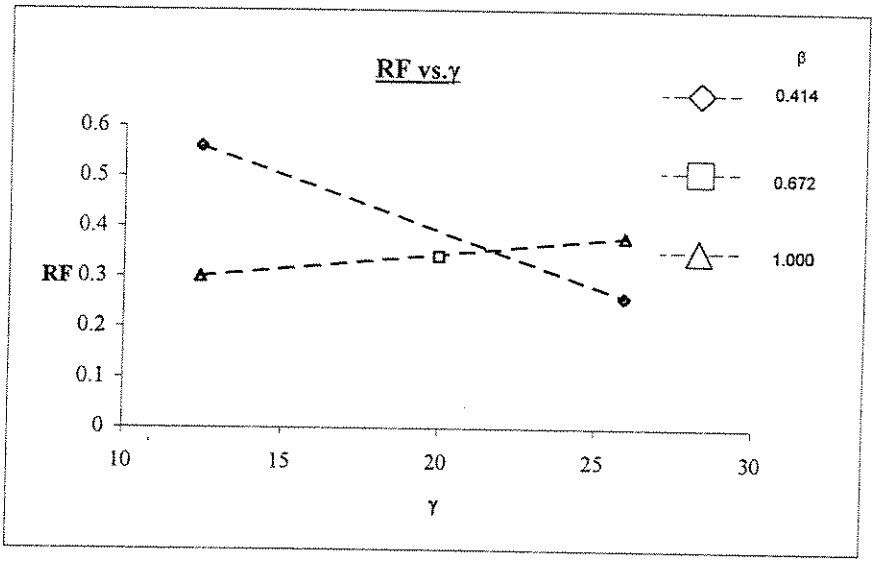




Fig. 18: DT Joints Under OPB, Brace Saddle



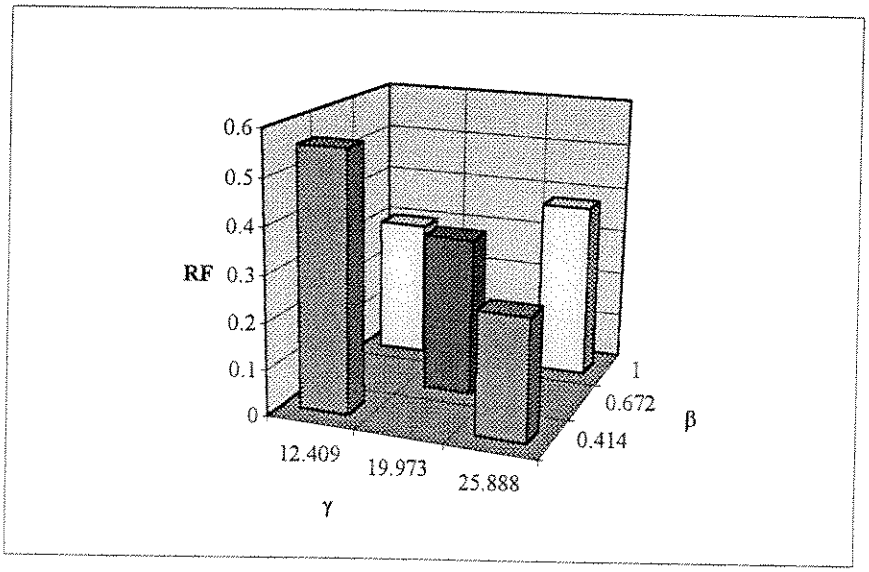
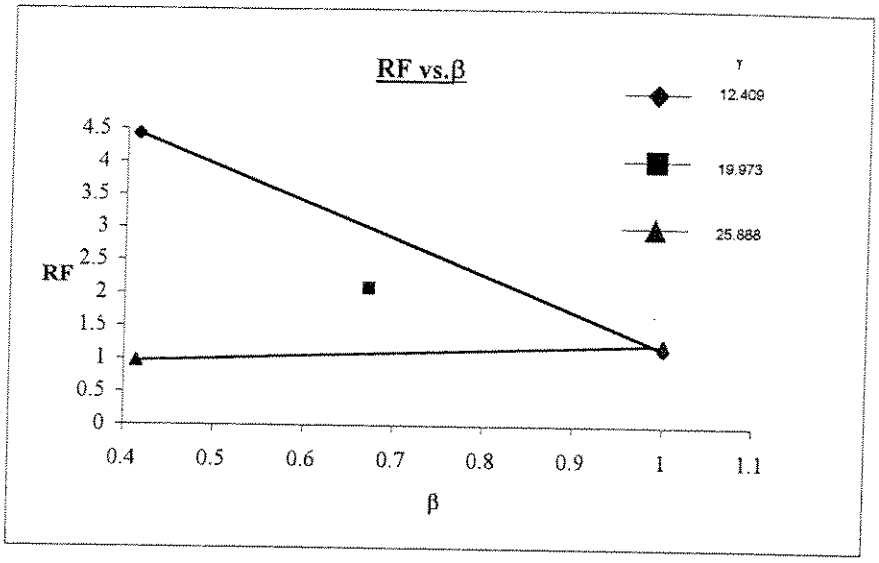
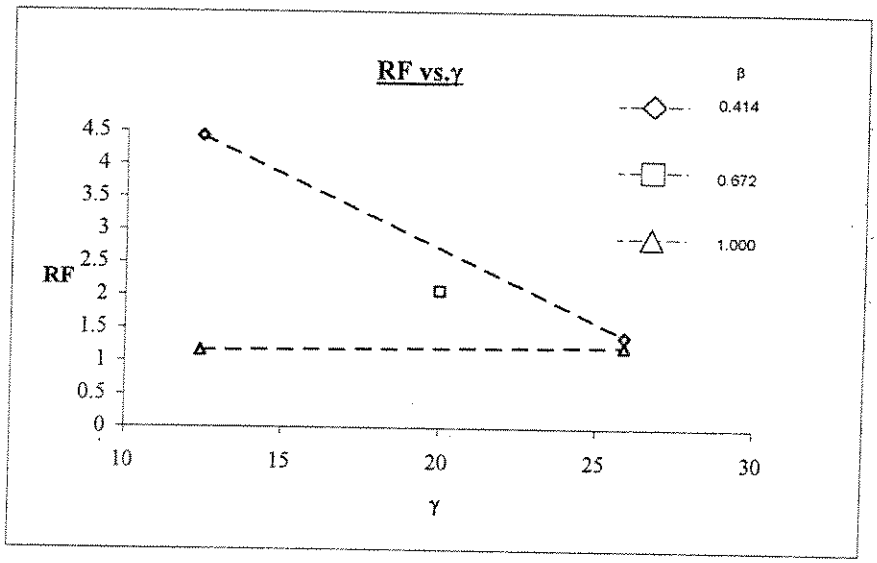




Fig. 19: T Joints Under Compression, Brace Saddle



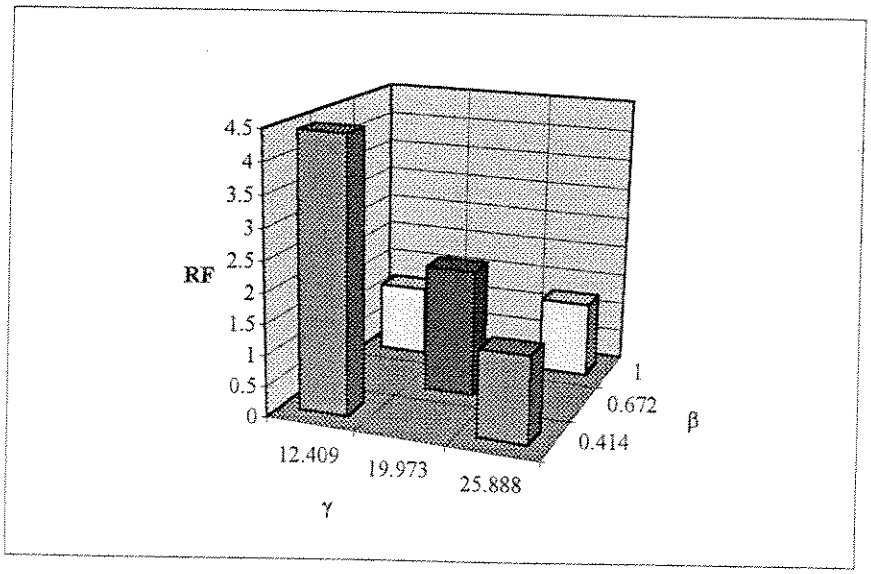
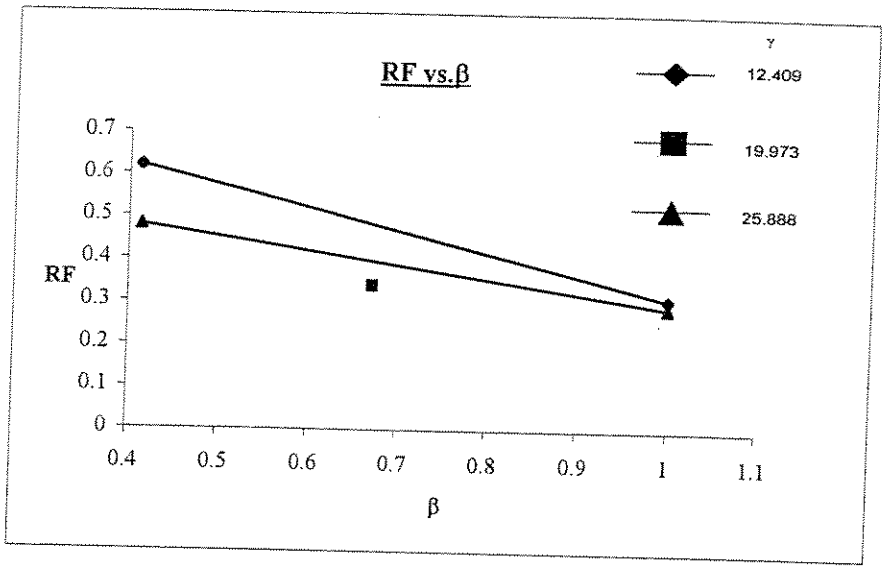
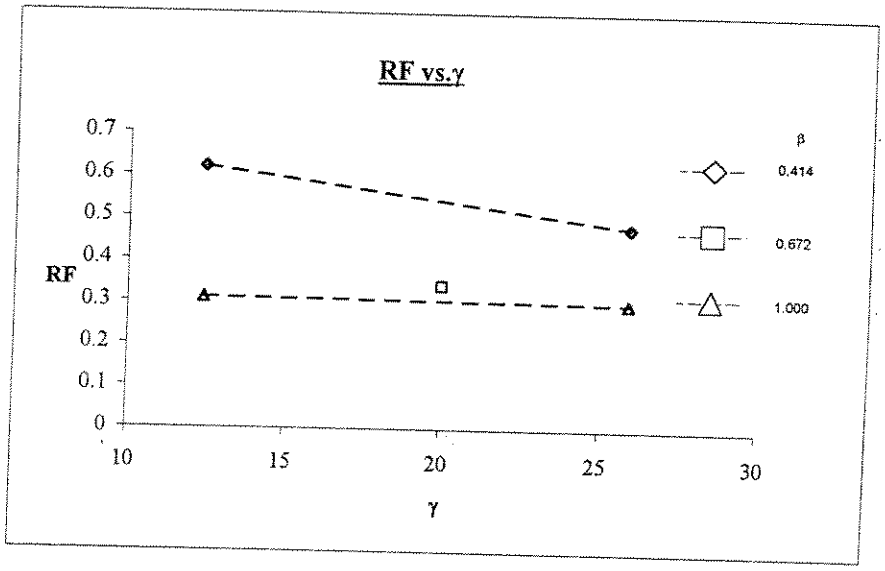




Fig. 20: T Joints Under Compression, Brace Crown



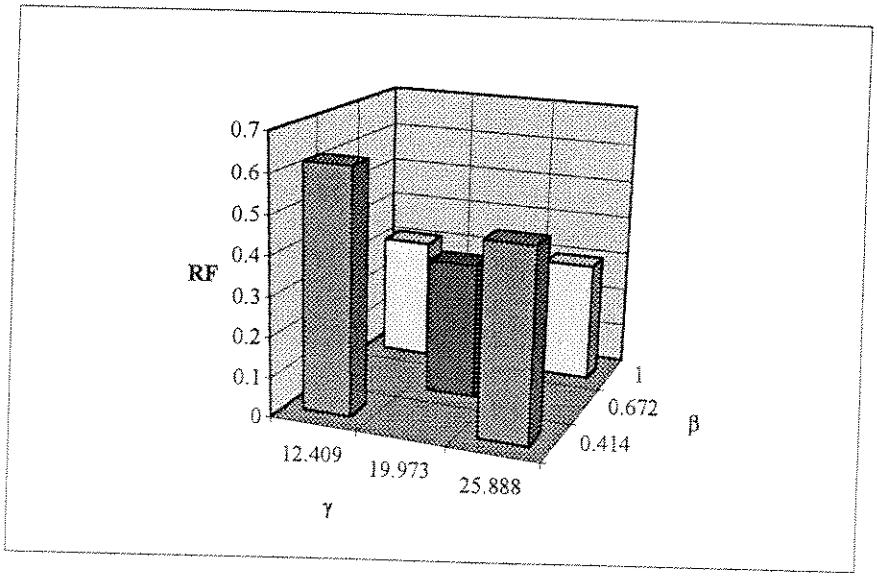
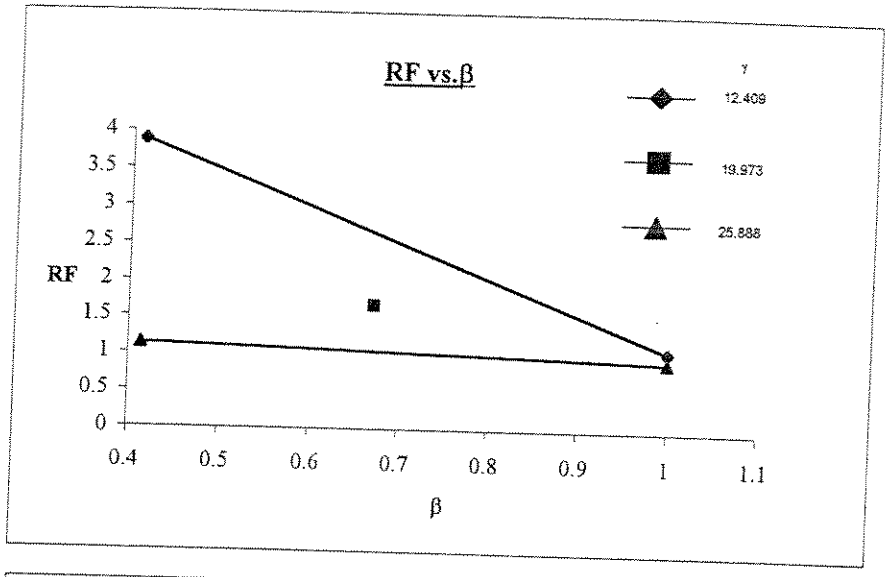
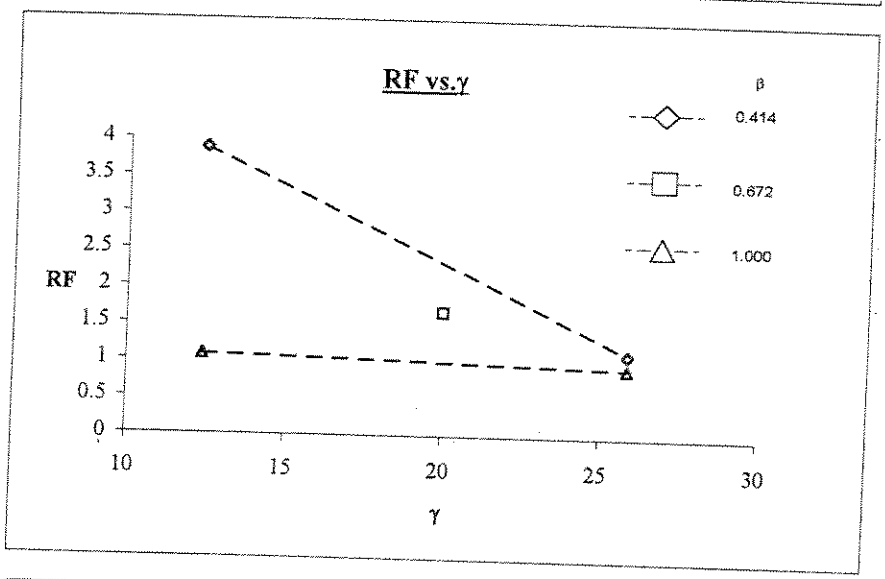




Fig. 21: T Joints Under Tension, Brace Saddle



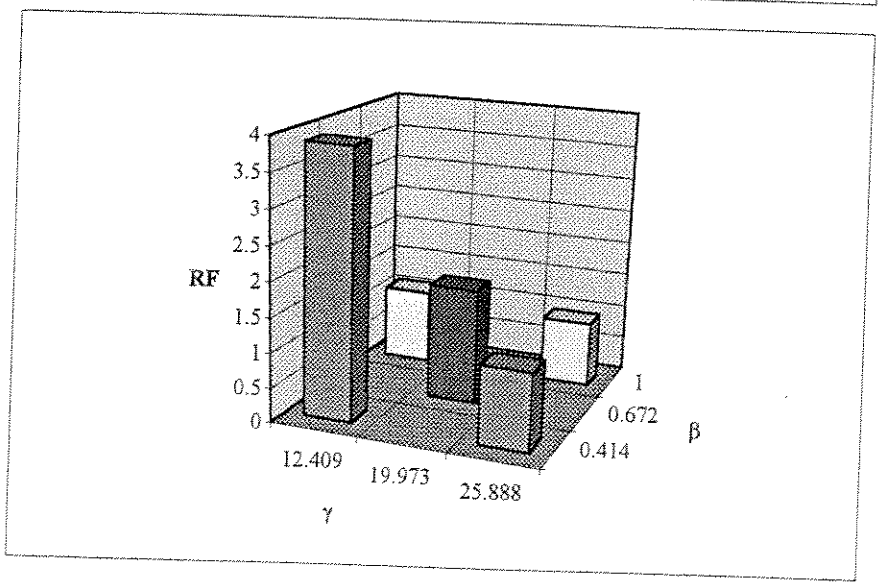
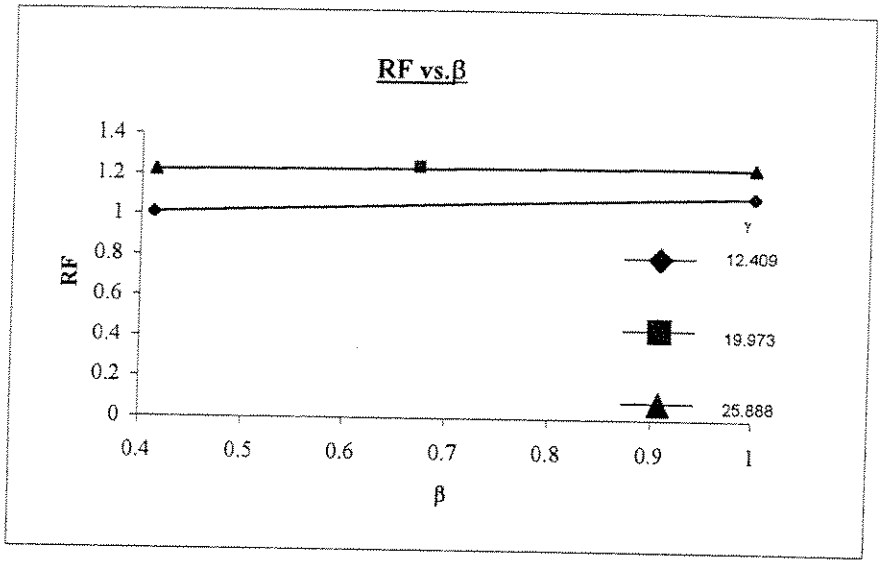
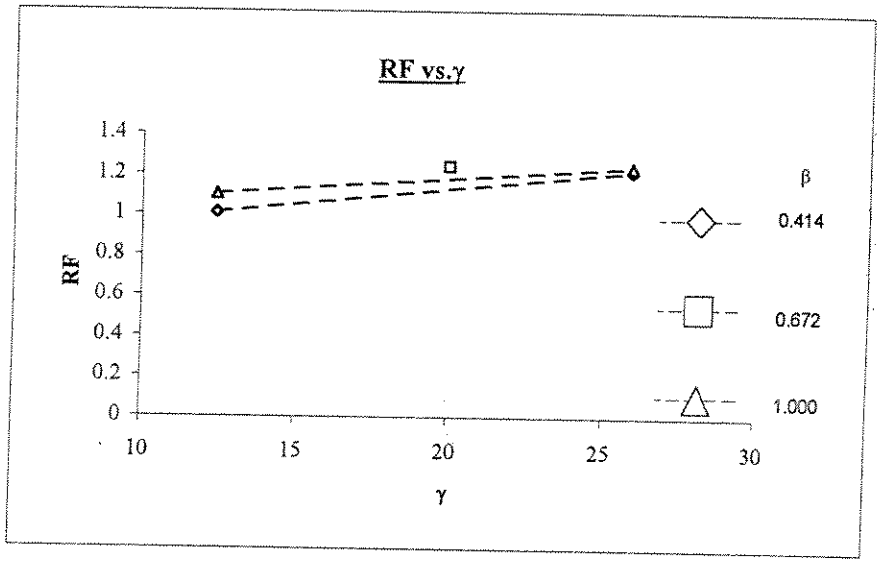




Fig. 22: T Joints Under Tension, Brace Crown



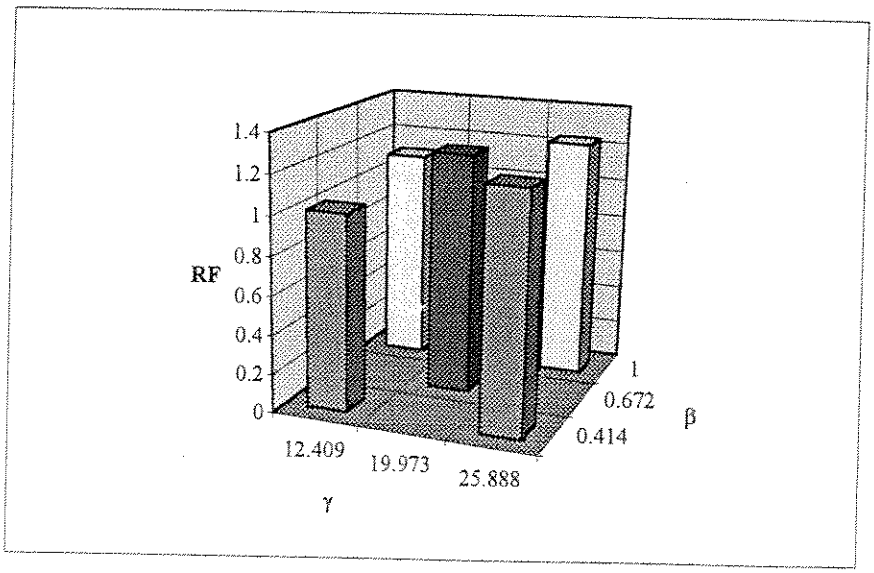
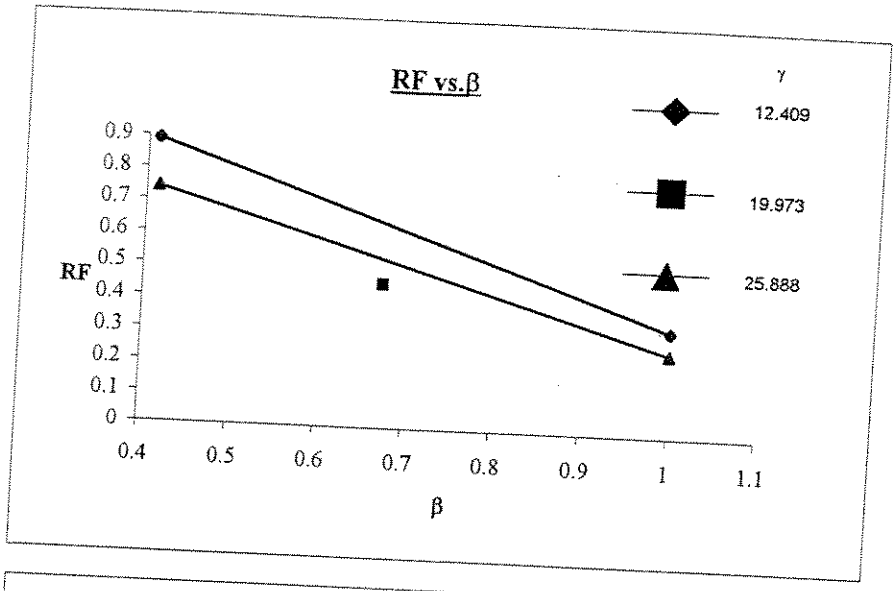
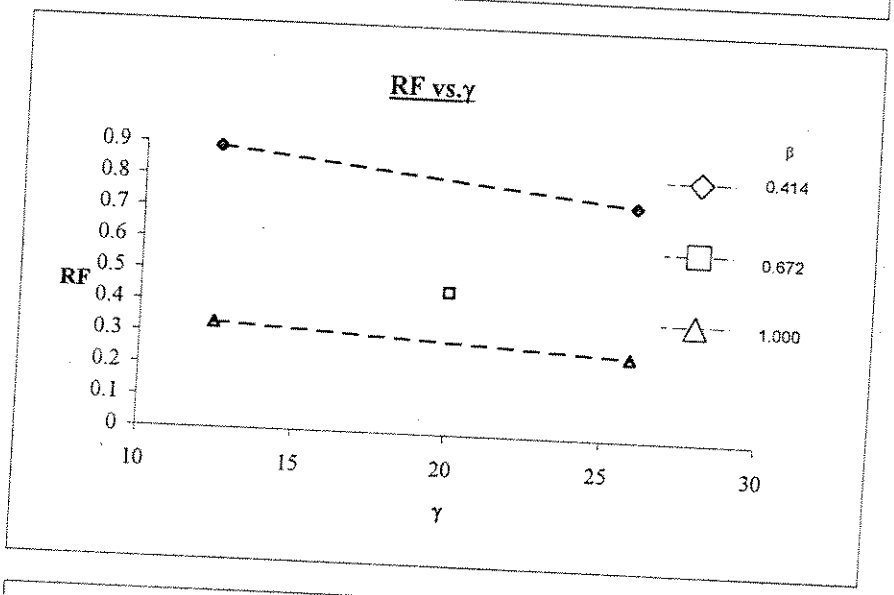




Fig. 23: T Joints Under IPB, Brace Crown



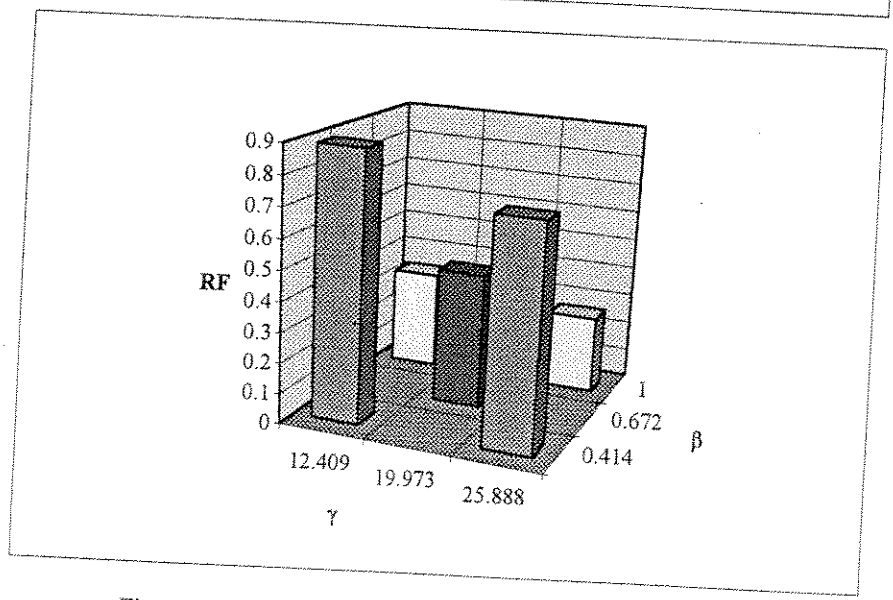
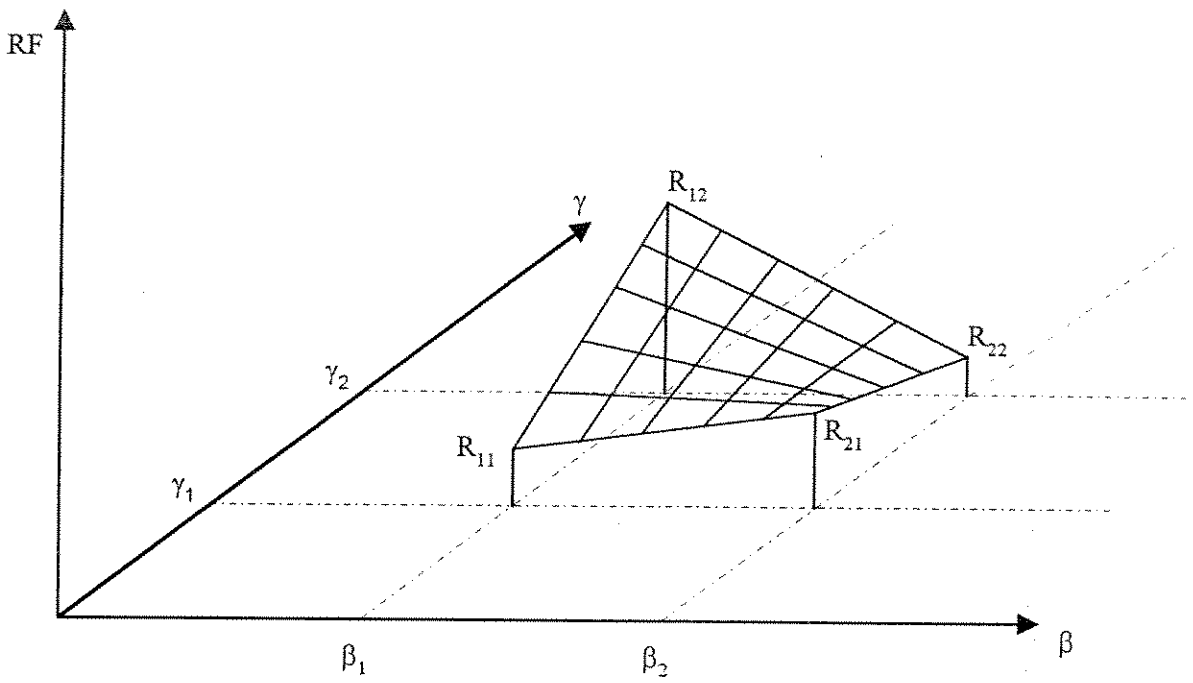




Fig. 24: T Joints Under OPB, Brace Saddle




$$RF = \frac{1}{(\beta_2-\beta_1)(\gamma_2-\gamma_1)} \{(R_{11}\beta_2\gamma_2-R_{12}\beta_2\gamma_1-R_{21}\beta_1\gamma_2+R_{22}\beta_1\gamma_1) + \beta(-R_{11}\gamma_2+R_{12}\gamma_1+R_{21}\gamma_2-R_{22}\gamma_1) + \gamma(-R_{11}\beta_2+R_{12}\beta_2+R_{21}\beta_1-R_{22}\beta_1) + \beta\gamma(R_{11}-R_{12}-R_{21}+R_{22})\}$$

Fig. 25: Geometry of a Twisted Plane

MSL

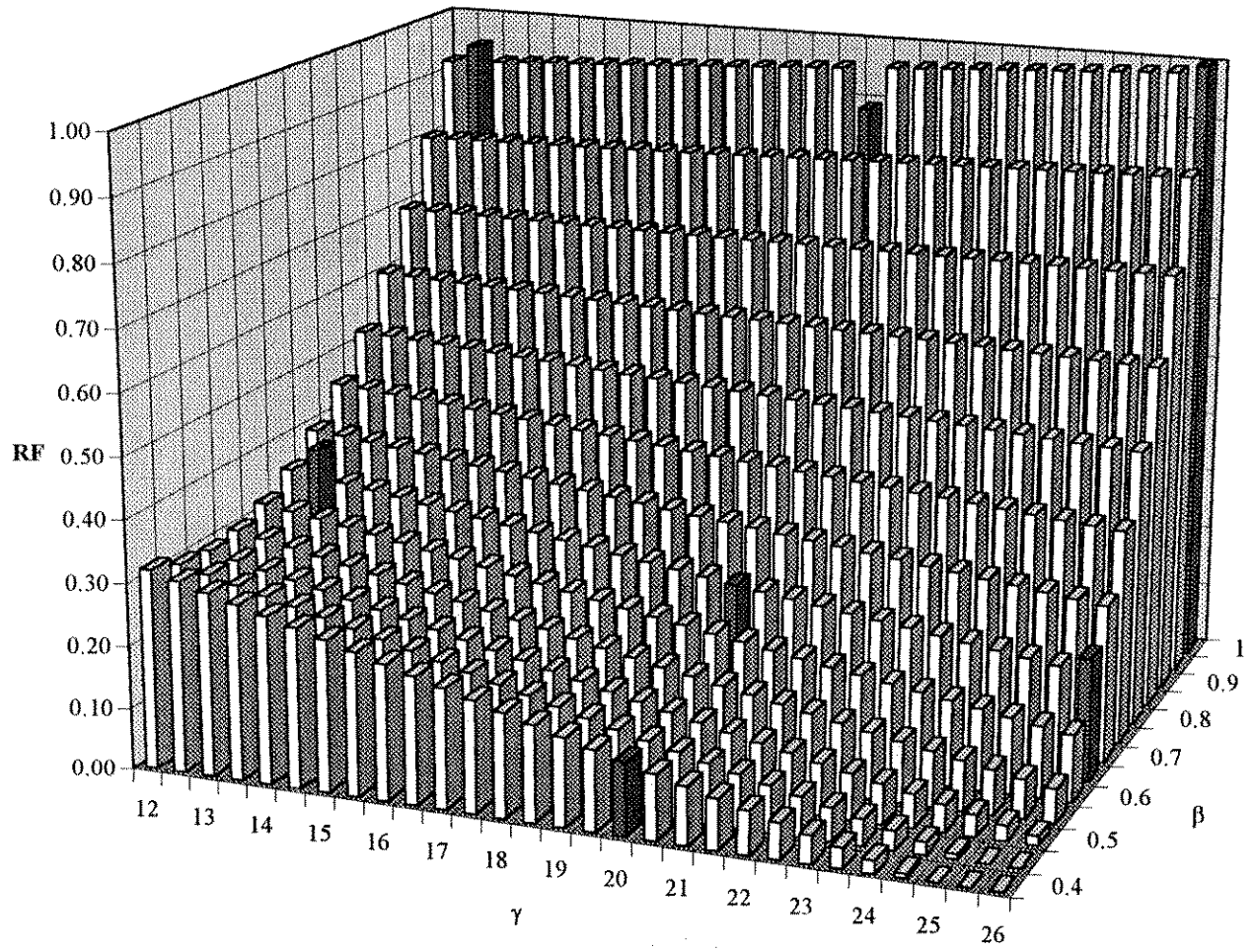



**Fig. 26: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Chord Saddle**

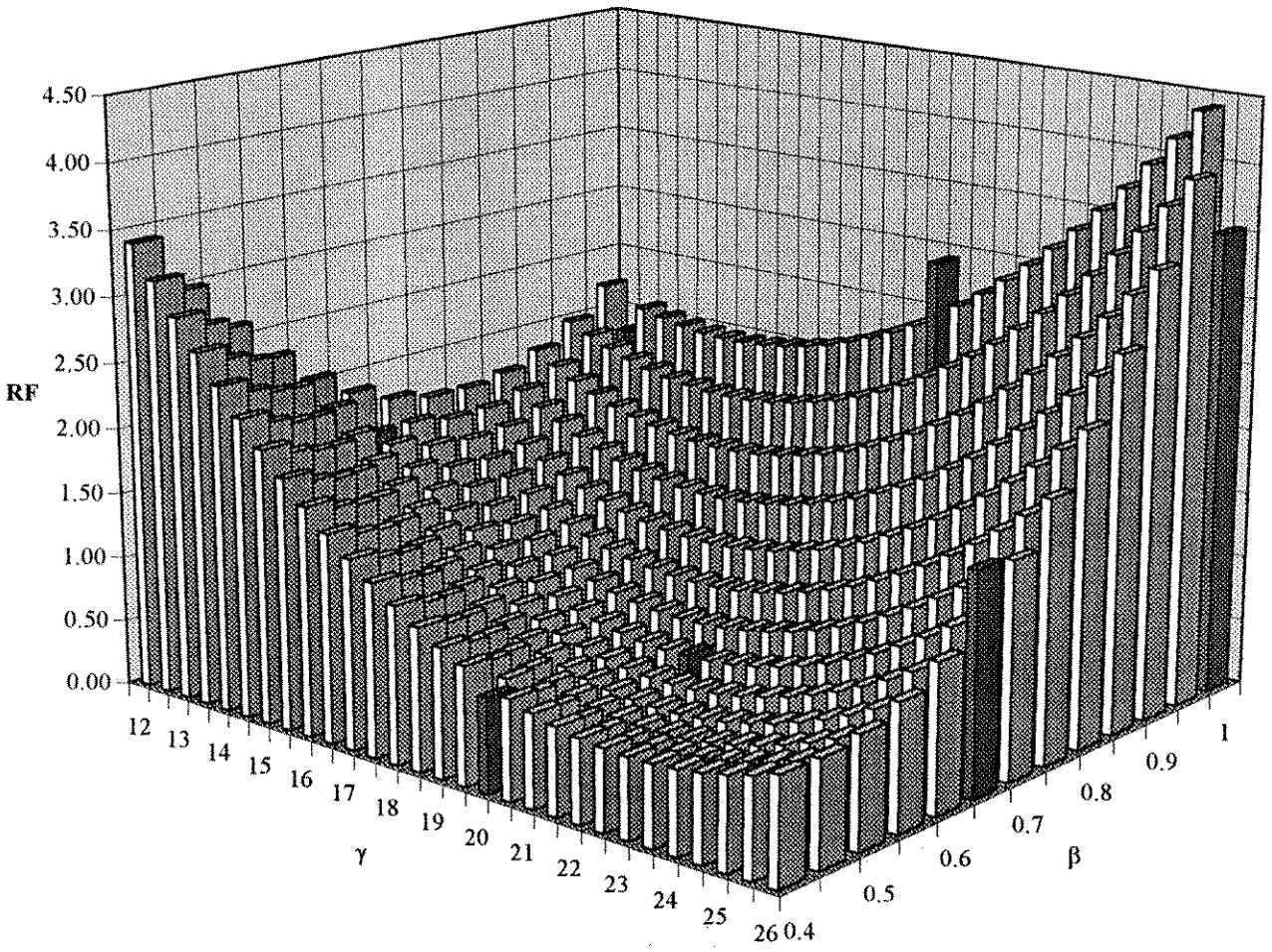



**Fig. 27: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Chord Crown (Interim)**

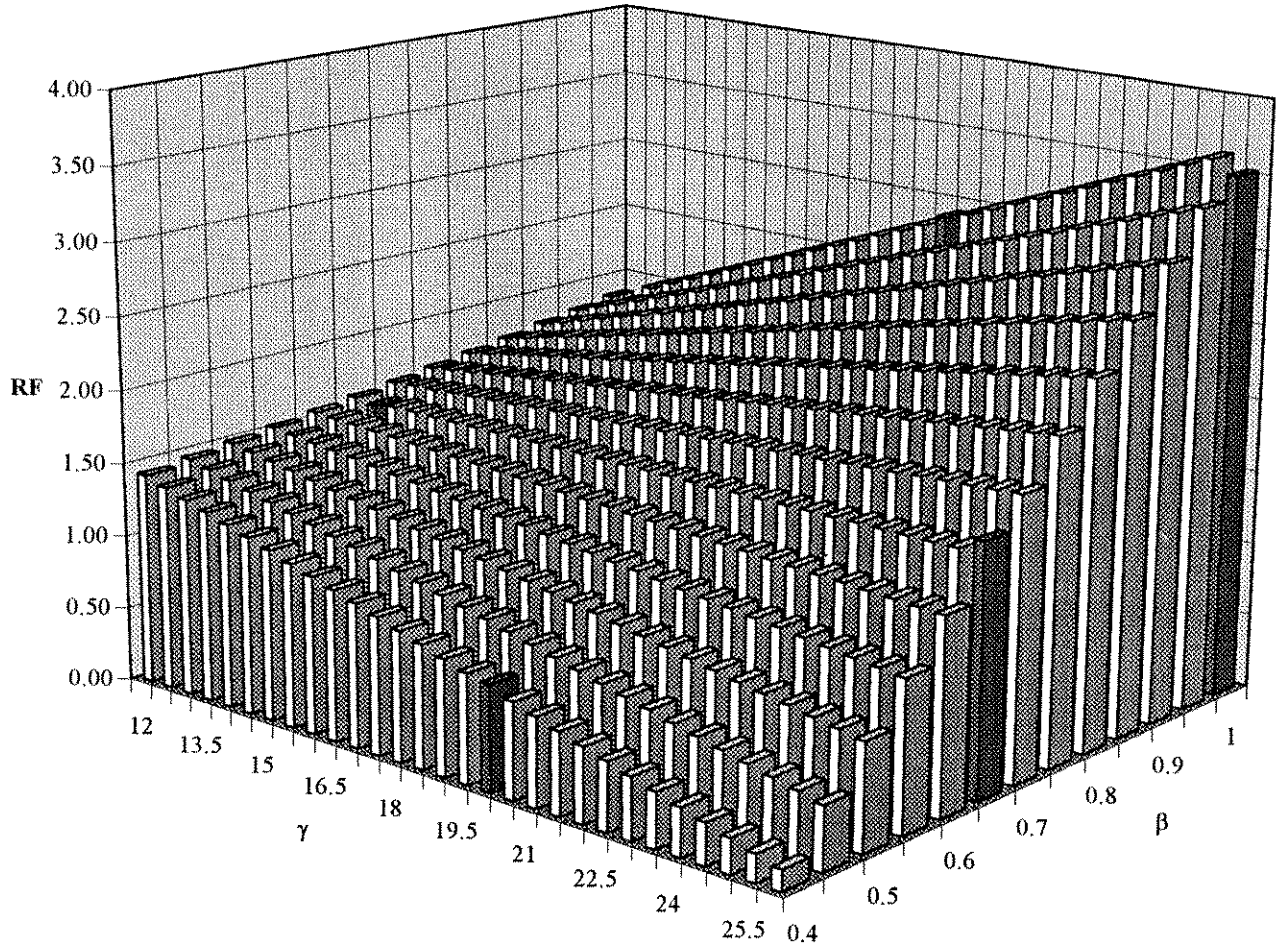



**Fig. 28: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Chord Crown (Final)**

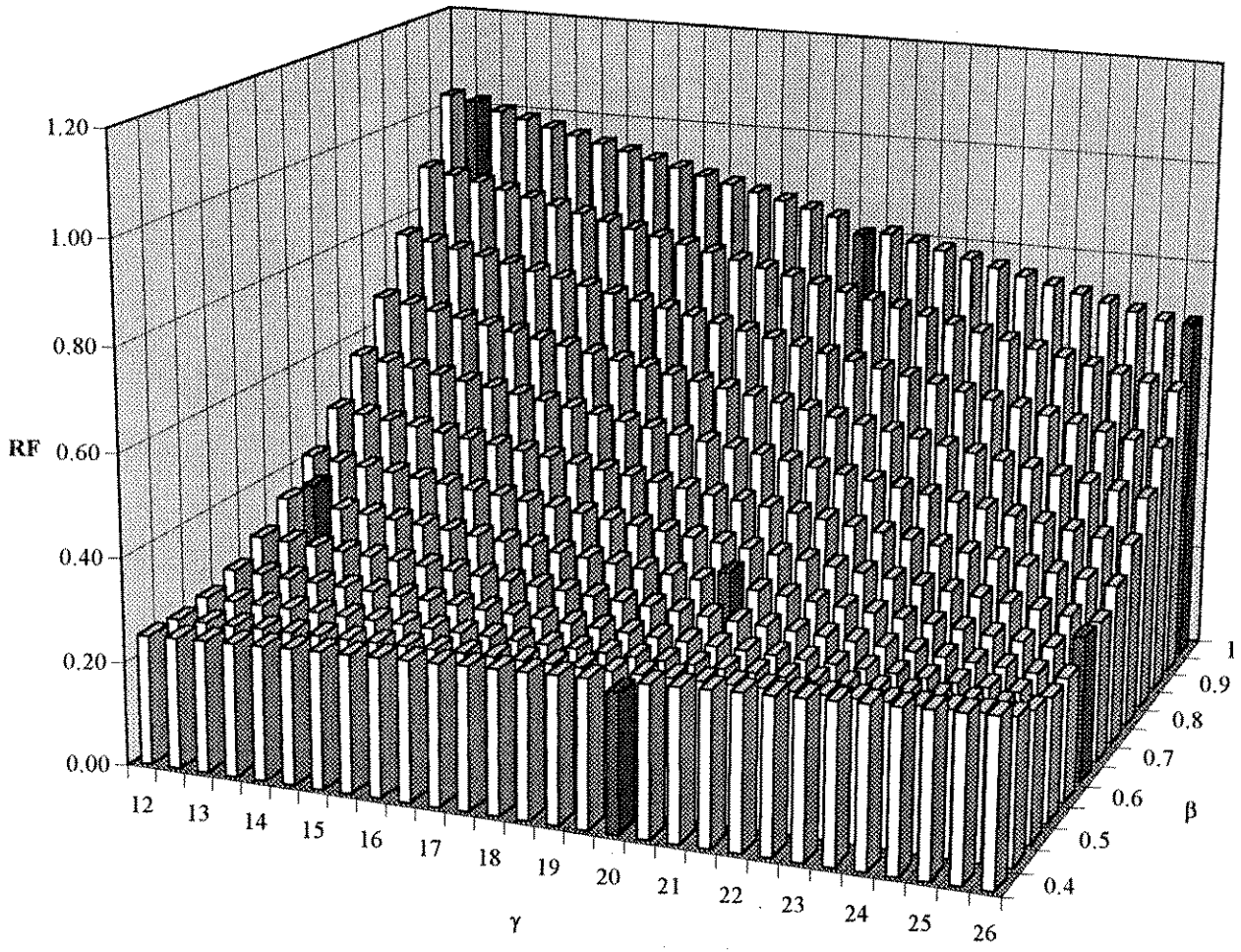



**Fig. 29: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Chord Saddle**

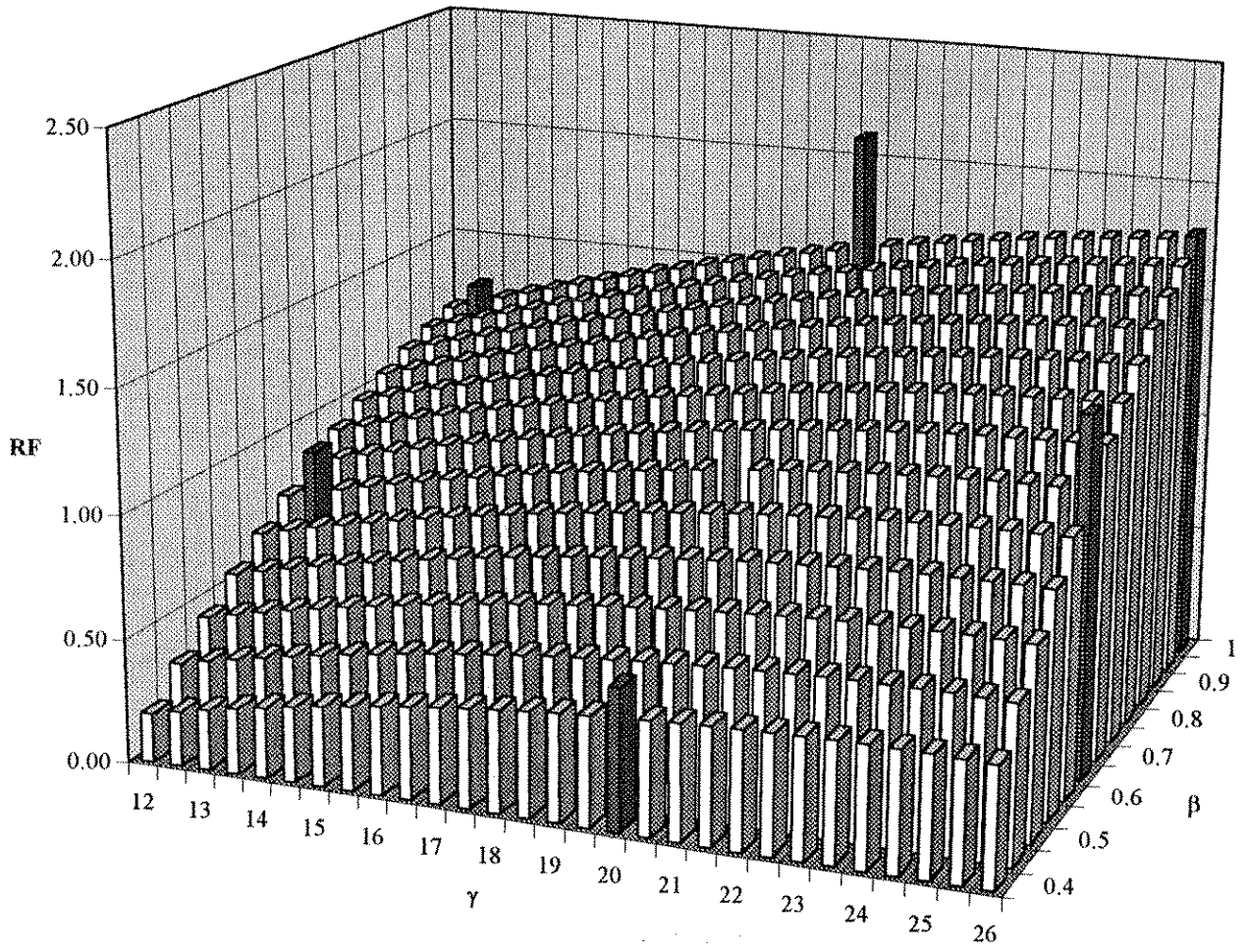



**Fig. 30: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Chord Crown (Interim)**

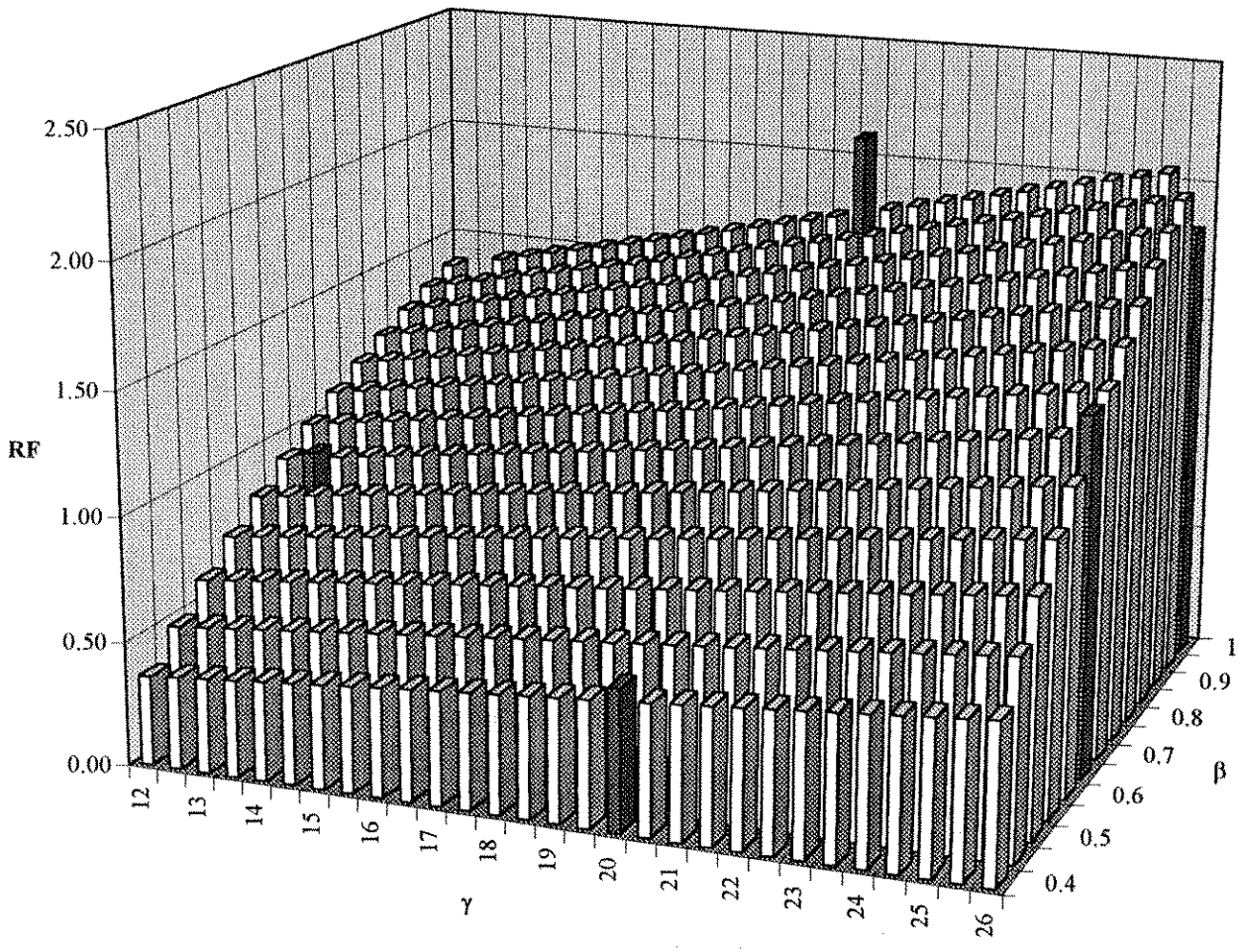



**Fig. 31: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Chord Crown (Final)**

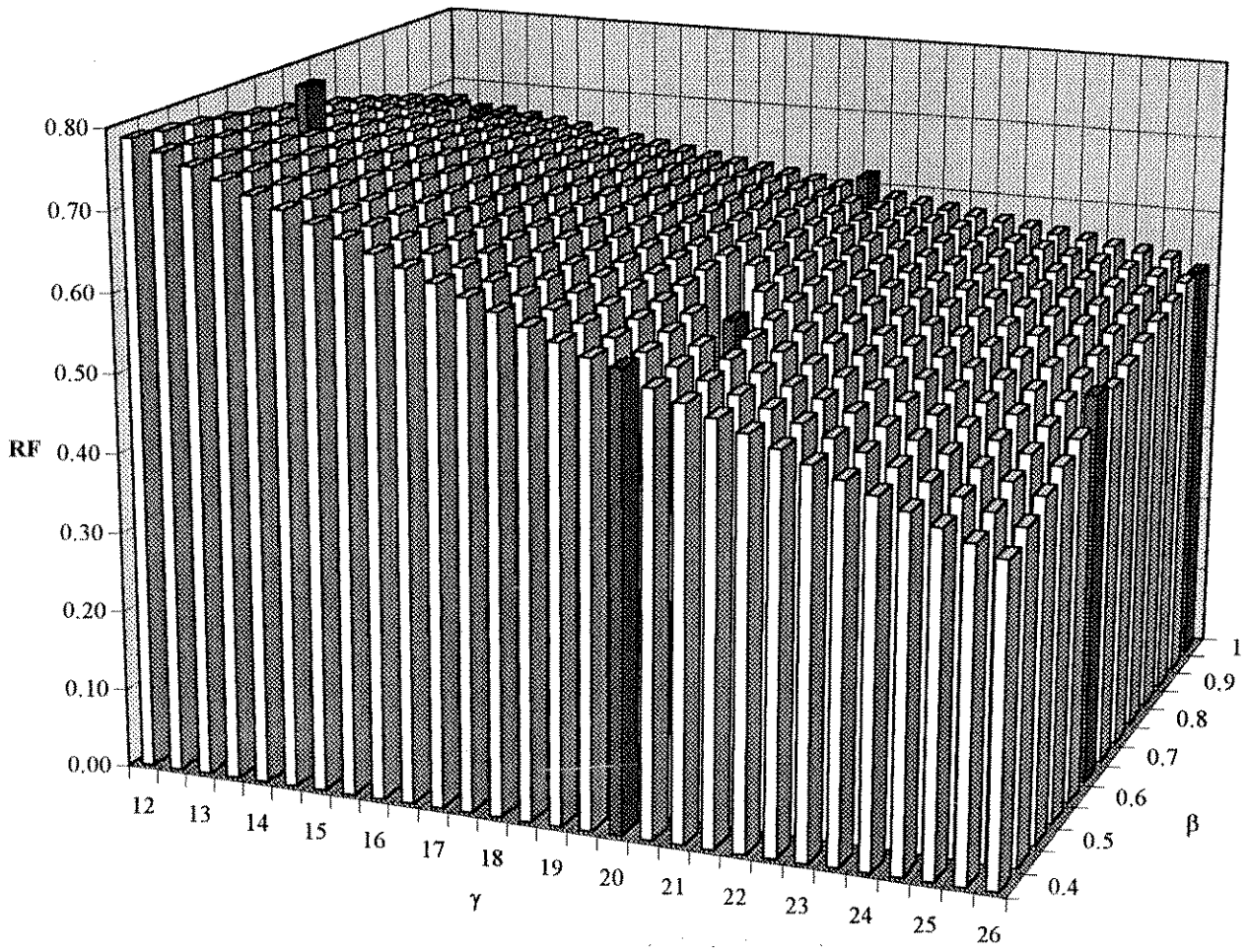



**Fig. 32: Comparison of Fitted Surface with Measured Values for DT Joints under IPB, Chord Crown**



MSL

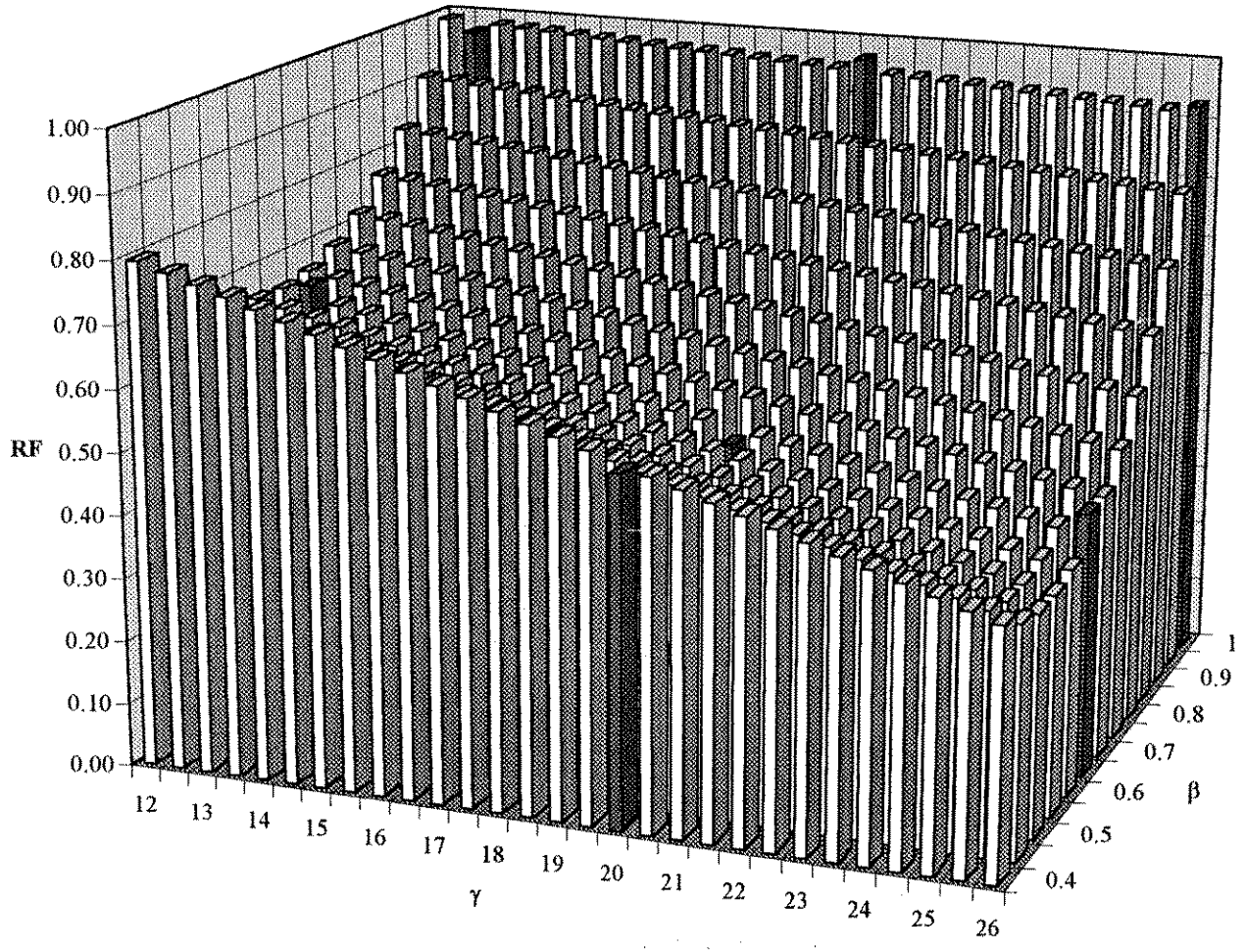



**Fig. 33: Comparison of Fitted Surface with Measured Values for DT Joints under OPB, Chord Saddle**

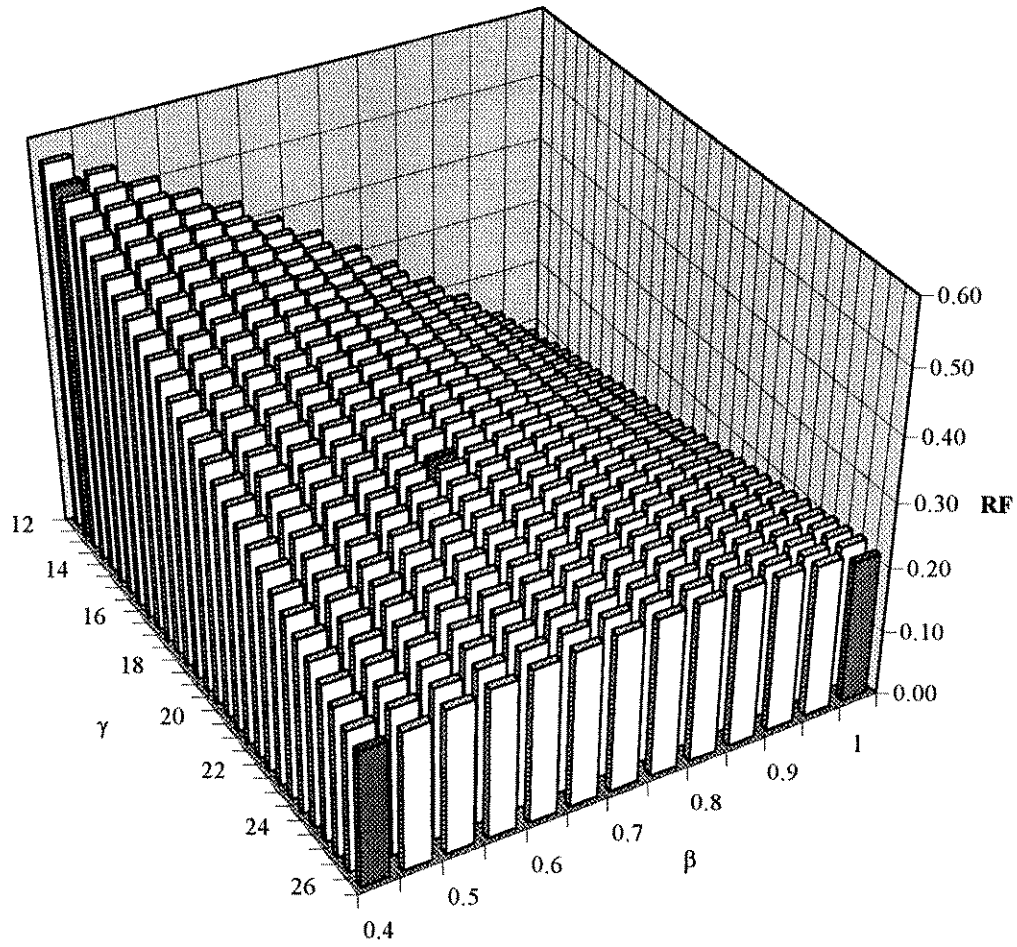



**Fig 34: Comparison of Fitted Surface with Measured Values for T Joints under Compression, Chord Saddle**

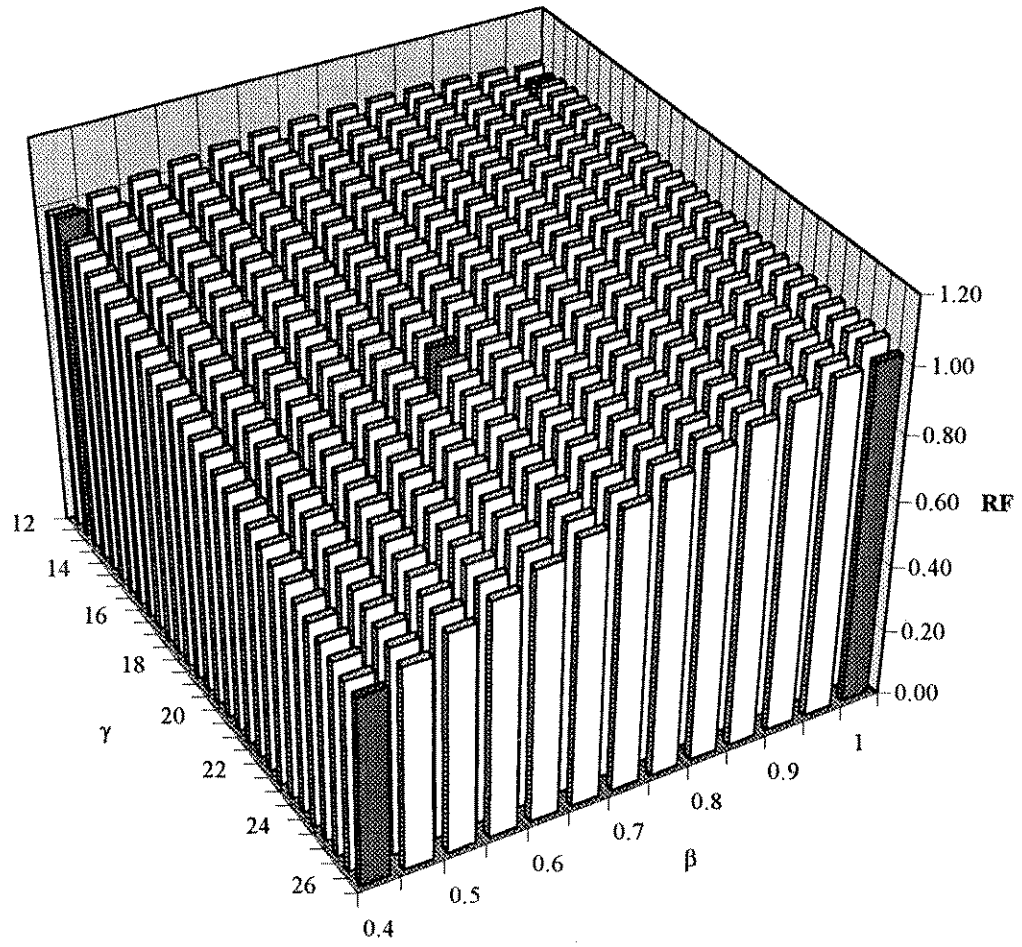



**Fig. 35: Comparison of Fitted Surface with Measured Values for T Joints Compression, Chord Crown**

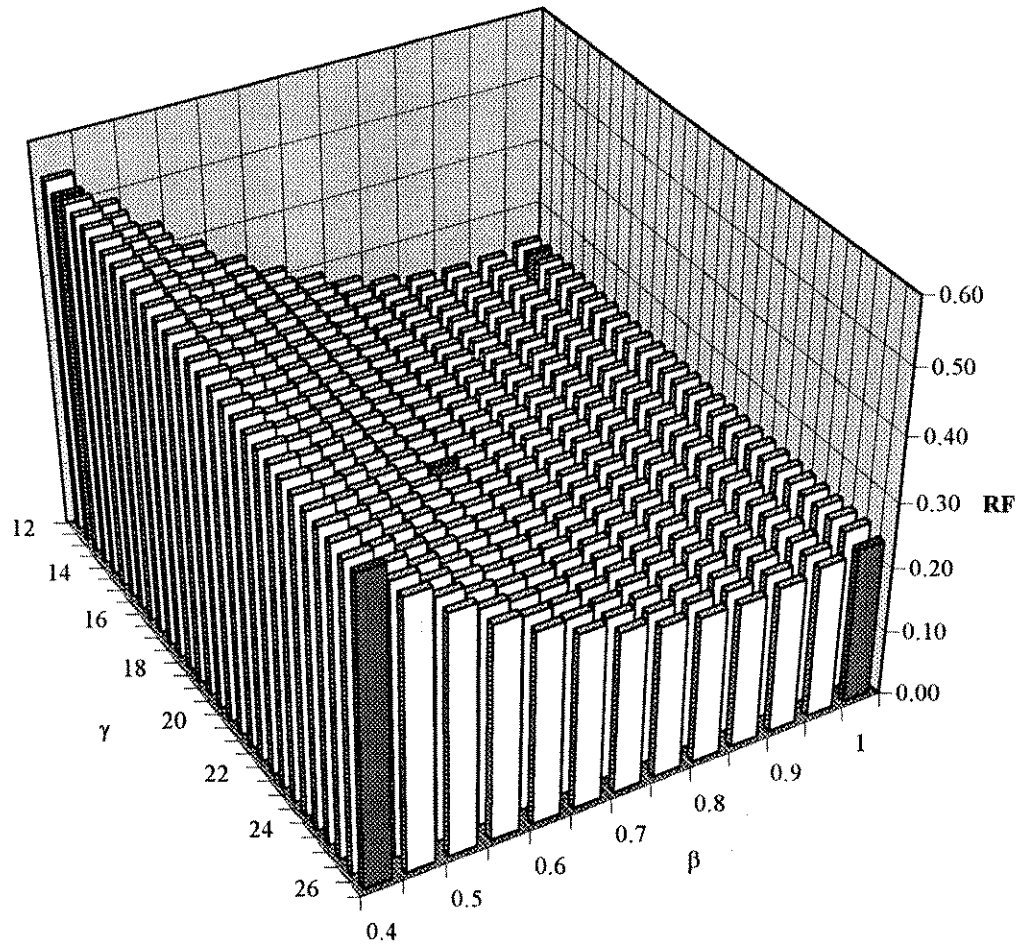



**Fig 36: Comparison of Fitted Surface with Measured Values for T joints under Tension, Chord Saddle**

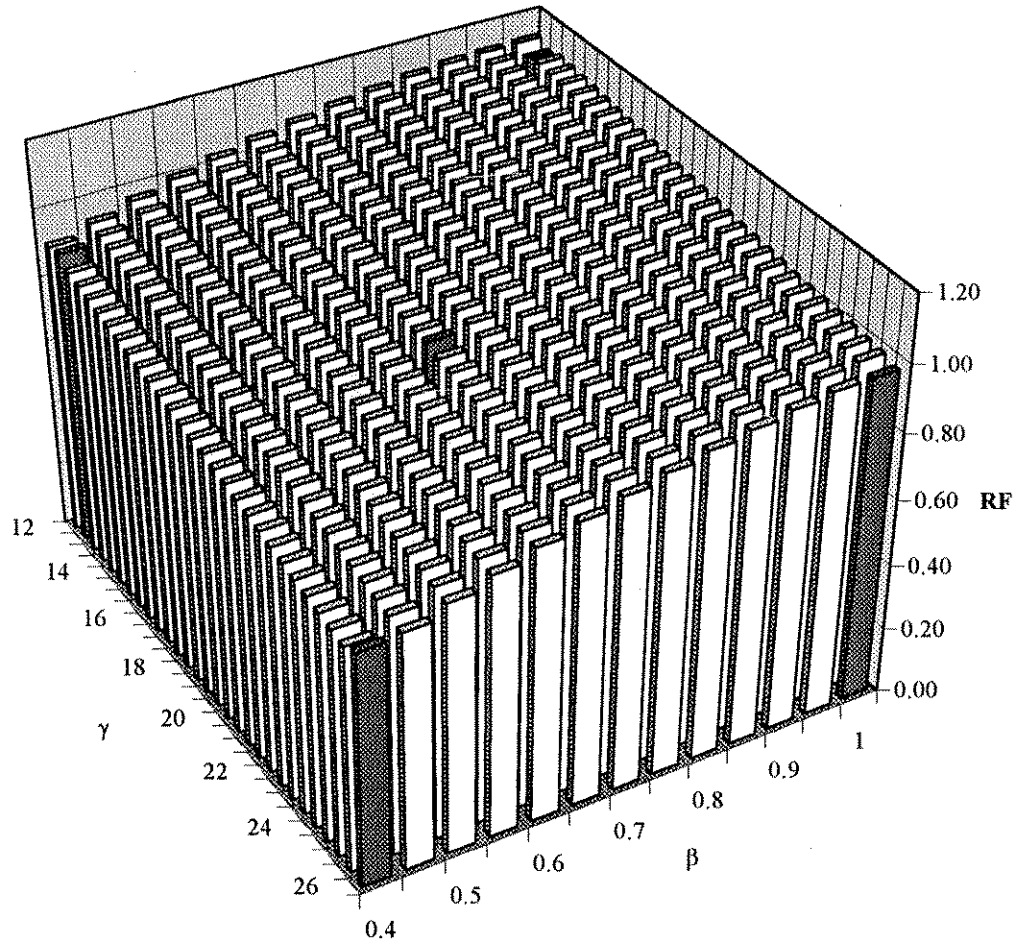



**Fig. 37: Comparison of Fitted Surface with Measured Values for T Joints under Tension, Chord Crown**

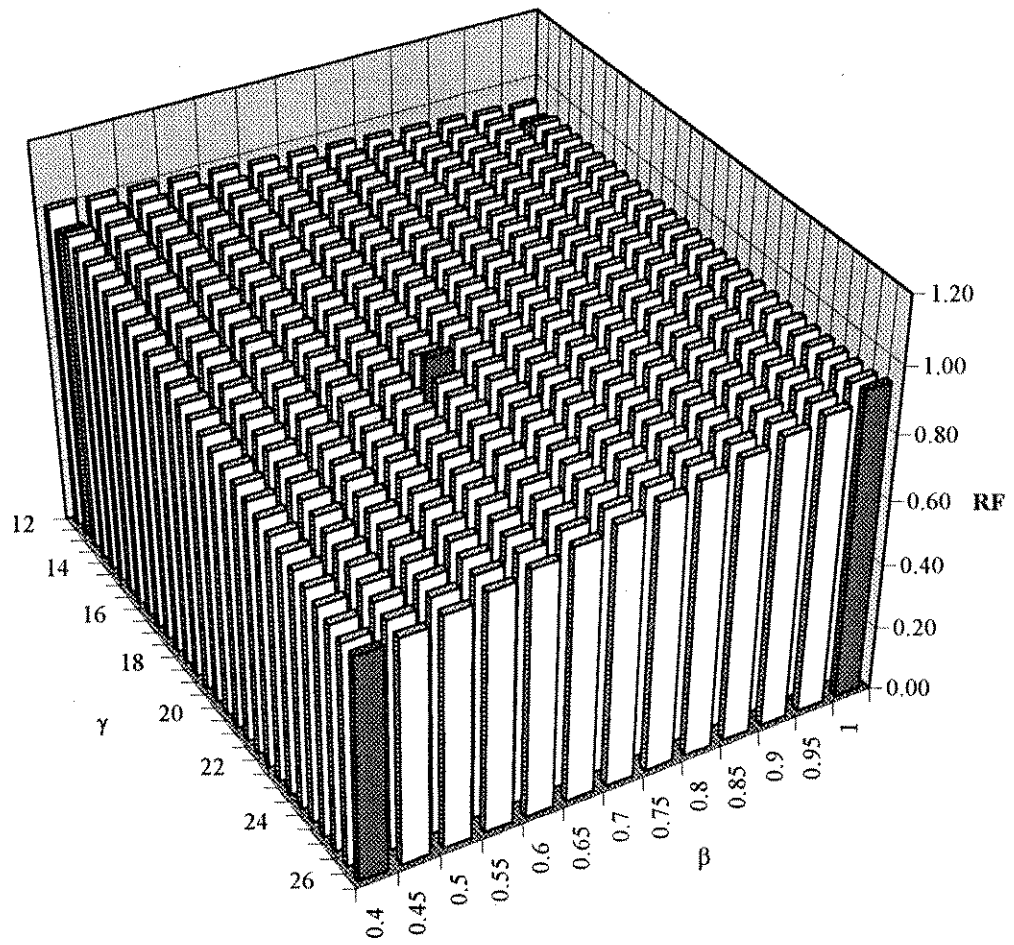



**Fig. 38: Comparison of fitted Surface with Measured Values for T Joints under IPB, Chord Crown**

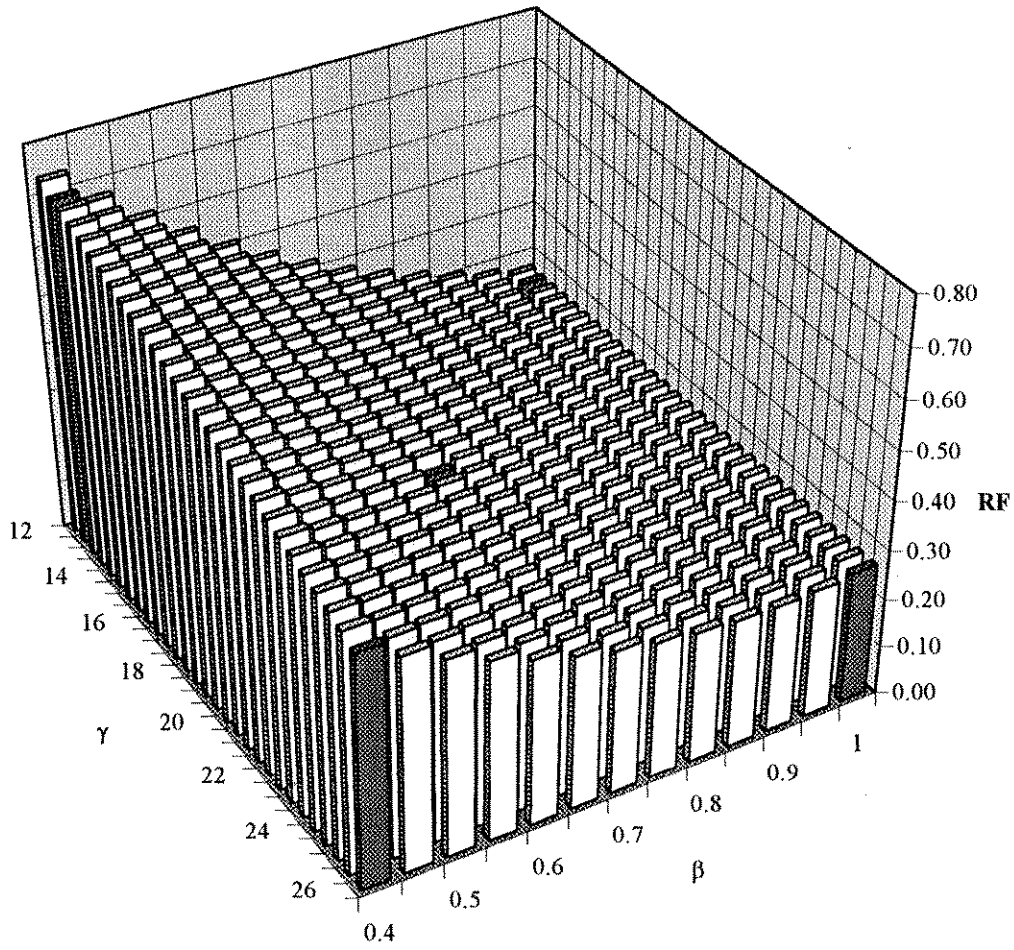



**Fig. 39: Comparison of Fitted Surface with Measured Values for T Joints under OPB, Chord Saddle**

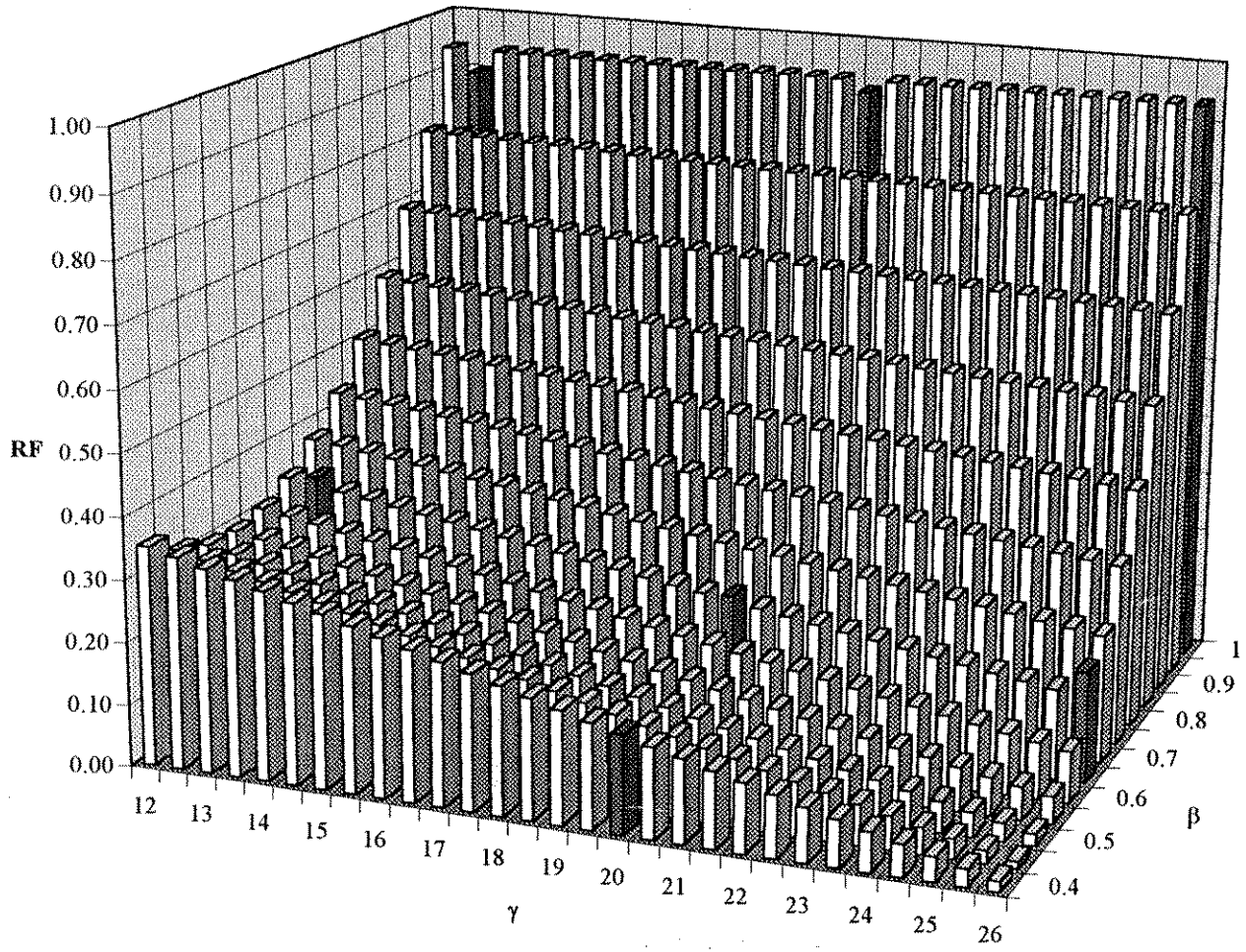



**Fig. 40: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Brace Saddle**

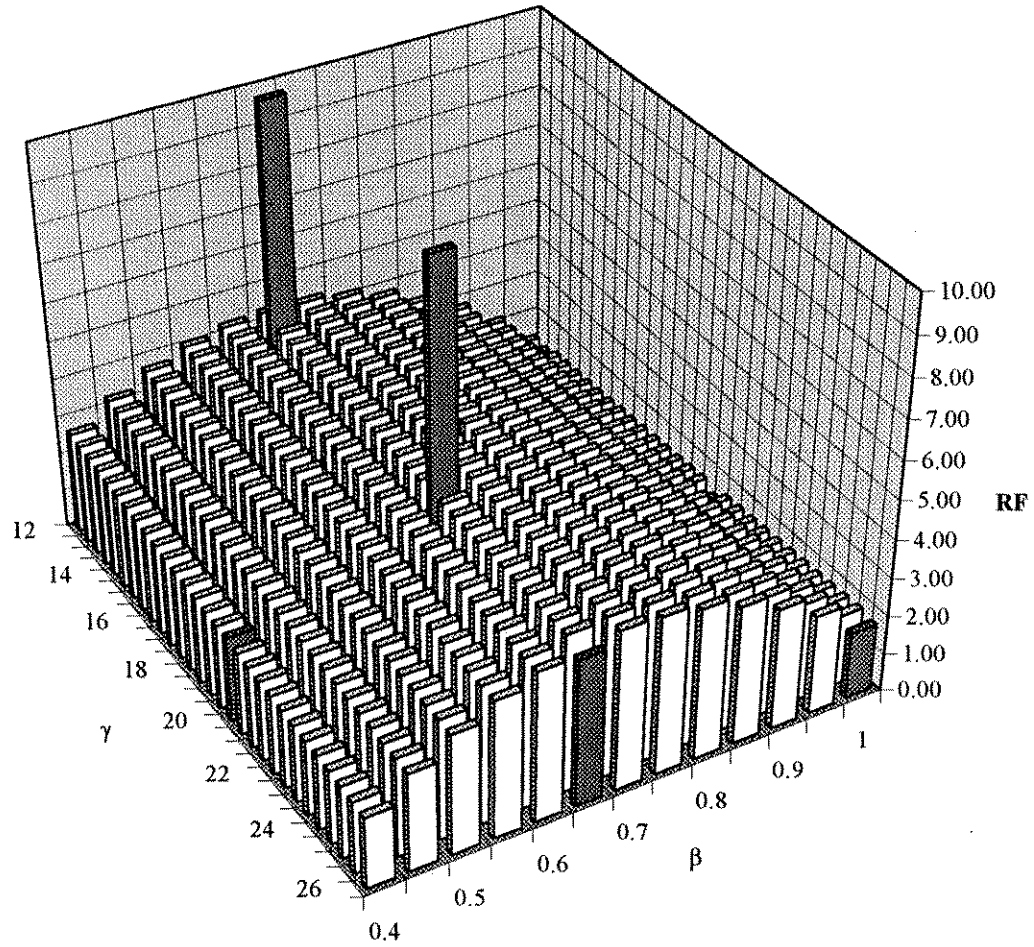



**Fig. 41: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Brace Crown**

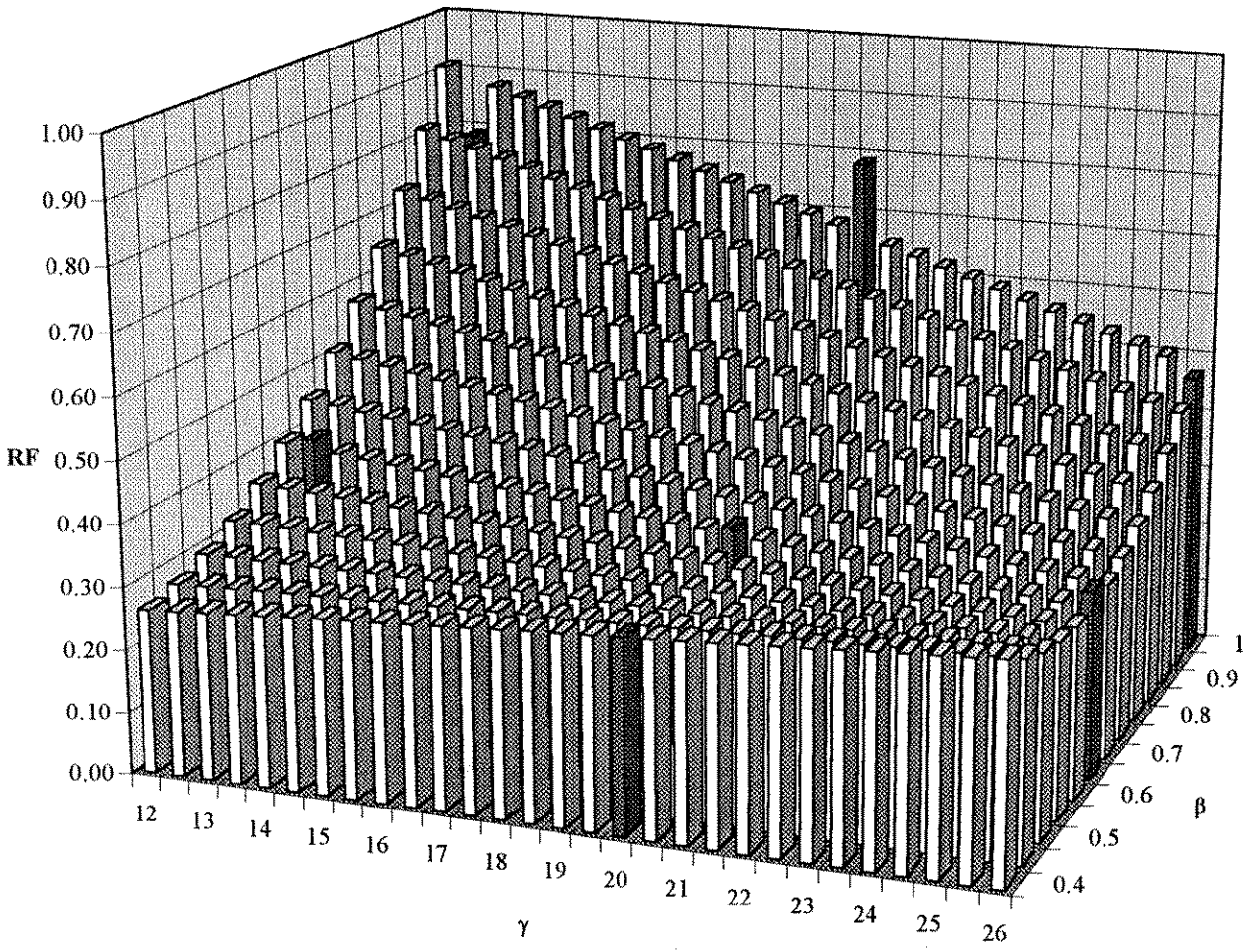



**Fig. 42: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Brace Saddle**

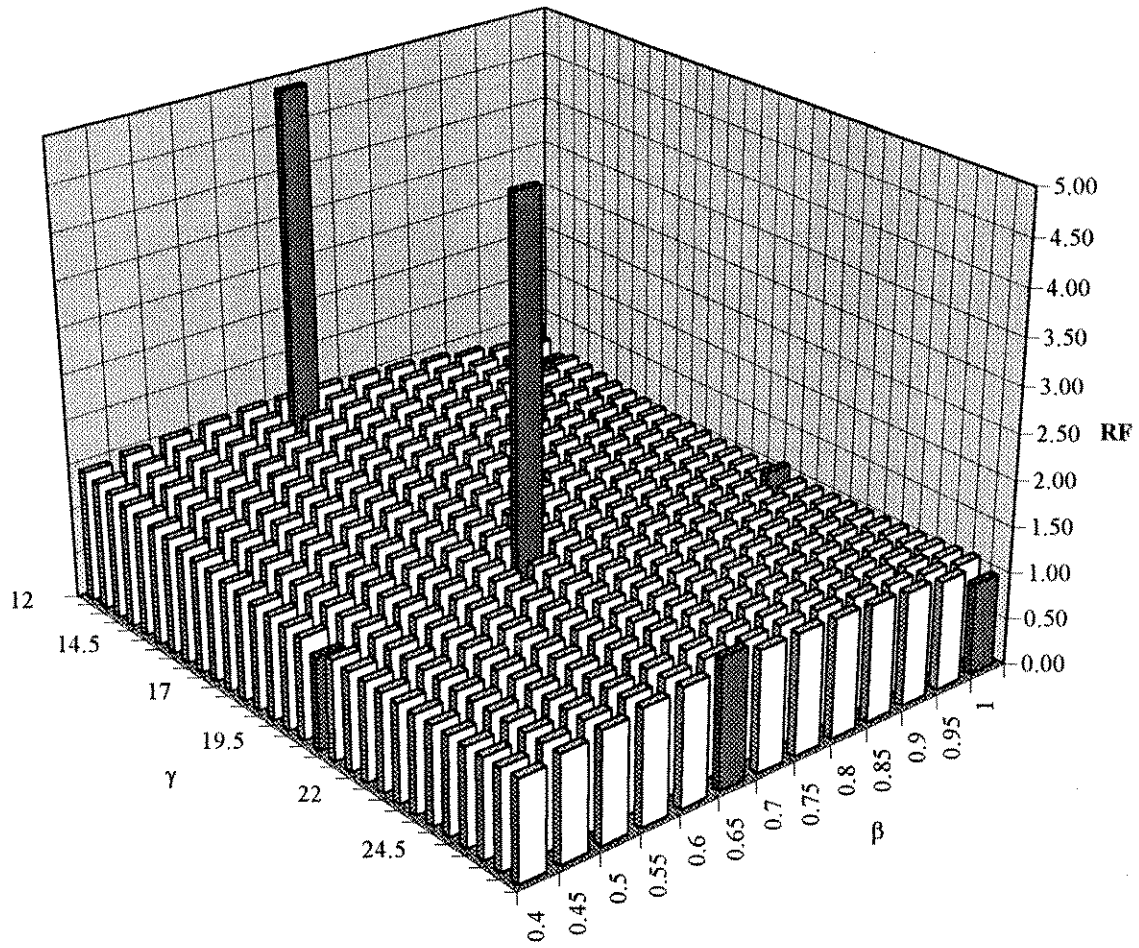



**Fig. 43: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Brace Crown**

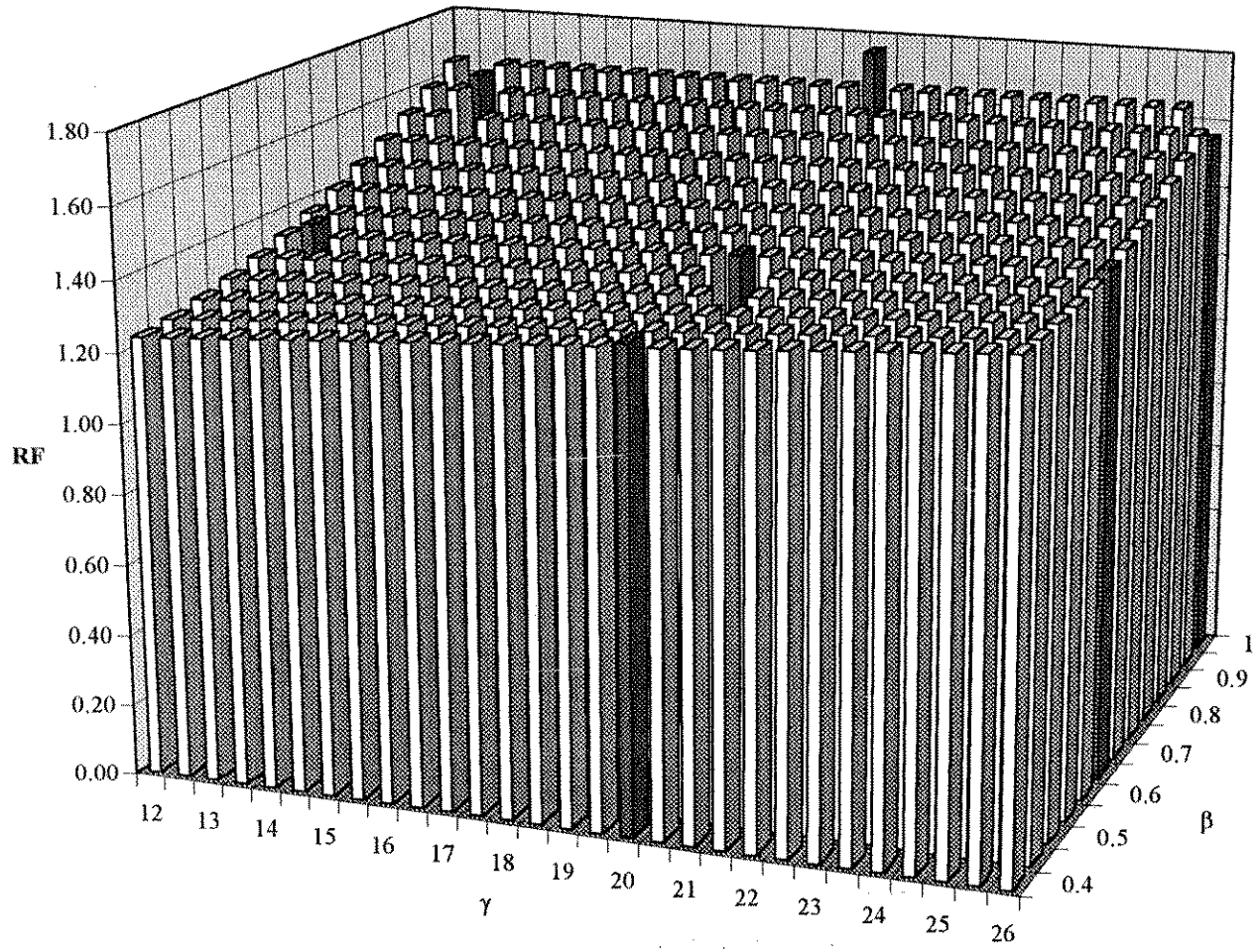



**Fig. 44: Comparison of Fitted Surface with Measured Values for DT Joints under IPB, Brace Crown**

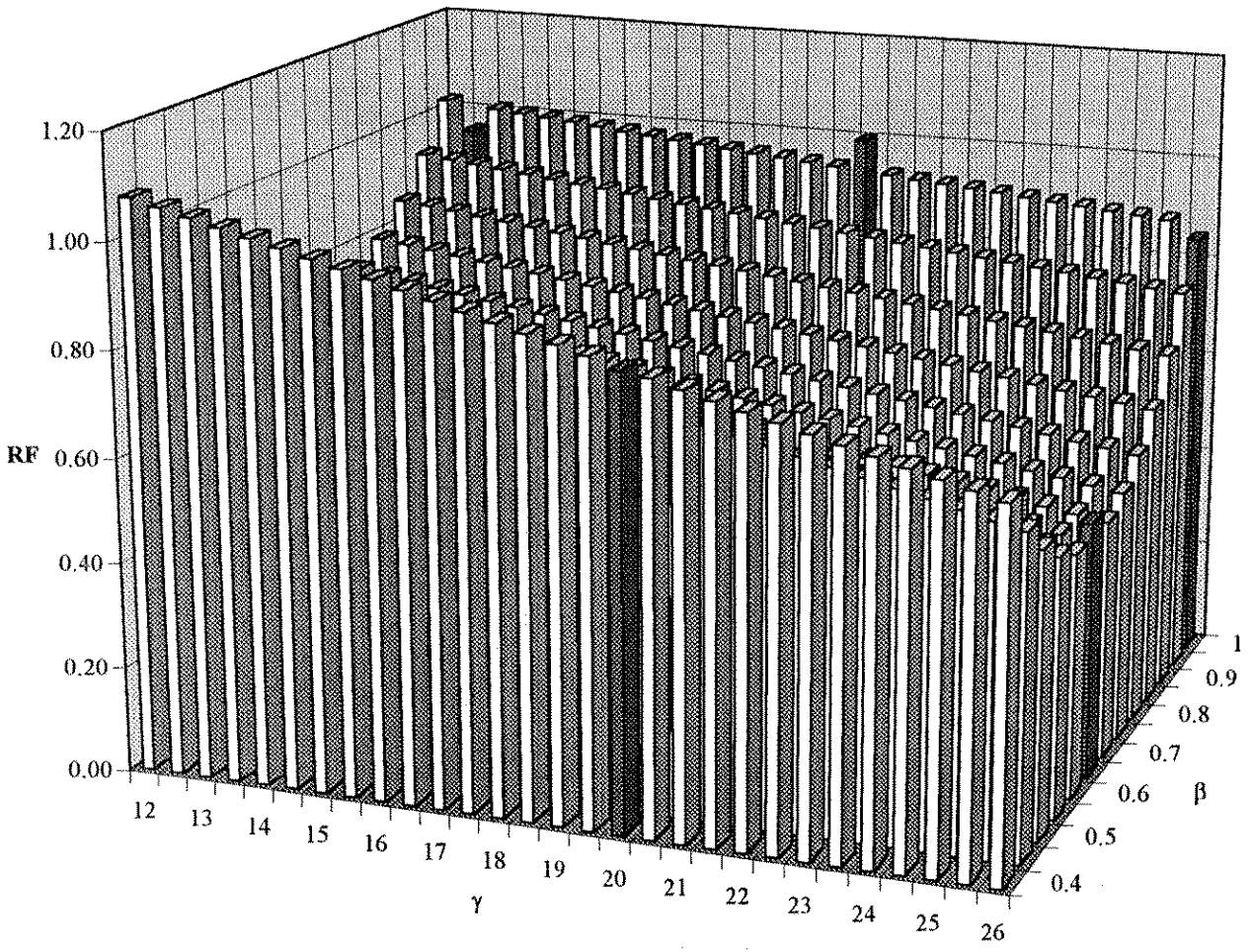



**Fig. 45: Comparison of Fitted Surface with Measured Values for DT Joints under OPB, Brace Saddle**

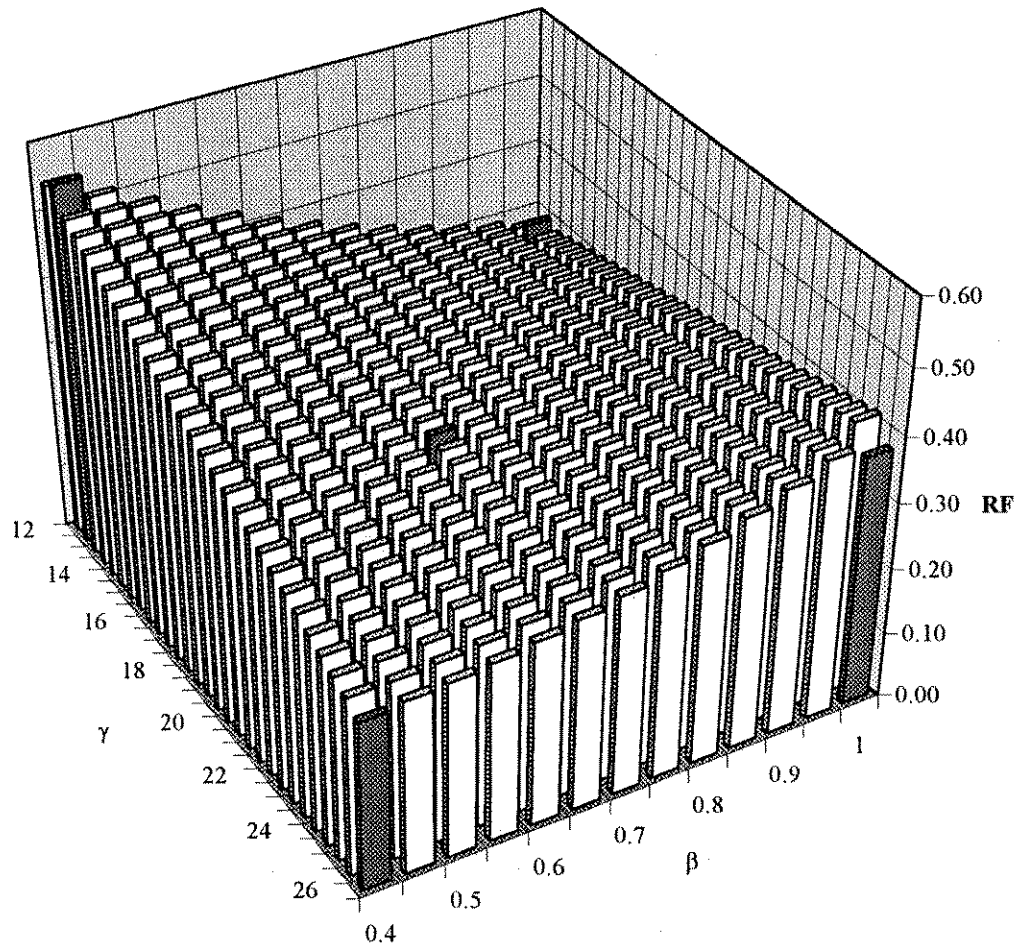



**Fig 46: Comparison of Fitted Surface with Measured Values for T Joints under Compression, Brace Saddle**

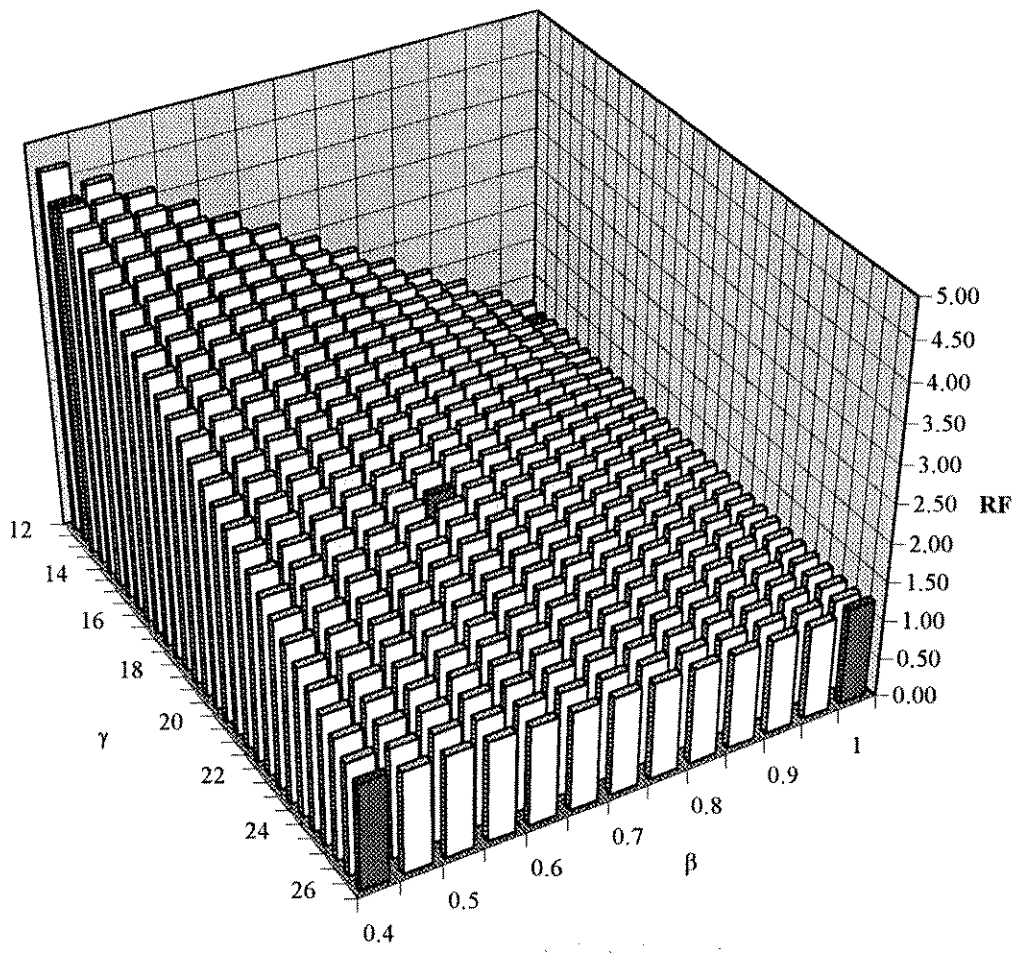



**Fig. 47: Comparison of Fitted Surface with Measured Values for T Joints Compression, Brace Crown**

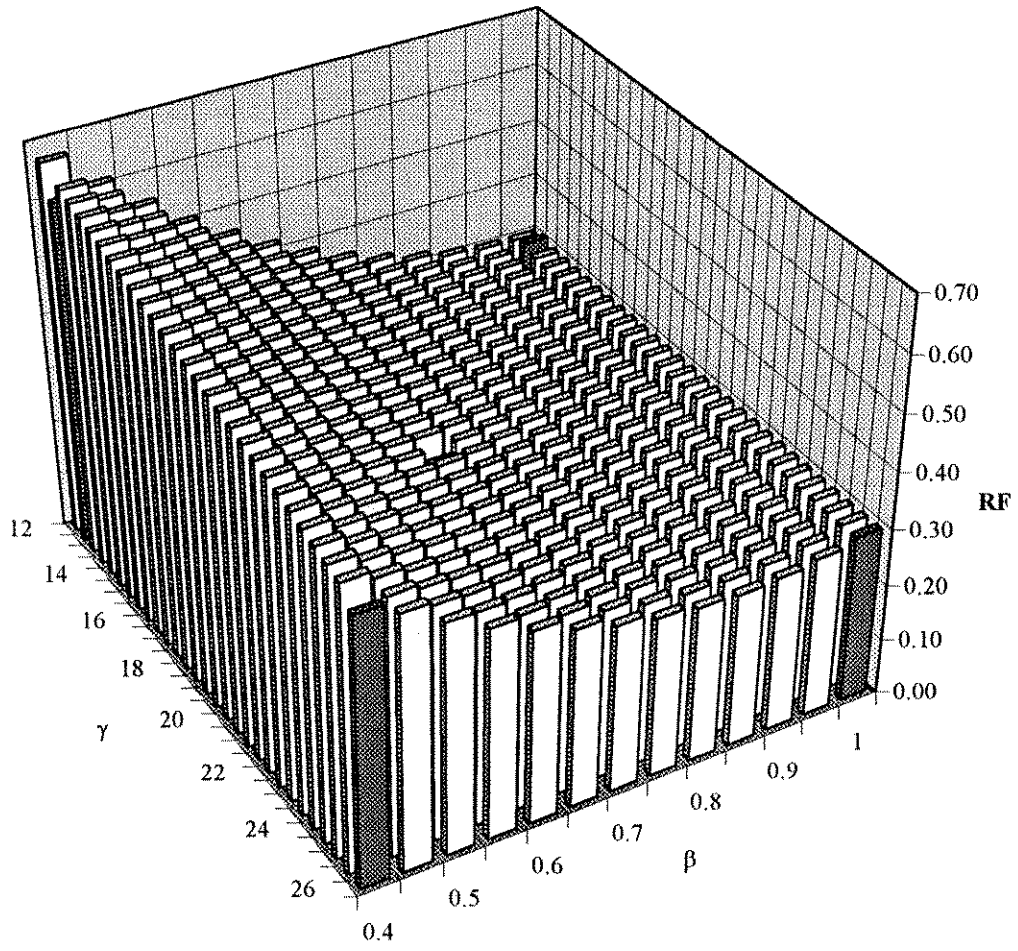



**Fig 48: Comparison of Fitted Surface with Measured Values for T joints under Tension, Brace Saddle**

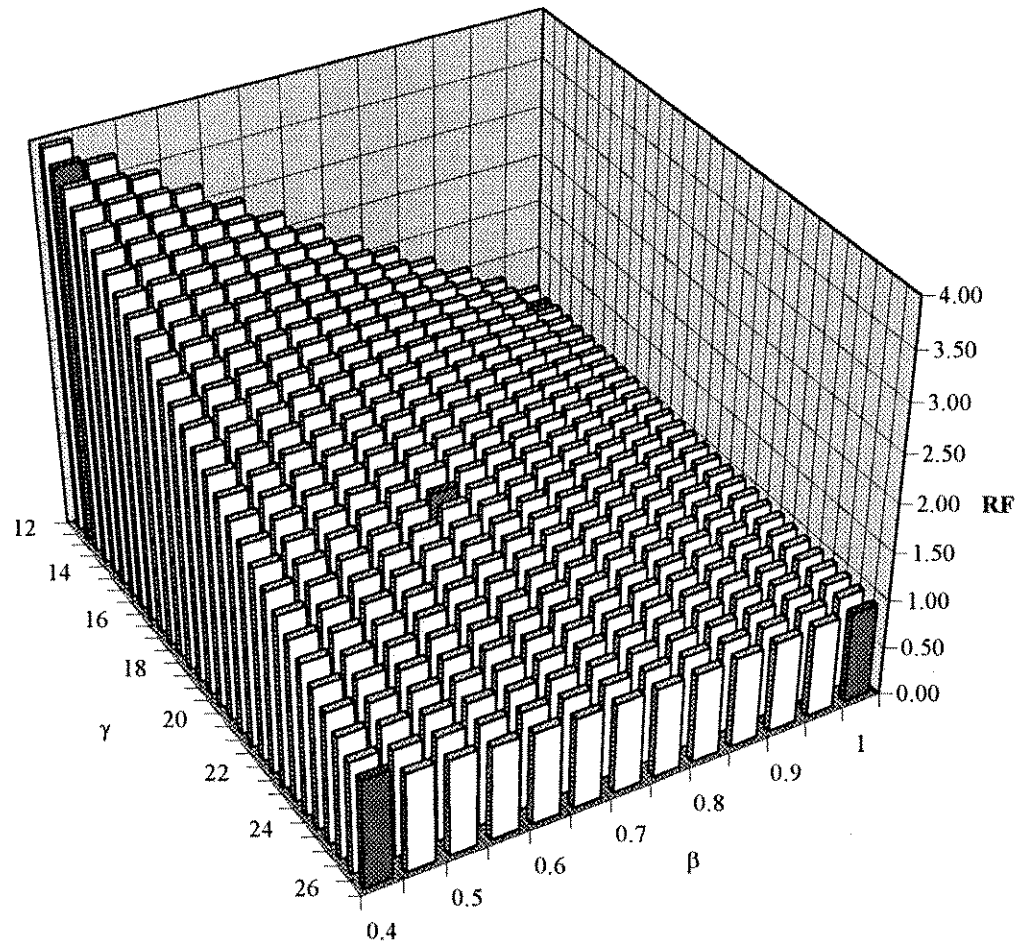



**Fig. 49: Comparison of Fitted Surface with Measured Values for T Joints under Tension, Brace Crown**

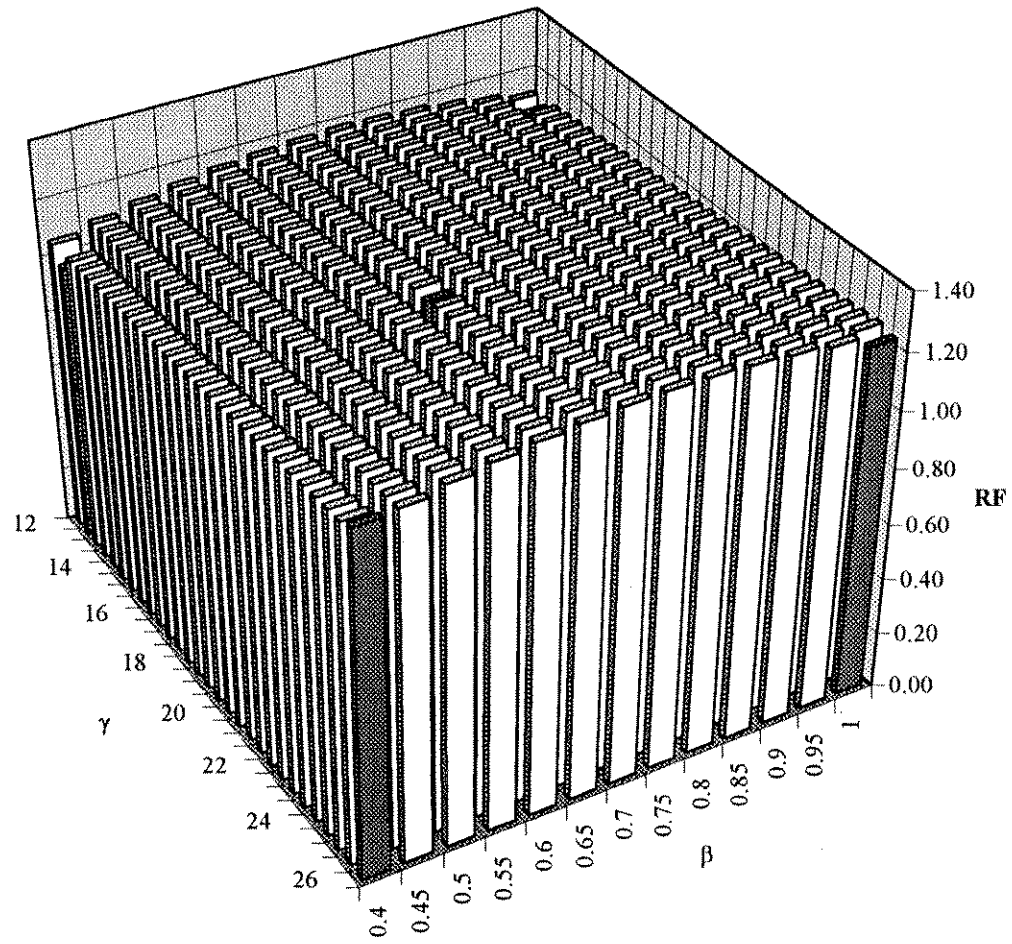



**Fig. 50: Comparison of fitted Surface with Measured Values for T Joints under IPB, Brace Crown**



MSL

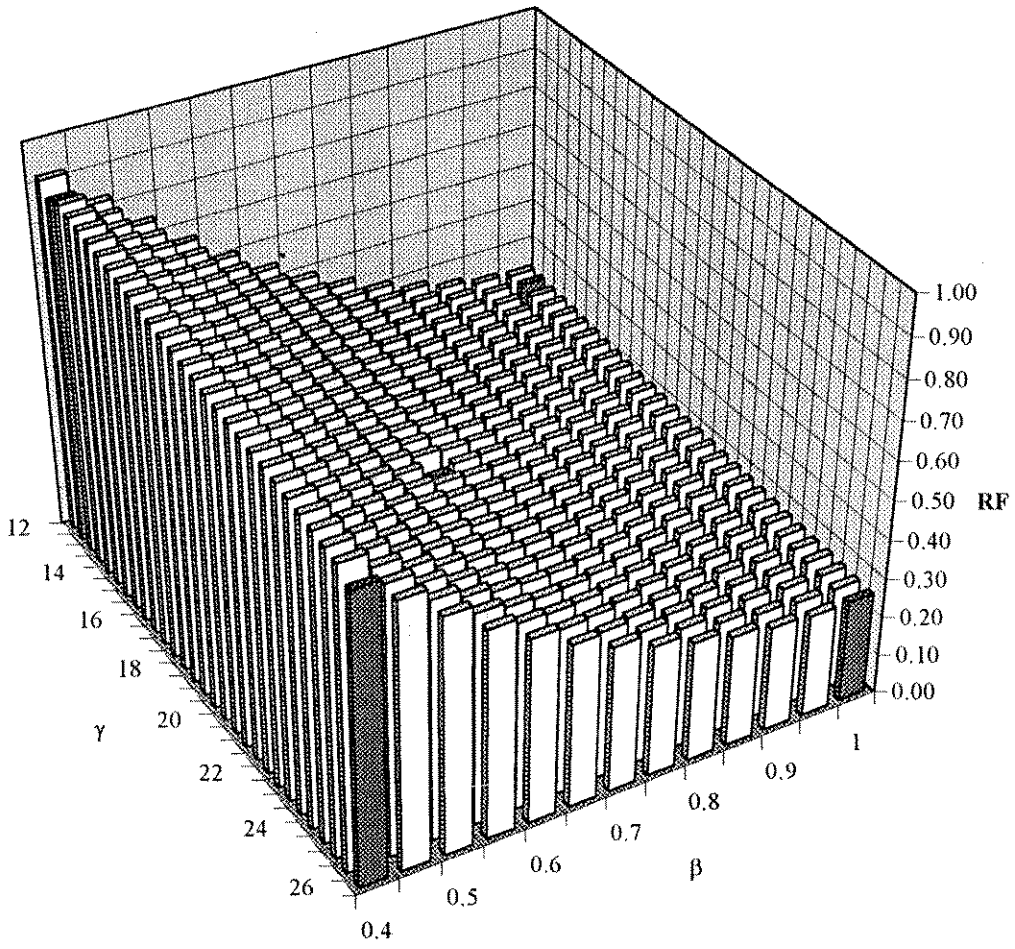



**Fig. 51: Comparison of Fitted Surface with Measured Values for T Joints under OPB, Brace Saddle**

**Development of Measured Grouted SNCF (x 1.2)/Efthymiou As-welded SCF Reduction Factors**

## DEVELOPMENT OF REDUCTION FACTORS

### 1 INTRODUCTION

This part of the appendix presents the development of formulations, using Efthymiou derived as-welded SCFs and measured grouted SCFs, to predict the SCF Reduction Factor (RF) for each joint and load type for both the chord and brace side of the weld. The definition of RF from which the formulations are derived is:

$$RF = \frac{\text{Measured value of SCF for grouted joint}}{\text{Efthymiou derived SCF for as-welded joint}}$$

### 2 DATA

The baseline data are the measured SCF values of the grouted joints and the as-welded SCF values derived using Efthymiou parametric equations. These data are discussed in Sections 7 and 8 of the main text and are presented in Appendix C. It is noted here that the grouted SCFs used in this appendix relate to the values obtained following the 50% preload cycle.

The resulting RFs, found by applying the above definition, are summarised in Table 1. The table shows the RF for each joint and load type, and differentiates between the saddle and crown position for axially loaded joints. For the sake of completeness, the RFs for the brace side of the weld are also given. In addition to the measured RF values, the values predicted by the formulations given below are also shown in the table. As can be observed, good agreement between the observed and predicted values is indicated across the board.

The data in Table 1 are presented in a series of figures (Figures 1 to 24), each figure relating to a single joint type (DT or T), load type (compression, tension, IPB or OPB) and, the SCF location (saddle or crown). Figures 1 to 12 relate to data on the chord side of the weld and Figures 13 to 24 to the brace side. Each figure contains three diagrams:

- plot of RF vs. $\beta$
- plot of RF vs. $\gamma$
- a 3-D representation of RF vs $\beta$ and $\gamma$.

The first two plots may have up to three lines, each line corresponding to a constant $\gamma$ or $\beta$ parameter. To visualise better these two diagrams, 3-D bar charts are given. Note, however, the bar chart axes are not true to scale (the 'skyscrapers' fall on a 3 x 3 regular matrix associated with the discrete values of $\beta$ and $\gamma$).

The philosophy adopted for those RF functions derived using measured as-welded SCFs and measured grouted SCFs also apply to the functions derived here. . The resultant RF functions, albeit including additional terms, perform well.

## 3. Concluding Remarks

Tables 4 to 7 present a comparison of predicted and measured as-welded and grouted SCFs for the two joint types at all locations. Of note are the predicted grouted SCFs derived using predicted RFs, from joint parameters, with measured as-welded SCFs and Efthymiou predicted as-welded SCFs. The results demonstrate that for a number of joint configurations, the crown SCF becomes critical, in the grouted condition, and even supercedes the highest as-welded SCF.

| Specimen Ident. | D (mm) | d (mm) | T (mm) | t (mm) | L (mm) | θ (°) | β | γ | τ | α | Condition | Chord RFs | | | | | | Brace RFs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | IPB | OPB | Comp. | | Tens. | | IPB | OPB | Comp. | | Tens. | |
| | | | | | | | | | | | | | | Ax-s | Ax-c | Ax-s | Ax-c | | | Ax-s | Ax-c | Ax-s | Ax-c |
| T1 | 406.78 | 167.81 | 16.39 | 16.32 | 2440 | 90.0 | 0.413 | 12.409 | 0.996 | 12.00 | Measured | 0.78 | 0.63 | 0.47 | 1.15 | 0.42 | 0.97 | 0.56 | 0.56 | 0.43 | 0.43 | 0.44 | 0.36 |
| | | | | | | | | | | | Predicted | 0.78 | 0.63 | 0.47 | 1.16 | 0.43 | 0.95 | 0.56 | 0.57 | 0.44 | 0.42 | 0.44 | 0.38 |
| T3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.000 | 12.409 | 0.982 | 12.00 | Measured | 0.97 | 0.28 | 0.07 | 1.29 | 0.16 | 1.37 | 0.62 | 0.45 | 0.45 | 0.82 | 0.46 | 0.76 |
| | | | | | | | | | | | Predicted | 1.00 | 0.28 | 0.07 | 1.30 | 0.17 | 1.36 | 0.62 | 0.45 | 0.44 | 0.84 | 0.47 | 0.78 |
| T5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 0.964 | 11.99 | Measured | 0.81 | 0.35 | 0.32 | 1.45 | 0.31 | 1.39 | 0.67 | 0.39 | 0.33 | 1.05 | 0.37 | 0.77 |
| | | | | | | | | | | | Predicted | 0.81 | 0.35 | 0.32 | 1.45 | 0.32 | 1.39 | 0.67 | 0.39 | 0.33 | 1.05 | 0.37 | 0.78 |
| T7 | 406.96 | 168.41 | 7.86 | 8.31 | 2440 | 90.0 | 0.414 | 25.888 | 1.057 | 11.99 | Measured | 0.61 | 0.55 | 0.23 | 0.82 | 0.49 | 0.93 | 0.55 | 0.49 | 0.20 | 0.63 | 0.36 | 0.52 |
| | | | | | | | | | | | Predicted | 0.58 | 0.55 | 0.23 | 0.81 | 0.50 | 0.94 | 0.55 | 0.49 | 0.20 | 0.62 | 0.35 | 0.51 |
| T9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 1.000 | 11.99 | Measured | 0.74 | 0.32 | 0.30 | 1.04 | 0.31 | 0.95 | 0.73 | 0.25 | 0.52 | 1.24 | 0.41 | 0.93 |
| | | | | | | | | | | | Predicted | 0.73 | 0.32 | 0.30 | 1.03 | 0.31 | 0.95 | 0.73 | 0.25 | 0.53 | 1.27 | 0.42 | 0.92 |
| | | | | | | | | | | | | | | | | | | | | | | | |
| DT2 | 406.78 | 273.09 | 16.39 | 15.76 | 2440 | 90.0 | 0.671 | 12.409 | 0.962 | 12.00 | Measured | 0.85 | 0.52 | 0.32 | 1.43 | 0.33 | 0.88 | 0.89 | 0.63 | 0.36 | 0.85 | 0.43 | 0.37 |
| | | | | | | | | | | | Predicted | 0.89 | 0.57 | 0.31 | 1.29 | 0.36 | 0.87 | 0.89 | 0.63 | 0.37 | 0.88 | 0.44 | 0.38 |
| DT3 | 406.78 | 407.02 | 16.39 | 16.10 | 2440 | 90.0 | 1.001 | 12.409 | 0.982 | 12.00 | Measured | 0.60 | 1.14 | 0.83 | 0.62 | 0.89 | 0.43 | 0.94 | 1.72 | 1.26 | 0.46 | 1.08 | 0.41 |
| | | | | | | | | | | | Predicted | 0.60 | 1.20 | 1.02 | 0.71 | 0.96 | 0.64 | 0.98 | 1.81 | 1.34 | 0.46 | 1.13 | 0.41 |
| DT4 | 407.05 | 168.57 | 10.19 | 9.95 | 2440 | 90.0 | 0.414 | 19.973 | 0.976 | 11.99 | Measured | 0.58 | 0.53 | 0.14 | 0.78 | 0.30 | 0.63 | 0.97 | 0.47 | 0.13 | 1.05 | 0.26 | 0.55 |
| | | | | | | | | | | | Predicted | 0.58 | 0.55 | 0.14 | 0.84 | 0.31 | 0.80 | 1.00 | 0.47 | 0.13 | 1.05 | 0.25 | 0.55 |
| DT5 | 407.05 | 273.34 | 10.19 | 9.82 | 2440 | 90.0 | 0.672 | 19.973 | 0.964 | 11.99 | Measured | 0.69 | 0.52 | 0.29 | 0.73 | 0.38 | 0.27 | 0.81 | 0.49 | 0.27 | 1.26 | 0.39 | 0.52 |
| | | | | | | | | | | | Predicted | 0.64 | 0.50 | 0.30 | 0.85 | 0.35 | 0.55 | 0.82 | 0.49 | 0.26 | 1.16 | 0.40 | 0.50 |
| DT6 | 407.05 | 407.60 | 10.19 | 9.61 | 2440 | 90.0 | 1.001 | 19.973 | 0.943 | 11.99 | Measured | 0.54 | 1.26 | 1.07 | 0.64 | 0.91 | 0.47 | 1.07 | 1.35 | 1.13 | 0.86 | 0.93 | 0.70 |
| | | | | | | | | | | | Predicted | 0.52 | 1.20 | 1.00 | 0.65 | 0.83 | 0.41 | 0.98 | 1.26 | 1.05 | 0.96 | 0.92 | 0.71 |
| DT8 | 406.96 | 273.21 | 7.86 | 7.88 | 2440 | 90.0 | 0.671 | 25.888 | 1.003 | 11.99 | Measured | 0.41 | 0.40 | 0.21 | 0.93 | 0.31 | 0.75 | 0.72 | 0.39 | 0.18 | 1.36 | 0.31 | 0.51 |
| | | | | | | | | | | | Predicted | 0.44 | 0.44 | 0.30 | 0.91 | 0.34 | 0.61 | 0.76 | 0.38 | 0.18 | 1.46 | 0.31 | 0.52 |
| DT9 | 406.96 | 406.96 | 7.86 | 7.86 | 2440 | 90.0 | 1.000 | 25.888 | 1.000 | 11.99 | Measured | 0.44 | 1.13 | 1.01 | 0.78 | 0.68 | 0.41 | 0.90 | 0.79 | 0.77 | 1.54 | 0.36 | 0.87 |
| | | | | | | | | | | | Predicted | 0.46 | 1.20 | 0.99 | 1.00 | 0.73 | 0.55 | 0.98 | 0.81 | 0.80 | 1.43 | 0.37 | 0.86 |

Measured RF values refer to measured grouted SNCFs/Efthymiou as-welded SNCFs.
Predicted RF values given by formulations in Tables 2 and 3.

**Table 1 : Summary of Reduction Factors**

$RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2 + a_6\beta^3\gamma^3$

| Joint Type | Load (Position) | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | COV | Max/Min Error |
|---|---|---|---|---|---|---|---|---|---|
| DT | COMP (Saddle) | 0.57 | -2.08 | 0.001 | -0.003 | 2.55 | 0 | 0.140 | 6.54%<br>-41.66% |
| | COMP (Crown) | 4.9 | -1.7 | -0.32 | 0.15 | -1.15 | 0.005 | 0.119 | 9.92%<br>-28.20% |
| | TENS (Saddle) | 0.25 | -1.28 | 0.03 | -0.047 | 2.2 | 0 | 0.083 | 8.74%<br>-10.43% |
| | TENS (Crown) | 3.9 | -2.9 | -0.2 | 0.04 | 1.01 | 0.004 | 0.307 | 19.56%<br>-101.95% |
| | IPB (Crown) | 1.8 | -0.08 | -0.08 | 0.07 | -1 | 0 | 0.054 | 7.78%<br>-7.66% |
| | OPB (Saddle) | 2.35 | -5.15 | -0.03 | 0.03 | 4 | 0 | 0.061 | 4.76%<br>-10.28% |
| T | COMP (Saddle) | 1.07 | -0.68 | -0.043 | 0.06 | -0.53 | 0 | 0.009 | 1.08%<br>-1.36% |
| | COMP (Crown) | -0.55 | 6.9 | -0.03 | 0.01 | -4.8 | 0 | 0.009 | 0.68%<br>-1.13% |
| | TENS (Saddle) | 0.87 | -1.49 | 0.001 | 0.01 | 0.65 | 0 | 0.010 | -1.54%<br>-4.06% |
| | TENS (Crown) | -1.37 | 7.4 | 0.02 | -0.05 | -4.3 | 0 | 0.013 | 2.28%<br>-0.91% |
| | IPB (Crown) | 0.45 | 1.5 | -0.01 | -0.01 | -0.7 | 0 | 0.026 | 4.10%<br>-3.28% |
| | OPB (Saddle) | 1.56 | -2.62 | -0.012 | 0.015 | 1.3 | 0 | 0.002 | 0.99%<br>0.32% |

Ranges of validity: $0.4 \le \beta \le 1.0$, $12 \le \gamma \le 26$, $\tau \cong 1.0$, $\theta = 90°$

**Table 2: Recommended Formulations for Reduction Factors on Chord Side**

$RF = a_0 + a_1\beta + a_2\gamma + a_3\beta\gamma + a_4\beta^2 + a_5\gamma^2 + a_6\beta^3\gamma^3$

| Joint Type | Load (Position) | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | COV | Max/Min Error |
|---|---|---|---|---|---|---|---|---|---|---|
| DT | COMP (Saddle) | -0.01 | -1.3 | 0.04 | -0.08 | 3.15 | 0 | 0 | 0.049 | 7.87% -6.64% |
| | COMP (Crown) | 1.1 | 0.56 | -0.056 | 0.09 | -1.78 | 0.001 | 0 | 0.070 | 7.87% -11.40% |
| | TENS (Saddle) | 1.92 | -4.4 | -0.08 | 0.1 | 3.4 | 0.001 | -0.0001 | 0.026 | 2.86% -4.73% |
| | TENS (Crown) | 1.37 | -3.09 | 0.002 | 0.07 | 1.39 | -0.001 | 0 | 0.021 | 3.50% -2.07% |
| | IPB (Crown) | 2.45 | -3.5 | -0.03 | 0.03 | 2.03 | 0 | 0 | 0.056 | 8.41% -8.89% |
| | OPB (Saddle) | -0.43 | -0.64 | 0.096 | -0.17 | 3.8 | 0 | 0 | 0.040 | 7.26% -5.33% |
| T | COMP (Saddle) | 1.1 | -1.33 | -0.034 | 0.04 | 0.6 | 0 | 0 | 0.011 | 1.23% -1.51% |
| | COMP (Crown) | -1.26 | 5 | 0.002 | 0.03 | -3.3 | 0 | 0 | 0.020 | 1.95% -2.29% |
| | TENS (Saddle) | 0.72 | -0.7 | -0.008 | 0.004 | 0.5 | 0 | 0 | 0.018 | 2.32% -2.25% |
| | TENS (Crown) | -0.74 | 3.1 | 0.01 | 0 | -1.7 | 0 | 0 | 0.023 | 1.75% -3.33% |
| | IPB (Crown) | 0.31 | 0.91 | -0.007 | 0.015 | -0.7 | 0 | 0 | 0.002 | 0.67% 0.12% |
| | OPB (Saddle) | 0.88 | -0.84 | 0.001 | -0.016 | 0.6 | 0 | 0 | 0.004 | 0.11% -0.94% |

Ranges of validity: $0.4 \le \beta \le 1.0$, $12 \le \gamma \le 26$, $\tau \equiv 1.0$, $\theta = 90°$

**Table 3: Recommended Formulations for Reduction Factors on Brace Side**

BRACE (T)

| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 3.08 | 8.37 | 1.33 | 3.60 | 0.43 | 0.43 | 0.42 | 0.44 | 1.30 | 3.65 |
| Ten. | 3.08 | 8.37 | 1.12 | 3.68 | 0.36 | 0.44 | 0.38 | 0.44 | 1.16 | 3.66 |
| OPB | | 5.85 | | 3.28 | | 0.56 | | 0.57 | | 3.31 |
| IPB | 2.87 | | 1.62 | | 0.56 | | 0.56 | | 1.60 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 2.52 | 16.53 | 1.58 | 3.32 | 0.63 | 0.20 | 0.62 | 0.20 | 1.56 | 3.32 |
| Ten. | 2.52 | 16.53 | 1.31 | 5.93 | 0.52 | 0.36 | 0.51 | 0.35 | 1.29 | 5.81 |
| OPB | | 12.11 | | 5.88 | | 0.49 | | 0.49 | | 5.93 |
| IPB | 4.38 | | 2.42 | | 0.55 | | 0.55 | | 2.39 | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 2.62 | 11.84 | 2.74 | 3.95 | 1.05 | 0.33 | 1.05 | 0.33 | 2.75 | 3.97 |
| Ten. | 2.62 | 11.84 | 2.03 | 4.36 | 0.77 | 0.37 | 0.78 | 0.37 | 2.03 | 4.37 |
| OPB | | 10.84 | | 4.21 | | 0.39 | | 0.39 | | 4.24 |
| IPB | 3.39 | | 2.26 | | 0.67 | | 0.67 | | 2.26 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 3.53 | 3.46 | 2.89 | 1.56 | 0.82 | 0.45 | 0.84 | 0.44 | 2.95 | 1.54 |
| Ten. | 3.53 | 3.46 | 2.69 | 1.60 | 0.76 | 0.46 | 0.78 | 0.47 | 2.76 | 1.63 |
| OPB | | 4.23 | | 1.88 | | 0.45 | | 0.45 | | 1.92 |
| IPB | 2.44 | | 1.52 | | 0.62 | | 0.62 | | 1.51 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 2.62 | 5.85 | 3.24 | 3.03 | 1.24 | 0.52 | 1.27 | 0.53 | 3.32 | 3.07 |
| Ten. | 2.62 | 5.85 | 2.43 | 2.39 | 0.93 | 0.41 | 0.92 | 0.42 | 2.41 | 2.43 |
| OPB | | 8.58 | | 2.17 | | 0.25 | | 0.25 | | 2.16 |
| IPB | 2.84 | | 2.09 | | 0.73 | | 0.73 | | 2.07 | |

**Table 4: Comparison of Brace T-Joint Measured and Predicted As-welded and Grouted SCFs.**

**CHORD (T)**

| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 2 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 6.06 | 13.28 | 7.00 | 6.20 | 1.15 | 0.47 | 1.16 | 0.47 | 7.05 | 6.27 |
| Ten. | 6.06 | 13.28 | 5.87 | 5.64 | 0.97 | 0.42 | 0.95 | 0.43 | 5.75 | 5.69 |
| OPB | | 8.29 | | 5.26 | | 0.63 | | 0.63 | | 5.19 |
| IPB | 3.65 | | 2.83 | | 0.78 | | 0.78 | | 2.83 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 7.25 | 29.62 | 5.93 | 6.84 | 0.82 | 0.23 | 0.81 | 0.23 | 5.90 | 6.74 |
| Ten. | 7.25 | 29.62 | 6.77 | 14.50 | 0.93 | 0.49 | 0.94 | 0.50 | 6.80 | 14.74 |
| OPB | | 18.41 | | 10.21 | | 0.55 | | 0.55 | | 10.09 |
| IPB | 6.52 | | 3.95 | | 0.61 | | 0.58 | | 3.81 | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 2 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 6.59 | 19.97 | 9.56 | 6.32 | 1.45 | 0.32 | 1.45 | 0.32 | 9.58 | 6.39 |
| Ten. | 6.59 | 19.97 | 9.13 | 6.10 | 1.39 | 0.31 | 1.39 | 0.32 | 9.16 | 6.32 |
| OPB | | 17.86 | | 6.18 | | 0.35 | | 0.35 | | 6.22 |
| IPB | 4.80 | | 3.91 | | 0.81 | | 0.81 | | 3.88 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 2 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 8.25 | 5.10 | 10.68 | 0.34 | 1.29 | 0.07 | 1.30 | 0.07 | 10.74 | 0.36 |
| Ten. | 8.25 | 5.10 | 11.34 | 0.80 | 1.37 | 0.16 | 1.36 | 0.17 | 11.20 | 0.85 |
| OPB | | 7.92 | | 2.26 | | 0.28 | | 0.28 | | 2.20 |
| IPB | 3.20 | | 3.10 | | 0.97 | | 1.00 | | 3.20 | |
| **19.973** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **25.888** | | | | | | | | | | |
| Comp. | 9.25 | 10.84 | 9.60 | 3.26 | 1.04 | 0.30 | 1.03 | 0.30 | 9.55 | 3.25 |
| Ten. | 9.25 | 10.84 | 8.81 | 3.35 | 0.95 | 0.31 | 0.95 | 0.31 | 8.82 | 3.41 |
| OPB | | 16.83 | | 5.32 | | 0.32 | | 0.32 | | 5.35 |
| IPB | 4.11 | | 3.05 | | 0.74 | | 0.73 | | 3.01 | |

**Table 5: Comparison of Chord T-Joint Measured and Predicted As-welded and Grouted SCFs.**

BRACE (DT)

| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 2.27 | 15.70 | 2.39 | 2.11 | 1.05 | 0.13 | 1.05 | 0.13 | 2.38 | 2.03 |
| Ten. | 2.27 | 15.70 | 1.24 | 4.13 | 0.55 | 0.26 | 0.55 | 0.25 | 1.24 | 3.96 |
| OPB | | 8.54 | | 4.02 | | 0.47 | | 0.47 | | 4.00 |
| IPB | 3.68 | | 3.58 | | 0.97 | | 1.00 | | 3.68 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 2.35 | 10.40 | 2.00 | 3.74 | 0.85 | 0.36 | 0.88 | 0.37 | 2.07 | 3.83 |
| Ten. | 2.35 | 10.40 | 0.88 | 4.51 | 0.37 | 0.43 | 0.38 | 0.44 | 0.88 | 4.53 |
| OPB | | 6.42 | | 4.03 | | 0.63 | | 0.63 | | 4.04 |
| IPB | 2.82 | | 2.50 | | 0.89 | | 0.89 | | 2.52 | |
| **19.973** | | | | | | | | | | |
| Comp. | 1.84 | 16.15 | 2.32 | 4.33 | 1.26 | 0.27 | 1.16 | 0.26 | 2.14 | 4.26 |
| Ten. | 1.84 | 16.15 | 0.96 | 6.36 | 0.52 | 0.39 | 0.50 | 0.40 | 0.92 | 6.46 |
| OPB | | 10.09 | | 4.90 | | 0.49 | | 0.49 | | 4.96 |
| IPB | 3.39 | | 2.76 | | 0.81 | | 0.82 | | 2.77 | |
| **25.888** | | | | | | | | | | |
| Comp. | 1.42 | 21.03 | 1.93 | 3.88 | 1.36 | 0.18 | 1.46 | 0.18 | 2.07 | 3.84 |
| Ten. | 1.42 | 21.03 | 0.72 | 6.43 | 0.51 | 0.31 | 0.52 | 0.31 | 0.74 | 6.54 |
| OPB | | 13.15 | | 5.10 | | 0.39 | | 0.38 | | 5.05 |
| IPB | 3.82 | | 2.76 | | 0.72 | | 0.76 | | 2.90 | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 3 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 2.35 | 3.08 | 1.07 | 2.11 | 0.46 | 0.69 | 0.46 | 1.34 | 1.07 | 4.14 |
| Ten. | 2.35 | 3.08 | 0.96 | 3.34 | 0.41 | 1.08 | 0.41 | 1.13 | 0.96 | 3.48 |
| OPB | | 1.41 | | 2.44 | | 1.72 | | 1.81 | | 2.56 |
| IPB | 2.44 | | 2.29 | | 0.94 | | 0.98 | | 2.40 | |
| **19.973** | | | | | | | | | | |
| Comp. | 1.84 | 4.24 | 1.58 | 4.80 | 0.86 | 1.13 | 0.96 | 1.05 | 1.76 | 4.43 |
| Ten. | 1.84 | 4.24 | 1.28 | 3.95 | 0.70 | 0.93 | 0.71 | 0.92 | 1.31 | 3.92 |
| OPB | | 2.14 | | 2.89 | | 1.35 | | 1.26 | | 2.69 |
| IPB | 2.65 | | 2.84 | | 1.07 | | 0.98 | | 2.60 | |
| **25.888** | | | | | | | | | | |
| Comp. | 1.42 | 5.43 | 2.18 | 4.20 | 1.54 | 0.77 | 1.43 | 0.80 | 2.03 | 4.37 |
| Ten. | 1.42 | 5.43 | 1.24 | 1.98 | 0.87 | 0.36 | 0.86 | 0.37 | 1.23 | 2.02 |
| OPB | | 2.90 | | 2.29 | | 0.79 | | 0.81 | | 2.36 |
| IPB | 2.84 | | 2.57 | | 0.90 | | 0.98 | | 2.78 | |

**Table 6: Comparison of Brace DT-Joint Measured and Predicted As-welded and Grouted SCFs.**

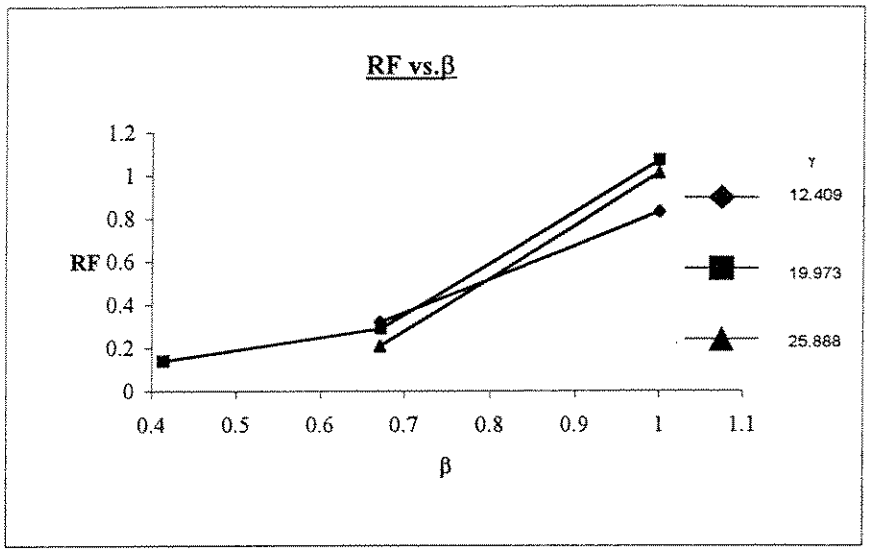
CHORD (DT)

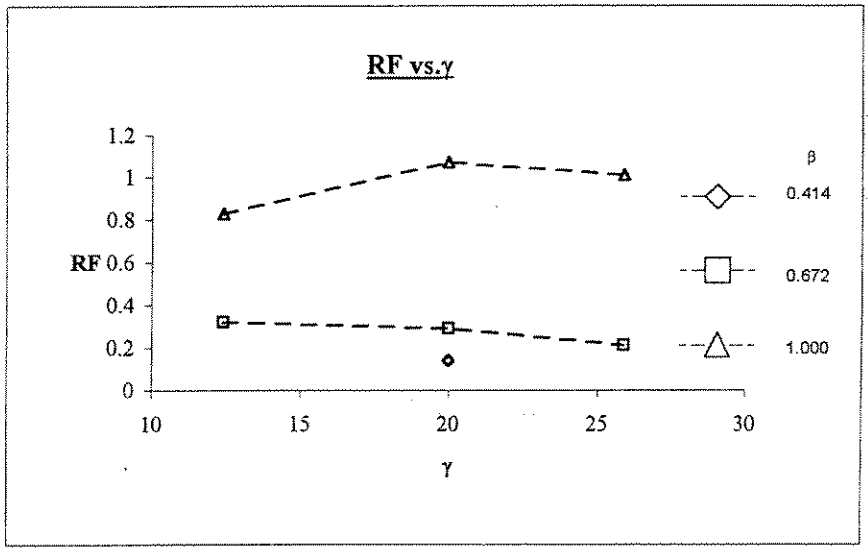
| γ | β = 0.414 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 2 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |
| **19.973** | | | | | | | | | | |
| Comp. | 3.99 | 27.99 | 3.12 | 3.91 | 0.78 | 0.14 | 0.84 | 0.14 | 3.36 | 3.95 |
| Ten. | 3.99 | 27.99 | 2.52 | 8.33 | 0.63 | 0.30 | 0.80 | 0.31 | 3.21 | 8.61 |
| OPB | | 12.28 | | 6.55 | | 0.53 | | 0.55 | | 6.78 |
| IPB | 5.06 | | 2.94 | | 0.58 | | 0.58 | | 2.92 | |
| **25.888** | | | | | | | | | | |
| Comp. | | | | | | | | | | |
| Ten. | | | | | | | | | | |
| OPB | | | | | | | | | | |
| IPB | | | | | | | | | | |

| γ | β = 0.672 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 2 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 2.28 | 18.97 | 3.26 | 6.08 | 1.43 | 0.32 | 1.29 | 0.31 | 2.94 | 5.90 |
| Ten. | 2.28 | 18.97 | 2.02 | 6.20 | 0.88 | 0.33 | 0.87 | 0.36 | 2.00 | 6.90 |
| OPB | | 10.32 | | 5.32 | | 0.52 | | 0.57 | | 5.92 |
| IPB | 3.70 | | 3.16 | | 0.85 | | 0.89 | | 3.28 | |
| **19.973** | | | | | | | | | | |
| Comp. | 2.71 | 30.60 | 1.98 | 8.96 | 0.73 | 0.29 | 0.85 | 0.30 | 2.32 | 9.29 |
| Ten. | 2.71 | 30.60 | 0.74 | 11.59 | 0.27 | 0.38 | 0.55 | 0.35 | 1.48 | 10.76 |
| OPB | | 16.64 | | 8.59 | | 0.52 | | 0.50 | | 8.30 |
| IPB | 4.80 | | 3.30 | | 0.69 | | 0.64 | | 3.06 | |
| **25.888** | | | | | | | | | | |
| Comp. | 3.08 | 41.26 | 2.86 | 8.72 | 0.93 | 0.21 | 0.91 | 0.30 | 2.82 | 12.27 |
| Ten. | 3.08 | 41.26 | 2.32 | 12.60 | 0.75 | 0.31 | 0.61 | 0.34 | 1.87 | 14.12 |
| OPB | | 22.44 | | 9.00 | | 0.40 | | 0.44 | | 9.89 |
| IPB | 5.72 | | 2.35 | | 0.41 | | 0.44 | | 2.52 | |

| γ | β = 1.000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efthymiou as-welded SCF | | Measured grouted SCF | | RF | | Table 2 Predicted RF | | Predicted grouted SCF | |
| | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle | Crown | Saddle |
| **12.409** | | | | | | | | | | |
| Comp. | 2.36 | 4.67 | 1.45 | 3.86 | 0.62 | 0.83 | 0.71 | 1.02 | 1.68 | 4.74 |
| Ten. | 2.36 | 4.67 | 1.02 | 4.14 | 0.43 | 0.89 | 0.64 | 0.96 | 1.51 | 4.48 |
| OPB | | 2.64 | | 3.01 | | 1.14 | | 1.20 | | 3.17 |
| IPB | 3.20 | | 1.93 | | 0.60 | | 0.60 | | 1.90 | |
| **19.973** | | | | | | | | | | |
| Comp. | 2.78 | 7.12 | 1.79 | 7.61 | 0.64 | 1.07 | 0.65 | 1.00 | 1.80 | 7.15 |
| Ten. | 2.78 | 7.12 | 1.31 | 6.46 | 0.47 | 0.91 | 0.41 | 0.83 | 1.14 | 5.94 |
| OPB | | 4.01 | | 5.04 | | 1.26 | | 1.20 | | 4.83 |
| IPB | 3.59 | | 1.93 | | 0.54 | | 0.52 | | 1.87 | |
| **25.888** | | | | | | | | | | |
| Comp. | 3.25 | 10.02 | 2.54 | 10.15 | 0.78 | 1.01 | 1.00 | 0.99 | 3.25 | 9.90 |
| Ten. | 3.25 | 10.02 | 1.34 | 6.84 | 0.41 | 0.68 | 0.55 | 0.73 | 1.79 | 7.31 |
| OPB | | 5.70 | | 6.42 | | 1.13 | | 1.20 | | 6.83 |
| IPB | 4.11 | | 1.82 | | 0.44 | | 0.46 | | 1.89 | |

**Table 7: Comparison of Chord DT-Joint Measured and Predicted As-welded and Grouted SCFs.**



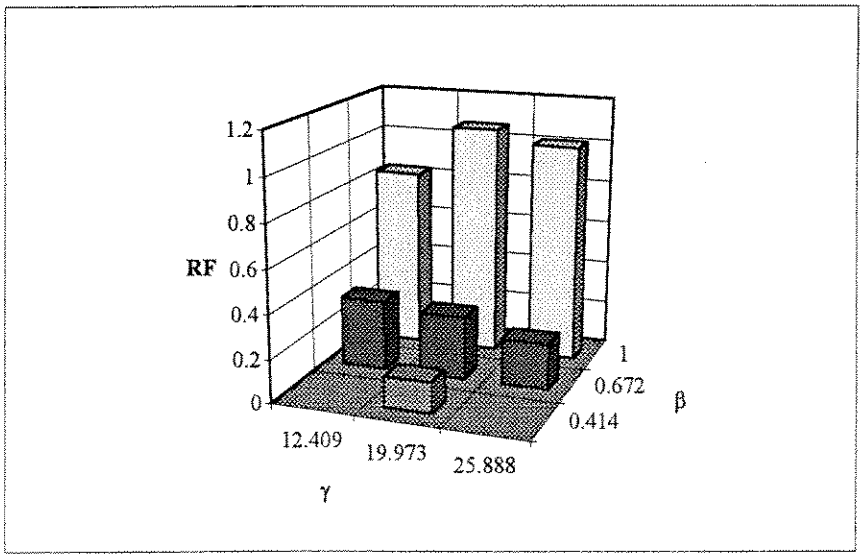
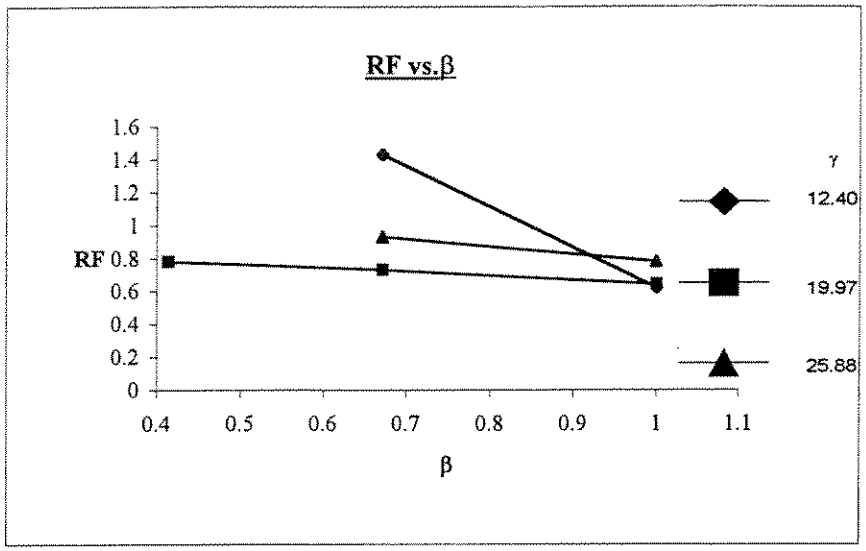
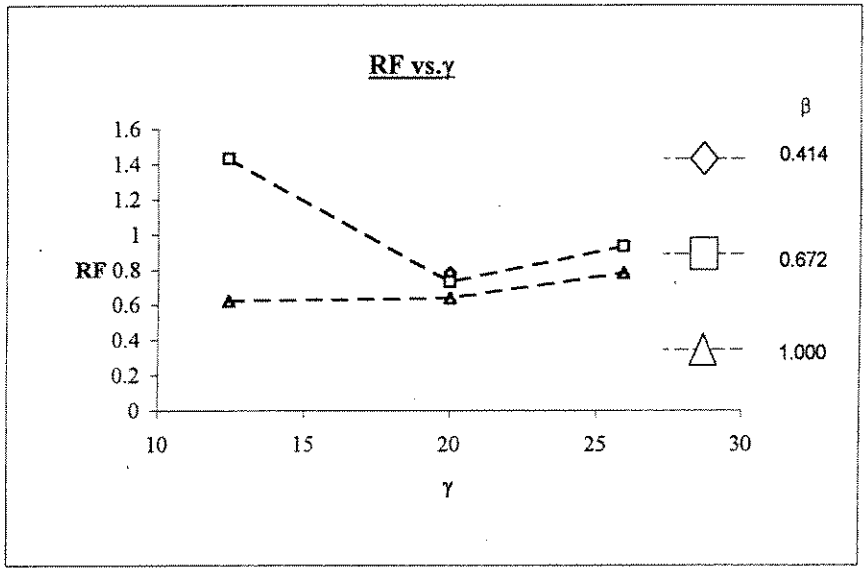




Fig. 1: DT Joints Under Compression, Chord Saddle



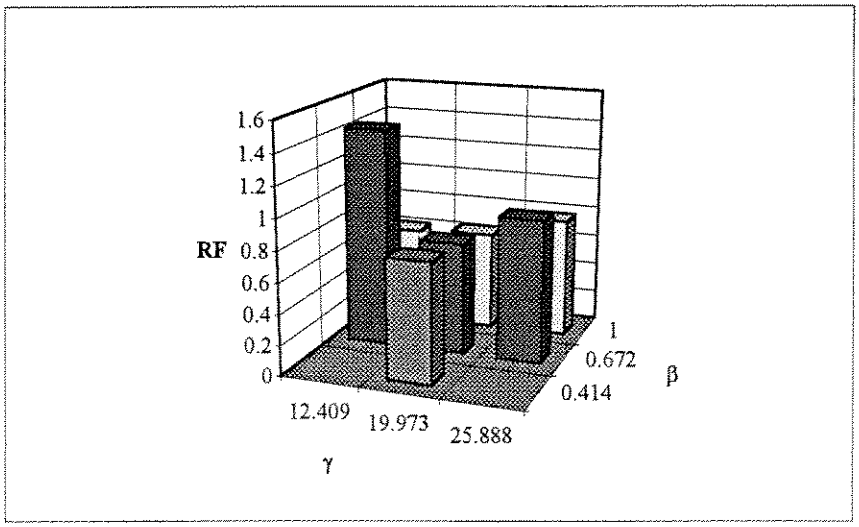
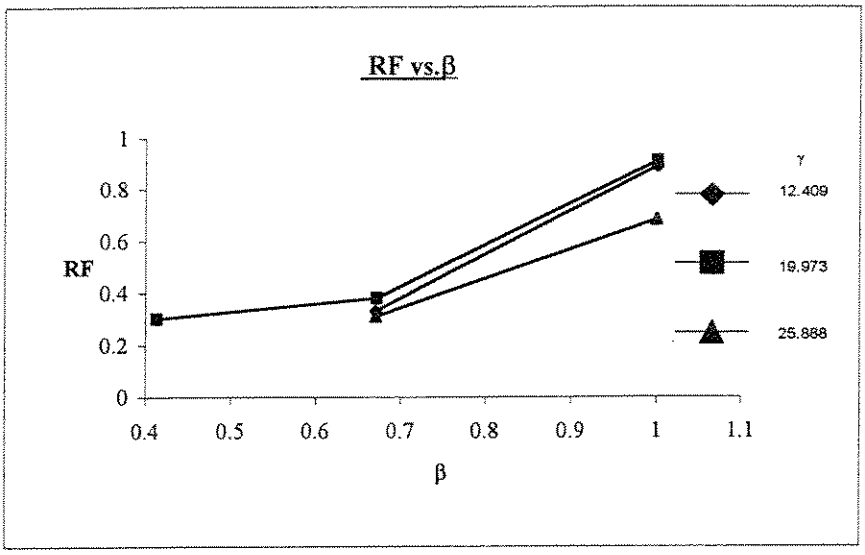
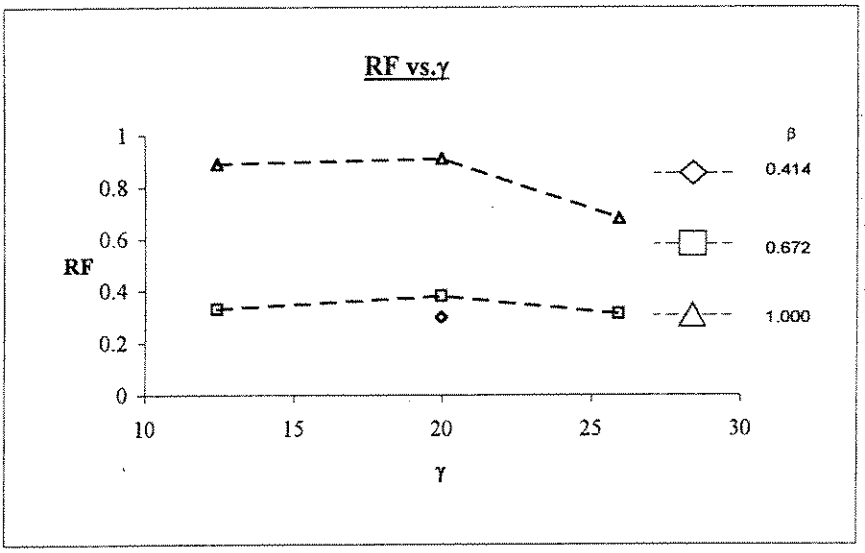




Fig. 2: DT Joints Under Compression, Chord Crown



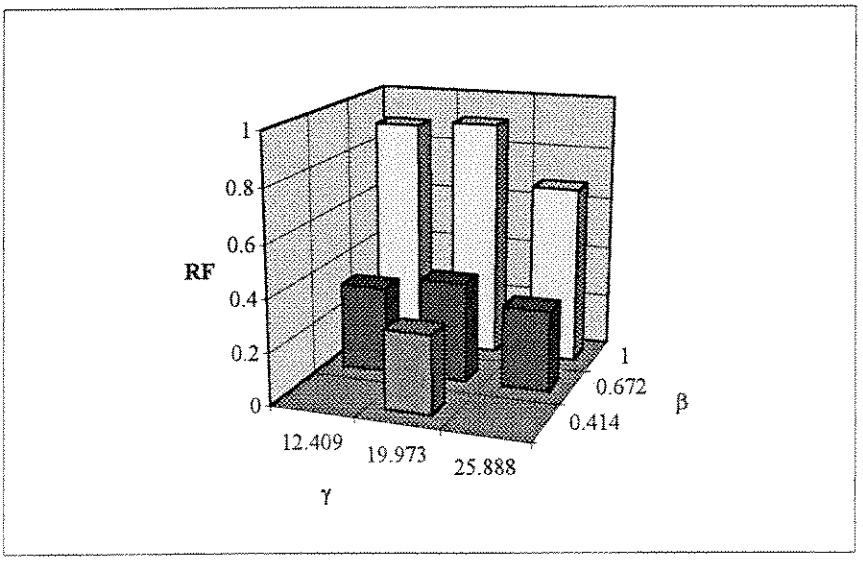
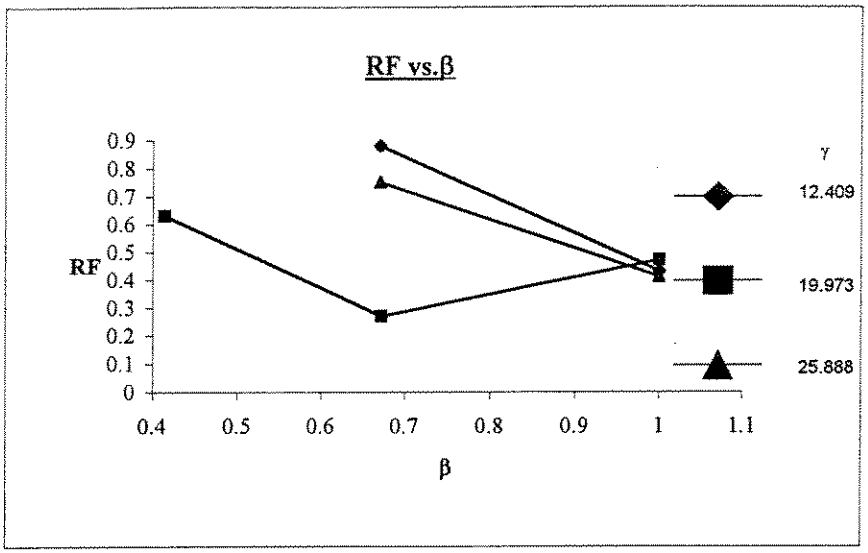
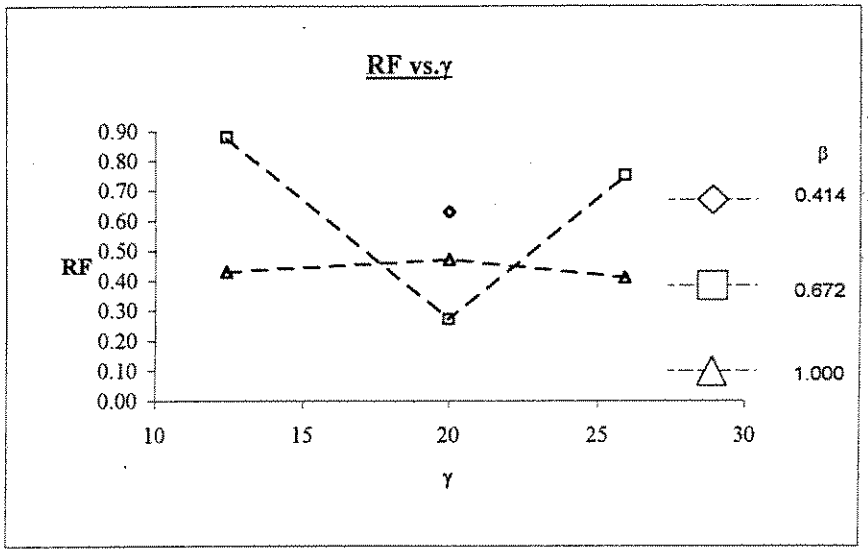




**Fig. 3: DT Joints Under Tension, Chord Saddle**



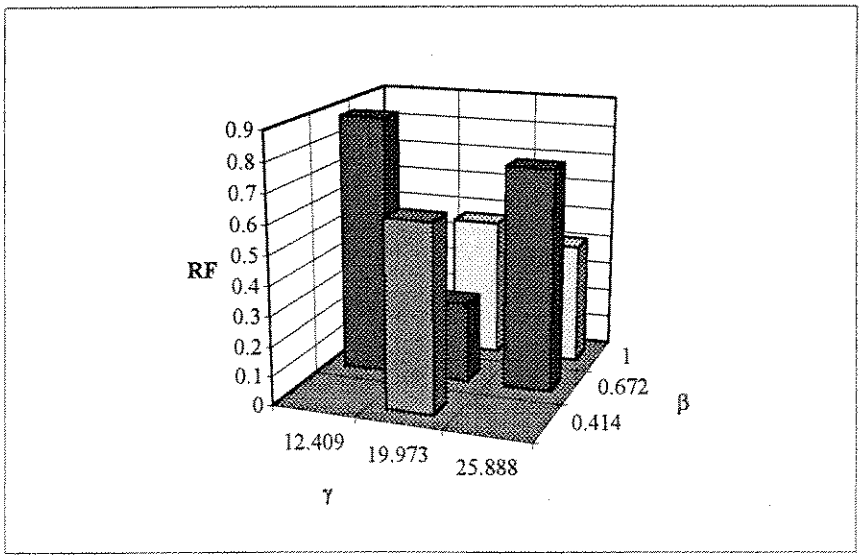
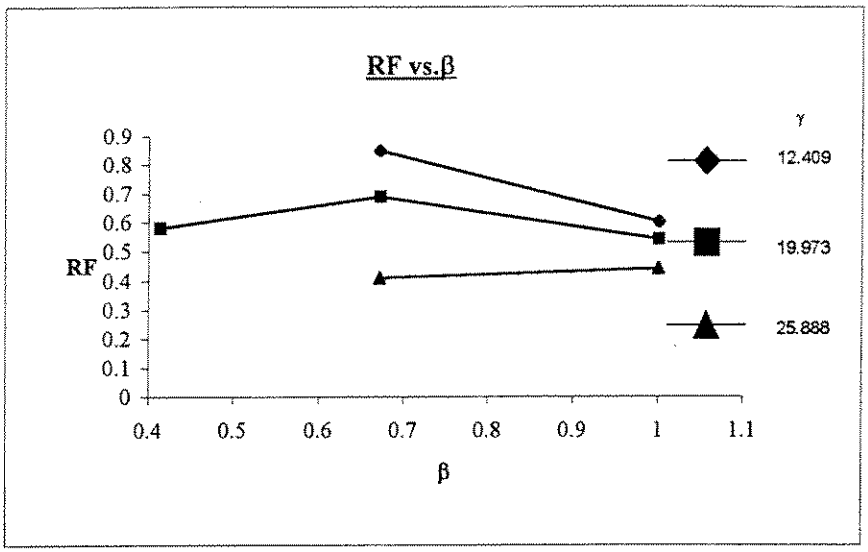
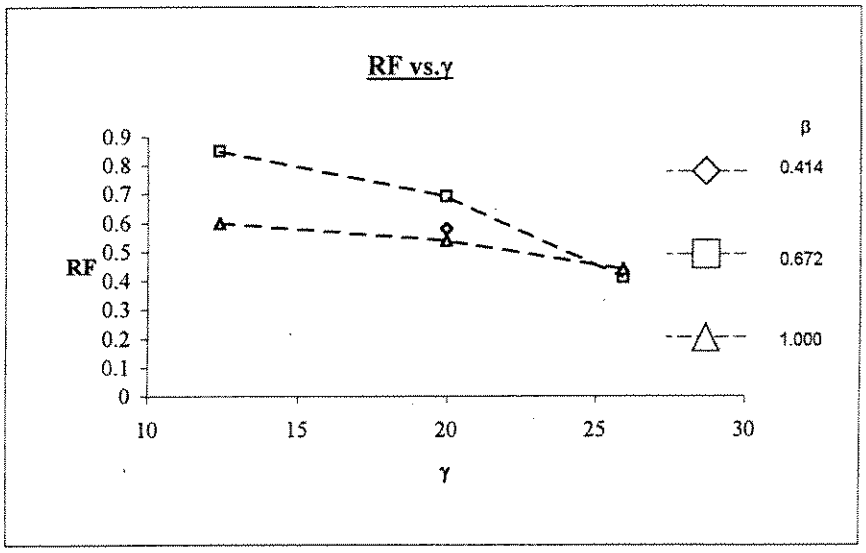




Fig. 4: DT Joints Under Tension, Chord Crown



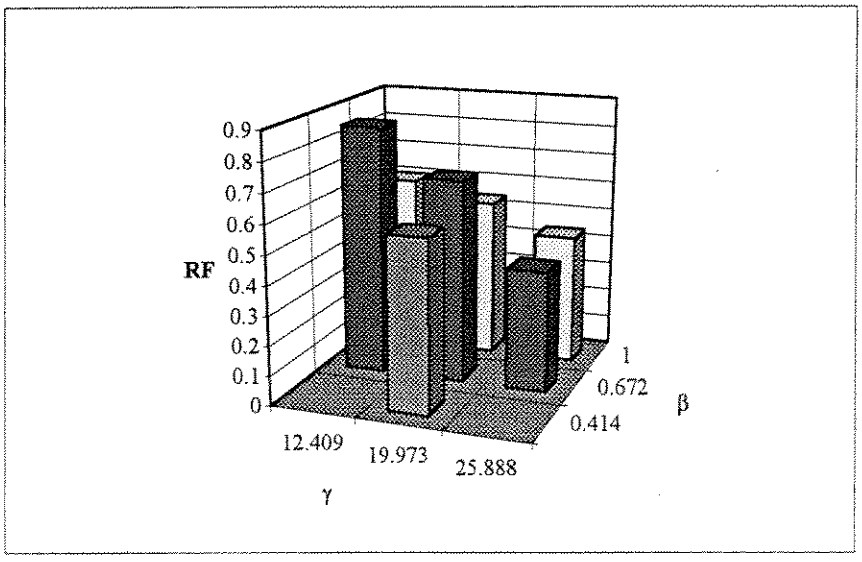
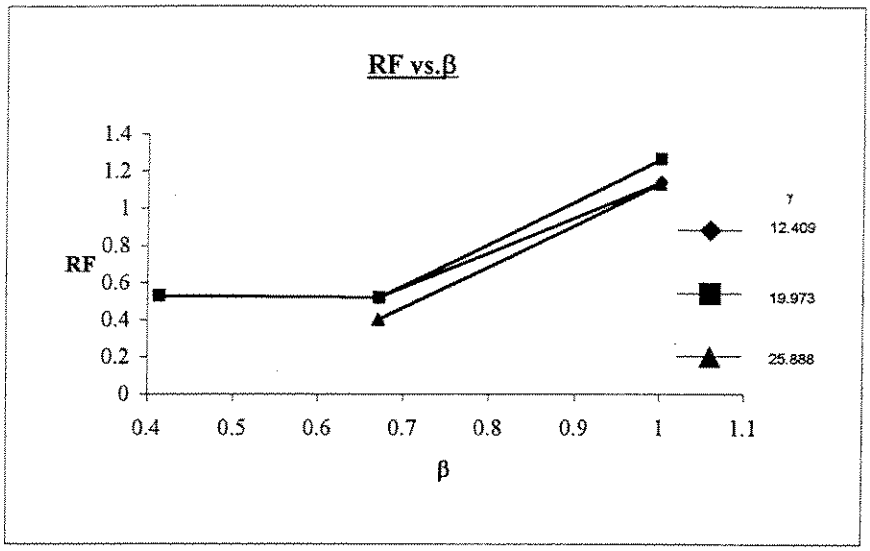
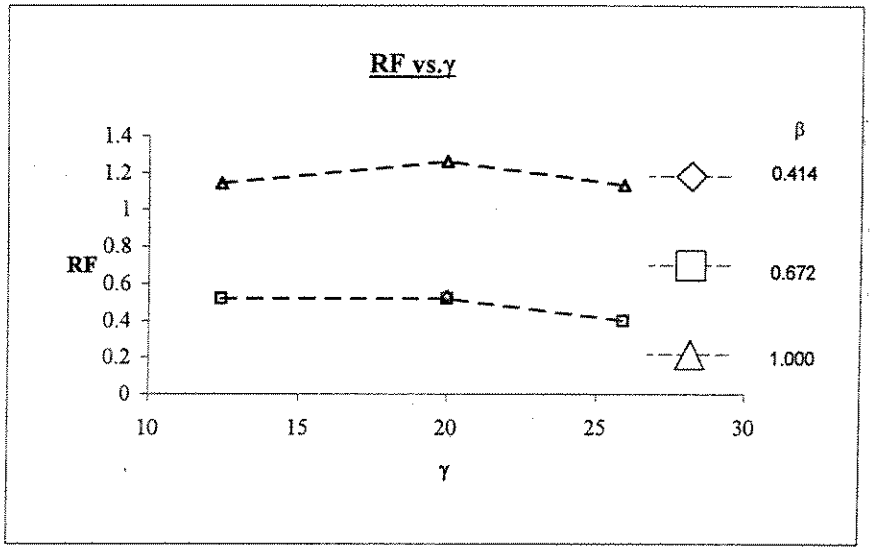




Fig. 5: DT Joints Under IPB, Chord Crown



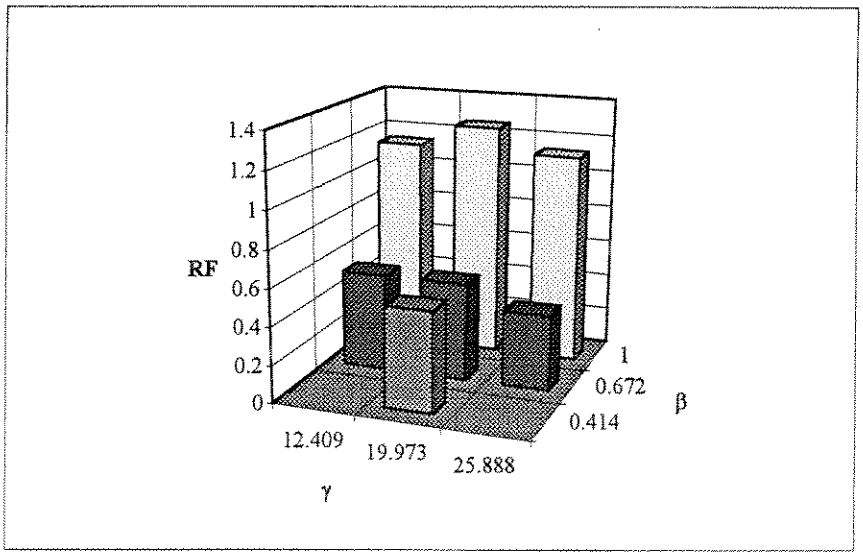
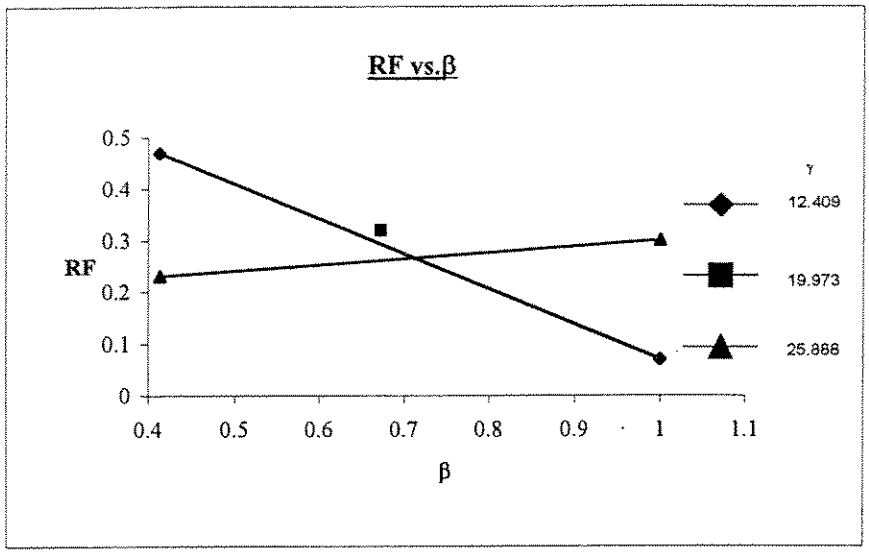
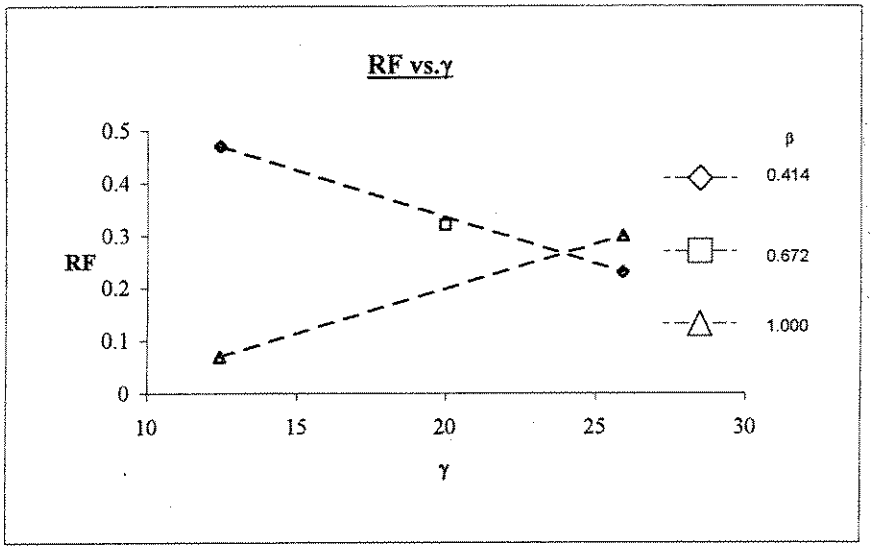




Fig. 6: DT Joints Under OPB, Chord Saddle



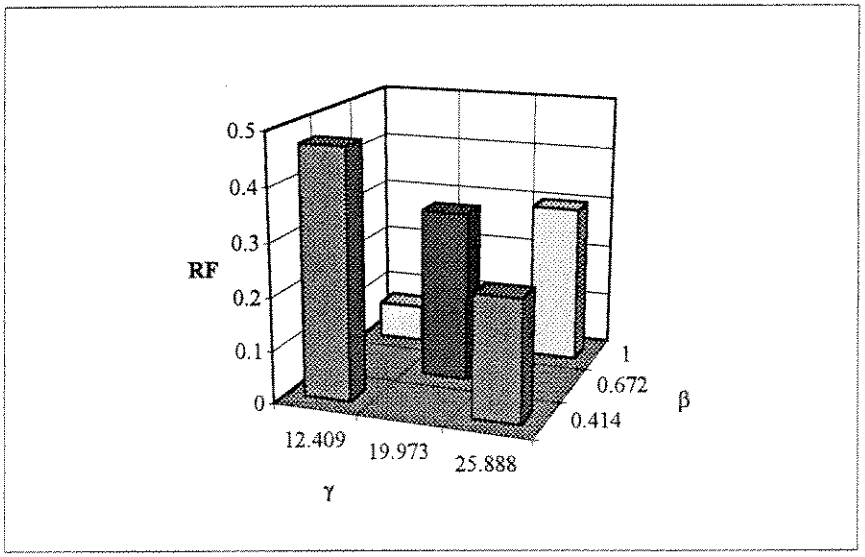
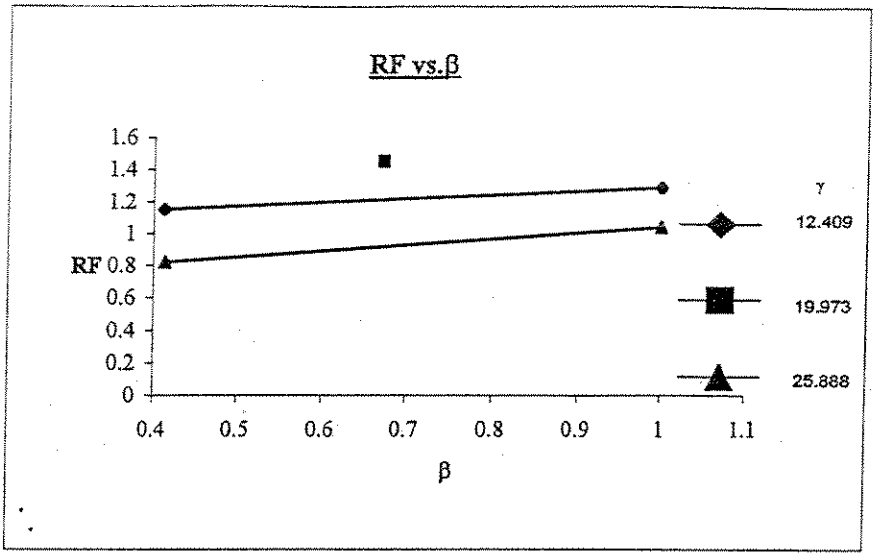
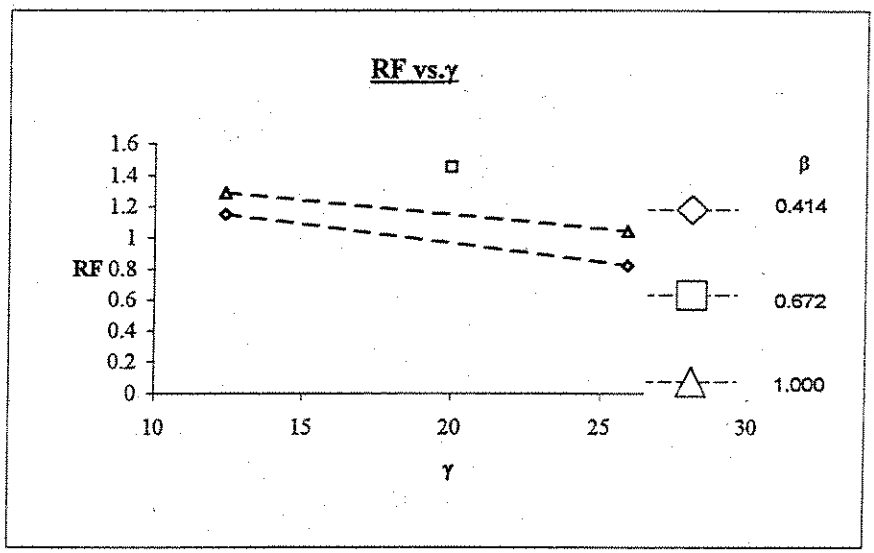




Fig. 7: T Joints Under Compression, Chord Saddle



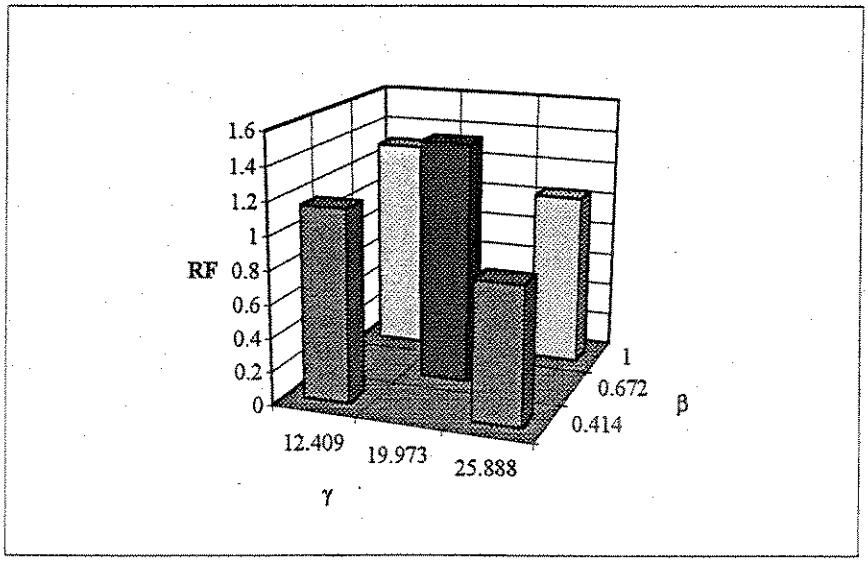
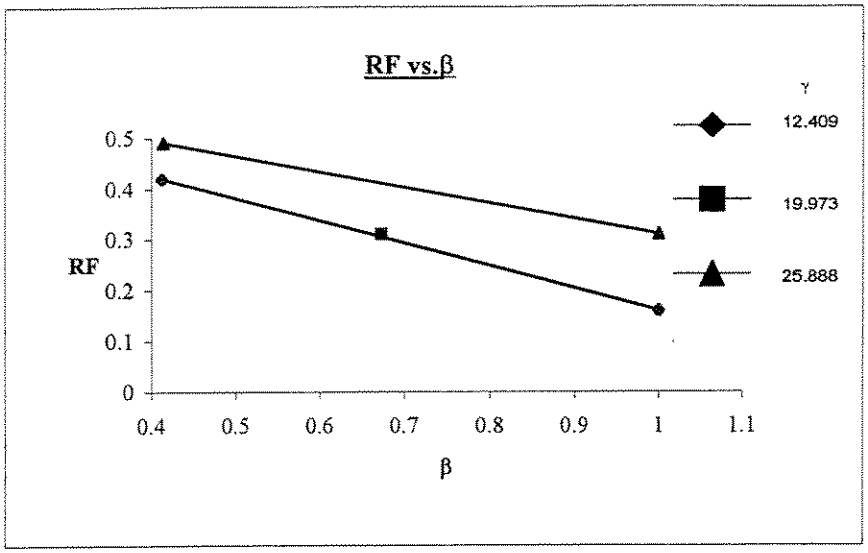
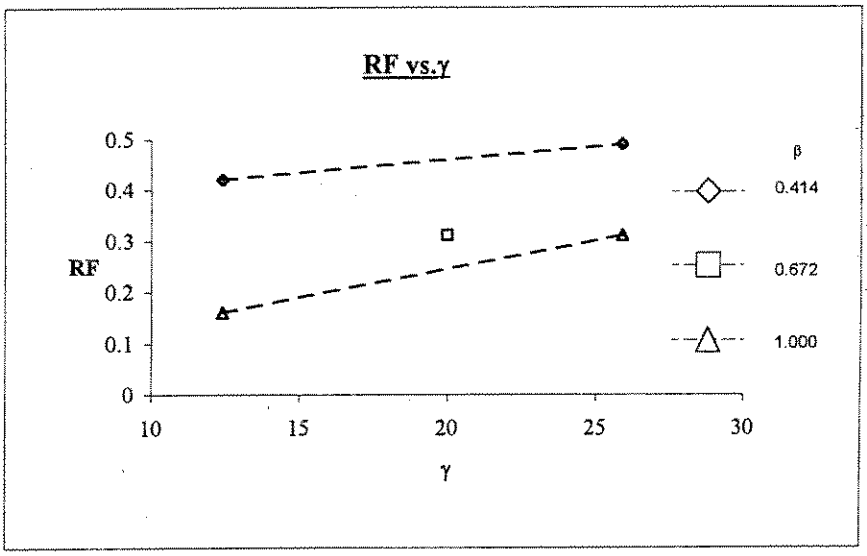




Fig. 8: T Joints Under Compression, Chord Crown



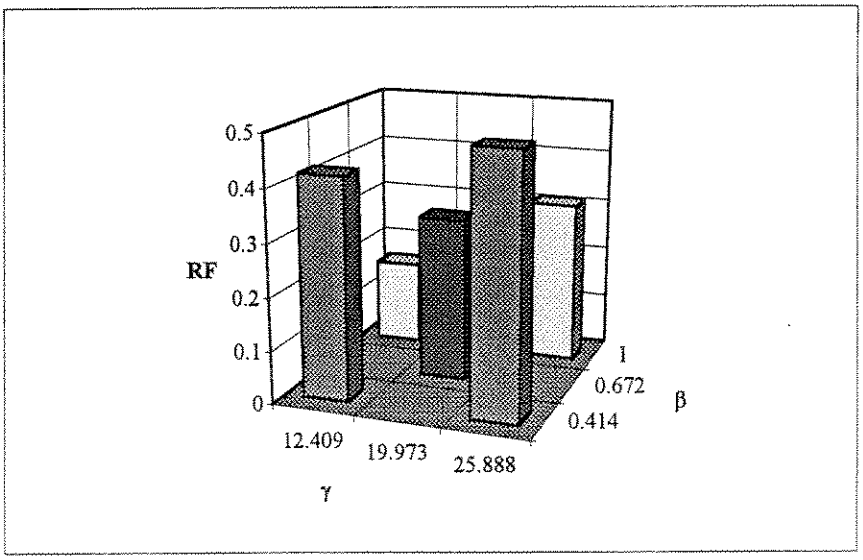
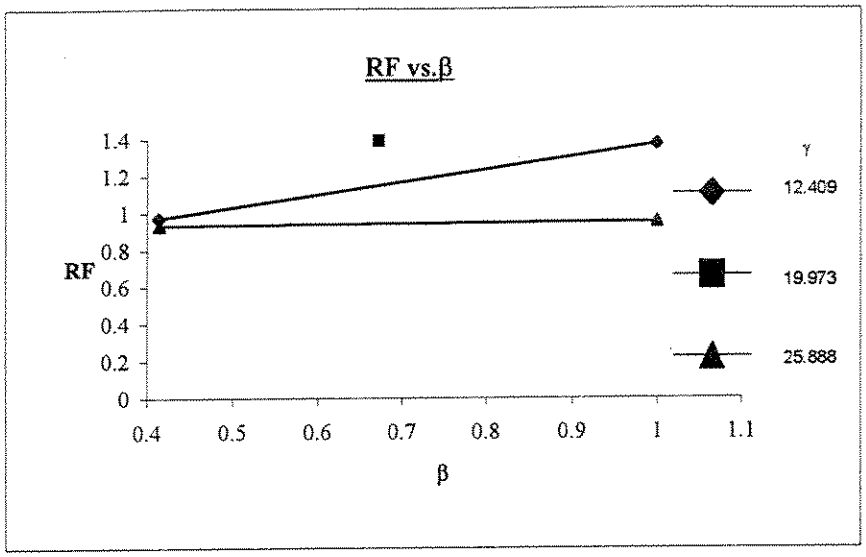
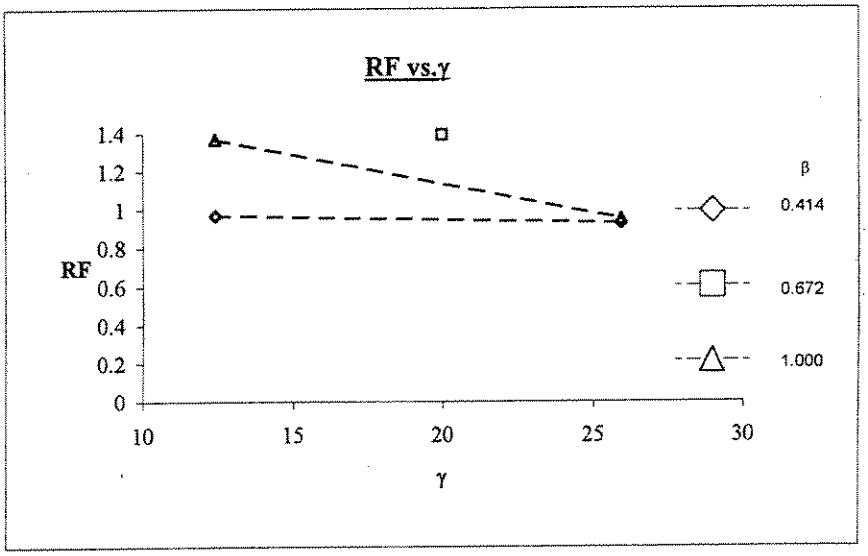




Fig. 9: T Joints Under Tension, Chord Saddle



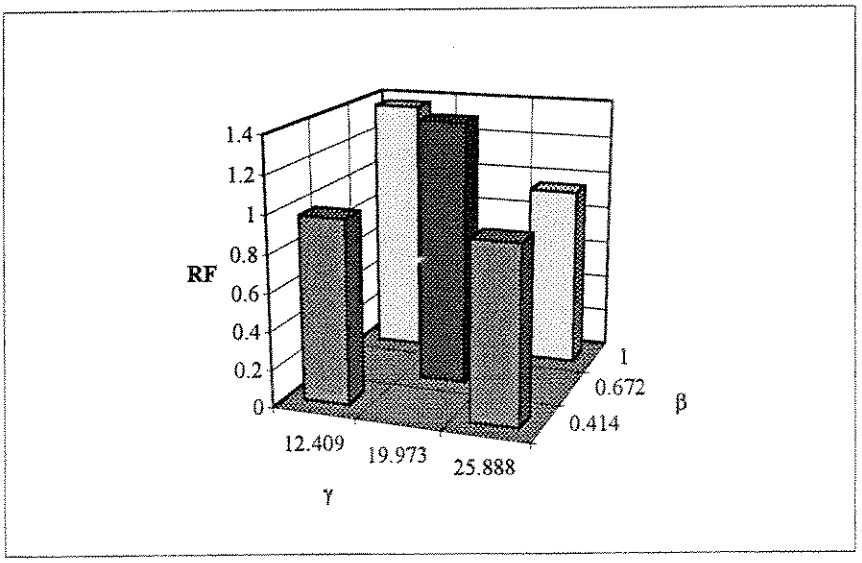
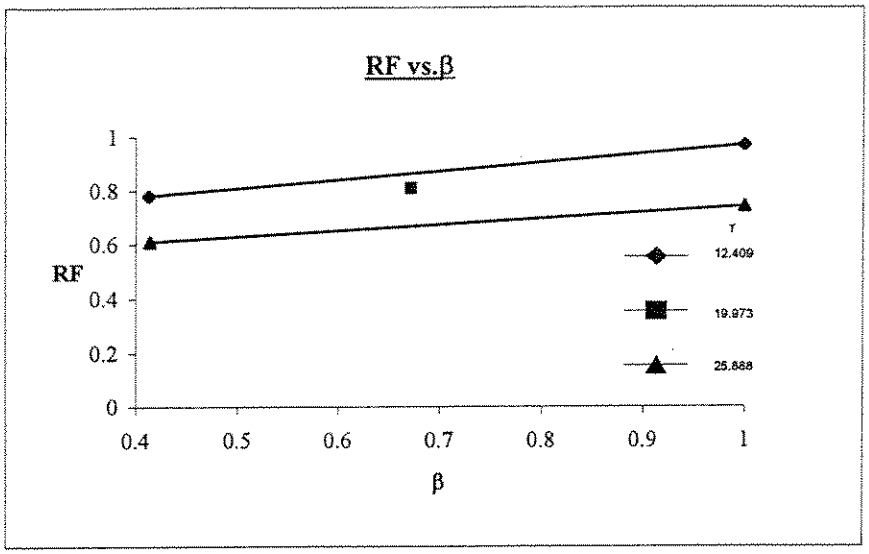
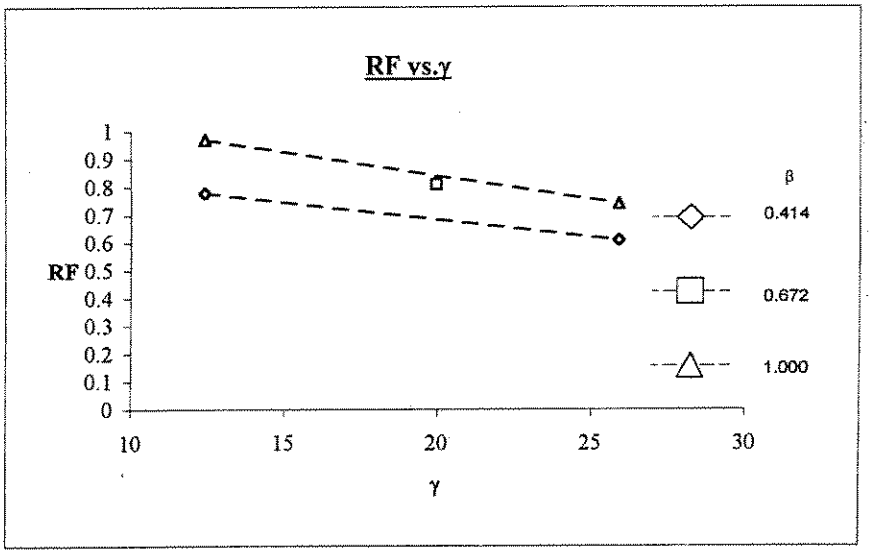




**Fig. 10: T Joints Under Tension, Chord Crown**



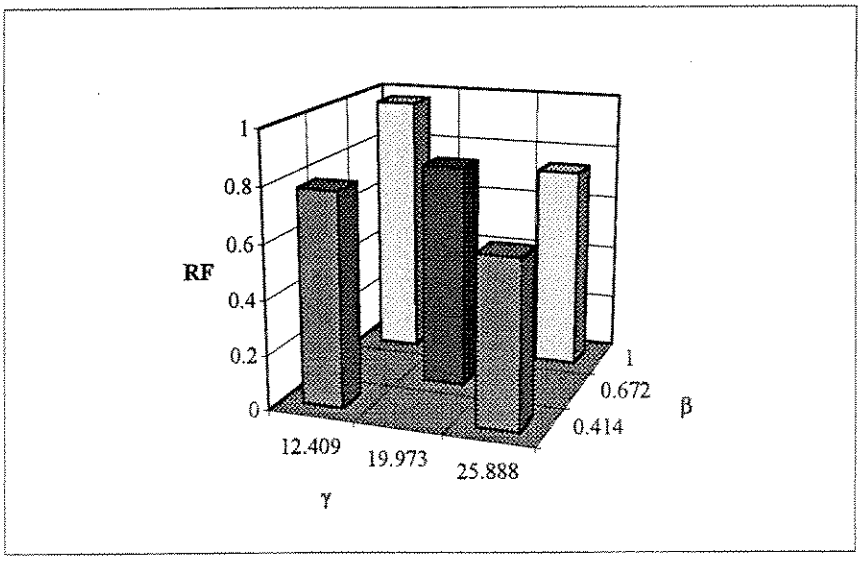
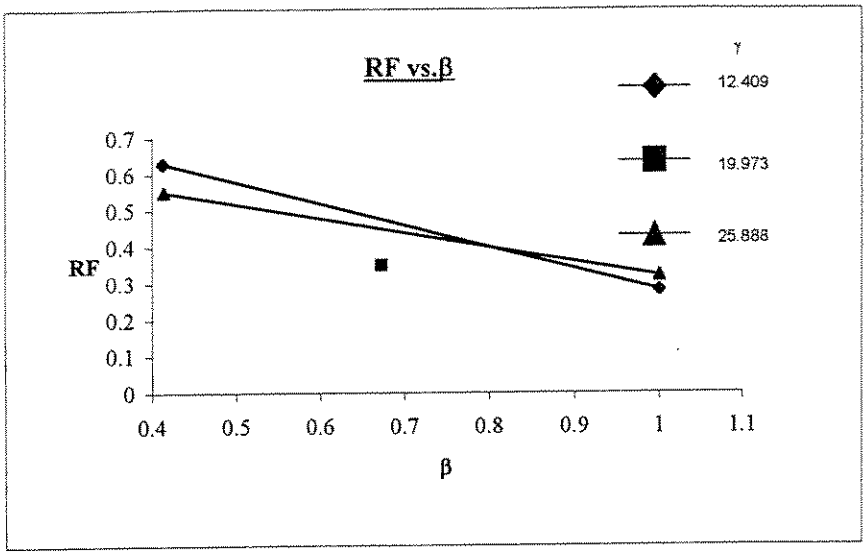
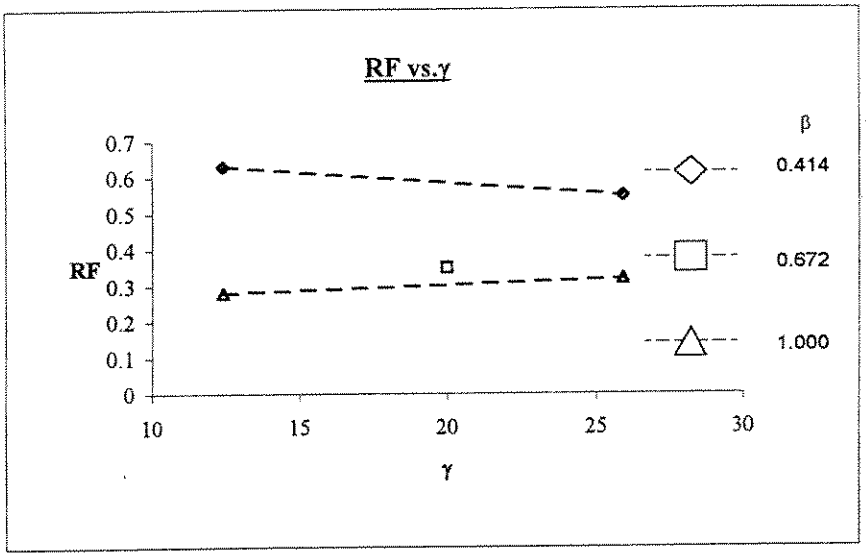




Fig. 11: T Joints Under IPB, Chord Crown



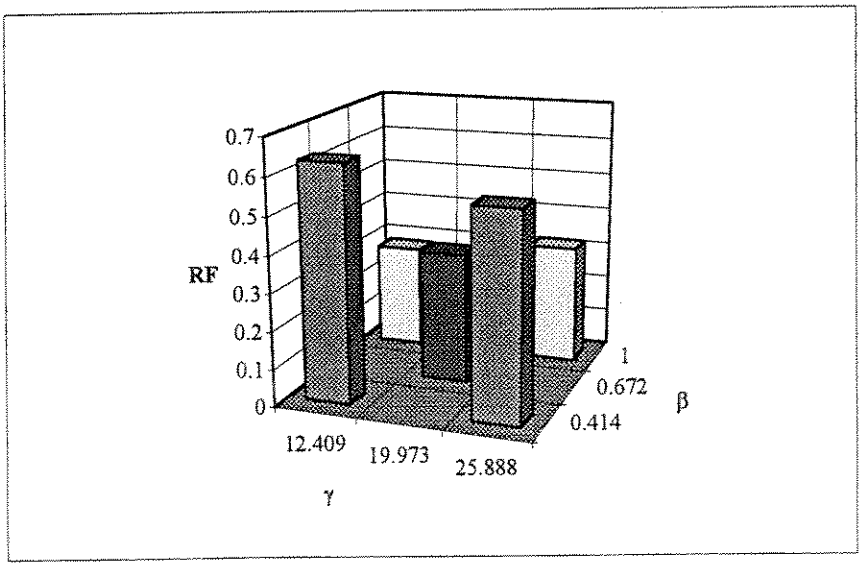
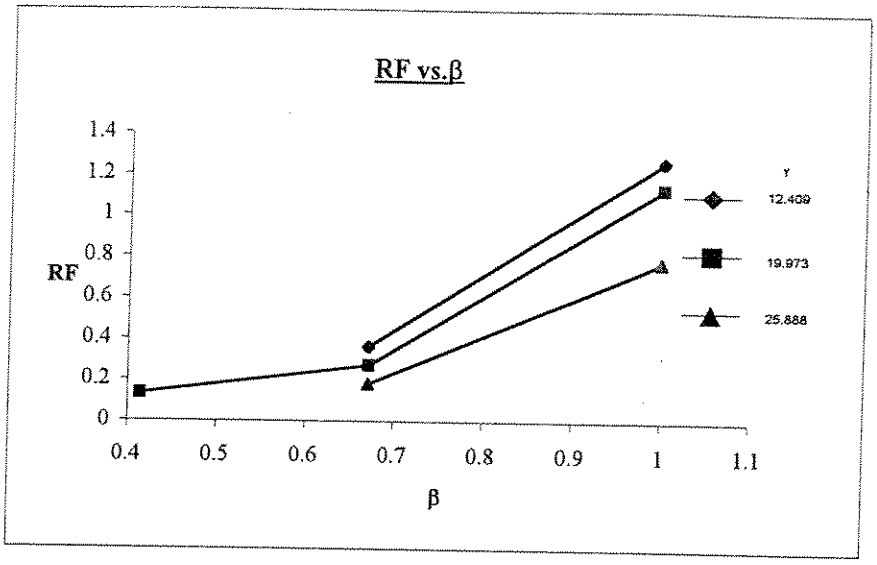
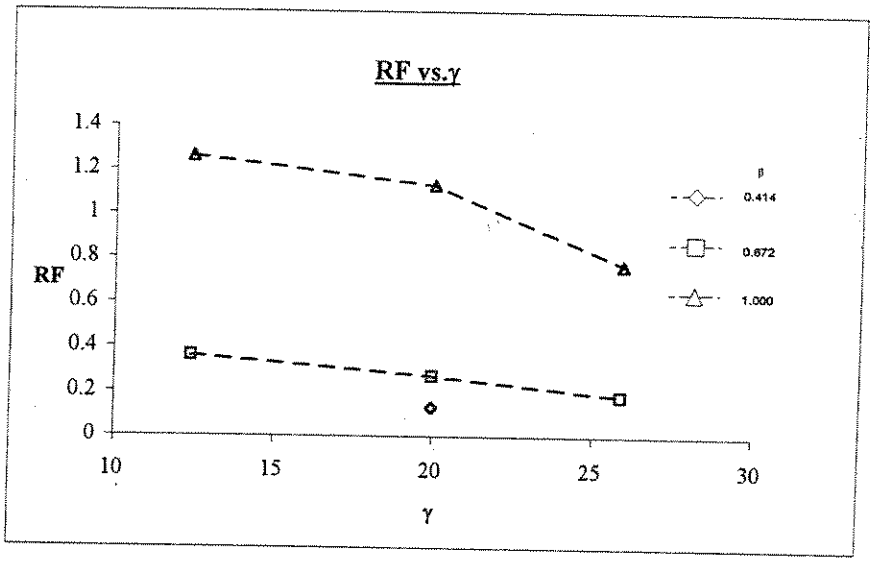




Fig. 12: T Joints Under OPB, Chord Saddle



MSL



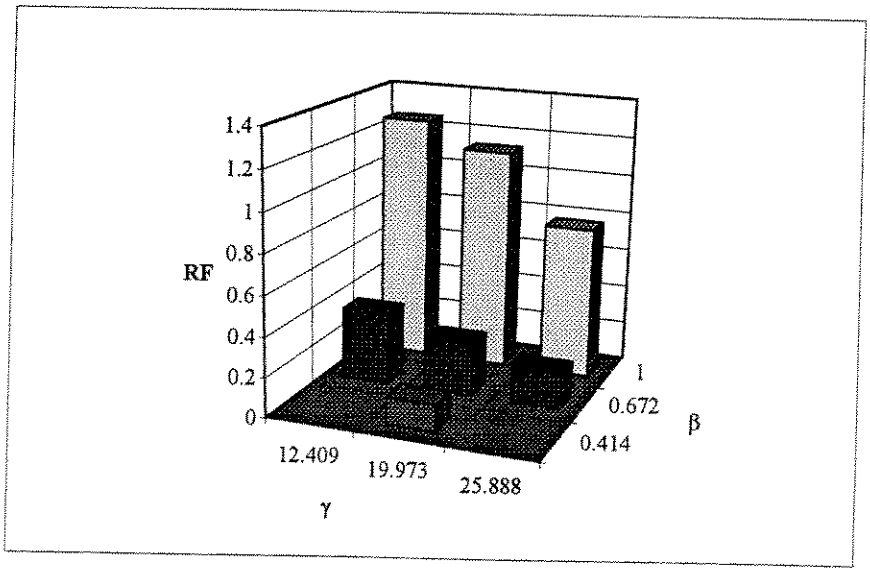
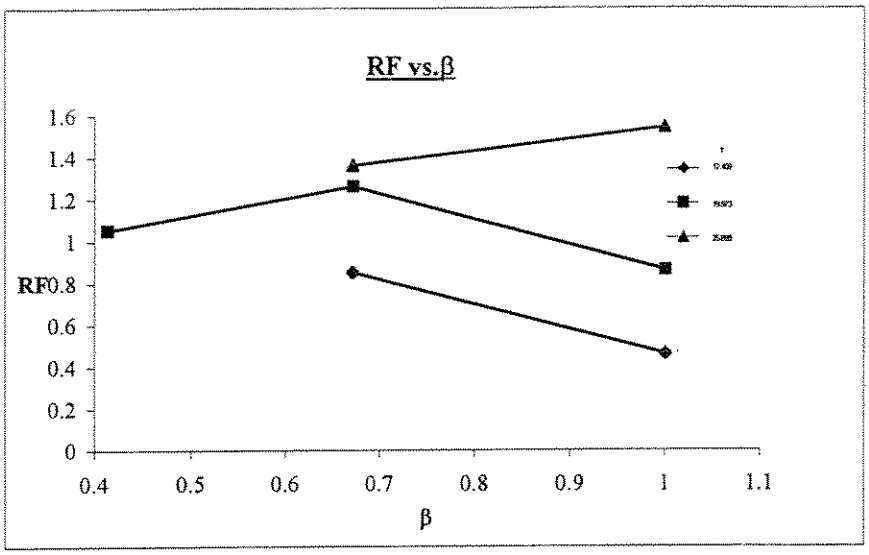
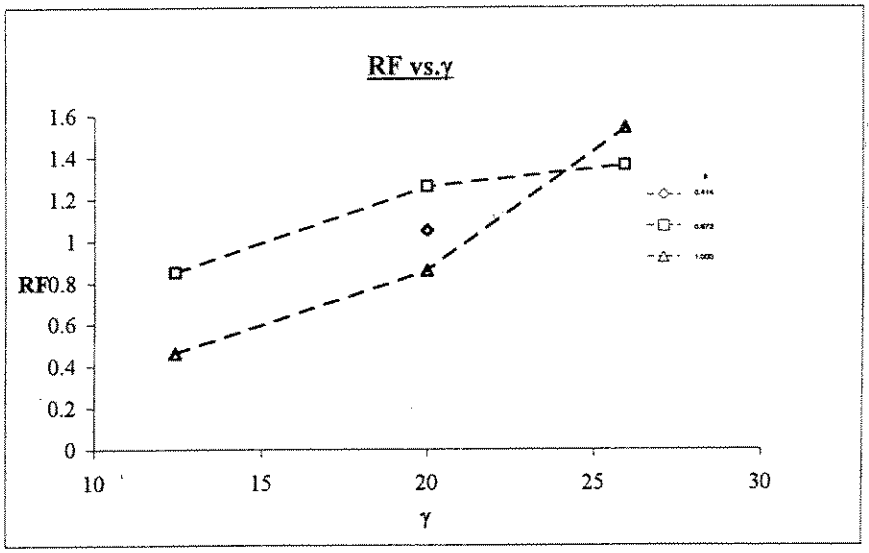




Fig. 13: DT Joints Under Compression, Brace Saddle



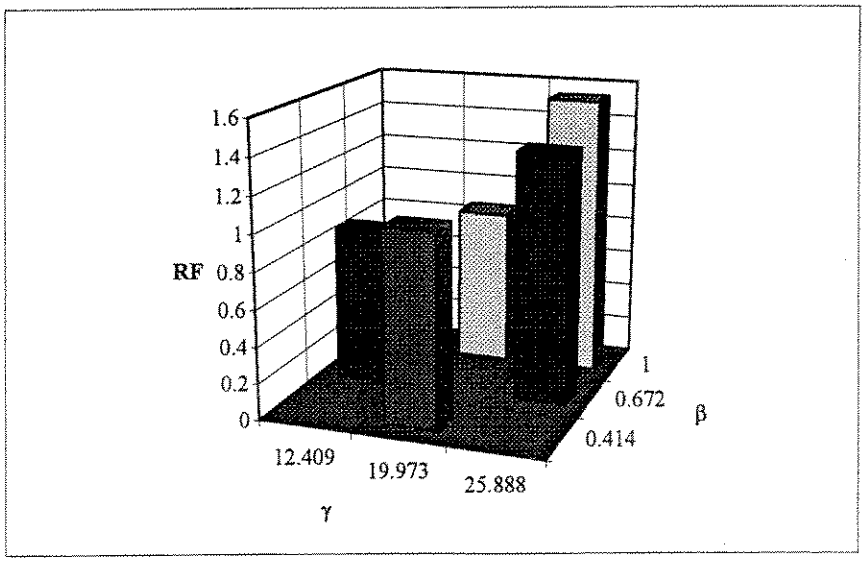
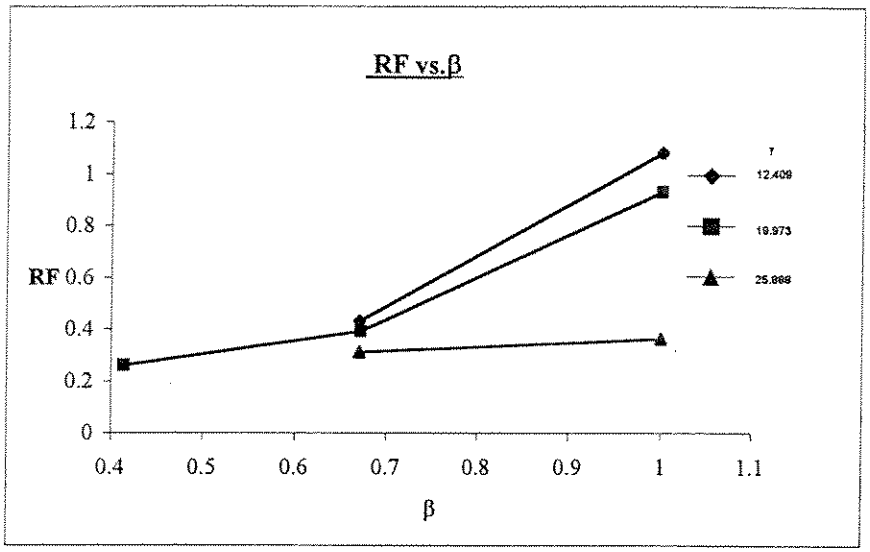
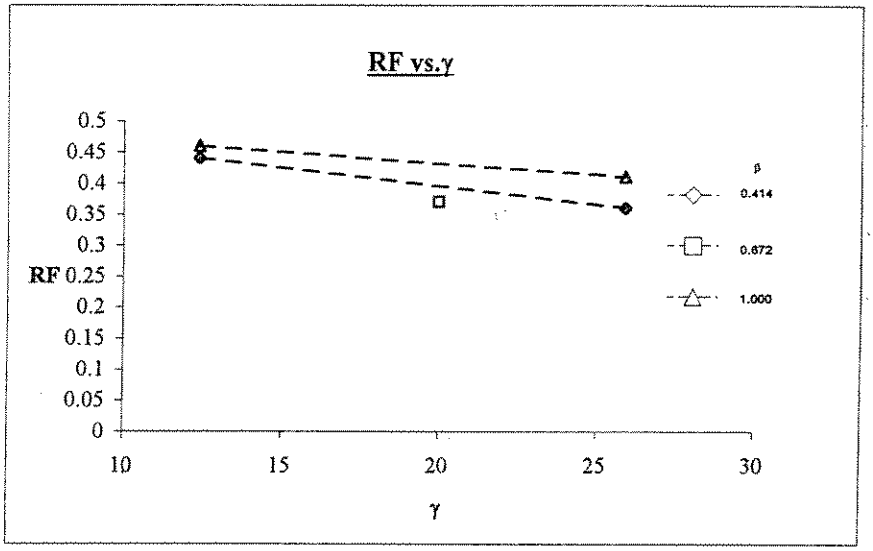




Fig. 14: DT Joints Under Compression, Brace Crown



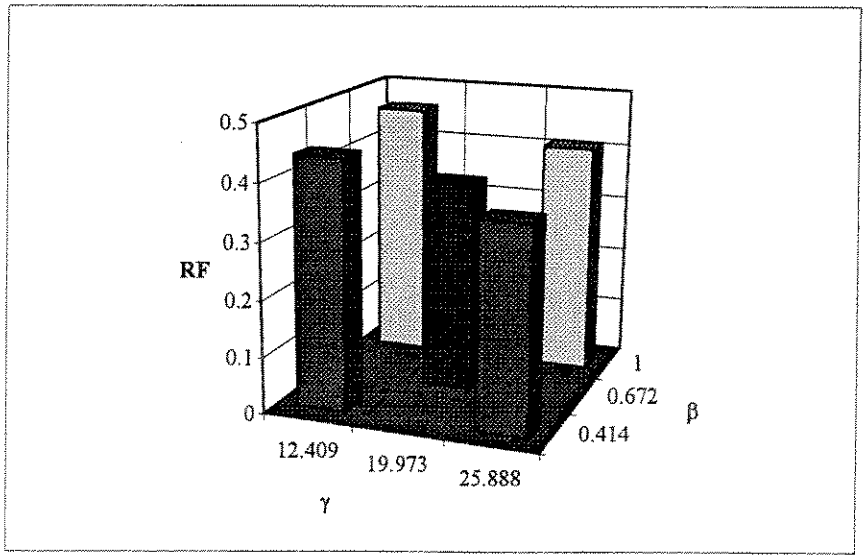
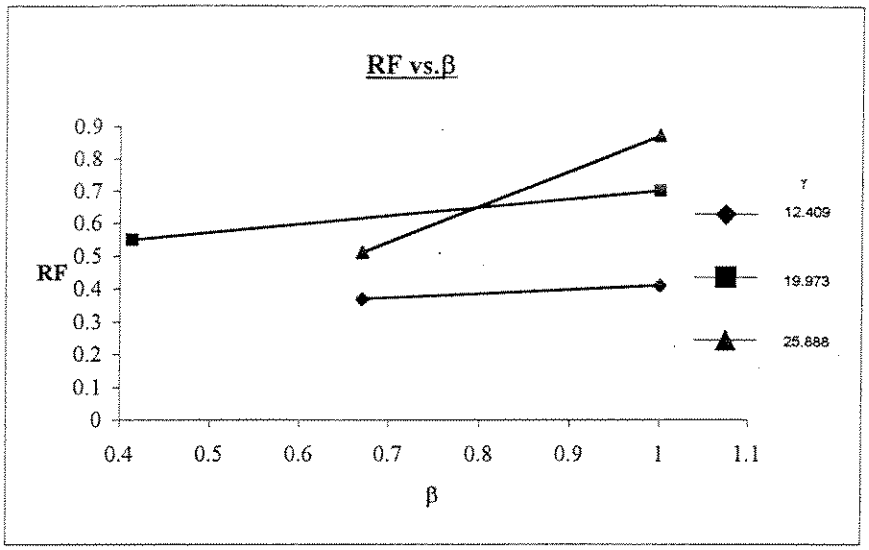
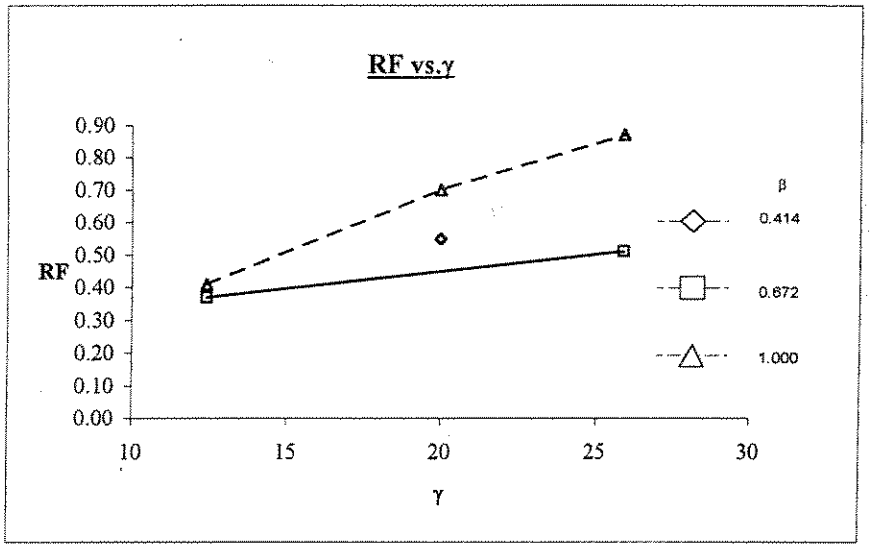




Fig. 15: DT Joints Under Tension, Brace Saddle



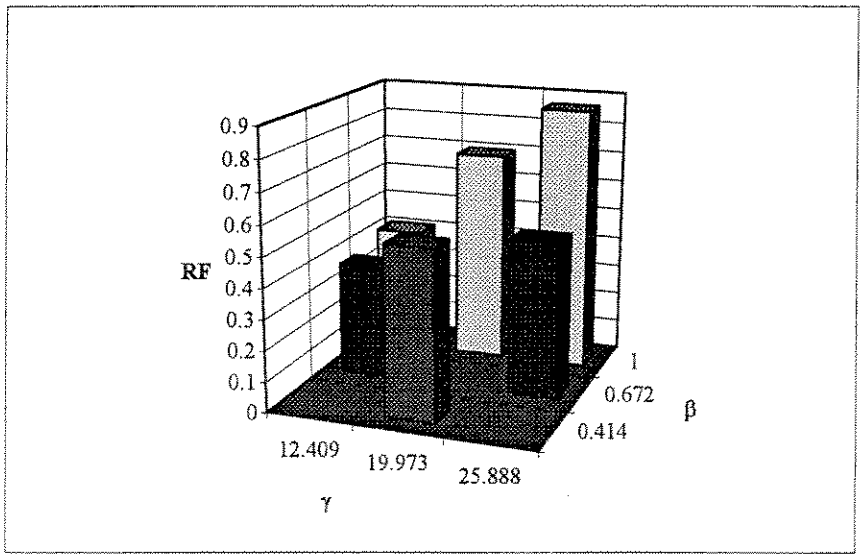
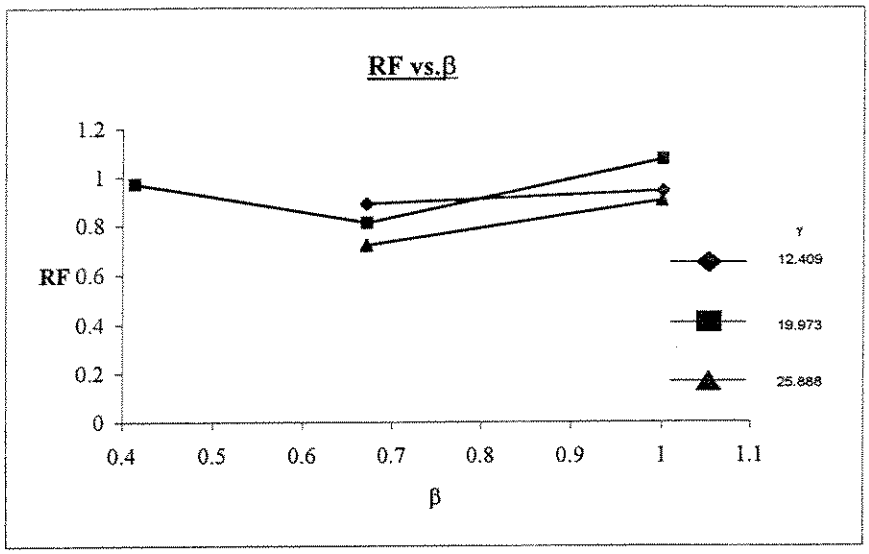
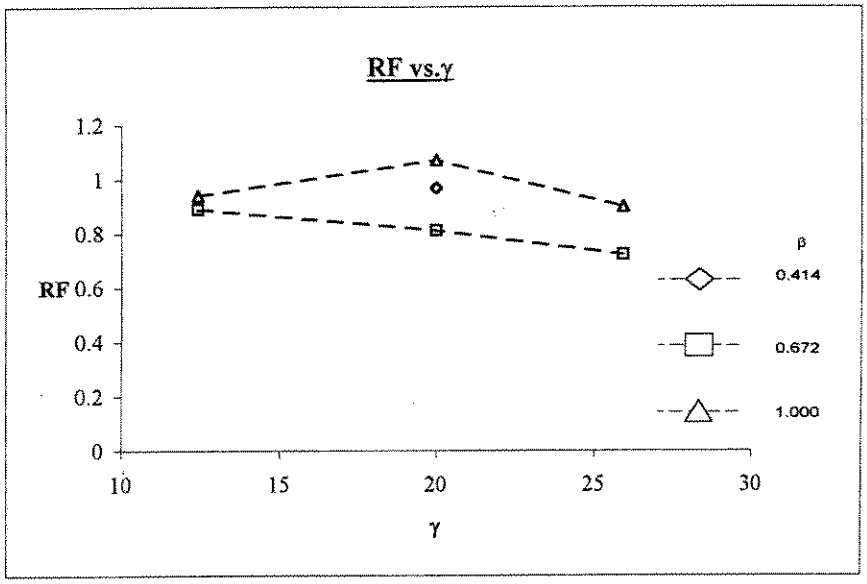




Fig. 16: DT Joints Under Tension, Brace Crown



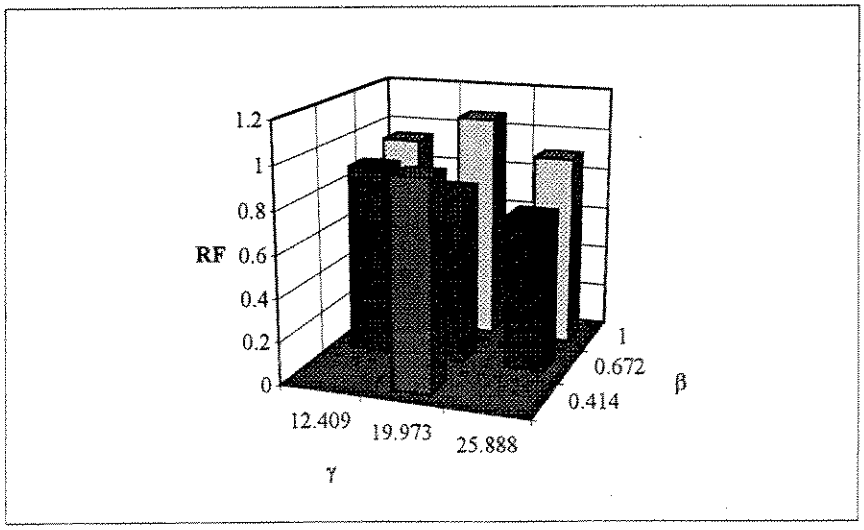
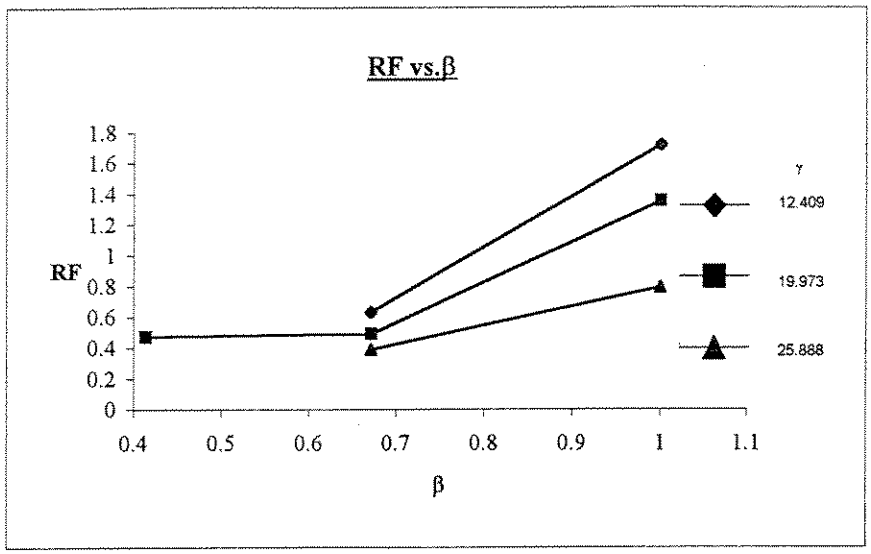
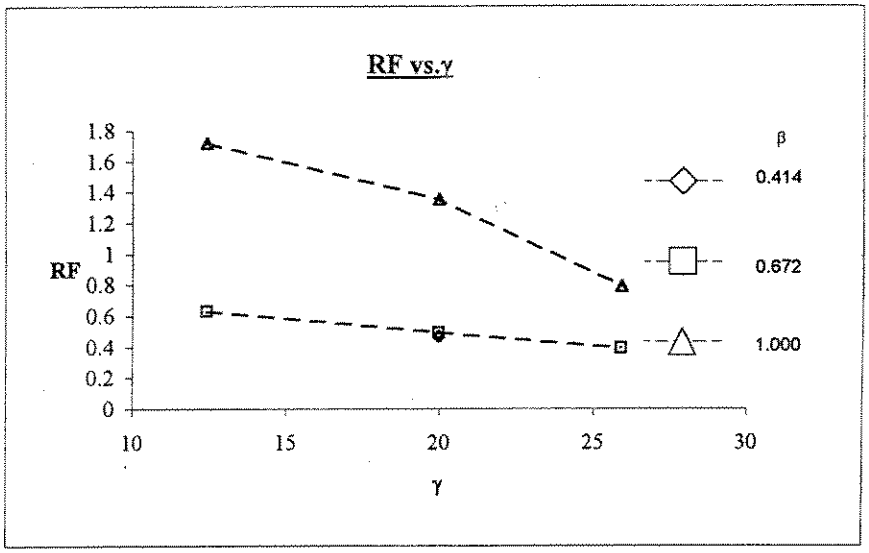




Fig. 17: DT Joints Under IPB, Brace Crown



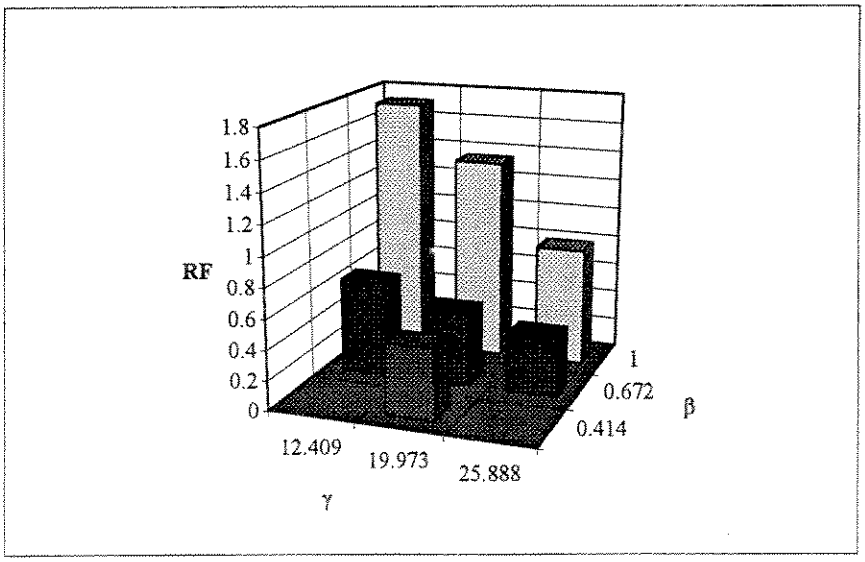
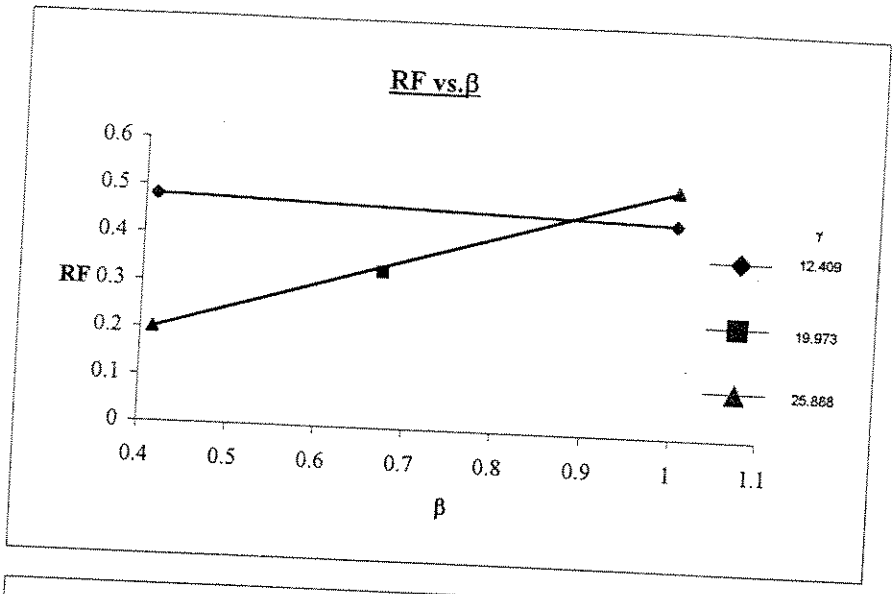
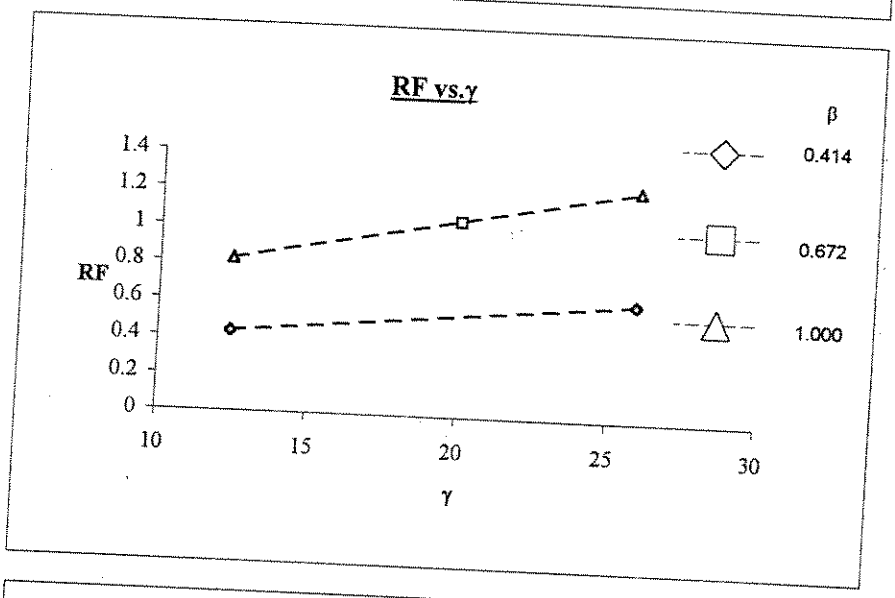




Fig. 18: DT Joints Under OPB, Brace Saddle



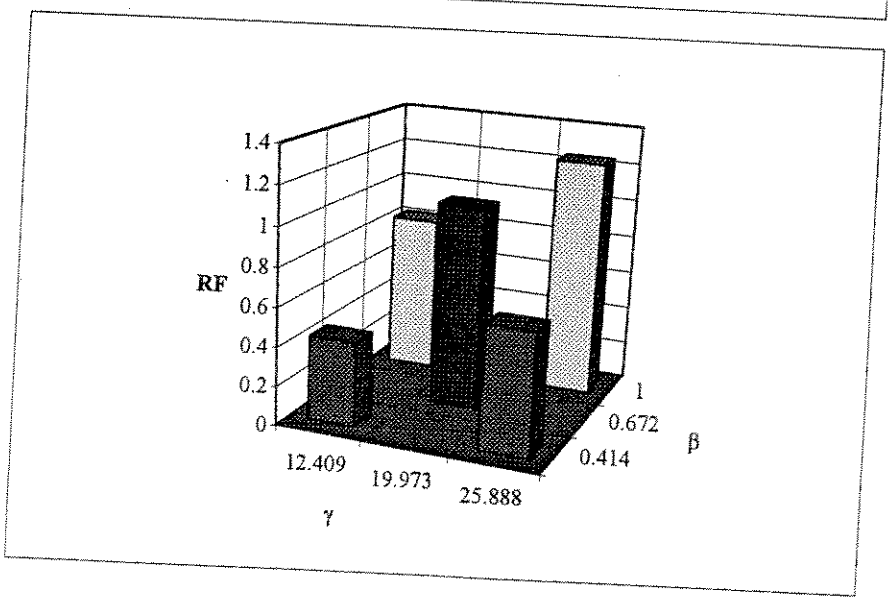
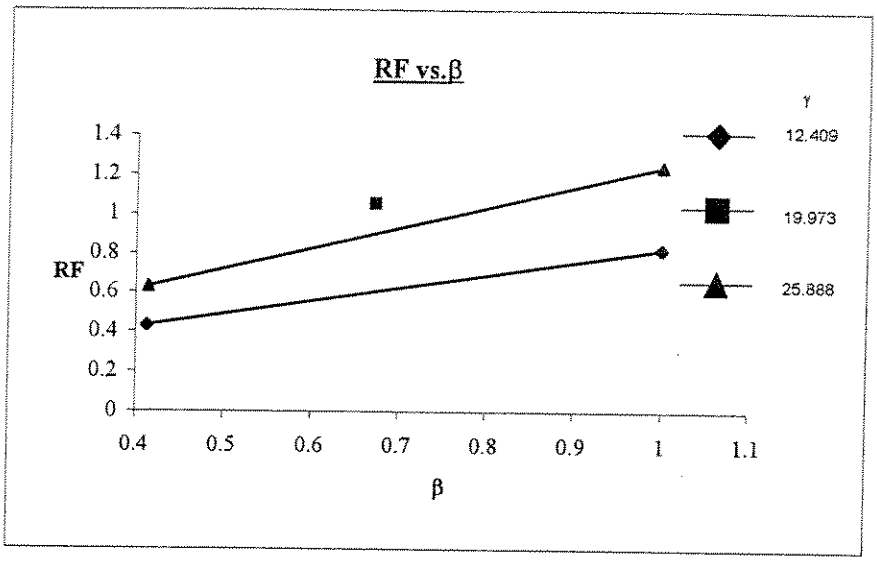
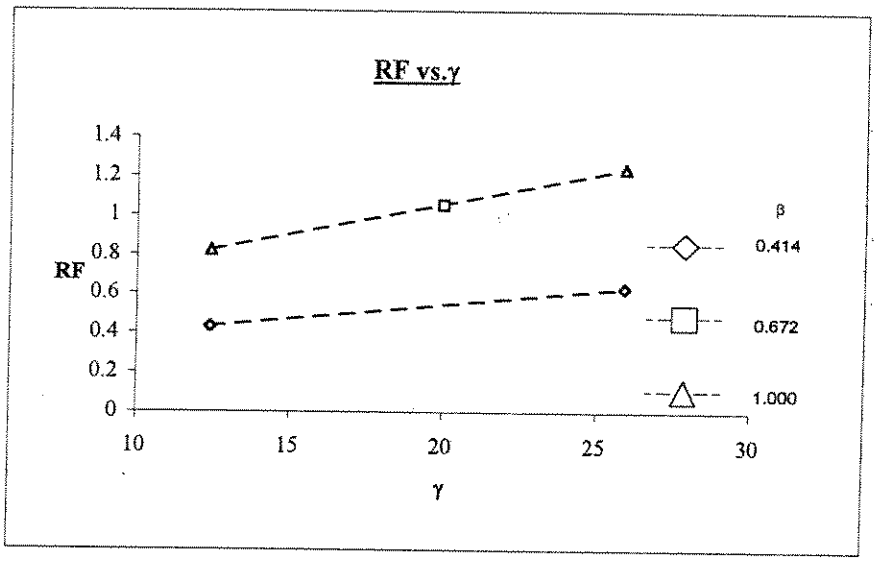




Fig. 19: T Joints Under Compression, Brace Saddle



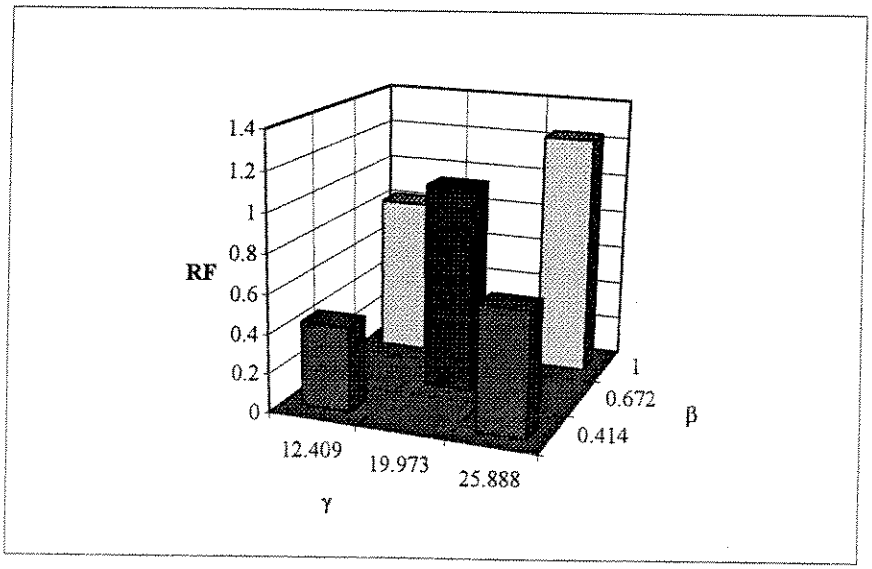
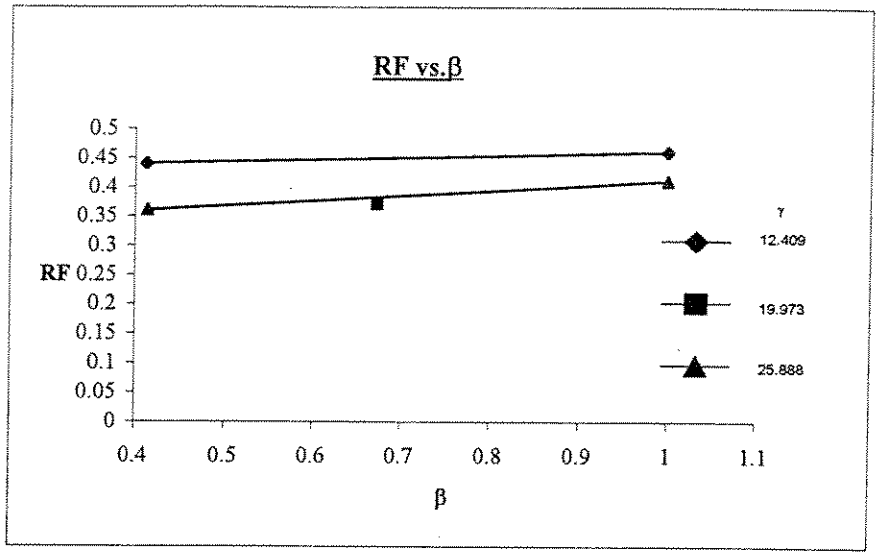
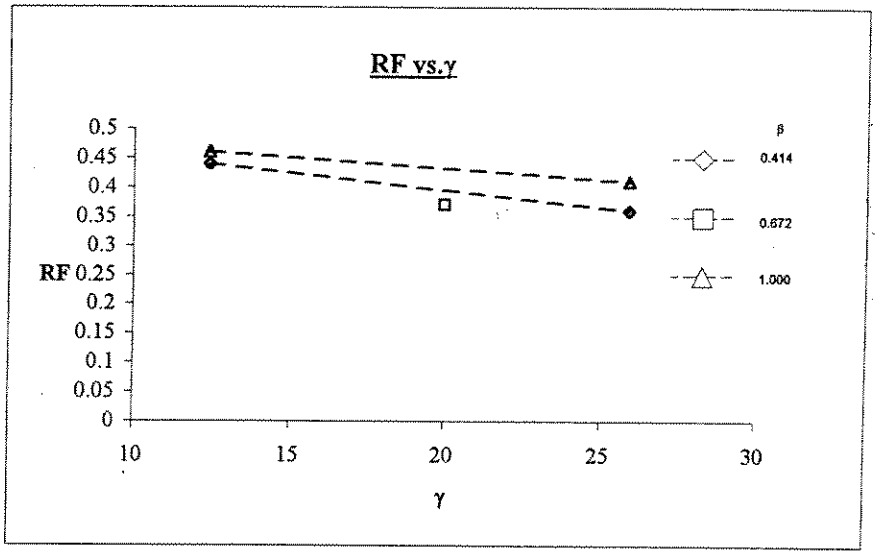




Fig. 20: T Joints Under Compression, Brace Crown



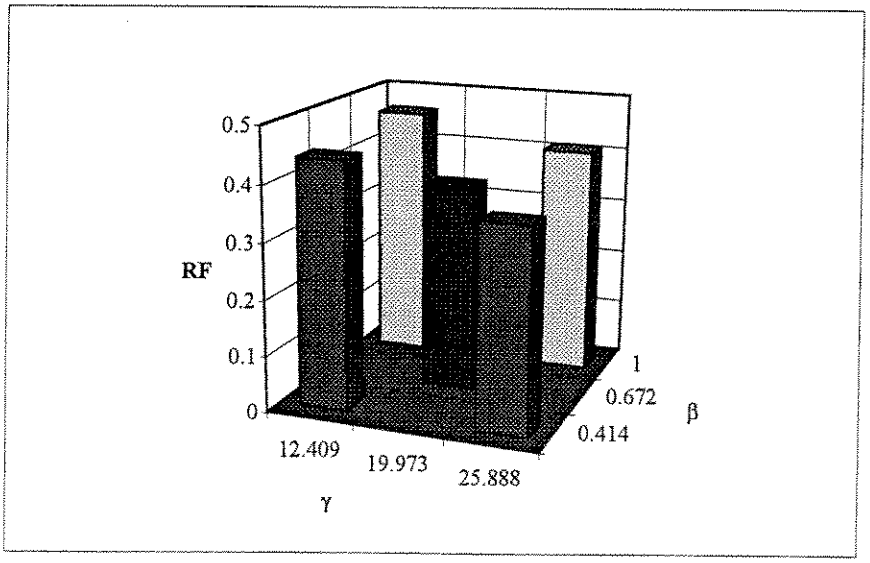
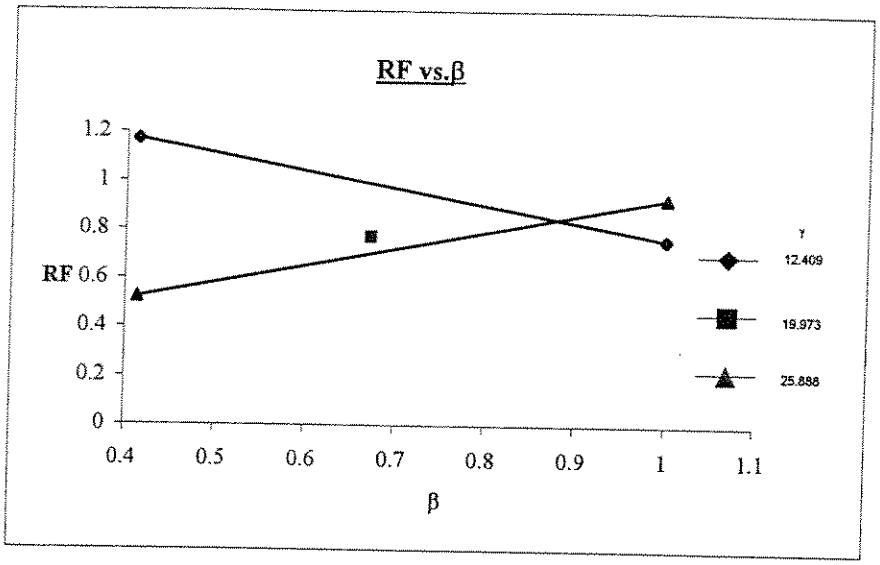
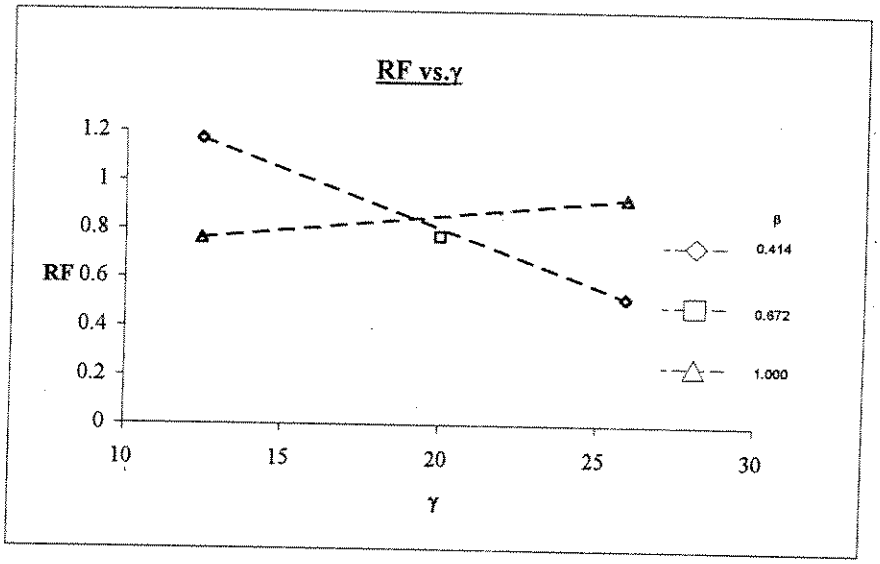




Fig. 21: T Joints Under Tension, Brace Saddle



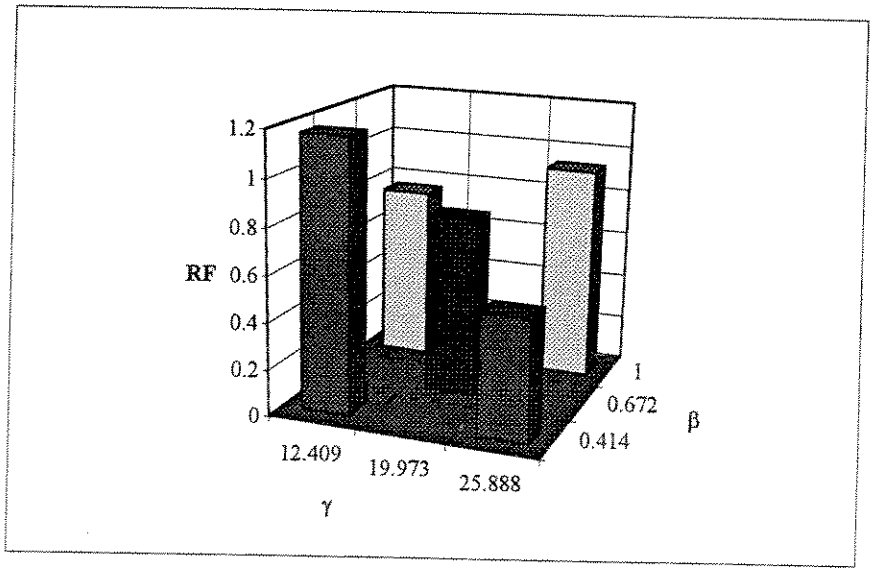
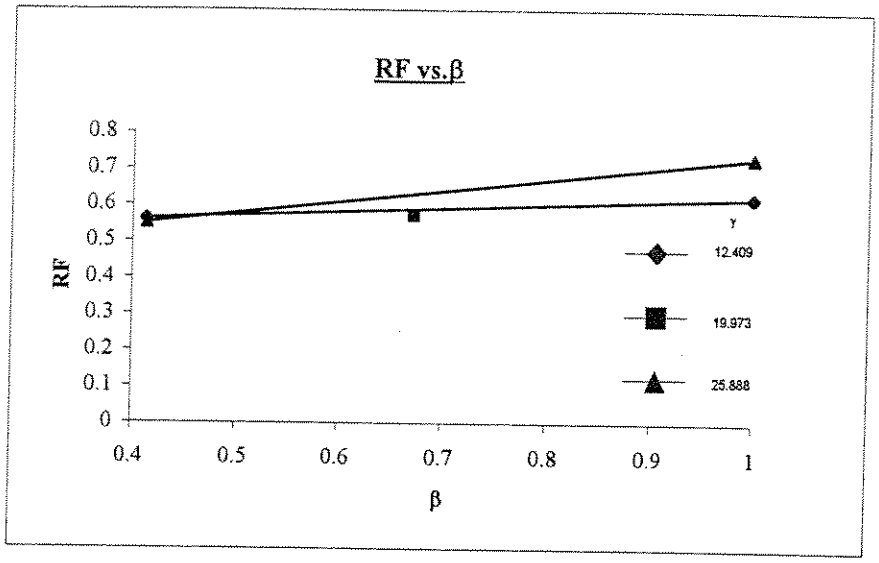
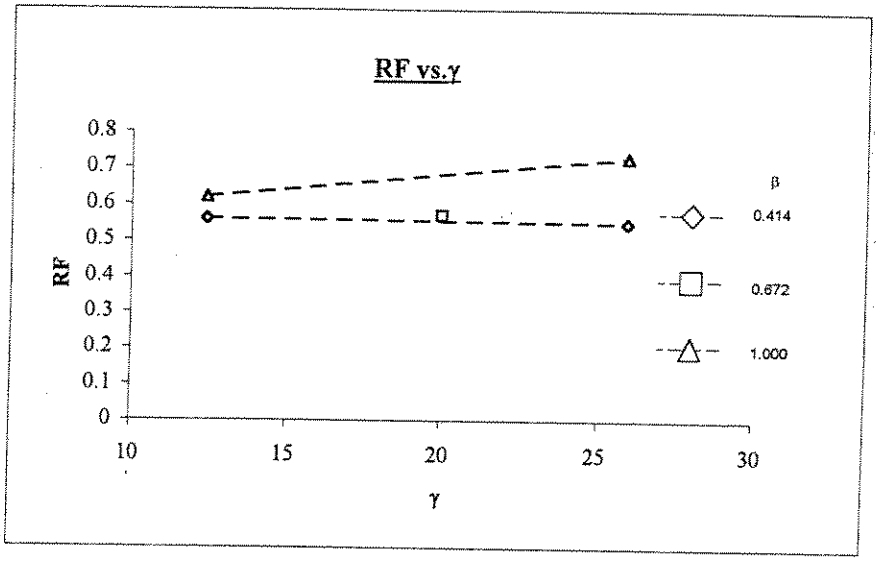




Fig. 22: T Joints Under Tension, Brace Crown



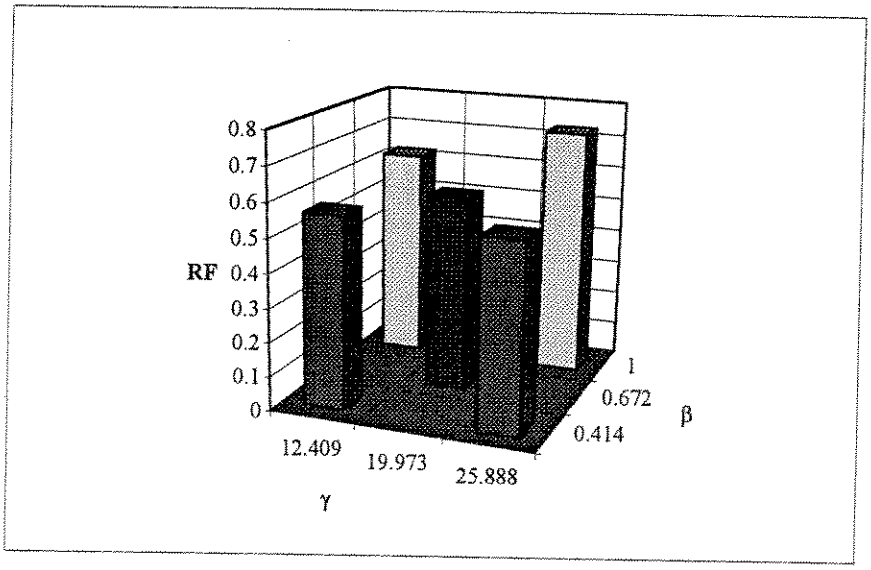
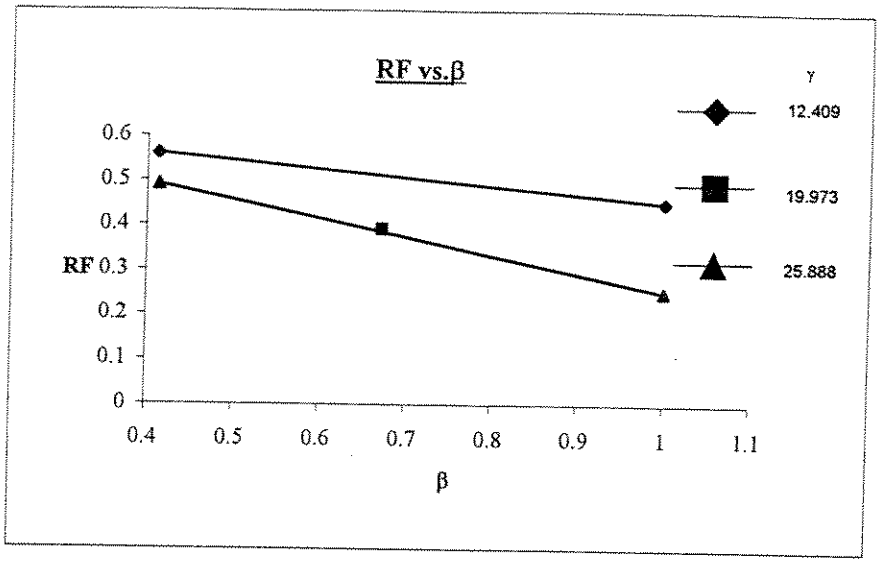
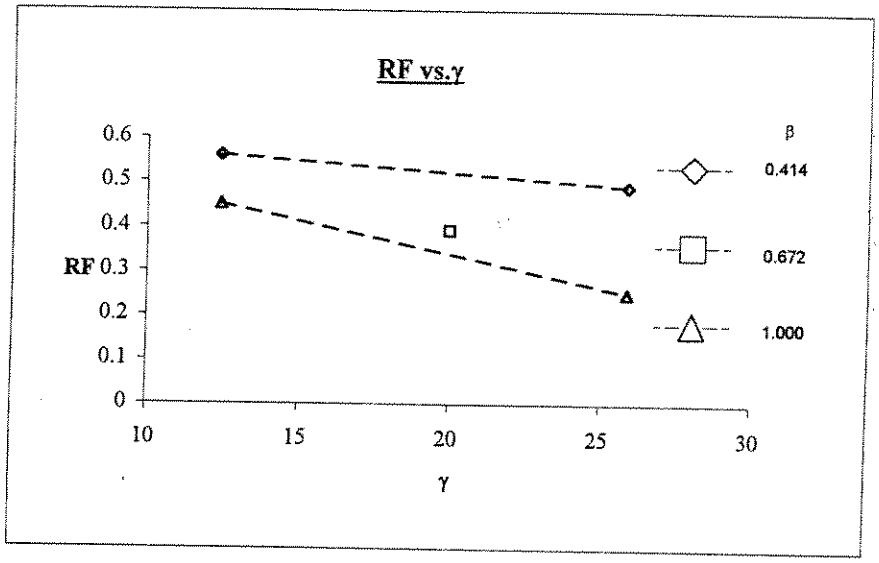




Fig. 23: T Joints Under IPB, Brace Crown



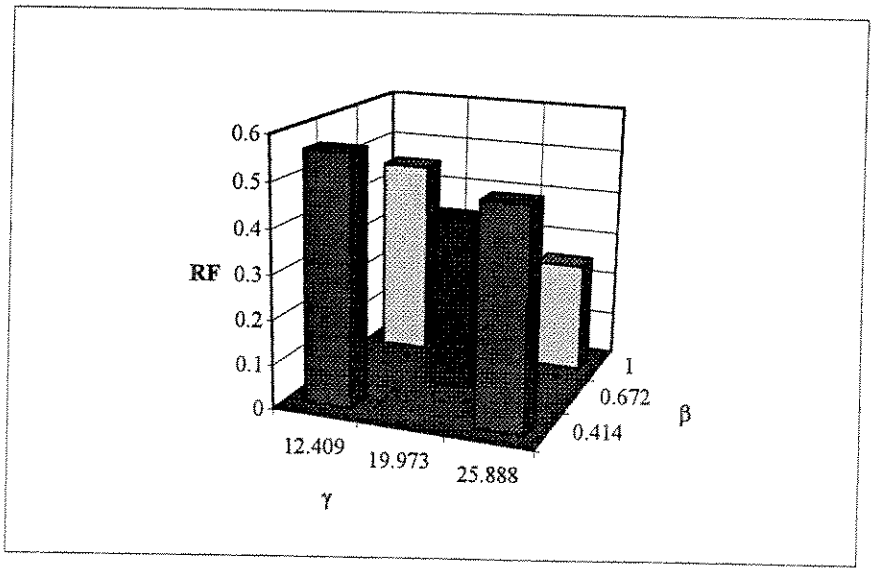
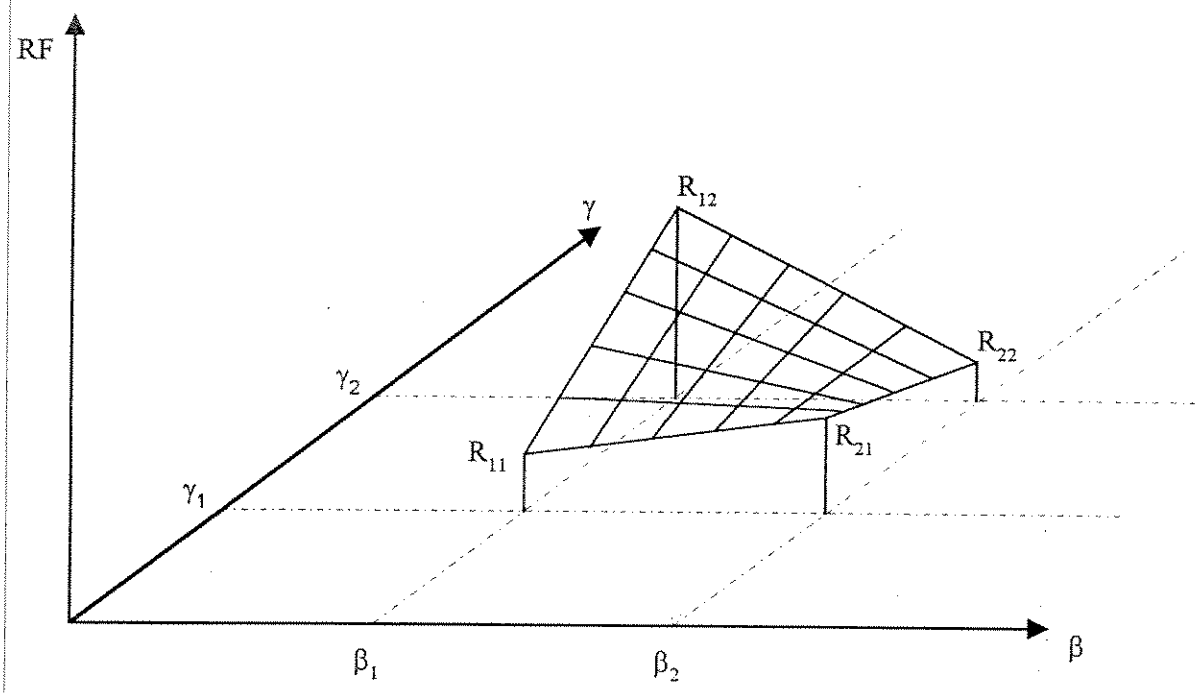




Fig. 24: T Joints Under OPB, Brace Saddle




$$RF = \frac{1}{(\beta_2-\beta_1)(\gamma_2-\gamma_1)} \{(R_{11}\beta_2\gamma_2-R_{12}\beta_2\gamma_1-R_{21}\beta_1\gamma_2+R_{22}\beta_1\gamma_1) + \beta(-R_{11}\gamma_2+R_{12}\gamma_1+R_{21}\gamma_2-R_{22}\gamma_1) + \gamma(-R_{11}\beta_2+R_{12}\beta_2+R_{21}\beta_1-R_{22}\beta_1) + \beta\gamma(R_{11}-R_{12}-R_{21}+R_{22})\}$$

**Fig. 25: Geometry of a Twisted Plane**

MSL

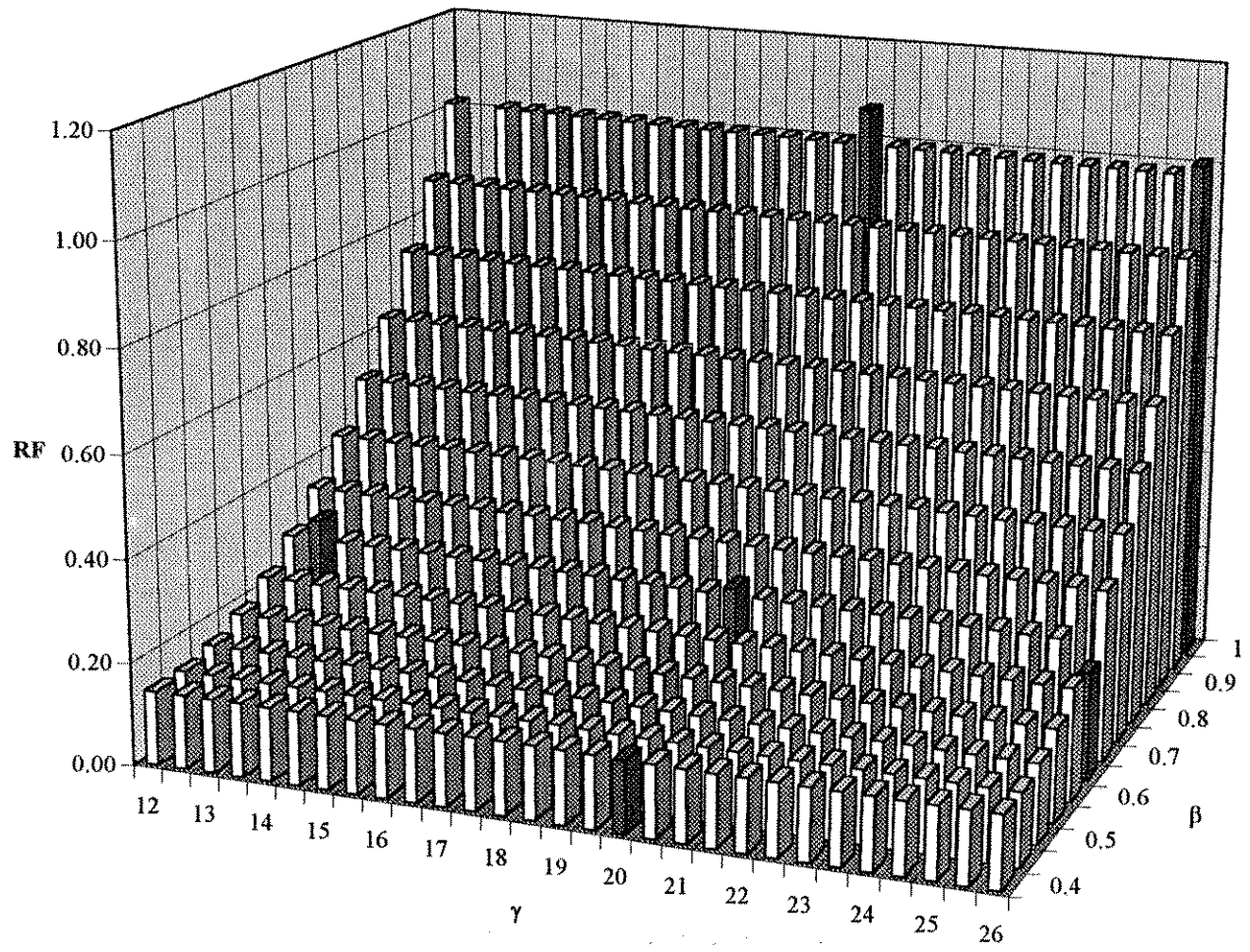



**Fig. 26: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Chord Saddle**

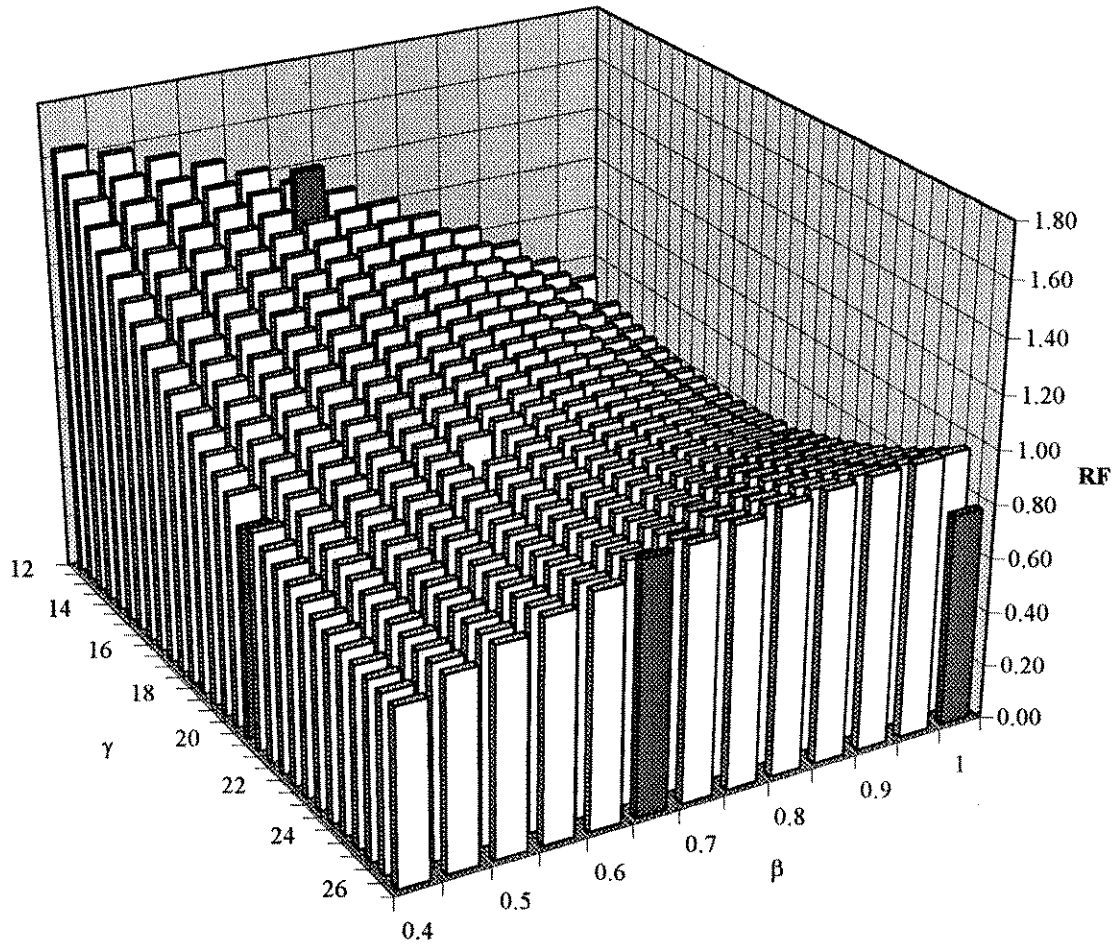



**Fig. 27: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Chord Crown (Final)**



MSL

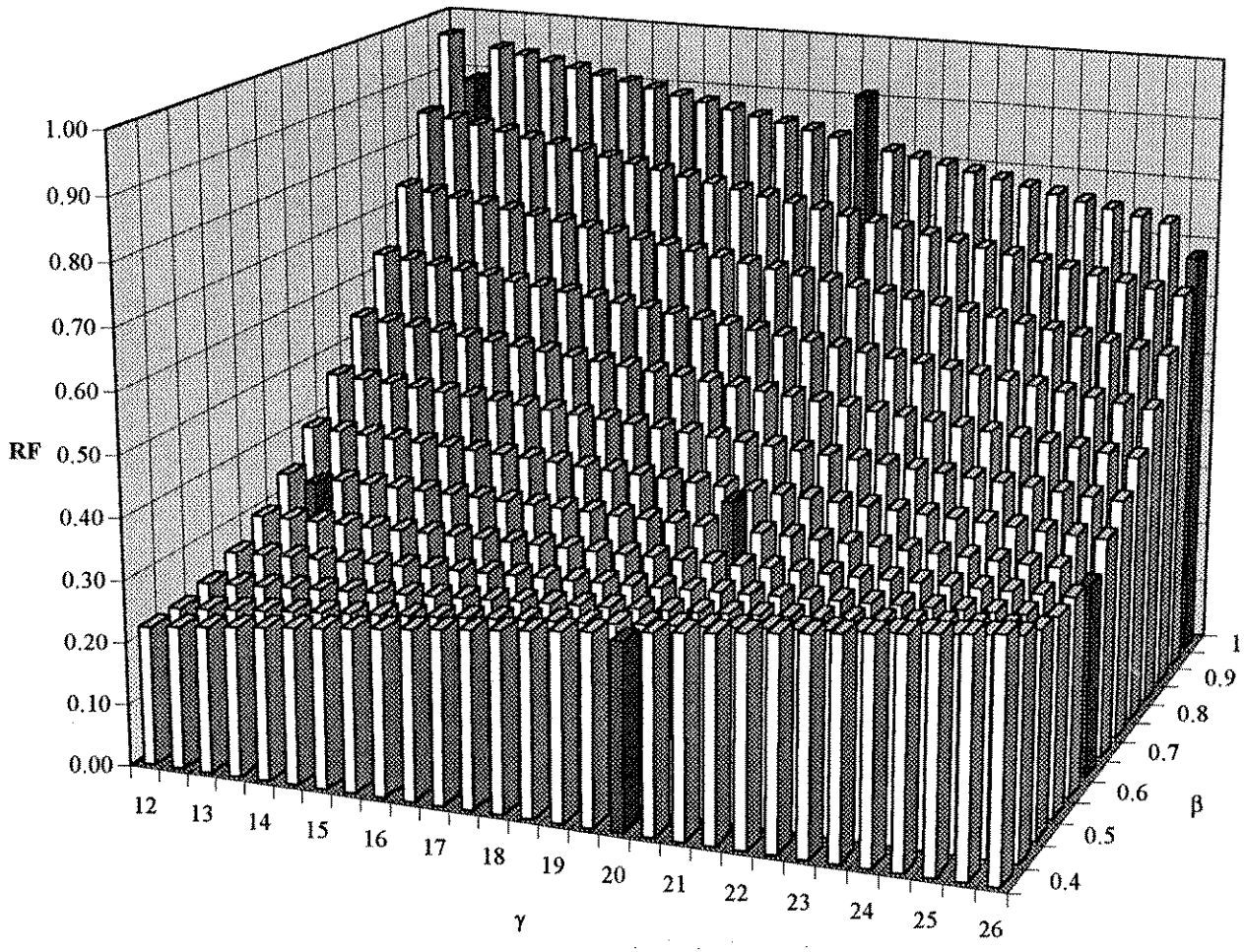



**Fig. 28: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Chord Saddle**

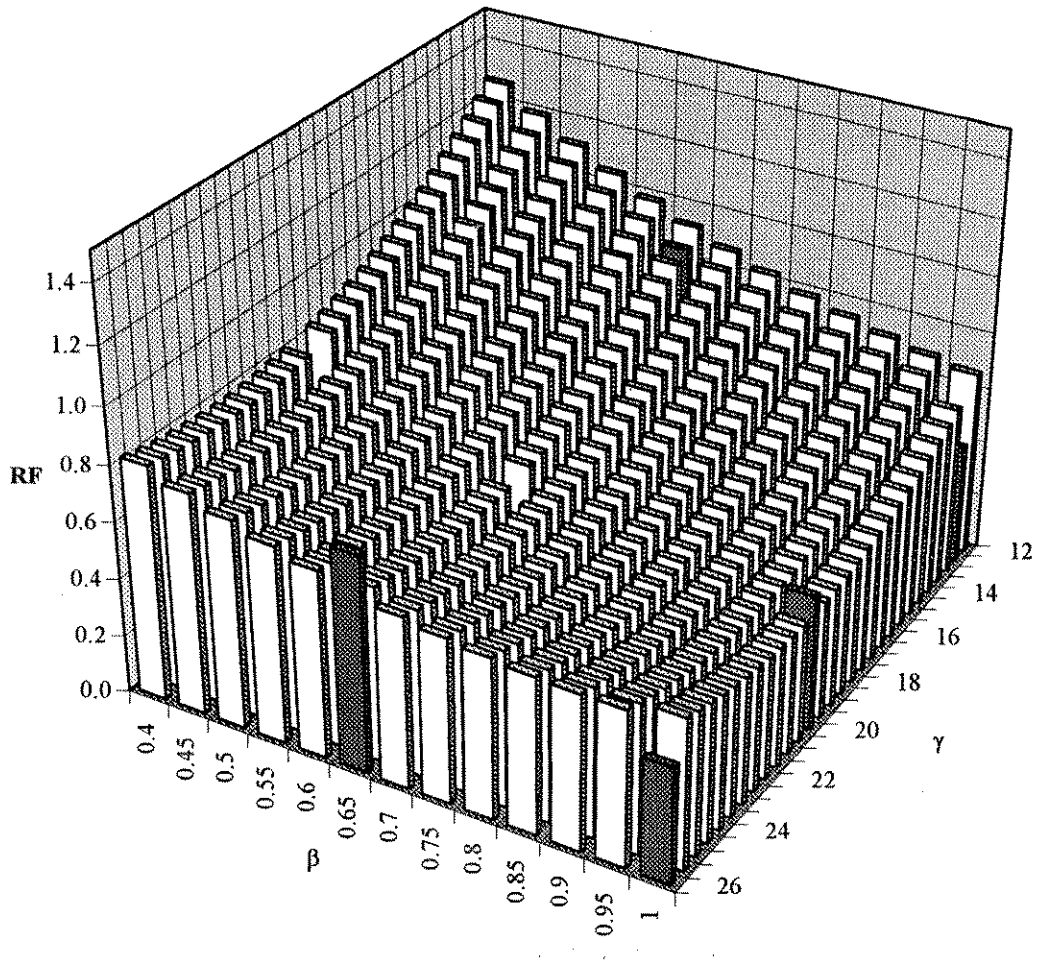



**Fig. 29: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Chord Crown (Final)**



MSL

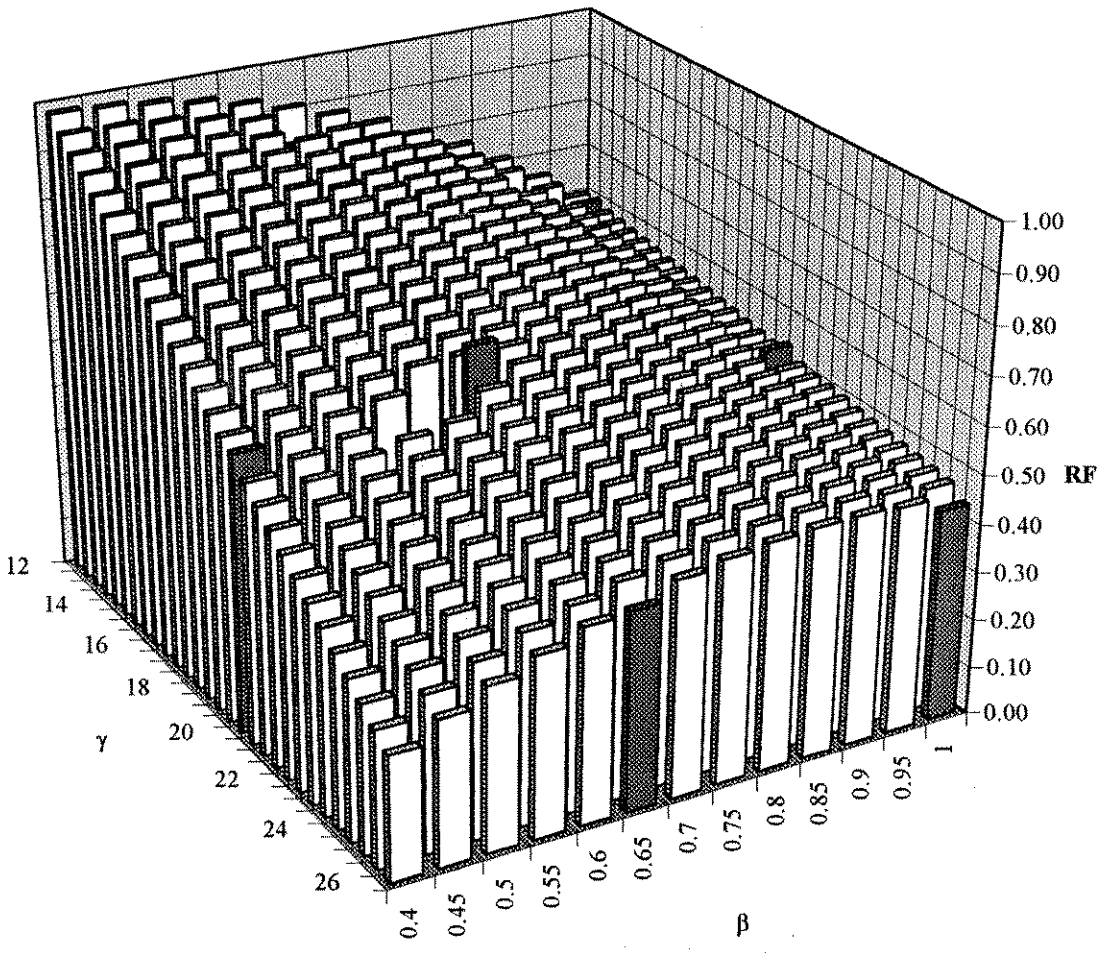



**Fig. 30: Comparison of Fitted Surface with Measured Values for DT Joints under IPB, Chord Crown**

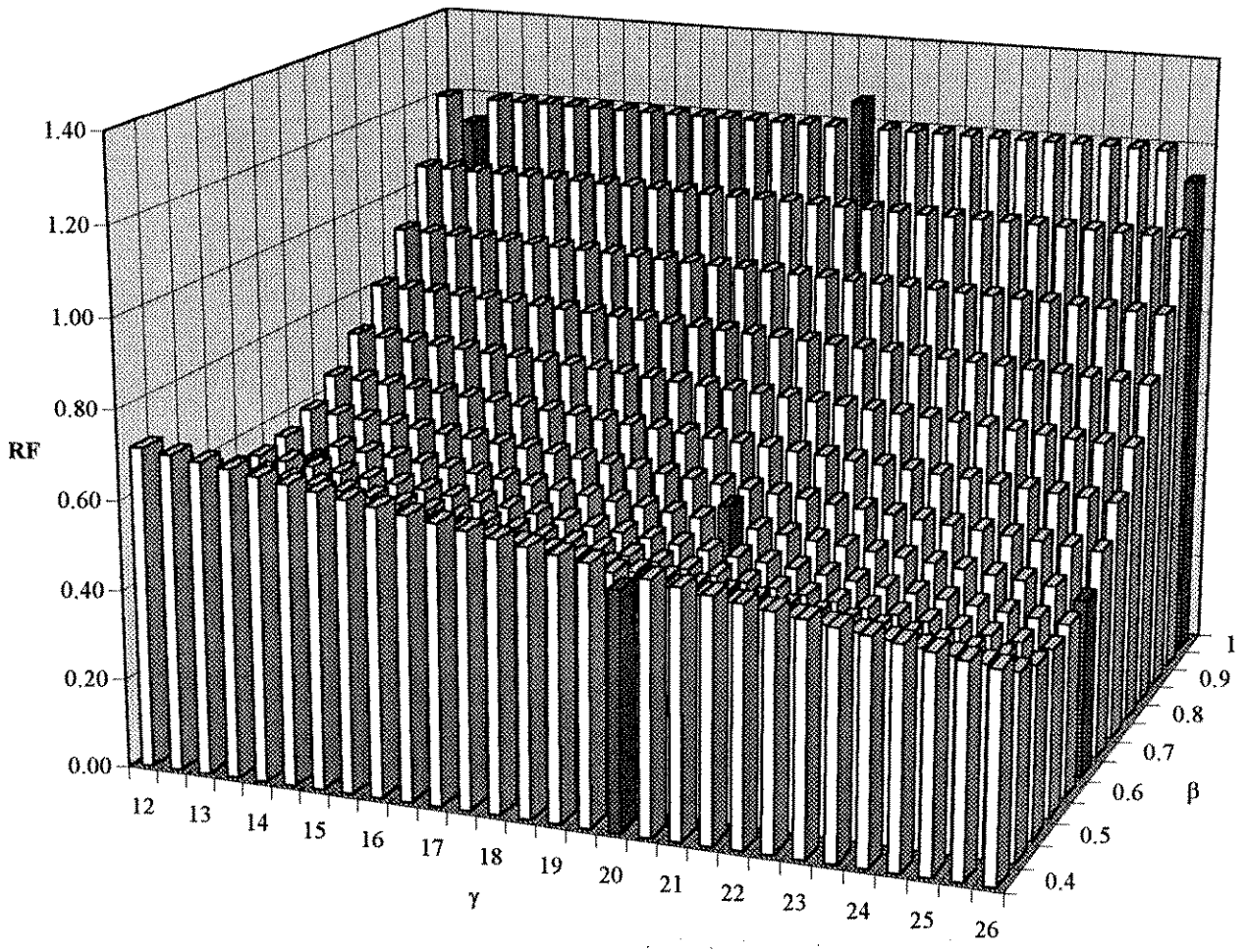



**Fig. 31: Comparison of Fitted Surface with Measured Values for DT Joints under OPB, Chord Saddle**

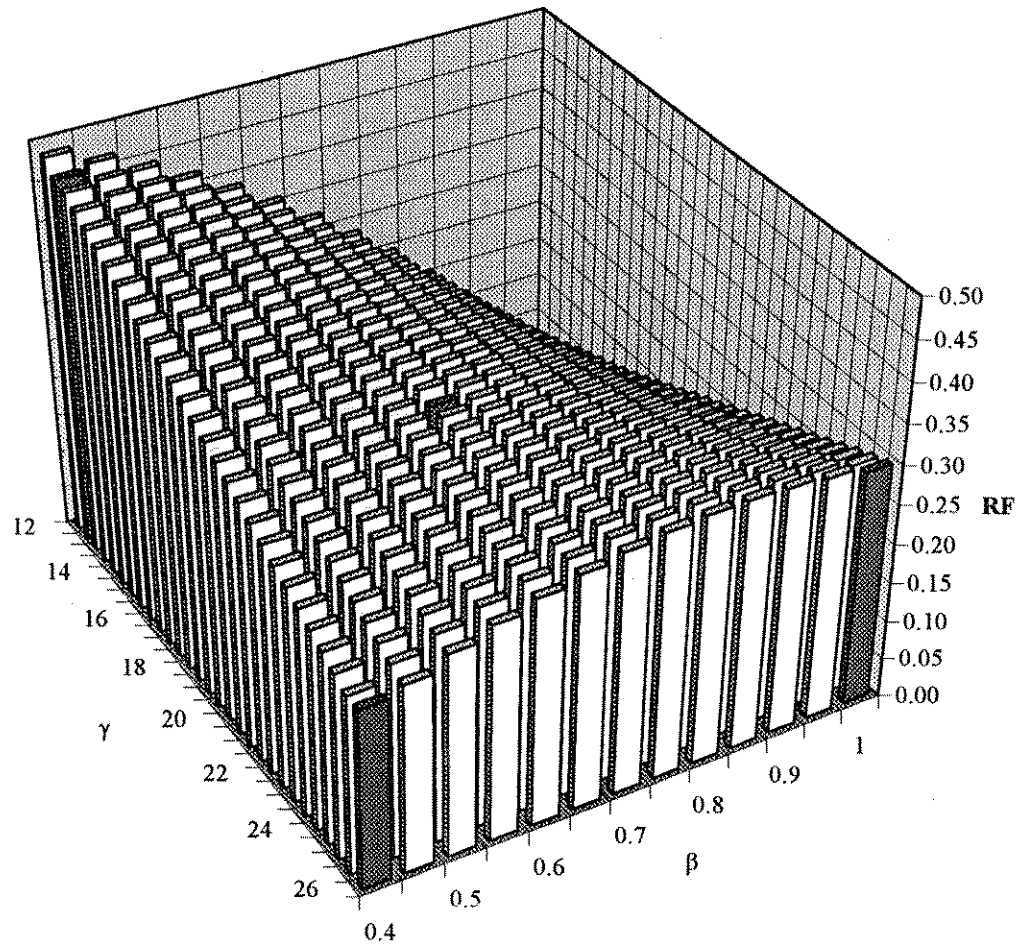



**Fig 32: Comparison of Fitted Surface with Measured Values for T Joints under Compression, Chord Saddle**



MSL

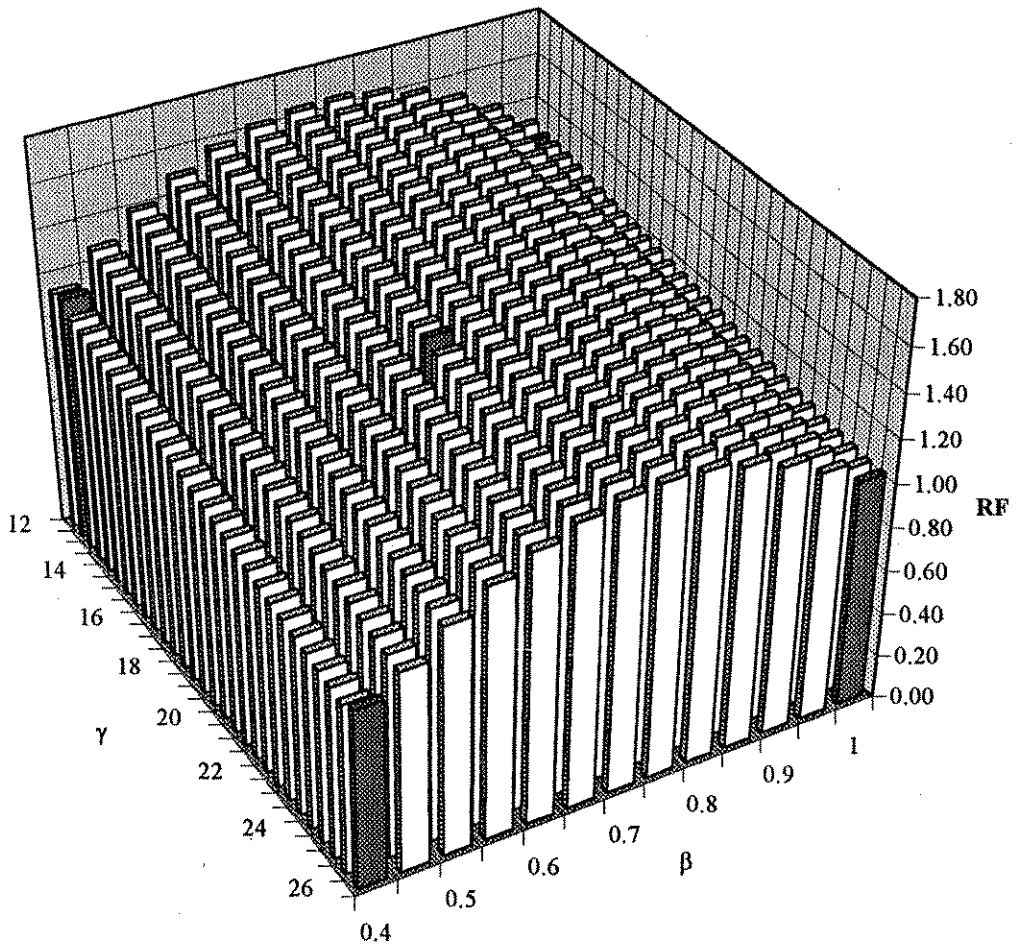



**Fig. 33: Comparison of Fitted Surface with Measured Values for T Joints Compression, Chord Crown**



MSL

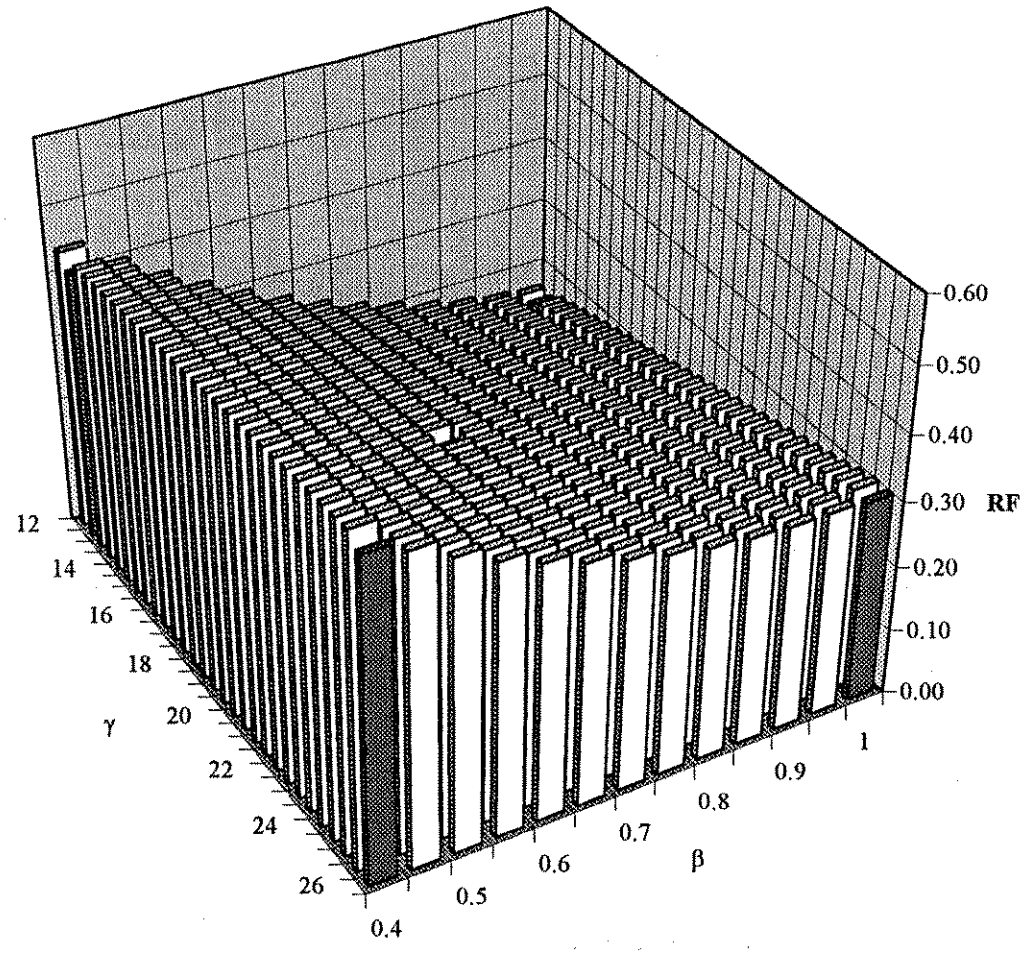



**Fig 34: Comparison of Fitted Surface with Measured Values for T joints under Tension, Chord Saddle**



MSL

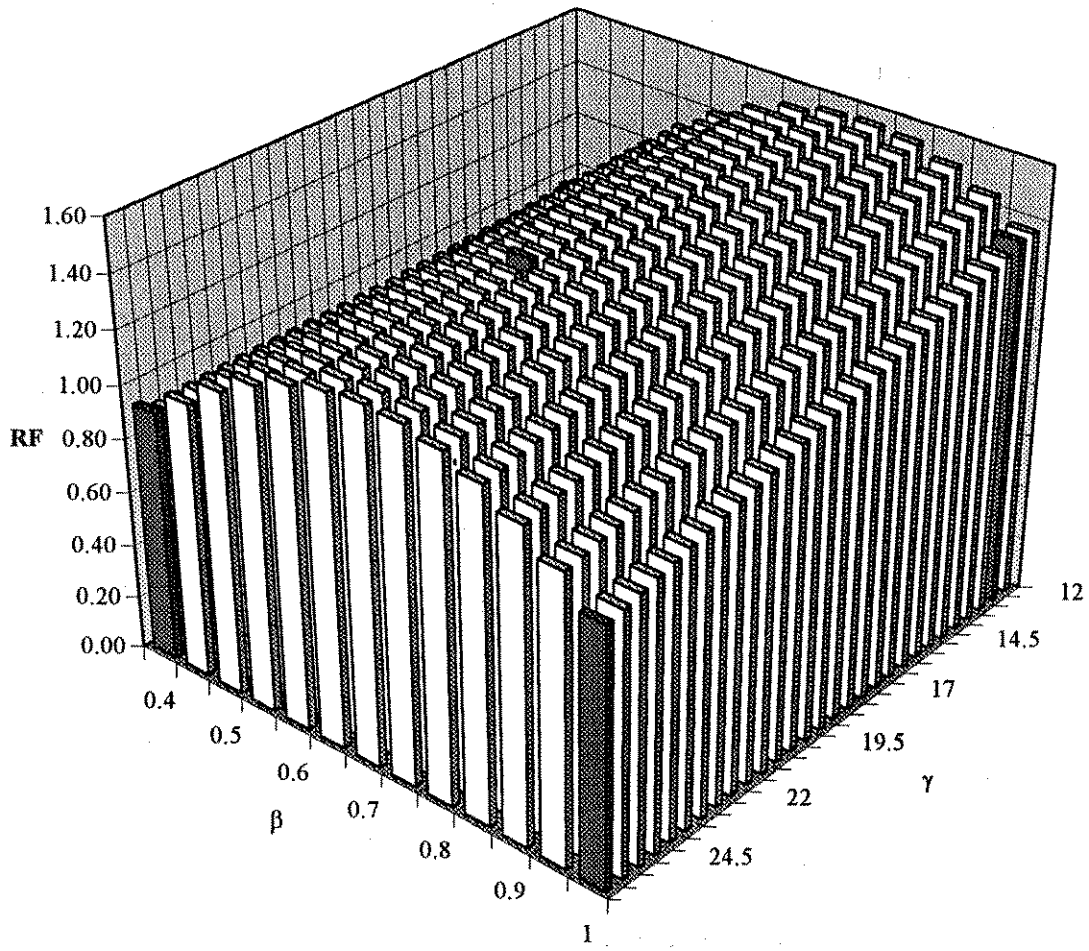



**Fig. 35: Comparison of Fitted Surface with Measured Values for T Joints under Tension, Chord Crown**



MSL

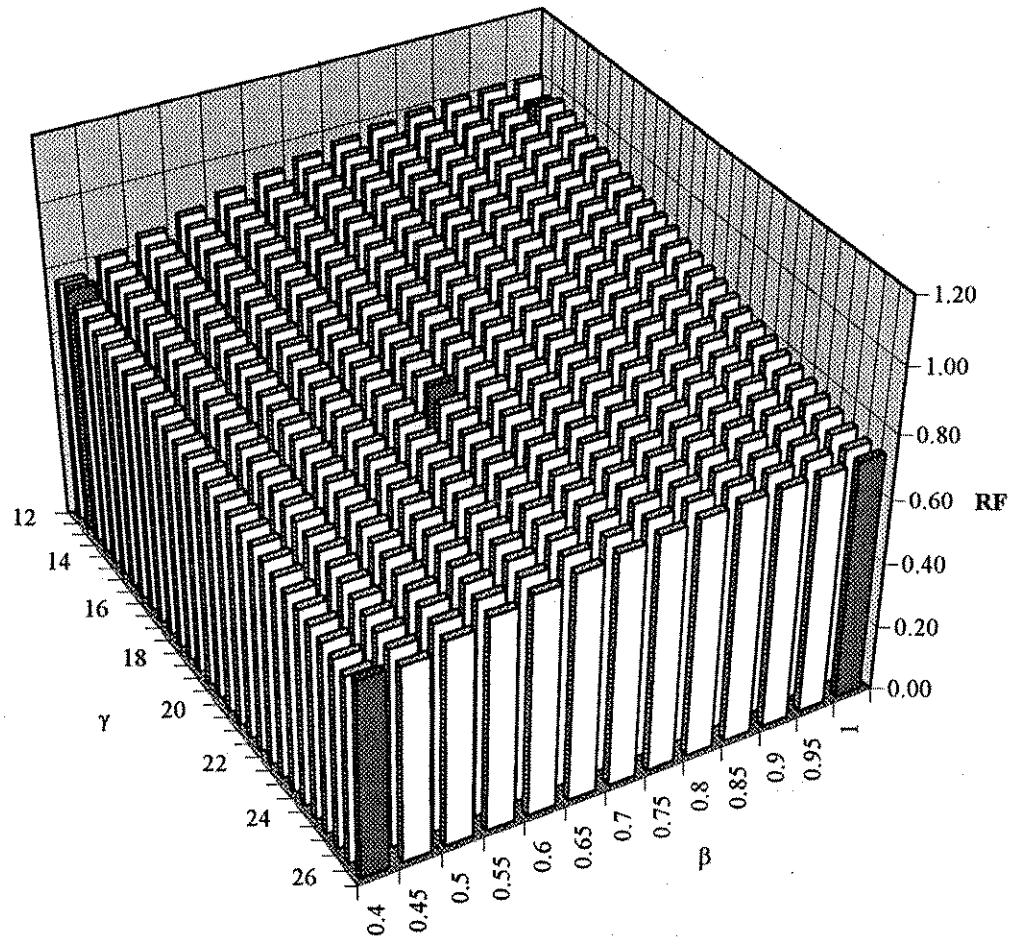



**Fig. 36: Comparison of fitted Surface with Measured Values for T Joints under IPB, Chord Crown**



MSL

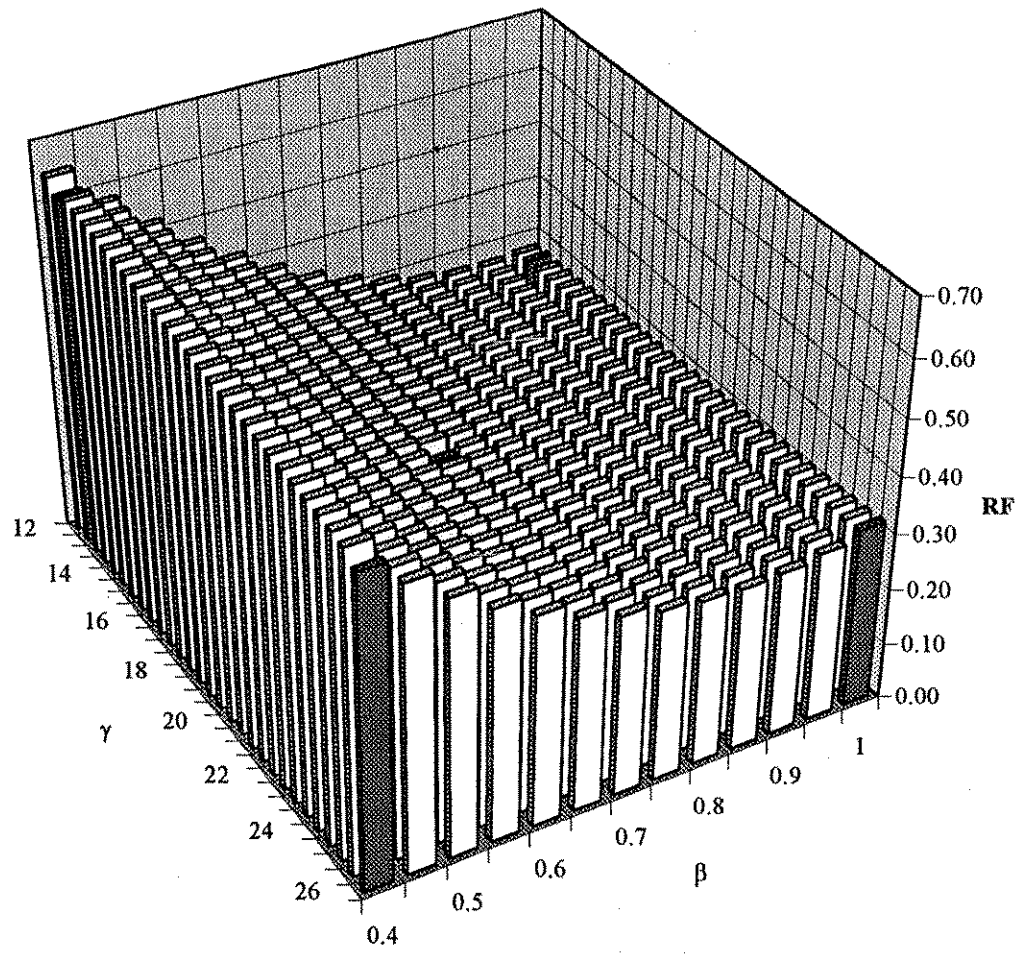



**Fig. 37: Comparison of Fitted Surface with Measured Values for T Joints under OPB, Chord Saddle**



MSL

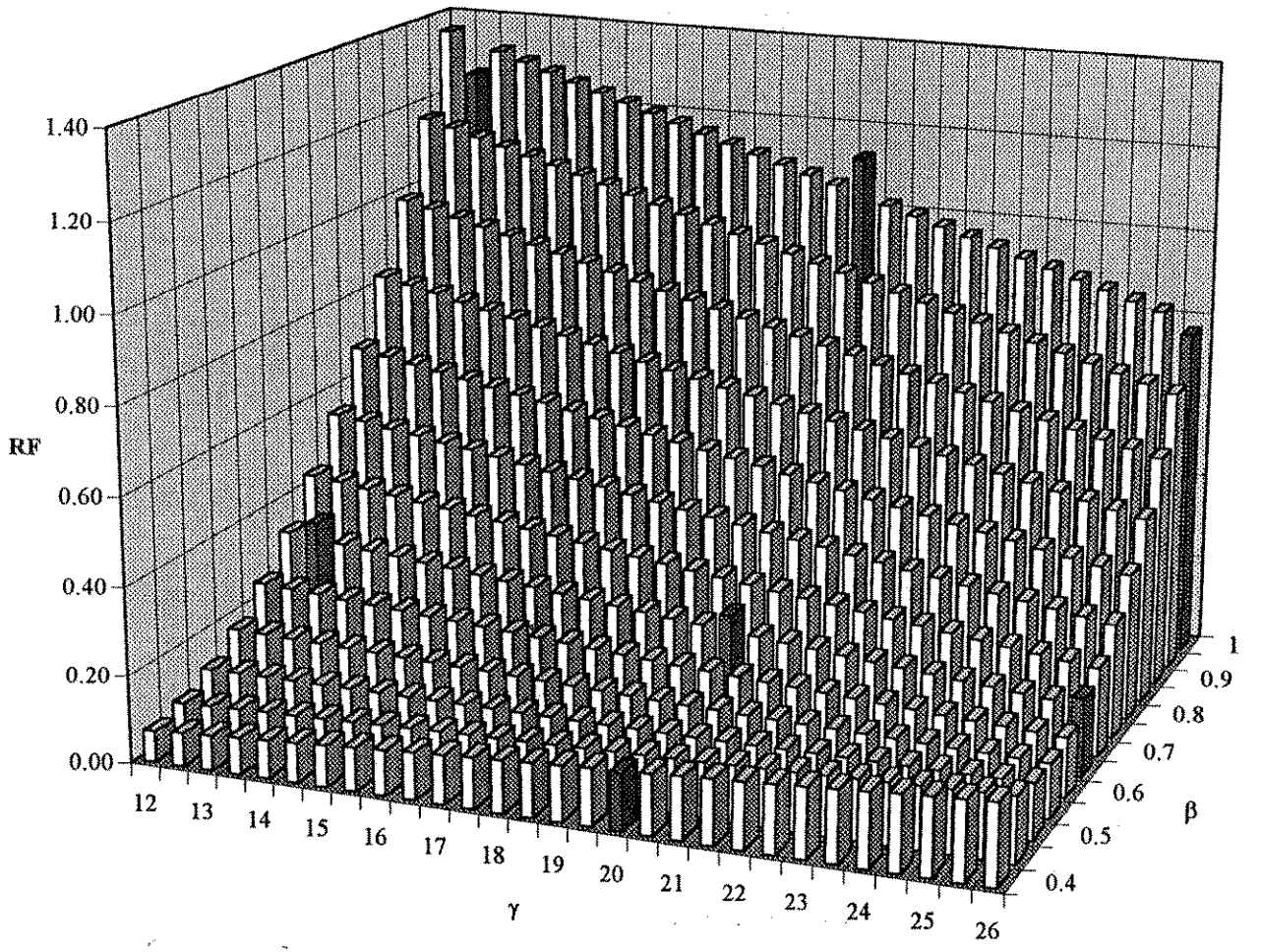



**Fig. 38: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Brace Saddle**

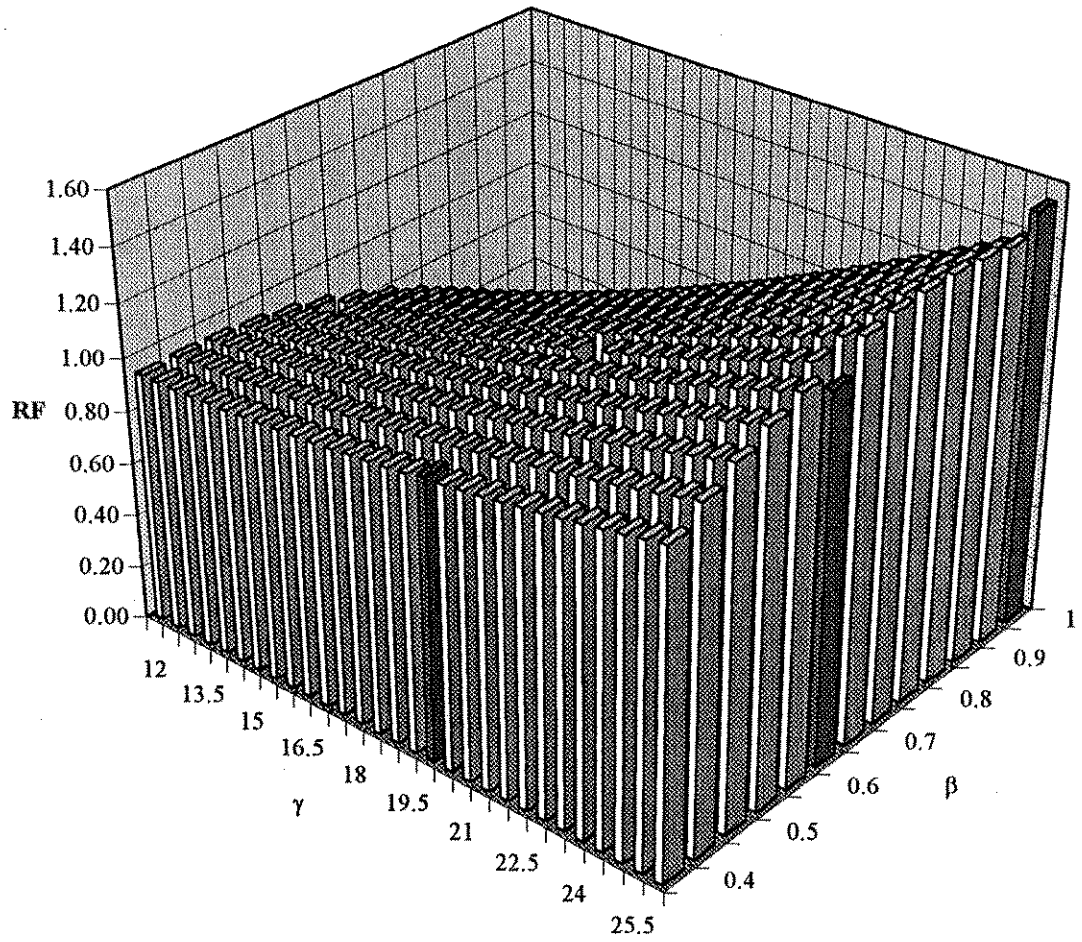



**Fig. 39: Comparison of Fitted Surface with Measured Values for DT Joints under Compression, Brace Crown**

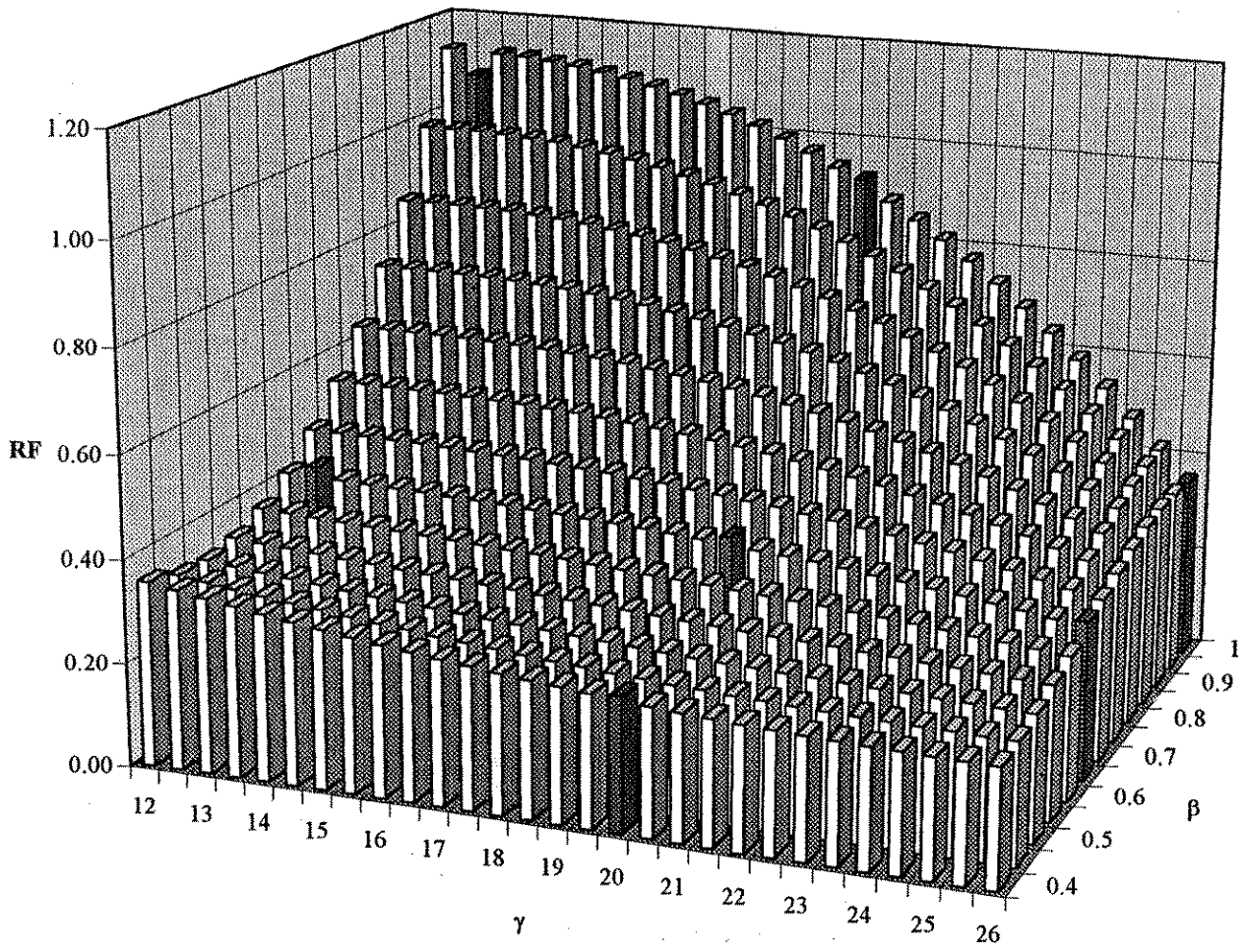



**Fig. 40: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Brace Saddle**



MSL

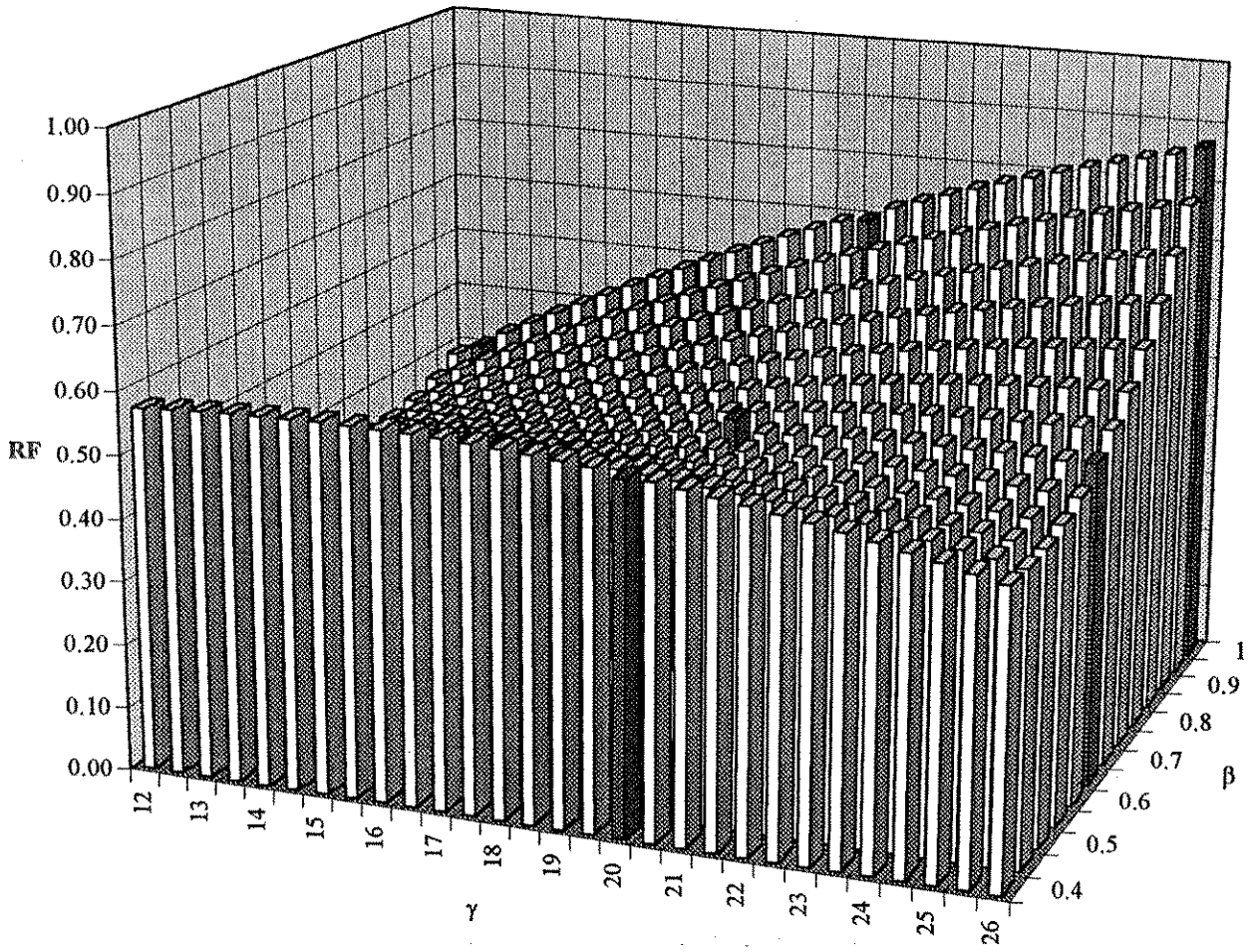



**Fig. 41: Comparison of Fitted Surface with Measured Values for DT Joints under Tension, Brace Crown**

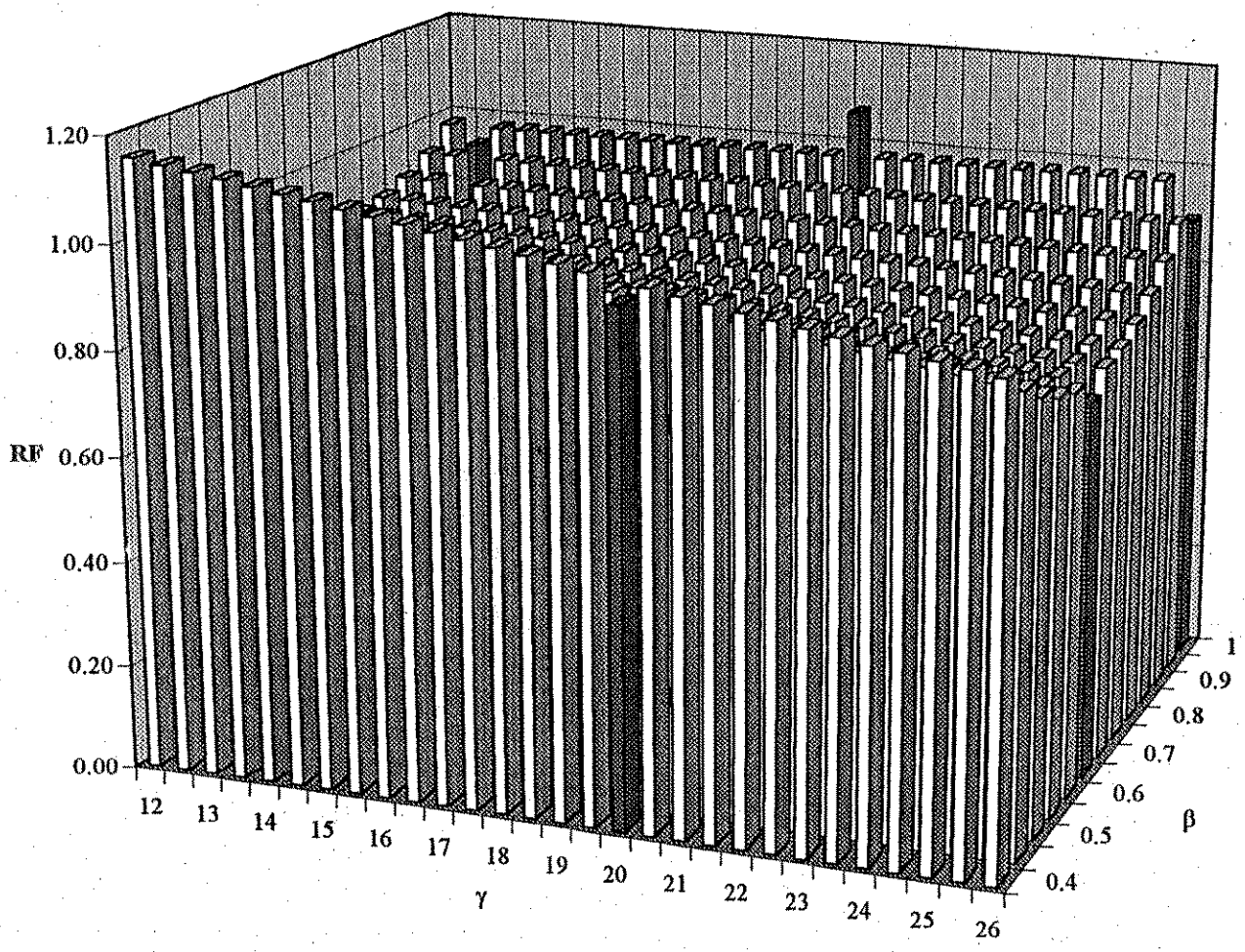



**Fig. 42: Comparison of Fitted Surface with Measured Values for DT Joints under IPB, Brace Crown**



MSL

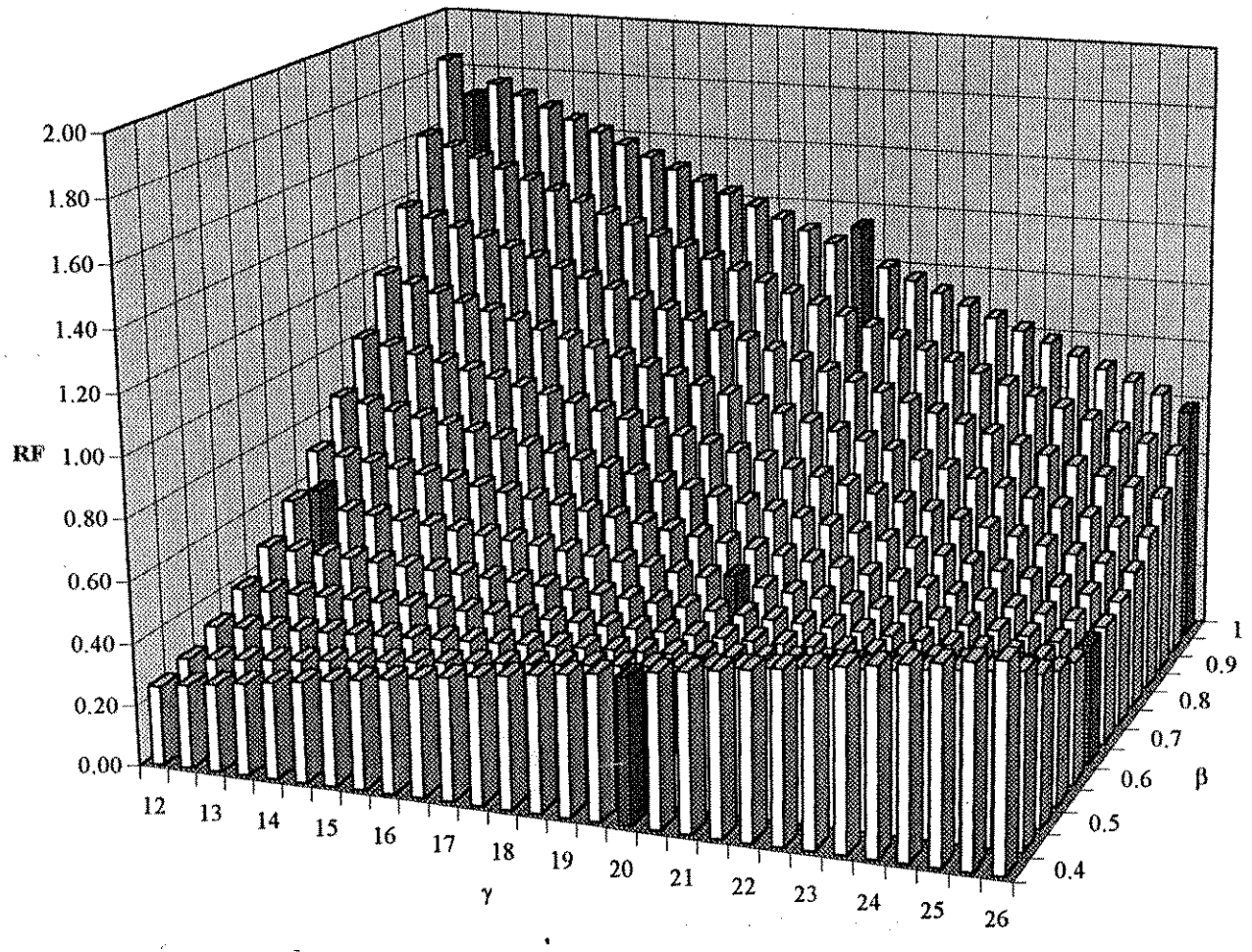



**Fig. 43: Comparison of Fitted Surface with Measured Values for DT Joints under OPB, Brace Saddle**

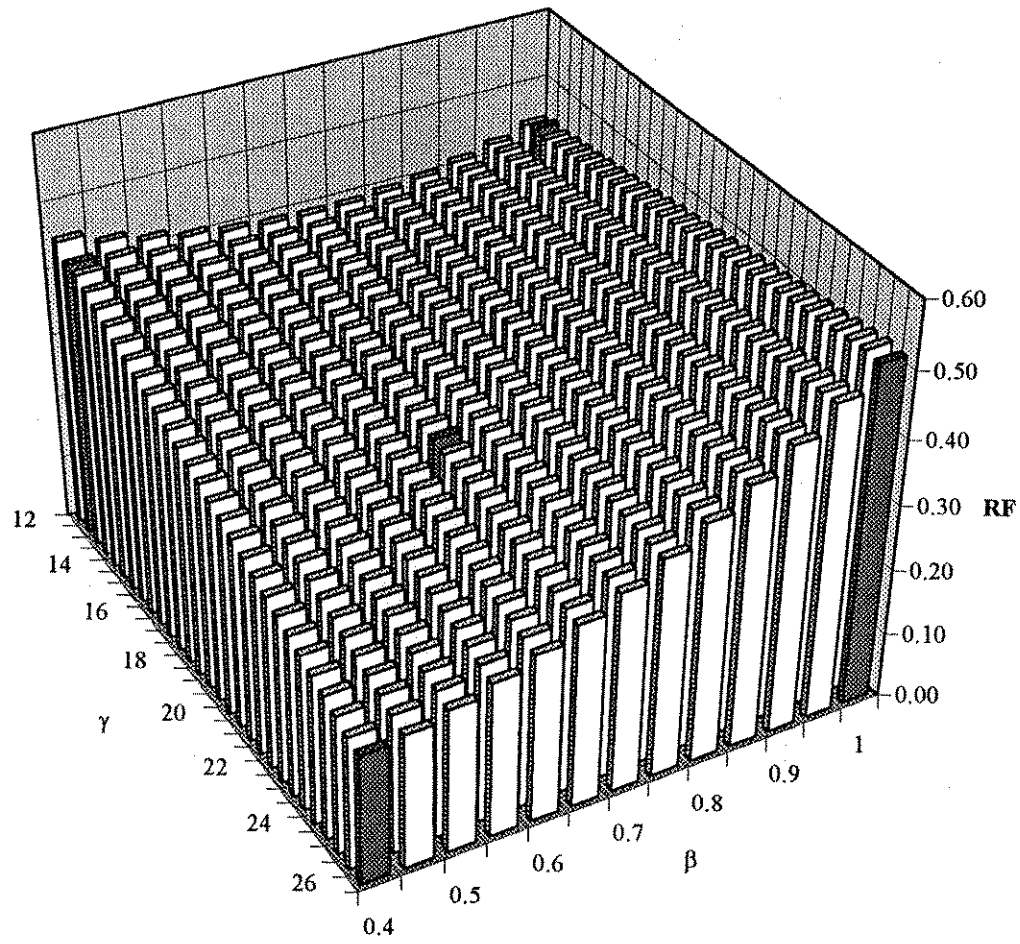



**Fig 44: Comparison of Fitted Surface with Measured Values for T Joints under Compression, Brace Saddle**



MSL

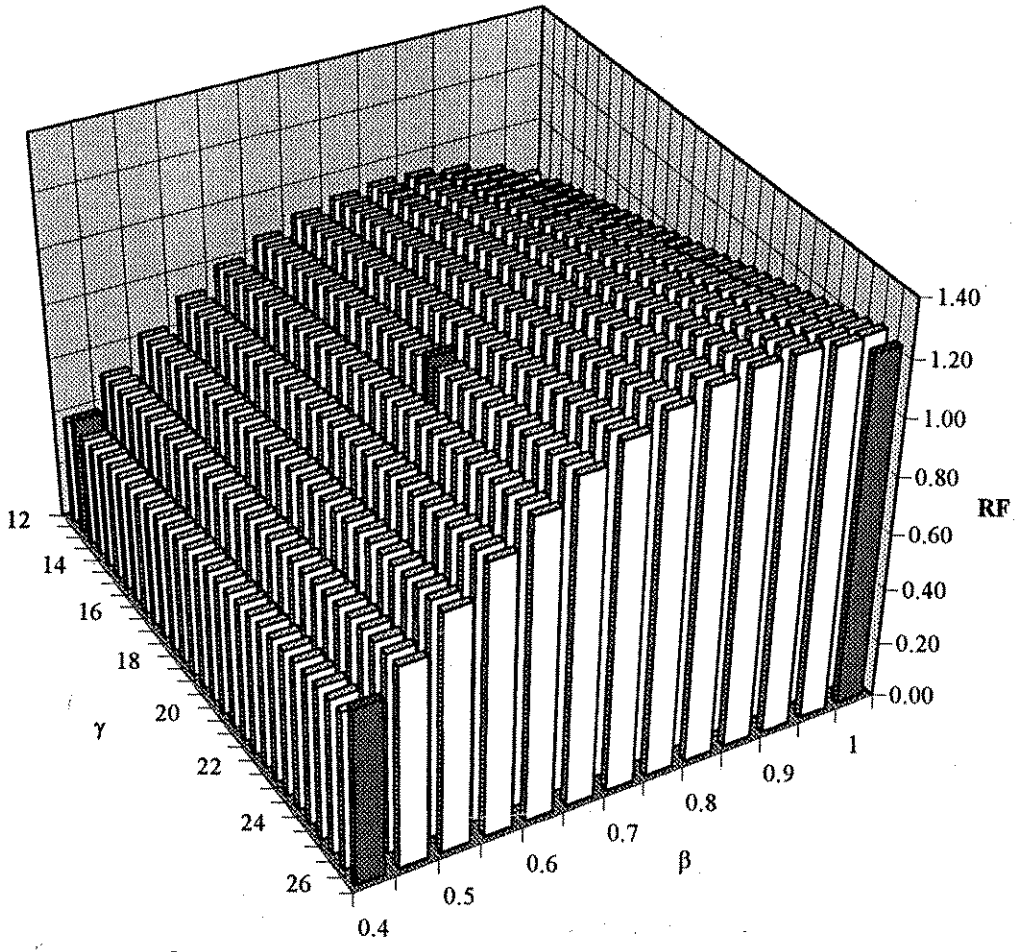



**Fig. 45: Comparison of Fitted Surface with Measured Values for T Joints Compression, Brace Crown**

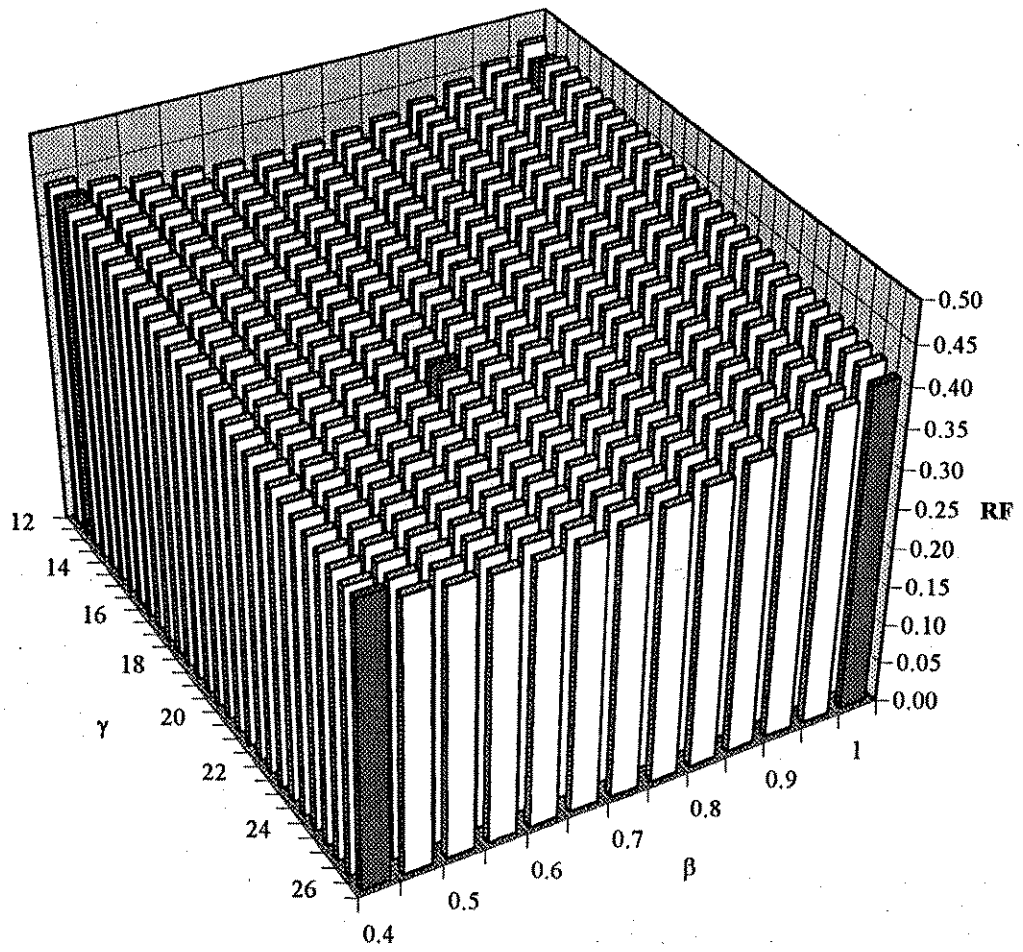



**Fig 46: Comparison of Fitted Surface with Measured Values for T joints under Tension, Brace Saddle**

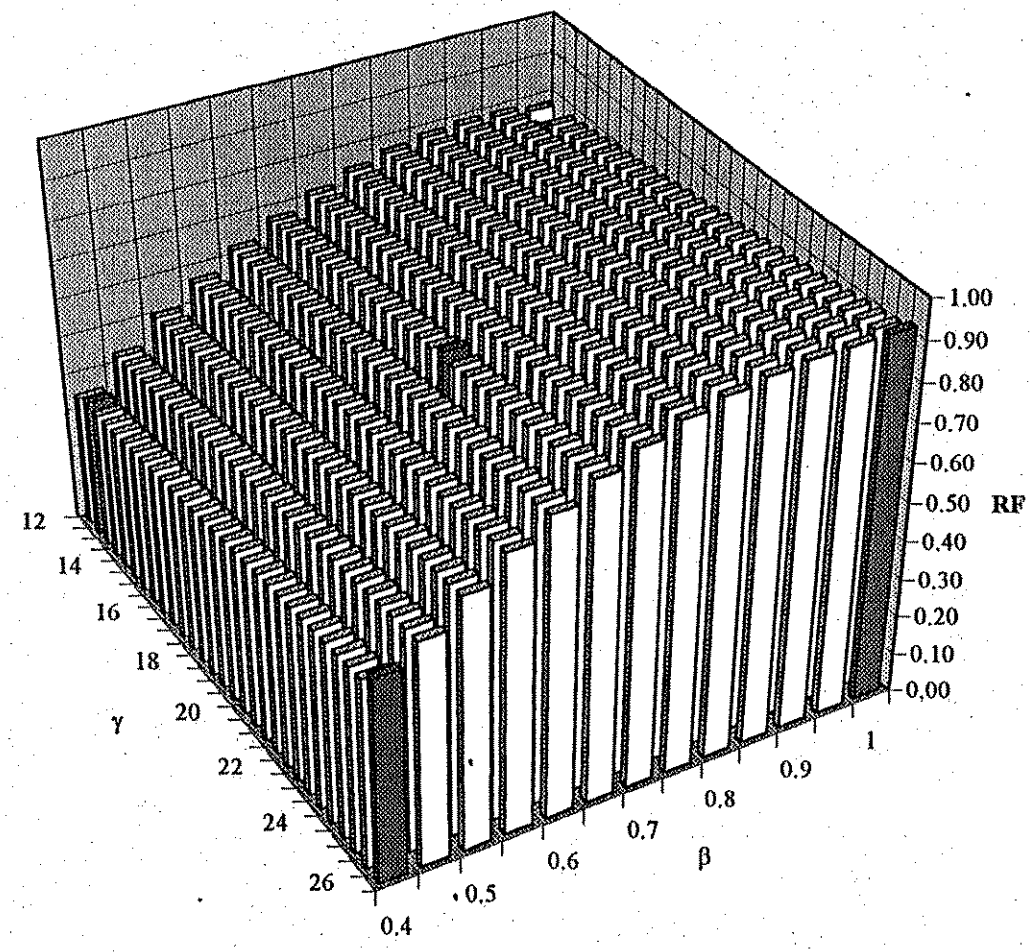



**Fig. 47: Comparison of Fitted Surface with Measured Values for T Joints under Tension, Brace Crown**

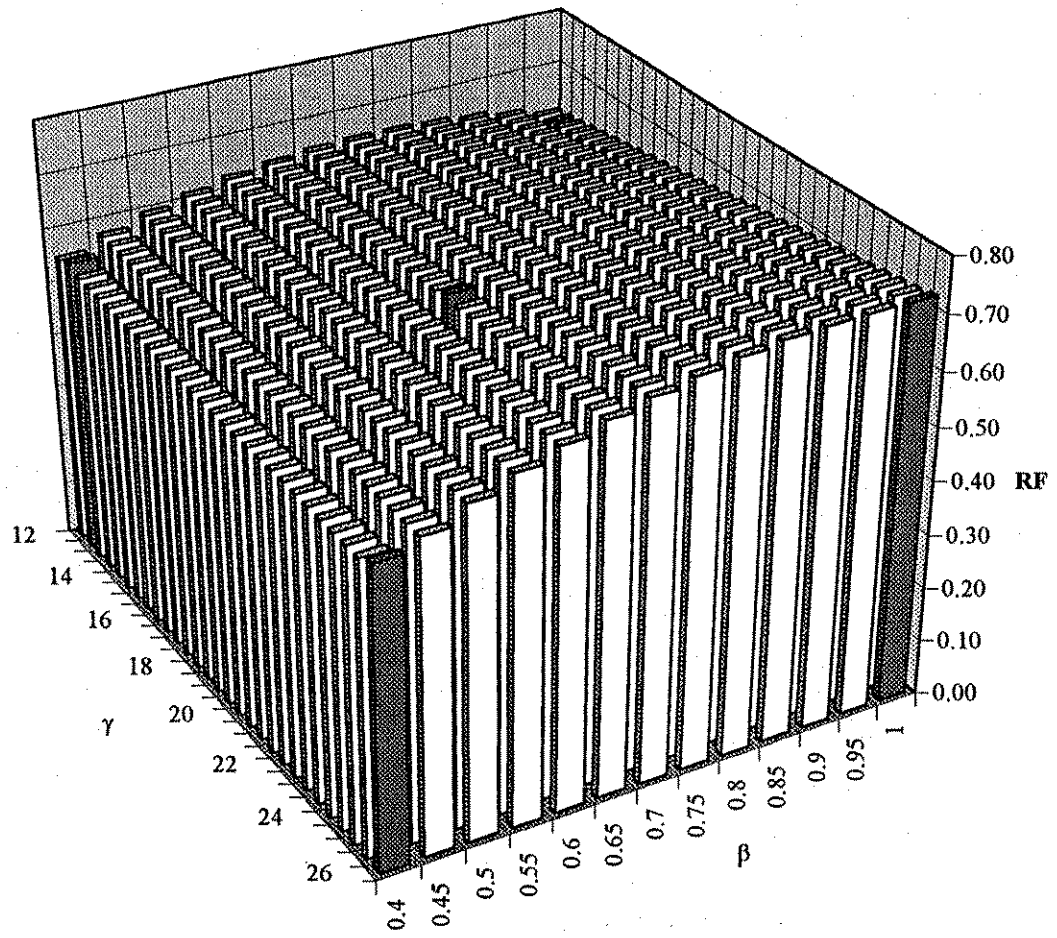



**Fig. 48: Comparison of fitted Surface with Measured Values for T Joints under IPB, Brace Crown**

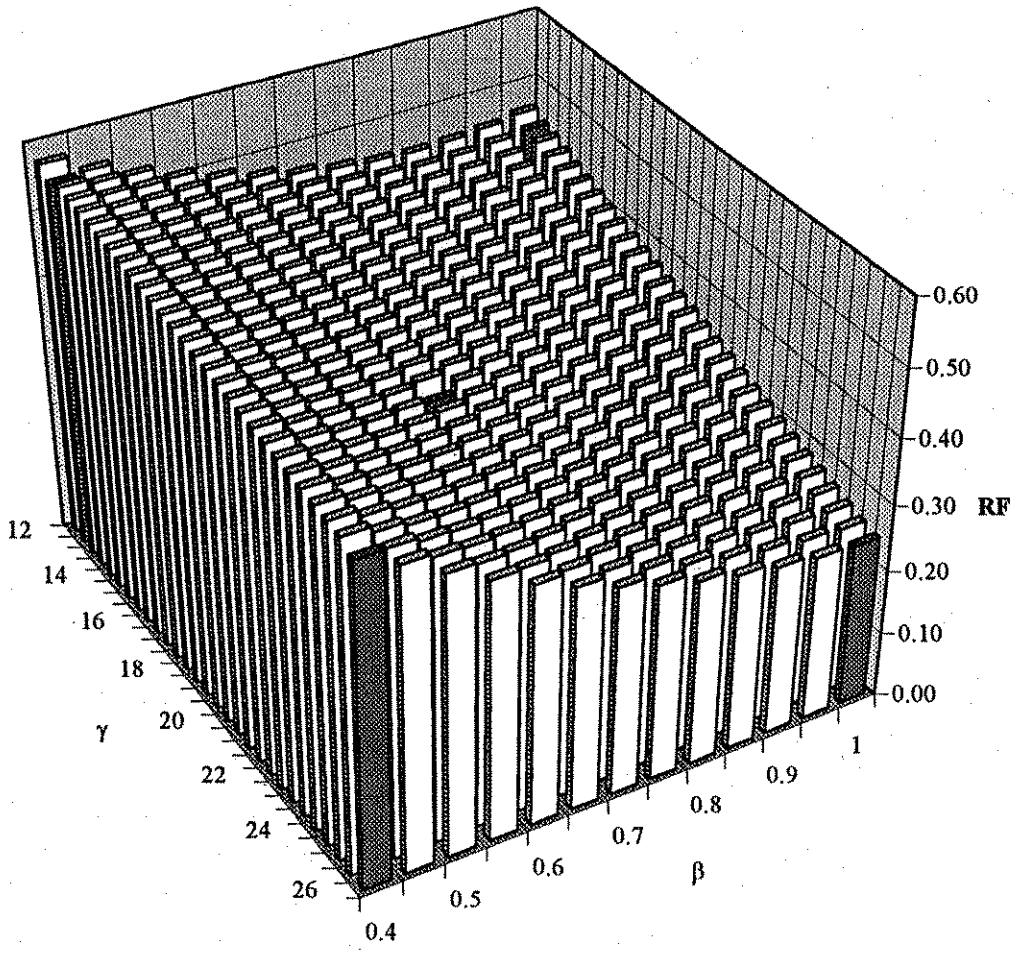



**Fig. 49: Comparison of Fitted Surface with Measured Values for T Joints under OPB, Brace Saddle**

# APPENDIX F

## Detailed Offshore Grouting Procedures

| Purpose of Issue | Rev | Date of Issue | Author | Agreed | Approved |
|---|---|---|---|---|---|
| Issued to PSC | 0 | December 1994 | EPS | DJM | |
| Final Issue | 1 | January 1995 | | | |

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**JOINT INDUSTRY PROJECT**

# DEVELOPMENT OF GROUTED TUBULAR JOINT TECHNOLOGY FOR OFFSHORE STRENGTHENING AND REPAIR

## OFFSHORE INSTALLATION STUDY

**DOC REF C14100R015 Rev 1 JANUARY 1995**

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| NUMBER | DETAILS OF REVISION |
|---|---|
| 0 | Issued to PSC, December 1994 |
| 1 | Final Issue, January 1995 |

## 1. INTRODUCTION

This document has been prepared within the Joint Industry Funded Project on Grouted Joints. It presents a collation of the experience gained and procedures used on a number of projects where member grouting has been used as a strengthening measure. Two scenarios are used to illustrate the procedures.

Reference is made to previous offshore projects to evaluate durations of offshore activities which are itemised for use by Participants in preparing timescale and cost estimates for future projects.

There is a certain amount of commonality in the detailed grouting procedures which is dependent of the particular scenario. Other diving related operational matters such as permissible dive times, diving support and detailed equipment needs are outside the scope of this document and so are not addressed

## 2. SUMMARY

Two repair scenarios are investigated where grouted member technology is used as a strengthening measure. One is horizontal member filling used for joint strengthening, and the other is an inclined member filling used, for example, to reinforce a dented brace member.

Information has been extracted from actual offshore diving logs to prepare timescale estimates for the two scenarios.

Cost estimates have not been prepared because of dependency on many variables such as, time of year, location, diver support vessel (DSV) requirements, number of operations utilising the DSV and complexity of diving operations. However typical cost for a shared DSV in summer could be £50,000 to £100,000 and for a DSV working solely on a job in winter could be £400,000 to £600,000.

Detailed grouting procedures, grout mixing and quality control procedures are provided.

## 3. SCENARIOS

Two scenarios for grouting of members are studied which represent the most likely applications for the technology offshore. Grouting of legs has not been considered for the following reasons:-

- In many cases there is a pile passing through the leg in which case the chord member is not fully grouted.
- Where there is not a pile inside the legs, many legs are used for storage of water or diesel, and so grout filling would not be an acceptable option.
- Legs may contain ring stiffeners and internal diaphragms at joints which have not been considered in this study in combination with grout filling.
- The volume of grout required is an order of magnitude greater and would require special consideration in regard to the heat of hydration generated.

### 3.1 Horizontal Member Grouting

Figure 3.1 shows the general arrangement of a horizontal member in a plan level conductor bay which has been grout filled. Grouting would be required in this instance to increase the fatigue life of the joints along the member length. Such a member may have a constant diameter all the way along or there may be expanded joint cans at intervals along the length, see Figure 3.2. This scenario may be taken as being representative of a horizontal member and the procedures may be repeated for similar configurations involving other sizes and lengths of members.

### 3.2 Inclined Member Grouting

Figure 3.3 shows the general arrangement of a jacket in which inclined member grouting was required to a face frame member due to damage which has occurred during installation. In this instance it may be necessary to fill the whole length of the member or it may only be required to fill the lower portion. Note, however, that the grout filling provided local stability around dents. It was not the intention to increase the axial capacity of the member above its design value. If such a case were required, the procedures proposed would not be satisfactory as they do not result in 100% filling of the member, see Section 4.2.

# 4. OFFSHORE GROUTING PROCEDURES

## 4.1 Horizontal Member

### 4.1.1 General Principles

In order to simplify diver operations it is assumed in these procedures that all access to the inside of the member is gained from the uppermost part of the tube. In this way the diver can sit on the tube whilst working rather than hanging underneath. A problem has now been created since it is not advisable to allow grout to free fall through the flooded member as dilution or segregation of the grout slurry will occur. To overcome the problem, the inlets are extended to within approximately 50 mm of the bottom inside surface of the tube, see Figure 4.1.

Two options have been used in the past to attach the inlets and outlets. The first is to drill and tap holes in the tube with threads which match those of the valves and fittings, see Figure 4.1. The second is to drill or burn and grind dress a hole and clamp the fittings over the hole, as illustrated in Figure 4.2. Drilling and tapping will withstand higher grout pressures but requires greater offshore effort. Clamped inlets and outlets may be more convenient on inclined members where it is difficult to locate and handle the drill framework.

In order to maximise the extent of grout filling, a number of simple rules should be followed:-

1. Displace water rather than air when grouting.

2. Grout from the bottom up; ie. inlet at lowest point of circumference at lower end of member.

3. Grout through one inlet only, otherwise water gets trapped in the middle and a void forms.

4. All grout placed in a single, essentially continuous, operation.

5. Grout should fill member as a wave front by starting at one end of the member and moving away from it.

Outlets and vents should be placed at intervals along the member to allow air to escape but also to allow 'bleed water' to migrate out of the member. Bleed is the phenomenon whereby grout particles in a grout column settle downwards during the setting process leaving a layer of water on the top surface of the column. The extent of bleed in the mixes given in Section 5 is usually less than 0.5%. Outlets and vents often serve a dual purpose as they act as sampling tubes to trap grout for testing. A typical sampling tube is manufactured from 2" NB piping and is 1.2 m (4 ft) long. If such a sampling

tube is to contain the likely maximum production of 'bleed water' from a grouted member then the sampling tubes/vents/outlets should have the following distribution.

| Member OD (mm) | Length of member per sampling tube/vent (m) |
|---|---|
| 324$\phi$ | 13.15 |
| 406$\phi$ | 8.37 |
| 457$\phi$ | 6.62 |
| 610$\phi$ | 3.71 |

If the sampling tubes are larger or grout returns are piped to the surface then fewer will be needed. However, in order to comply with the five simple rules above it is still necessary to have a minimum of two outlets per member and two inlets (one to use and one spare in case of blockage or damage). Also a vent/sampling tube shall be placed at each high point, eg expanded joint can, see Figure 3.2 where a pocket of air or water can form.

4.1.2 Seals For Partial Grout Filling

In certain circumstances it may not be desirable to completely grout fill a member as to do so may involve an unduly large volume of grout or the additional weight may not be acceptable. Should this be the case then internal member seals (or plugs) shall be used to confine the grout. The accepted method of achieving this type of seal is with grout bags. Typical details and specifications are provided in Section 4.4.2. Grout bags are deployed through, typically, a 4"$\phi$ hole in the member and filled with grout to a specified pressure which is then locked into the bag. The grout is allowed to set for approximately 24 hours, before the main grouting operation commences. This technology was originally developed for grouted clamps where an annulus has to be sealed. The material is more robust than neoprene or similar elastomers and can be manufactured in thinner, lighter, more easily handled cross sections, It also has the advantage that pressure does not have to be maintained while the main grouting job is underway. Furthermore, the seal also has the same stiffness and strength characteristics as the body of the grout, which is of particular benefit with clamped repairs.

Particular attention should be taken in the use of internal seals where it is proposed to take grout returns back to the surface for sampling. An internal seal must generate sufficient friction/adhesion to the inside surface of the member so that it can withstand the pressure generated by the head of grout. Where a large pressure would be generated then grouting to surface returns may not be possible, and sample tubes will have to be used.

4.1.3 Grouting Procedure

A typical grouting procedure is given in this section.

The member to be grout-filled shall be fitted with two (2 N°) grout inlet points and three (3 N°) grout outlet points. The general arrangement and locations of inlets and outlets are shown in Figures 3.2,4.1 and 4.3. The locations shall be chosen to avoid circumferential girth welds. Precise details of pipe fittings can be confirmed in liaison with the diving/grouting contractor. However it is not recommended that any smaller fittings than 1½" are used, as large grouting back pressures could be generated due to the resistance to flow of grout in a smaller inlet.

Members shall be fitted with grout inlet and outlet points by drilling and tapping the upper surface of each horizontal member. Similar procedures would be followed if clamped inlets and outlets are used. The method described in this procedure for grouting relies on grout return lines to the surface. However, the use of sample tubes at grout outlet points is permitted within the framework of the procedure described herein.

It is essential that leak testing and grouting operations are immediately consecutive and are not commenced until a suitable weather window is forecast. The required timescale will be reviewed by the Grouting Contractor, who will take the decision to proceed in consultation with the Client.

The diver will operate the valves as instructed by the Grouting Supervisor. Grout should be allowed to issue through the outlet points until good quality grout is observed. As a general rule, there should be a steady and consistent flow of dense grout with no intermingling of sea water and no sign of air bubbles.

The grout inlet points are defined as IP1 and IP2, and the grout outlet points (vents) are defined as OP1, OP2 and OP3, see Figure 3.2. The inlet and outlet valve arrangements are shown schematically in Figures 4.1 and 4.3. Suitable outlet arrangements shall be specified if sampling tubes are adopted.

4.1.3.1 **Grout Connections**

Grout inlet and outlet points will be fitted with valves as shown in Figures 4.1 and 4.3. In addition, grout inlet points IP1 and IP2 will be fitted with bypass valves. All grout inlet/outlet points will also be fitted with a half 'Weco' coupling to take the grout inlet and vent hoses. Suitable connection and valve details shall be specified at the vent locations if sampling tubes are adopted.

BEFORE FITTING, CHECK THE OPERATION OF ALL VALVES. All connections should be well greased. The grout inlet line shall be attached to the member at grout inlet point IP1 (see Figure 3.2). If

grouting operations run smoothly (ie. no blockages occur and weather remains favourable), all grout is input through this point. The grout return lines to the surface shall be attached to outlet points OP1, OP2 and OP3 or; conversely, sampling tubes shall be attached at these locations.

NOTE: If grouting operations have to be abandoned part-way through operations, detailed contingencies are given in Section 4.1.3.13.

4.1.3.2 **Leak Testing**

NOTE: Before proceeding beyond this point, it is essential that a suitable weather window is expected.

BEFORE ANY PUMPING COMMENCES ENSURE THAT AT LEAST ONE VALVE IS OPEN AT THE MEMBER.

4.1.3.3 **Filling Member with Dye**

Close all valves at IP2, and open all valves at OP1, OP2 and OP3. Close bypass valve at IP1. Connect inlet grout hose to IP1, and return lines/sampling tubes to OP1, OP2 and OP3.

Pump water containing fluorescent dye, concentration 1:1,000,000, through the grout inlet line. Stop pumping when dye issues from grout inlet points. Close valves at OP1, OP2 and OP3.

Pressurise water to a pressure equivalent to the head of grout for surface return lines or 12m head of grout for sampling tube arrangements. The pressure reading will depend on type of mixer used.

4.1.3.4 **Inspection for Leaks**

Identify any leak points by evidence of dye. All inlet points and outlet points should be checked. In addition, the intersection welds at the member ends shall be checked. Go to Sections 4.1.3.5 or 4.1.3.6 if leaks noted.

If no leaks are apparent after a period of three minutes, go to Section 4.1.3.7.

4.1.3.5 **Remedial Procedure - Leak at Inlet or Outlet Points**

Check that valves are closed. Check that valves are correctly attached to the member at the threaded fitting. If leak persists, detach subject valve fitting and remove to surface for inspection and check integrity of threaded grout point in member wall.

4.1.3.6 **Minor Leaks**

If leaks are minor it is probable that they will be self-sealing when grouting commences. Minor leaks are those evidenced by dye locally present in the sea water but not visibly issuing from the leak point. The Grouting Supervisor shall be responsible for confirming any leak as minor and will decide whether remedial action is necessary, prior to grouting. Minor leaks and leaks at member welds may be remedied by sealing the leak point with underwater tape.

4.1.3.7 **No Leaks**

If no leaks are evident, or only minor leaks deemed acceptable by the Grouting Supervisor, a second (confirmatory) inspection shall be made.

4.1.3.8 **Check Valve Operation**

Open the valves in the following sequence, whilst slowly pumping dye water, ensuring in each case an immediate and abundant flow of dye water, before reclosing valve.

Sequence OP1, OP2, IP2 (bypass valve remains closed), OP3.

In the event that no flow occurs at a valve, the valve shall be replaced and the procedure from Section 4.1.3.1 onwards shall be repeated.

4.1.3.9 **Grouting the Member**

This operation should follow immediately after a successful leak test.

It is vital that at least one outlet point is open at all times.

4.1.3.10 **Grouting Procedure**

Before any grout is injected, divers will confirm the valves are set as follows:-

(i) Grout inlet hose line is attached at IP1, inlet valve closed, bypass valve open.

(ii) Grout return hose lines/sampling tubes are attached at OP1, OP2 and OP3, outlet valves open.

(iii) Inlet valve at IP2 open, bypass valve closed.

Thus, valve status required is as scheduled below:-

| Inlet Point | Valve Position | Outlet Point | Valve Position |
|---|---|---|---|
| IP1 - inlet valve | Closed | OP1 | Open |
| - bypass valve | Open | | |
| IP2 - inlet valve | Open | OP2 | Open |
| - bypass valve | Closed | | |
| | | OP3 | Open |

Mix Grout

Mix grout to a specific gravity of 2.02 $\pm$ 0.02. Confirm SG=2.02 using a pressurised mud-balance. If acceptable, take a sample for grout cubes. If SG is less than 2.00, continue mixing grout until desired density is achieved and then take sample for grout cubes.

See Section 5 for mixing, sampling and testing of grout.

Valve Operating Sequence

Ensure grout inlet hose from surface to member is free of any obstructions, 'kinks' or 'crimps'.

Pump grout down the inlet hose until the line is full of grout and grout issues from the bypass valve.

Open inlet valve at IP1.

Close bypass valve at IP1.

Pumping is continuous. The Grouting Supervisor will assess when grout samples are to be recovered for density checks, in accordance with the specification noted in Section 5.

When grout issues from IP2, check that at OP1, OP2 and OP3 all valves are open. Close inlet valve at IP2.

Close valve at outlet point OP1.

- When grout issues from the outlet points OP2 and OP3, continue pumping, and take density measurements. Once satisfactory grout has been confirmed from OP2 and OP3, first open valve at OP1, and then, close valves at OP2 and OP3.

- When grout issues from the outlet point OP1, continue pumping and take density measurements.

- Once satisfactory grout has been confirmed from OP1, open valves at OP2 and OP3, and reconfirm satisfactory grout density from all three outlet points.

- Following confirmation of satisfactory grout densities, close inlet valve at IP1, and open bypass valve at IP1.

- DO NOT REMOVE INLET HOSE OR SAMPLING TUBES UNTIL SATISFACTORY GROUT DENSITIES HAVE BEEN CONFIRMED AT ALL THREE OUTLET POINTS OP1, OP2 AND OP3.

- Pump seawater down the grout line, to flush to sea. Disconnect grout inlet hose at IP1 at member and retrieve to surface. DO NOT remove the grout return lines/sampling tubes, as the head of grout serves the required function of surplus 'feed' grout during the initial set phase of the grout in the member. Ensure that all three valves at OP1, OP2 and OP3 are open.

4.1.3.11 **Short Stoppages**

If a blockage occurs during grouting, adopt the following procedure:-

Open bypass valve at IP1.

Close inlet valve at IP1.

If no grout flows, change the inlet grout hose. If grout flows, the problem is not in the hose. Flush the inlet grout line with seawater, detach the Weco coupling from IP1 and reattach at IP2. Close inlet valve at IP2, open bypass valve, fill the hose with grout. When grout issues from the bypass valve, open inlet valve at IP2, close the bypass valve and revert to the procedures in Section 4.1.3.10.

4.3.1.12 **Longer Stoppages**

In the event of a grout flow problem or delay during grouting operations, where such delays may exceed one hour, member flushing procedures must start.

4.1.3.13 **Flushing Procedure**

Flushing must be carried out if grout flow problems occur which may delay operations for more than one hour.

(i) Open bypass valve at IP1, shut inlet valve at IP1, and flush grout hose to sea. Wash out grout mixer.

(ii) Pumping seawater, open and close the valves in the following sequence. Do not close a valve until grout has ceased to issue from the valve.

(iii) Open inlet valves at IP1 and IP2. Close bypass valve at IP2. Flush for 15 minutes.

(iv) Close by-pass valve at IP1.

(v) Close inlet valve at IP2 and open all remaining outlet valves and flush for a minimum of 15 minutes. Open inlet valve at IP2, and continue flushing for a further 10 minutes.

(vi) Diver to inspect all valves and 'rake out' where necessary.

4.1.3.14 **Post Grouting Procedure**

**Flush Grout Inlet Line**

Immediately after satisfactory grouting, flush the grout inlet line (via bypass) and retrieve to surface.

**Return Lines/Sampling Tubes and Valve Assemblies**

The return lines/sampling tubes and valves will remain in situ until the grout has achieved initial set. This will be agreed with the Client, but will not be less than 24 hours after completion of grouting. Retrieve return lines/sampling tubes and valves thereafter and place thread protector caps over inlets/outlets.

Underwater tape will be wrapped around exposed inlets/outlets if appropriate to prevent corrosion of the threads.

## 4.2 Inclined Member

The general principles for grouting horizontal members outlined in Section 4.1.1 are equally applicable to inclined members. Since the member is inclined there is no clear advantage to divers working from the uppermost surface of the member and so inlets will be placed directly on the underside of the member.

Intermediate outlets are not necessary as a vertical path is already provided for air and 'bleed water' to escape. Also fewer inlets are provided as the extreme low point of the void is comparatively small unlike a horizontal member. Sealing is provided by the lower and upper brace member welds and no further sealing is considered.

A particular difficulty arising with inclined members is getting grout to fill all the way to the top. It is not possible either due to space restrictions or geometrical

limitations to place the uppermost grout outlet exactly at the top of the member. Consequently, a void is formed by the air or water which is trapped above the outlet, see Figure 4.4. This is the reason why, in Section 3.2, it was stated that these procedures are not appropriate where the axial capacity needs to be increased above the design value. Figure 4.5 shows how the use of a weep hole can reduce the void size, (but not eliminate it completely). The following procedures are written assuming a weep hole is used, but are equally applicable if one is not.

The general arrangements of inlets and outlets are shown in Figures 4.2 and 4.6. The precise locations shall avoid circumferential girth welds, anodes and any other surface attachments.

Members shall be fitted with grout inlet and outlet points. The method described in this procedure for grouting relies on grout return lines to the surface. Where appropriate, at the upper end of each member, a small weep hole is drilled in the brace wall which permits a greater degree of member filling than would otherwise be possible. The procedures assume that only one inlet is provided and all work is carried out through a single point. It may in some circumstances be prudent to provide a second inlet to be used as a contingency.

It is essential that leak testing and grouting operations are immediately consecutive and are not commenced until a suitable weather window is forecast. The required timescale will be reviewed by the Grouting Contractor, who will take the decision to proceed in consultation with the client.

Grout Mix and Grouting Specifications are contained in Section 5.

The diver will operate the valves as instructed by the Grouting Supervisor. Grout should be allowed to issue through the outlet points (and weep holes where appropriate) until good quality grout is observed. As a general rule, there should be a steady and consistent flow of dense grout with no intermingling of sea water and no sign of air bubbles.

The grout inlet and outlet points are shown in Figures 4.2 and 4.6. Weep hole details are shown in Figure 4.5.

### 4.2.1 Member Preparation

#### 4.2.1.2 General

Holes in the grout inlet and outlet points shall be placed at the locations indicated on Figure 4.7. Details of grout inlets and outlets are shown in Figures 4.2 and 4.6. Details of the inlet point indicated in Figure 4.2 shows a 6 o'clock position with respect to the brace circumference. As an alternative, a 12 o'clock position can be adopted, provided an insert pipe is specified to ensure that grout injection takes place close to the 6 o'clock location. No inlet point shall be placed within 300mm of a girth weld or tubular joint weld. In

addition, no inlet point shall be placed at any longitudinal seam weld location. If the inlet point is closer than 150mm from a longitudinal seam weld, the inlet point position shall be rotated to give a minimum circumferential separation of 150mm from the longitudinal seam weld.

Outlet points shall be placed at the highest end on the member circumference, at the locations defined, except that no outlet point shall be placed within 300mm of a girth weld or tubular joint weld. In addition, no outlet point shall be placed at any longitudinal seam weld location. If the outlet point is closer than 75mm from a longitudinal seam weld, the outlet point position shall be rotated to give a minimum circumferential separation of 75mm from the longitudinal weld.

Where appropriate, near the outlet point position, a small (ie. 12mm max diameter) weep hole is to be drilled in the brace wall, at the location shown in Figure 4.5. As an alternative, the hole can be made using a cutting rod, provided that a smooth profile free of burrs, notches and molten spatter is achieved. No longitudinal or rotational displacement of the weep hole is permitted.

The purpose of the weep hole is to permit trapped air and seawater to escape.

At each inlet and outlet location, where an inlet/outlet clamp is to be placed, all longitudinal seam welds and other surface irregularities shall be ground down to give a flush surface to the brace wall on which to place the grouting clamp. This will minimise any leakage problems associated with the clamp-member interface.

4.2.1.3 Weep hole sealing

After making the weep hole, it shall be sealed by hammering in a rubber bung or similar device. If necessary, during leak testing and grout curing, the bung shall be held in place by a nylon strap passed around the brace. The bung shall be removed during grout injection procedures to allow grout-filling to the required level; the bung shall thereafter be replaced to permit grout pressure to build and ensure grout returns to the surface.

4.2.2 Grouting Procedure

Grout inlet and outlet points will be fitted with valves as shown in Figures 4.2 and 4.6. In addition, grout inlet and outlet points will be fitted with bypass valves. All grout inlet/outlet points will also be fitted with a half 'Weco' coupling to take the grout supply and return hoses.

BEFORE FITTING, CHECK THE OPERATION OF ALL VALVES.

All connections should be well greased. The grout inlet line shall be attached to the member at the grout inlet point. If grouting operations run smoothly (ie. no blockages occur and weather remains favourable), all grout is input through this point. At the grout outlet, return lines to the surface shall be attached to the outlet valve.

NOTE: If grouting operations have to be abandoned part-way through operations, detailed contingencies are given in Section 4.2.2.11.

4.2.2.1 Leak Testing

NOTE: Before proceeding beyond this point, it is essential that a suitable weather window is expected.

BEFORE ANY PUMPING COMMENCES ENSURE THAT THE OUTLET VALVE IS OPEN AT THE MEMBER.

4.2.2.2 Filling Member with Dye

Open valve at the outlet point. Close bypass valve at outlet point. Close bypass valve at inlet point. Connect inlet grout hose to inlet point, and return line to outlet point.

Pump water containing fluorescent dye, concentration 1:1,000,000, through the grout inlet line. Stop pumping when dye issues from grout outlet point. Close outlet valve.

Pressurise water to a pressure equivalent to the head of grout held in the surface return line. The pressure reading will depend on type of mixer used.

4.2.2.3 Inspection for Leaks

Identify any leak points by evidence of dye. All inlet points and outlet points should be checked. In addition, the damage locations, weep hole seals (where appropriate) tubular joint welds and girth welds shall be checked. Go to Sections 4.2.2.4 or 4.2.2.5 if leaks are identified.

If no leaks are apparent after a period of three minutes, go to Section 4.2.2.6.

4.2.2.4 Remedial Procedure - Leak at Inlet or Outlet Points

Check that valves are closed. Check that valves are correctly attached to the grouting clamp at the fitting. If leak persists, detach subject valve fitting and remove to surface for inspection. Check integrity of

the grouting clamp gasket seal to member wall, tighten studbolts if necessary.

4.2.2.5 Minor Leaks

If leaks are minor, it is probable that they will be self-sealing when grouting commences. Minor leaks are those evidenced by dye locally present in the sea water but not visibly issuing from the leak point. Major leaks are those evidenced by a jet of dye flowing from the defective spot. The Grouting Supervisor shall be responsible for confirming any leak as minor and will decide whether remedial action is necessary, prior to grouting. Minor leaks may be remedied by sealing the leak point with underwater tape.

4.2.2.6 No Leaks

If no leaks are evident, or only minor leaks deemed acceptable by the Grouting Supervisor, a second (confirmatory) inspection shall be made.

4.2.2.7 Check Valve Operation

Open the outlet valve whilst slowly pumping dye water, ensuring an immediate and abundant flow of dye water, before reclosing valve.

In the event that no flow occurs at a valve, the valve shall be replaced and the procedure from Section 4.2.2.1 shall be repeated.

4.2.2.8 Grouting the Member

This operation should follow immediately after a successful leak test.

It is vital that the outlet point is open at all times.

4.2.2.9 Grout Injection

Before any grout is injected, divers will confirm the valves are set as follows:-

(i) Grout inlet hose line is attached at inlet point, inlet valve closed, bypass valve open.

(ii) Grout return hose line is attached at outlet point, outlet valve open, bypass valve closed.

(iii) Remove seal from weep hole (if appropriate).

Thus, valve status required is scheduled below:-

| Inlet Point | Valve Position | Outlet Point | Valve Position |
|---|---|---|---|
| Inlet valve | Closed | Outlet Valve | Open |
| Bypass Valve | Open | | |

Mix Grout

Mix grout to a specific gravity of 2.02 $\pm$ 0.02. Confirm this specific gravity using a pressurised mud-balance. If acceptable, take a sample for grout cubes. If the specific gravity is less than 2.00, continue mixing grout until desired density is achieved and then take sample for grout cubes.

See Section 5 for mixing, sampling and testing of grout.

Valve Operating Sequence

- Ensure grout inlet hose from surface to member is free of any obstructions, 'kinks' or 'crimps'.
- Pump grout down the inlet hose until the line is full of grout and grout issues from the bypass valve.
- Open inlet valve at inlet point.
- Close bypass valve at inlet point.
- Pumping is continuous. The Grouting Supervisor will assess when grout samples are taken for density checks, in accordance with the specification noted in Section 5.
- When good consistency grout issues from the weep hole, check that the outlet valve is open. SEAL THE WEEP HOLE AT THIS STAGE.
- When grout issues from the return line at the surface, continue pumping slowly, and take density measurements.
- Following confirmation of satisfactory grout densities, close inlet valve at inlet point, and open bypass valve at inlet point. Ensure that outlet valve is open. Take sample for grout cubes from remaining grout in the grout mixer.

- DO NOT REMOVE INLET OR OUTLET HOSE UNTIL SATISFACTORY GROUT DENSITY HAS BEEN CONFIRMED AT OUTLET POINT.

- Pump seawater down the grout inlet lines, to flush to sea. Disconnect grout inlet hoses at Weco union connection locations, and retrieve to surface. Attach 'feed' hose at the outlet point to the leg using lashing material. The grout in this 'feed' hose will provide a head of grout during the initial grout set phase and permit surplus 'bleed' water to migrate out of the member.

4.2.2.10 Short Stoppages

If a blockage occurs during grouting, adopt the following procedure:-

Open bypass valve at inlet point.

Close inlet valve at inlet point.

If no grout flows, change the inlet grout hose. If grout flows, the problem is not in the hose. Therefore, it is either a fault in the inlet valve or a blockage in the grouting clamp. In either event, the grouting operation must be aborted so that the inlet valve and grouting clamp can be inspected and the fault remedied.

4.2.2.11 Longer Stoppages

In the event of a grout flow problem or delay during grouting operations, where such delays may exceed one hour, member flushing procedures must start.

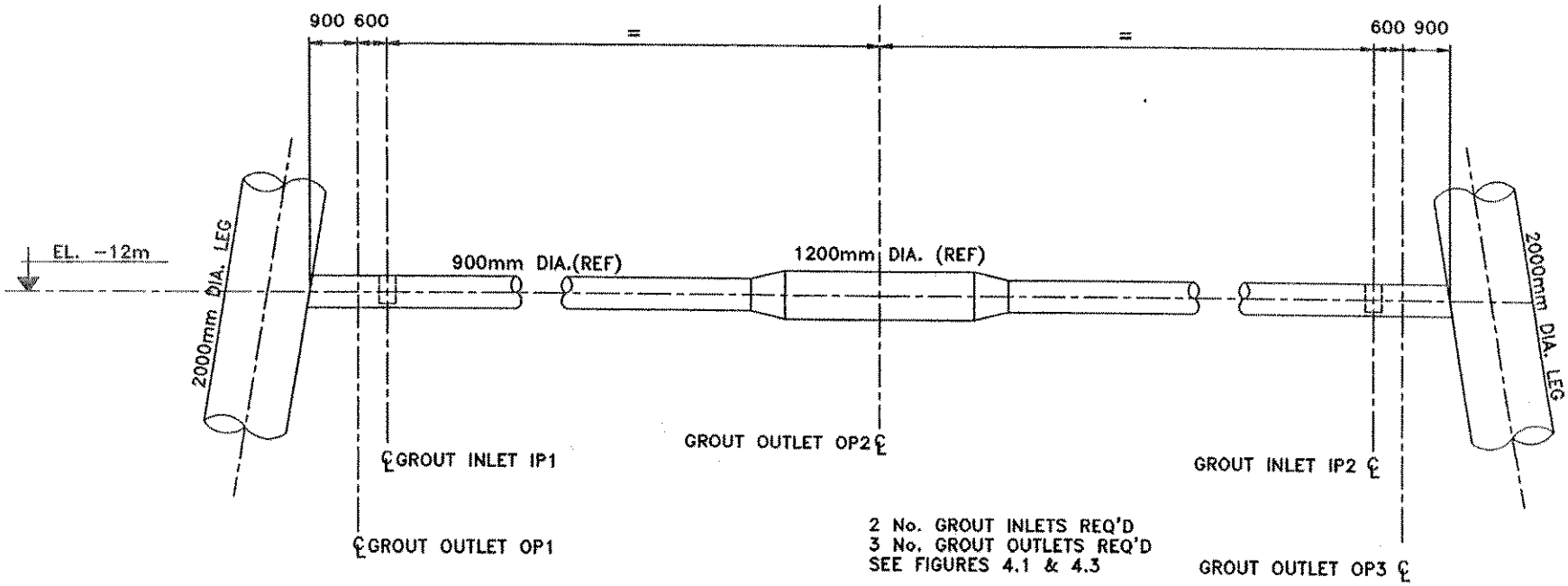
4.2.2.12 Flushing Procedure

Flushing must be carried out if grout flow problems occur which may delay operations for more than one hour.

(i) Open bypass valve at inlet point, close inlet valve at inlet point, and flush inlet hose to sea.

(ii) Pumping seawater, open and close the valves in the following sequence. Do not close a valve until grout has ceased to issue from the valve.

(iii) Open inlet valve at inlet point. Open outlet valve at outlet point. Close bypass valve at inlet point. Flush for 15 minutes using the outlet point to pump seawater. Repeat flushing for




VIEW ON X-X

Figure 3.2 MEMBER GROUT FILLING DETAILS

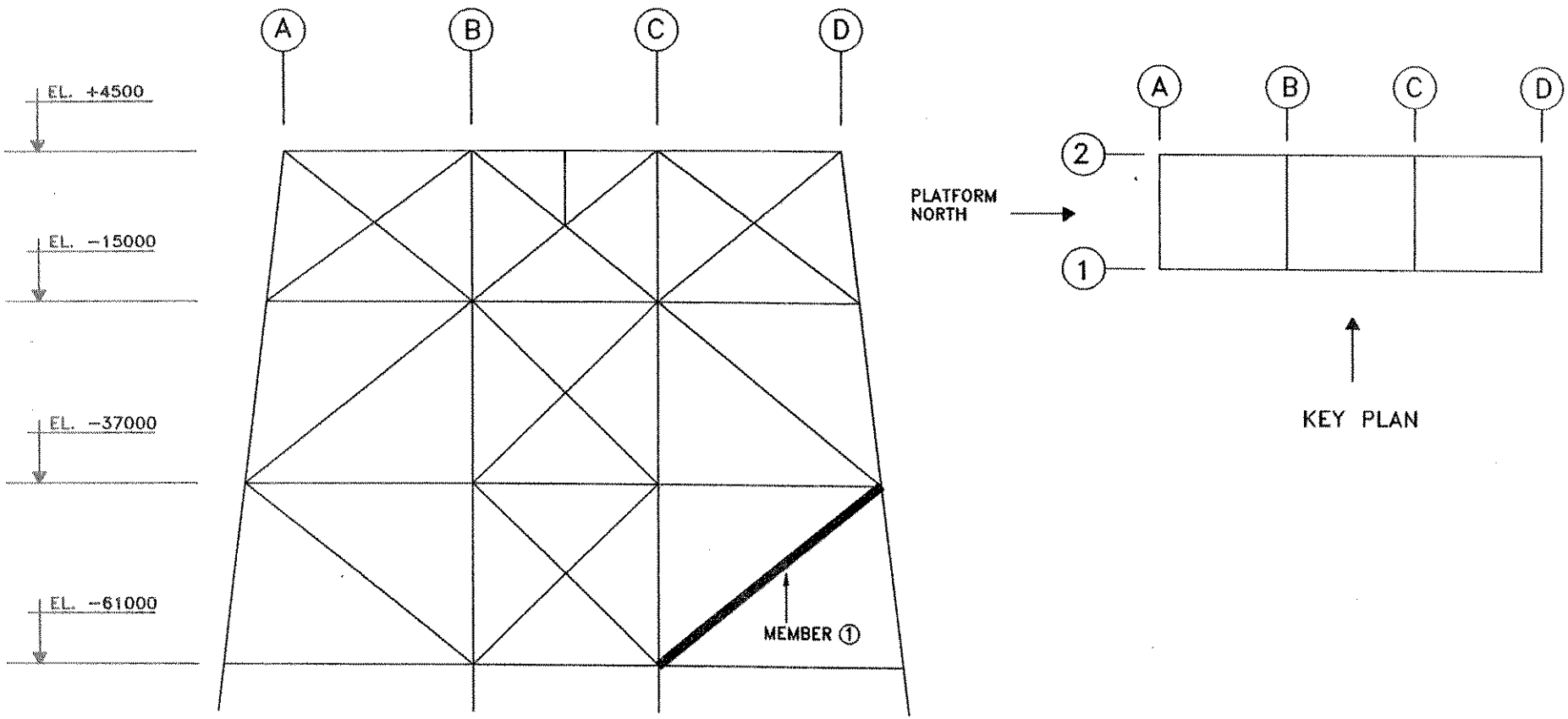



Figure 3.3 ELEVATION ON ROW 1

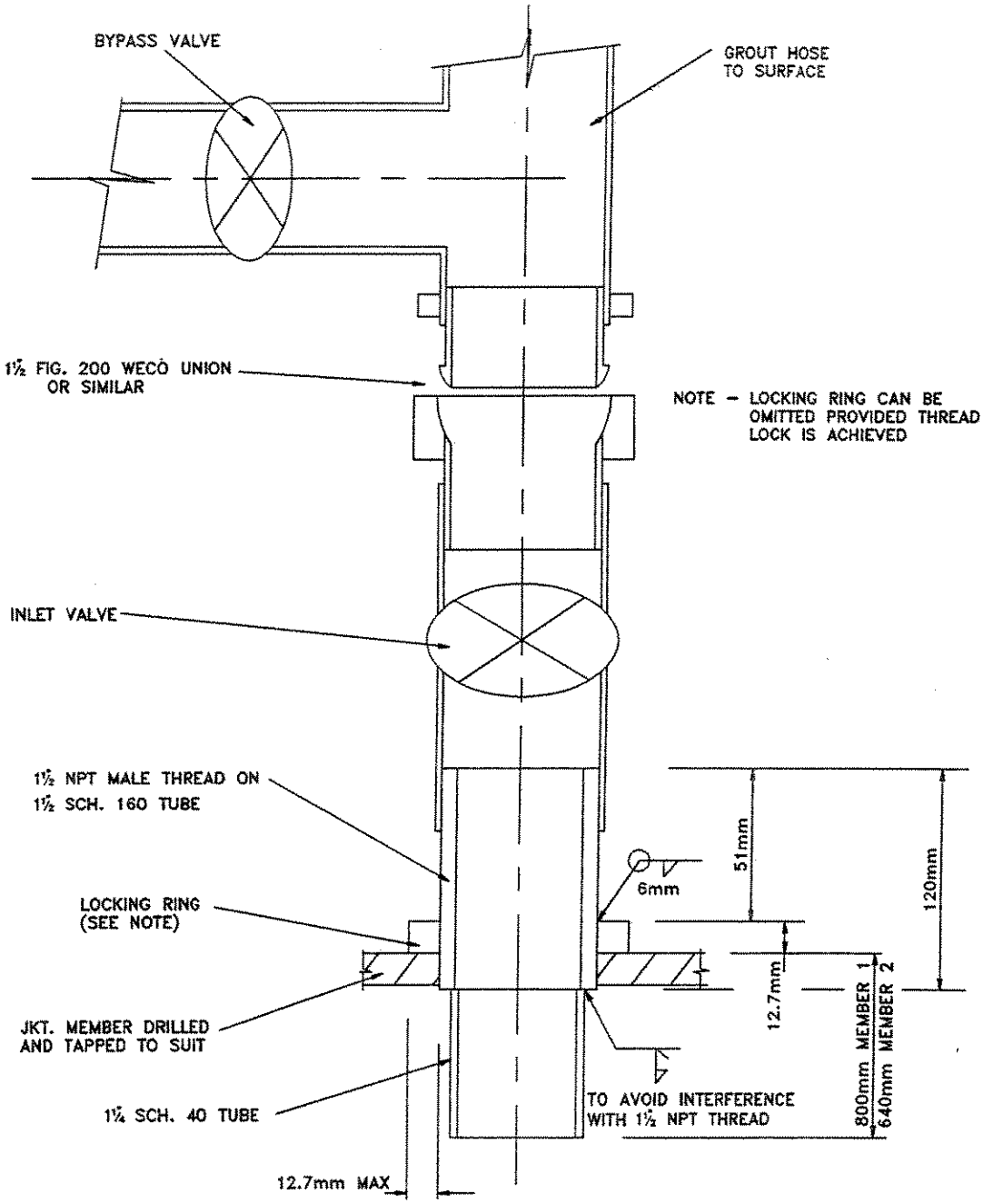
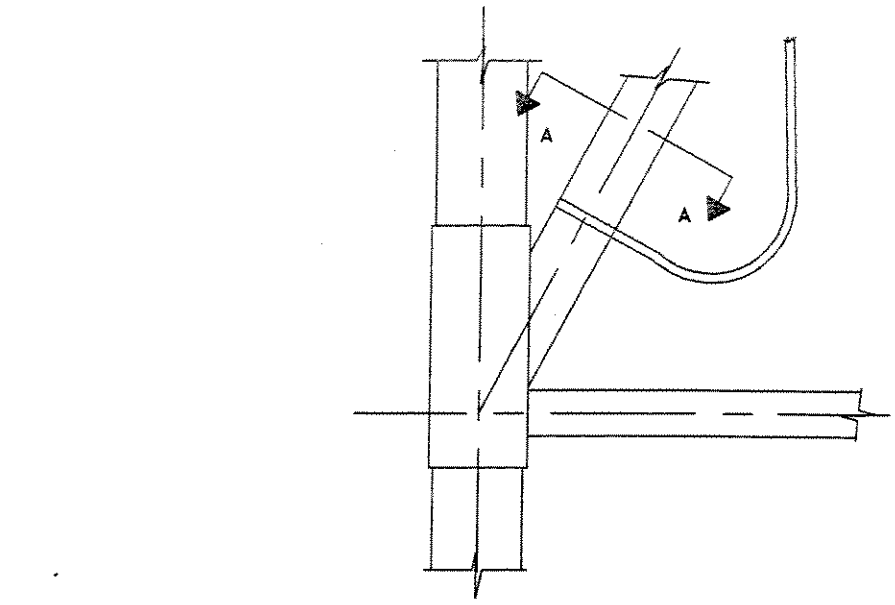


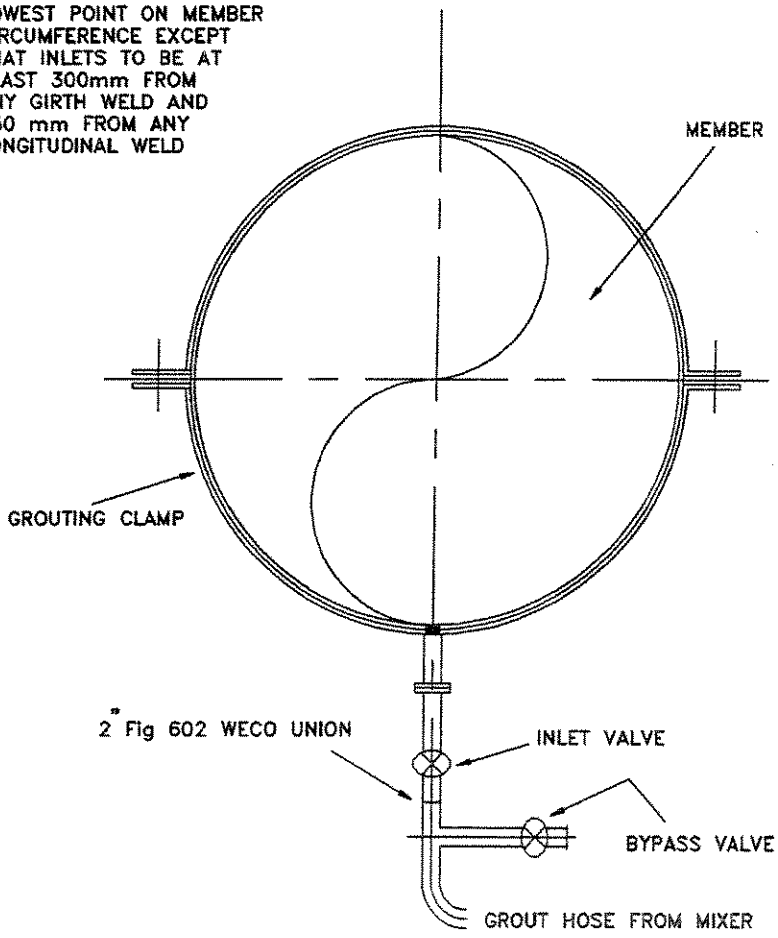

Figure 4.1 ARRANGEMENT OF GROUT INLET CONNECTIONS




ELEVATION

NOTE

INLETS TO BE PLACED AT LOWEST POINT ON MEMBER CIRCUMFERENCE EXCEPT THAT INLETS TO BE AT LEAST 300mm FROM ANY GIRTH WELD AND 150 mm FROM ANY LONGITUDINAL WELD




VIEW A–A

Figure 4.2 DETAIL OF INLET

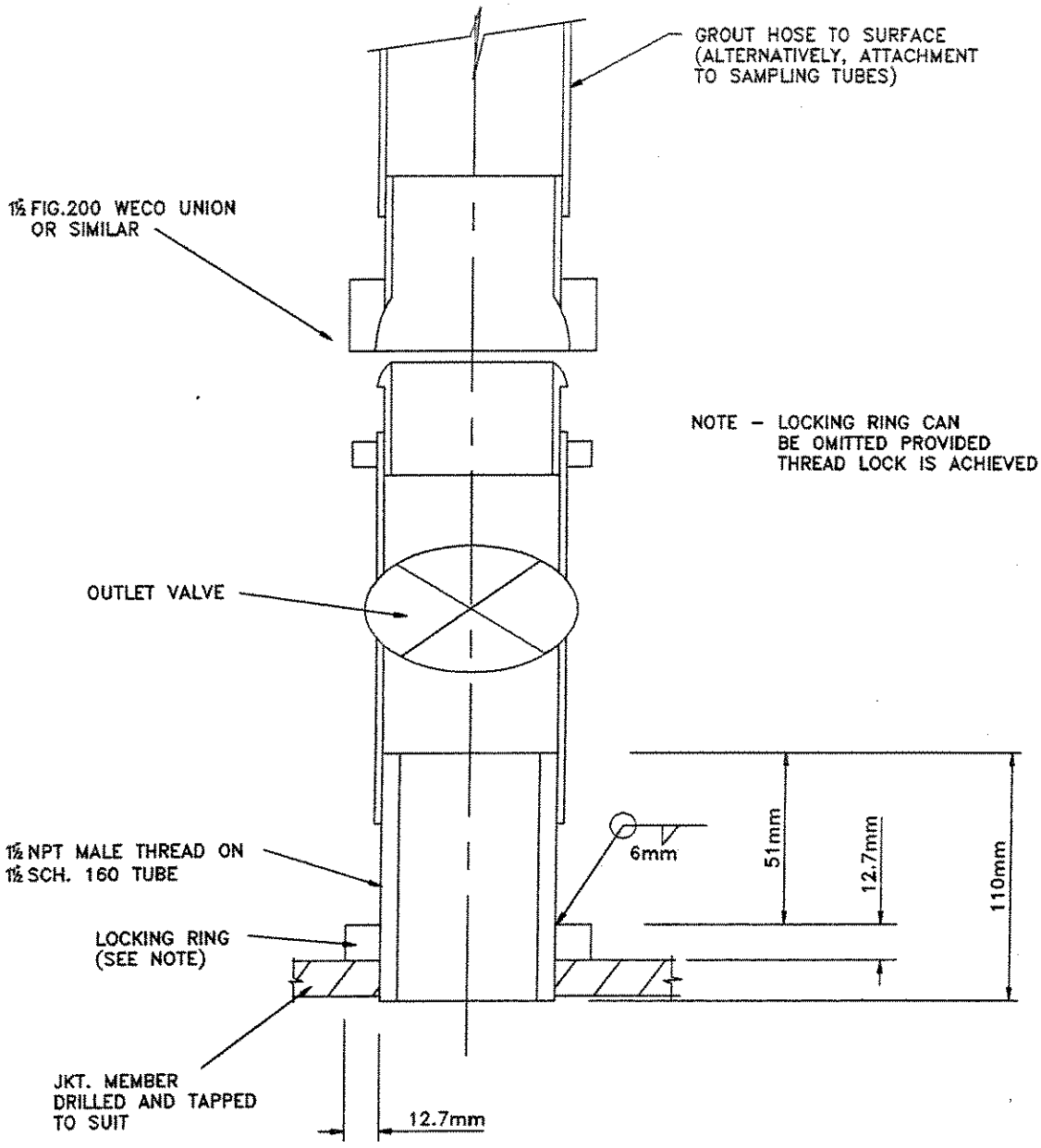



Figure 4.3 ARRANGEMENT OF GROUT OUTLET CONNECTIONS

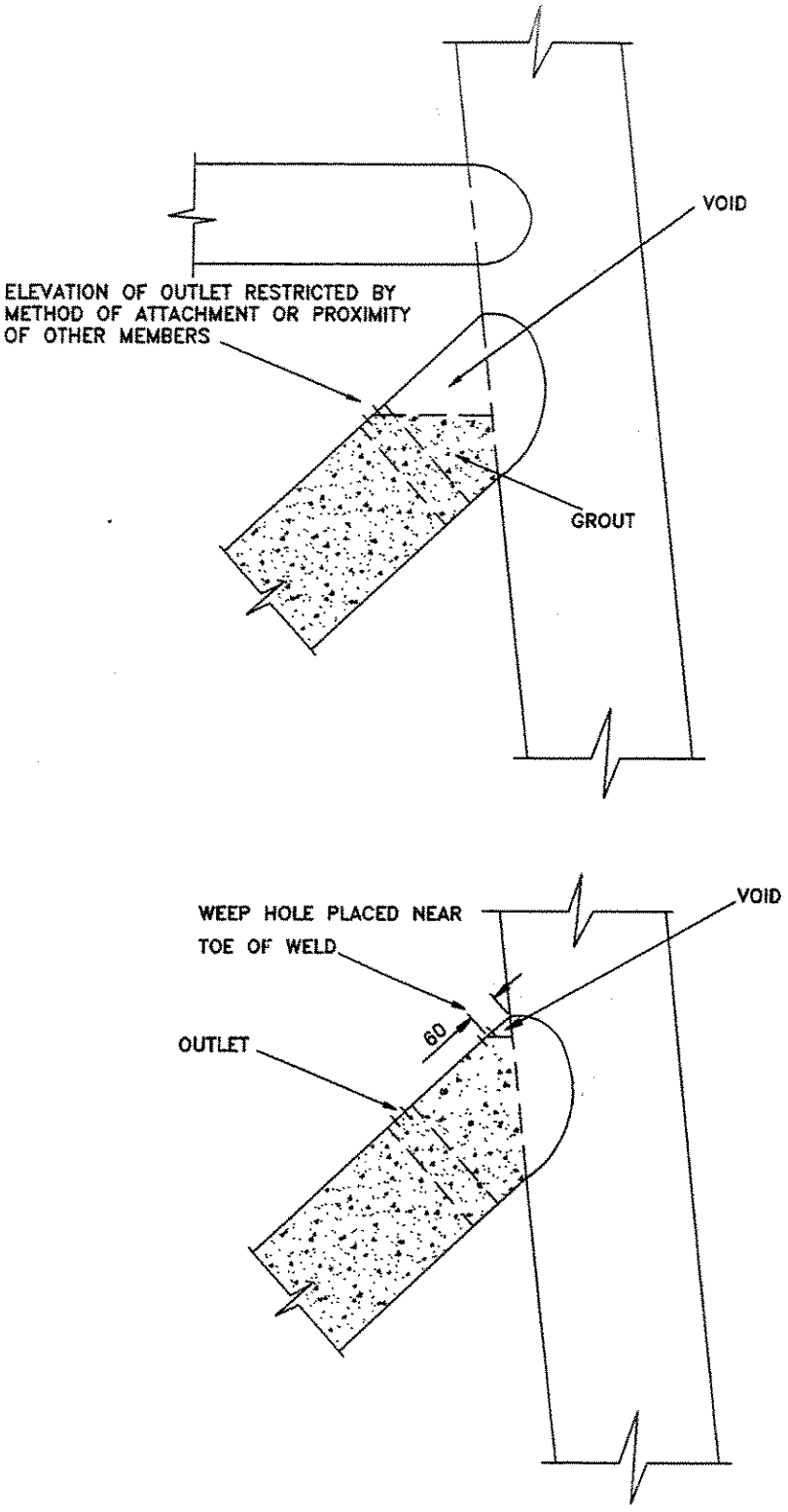



Figure 4.4 – OUTLET DETAILS

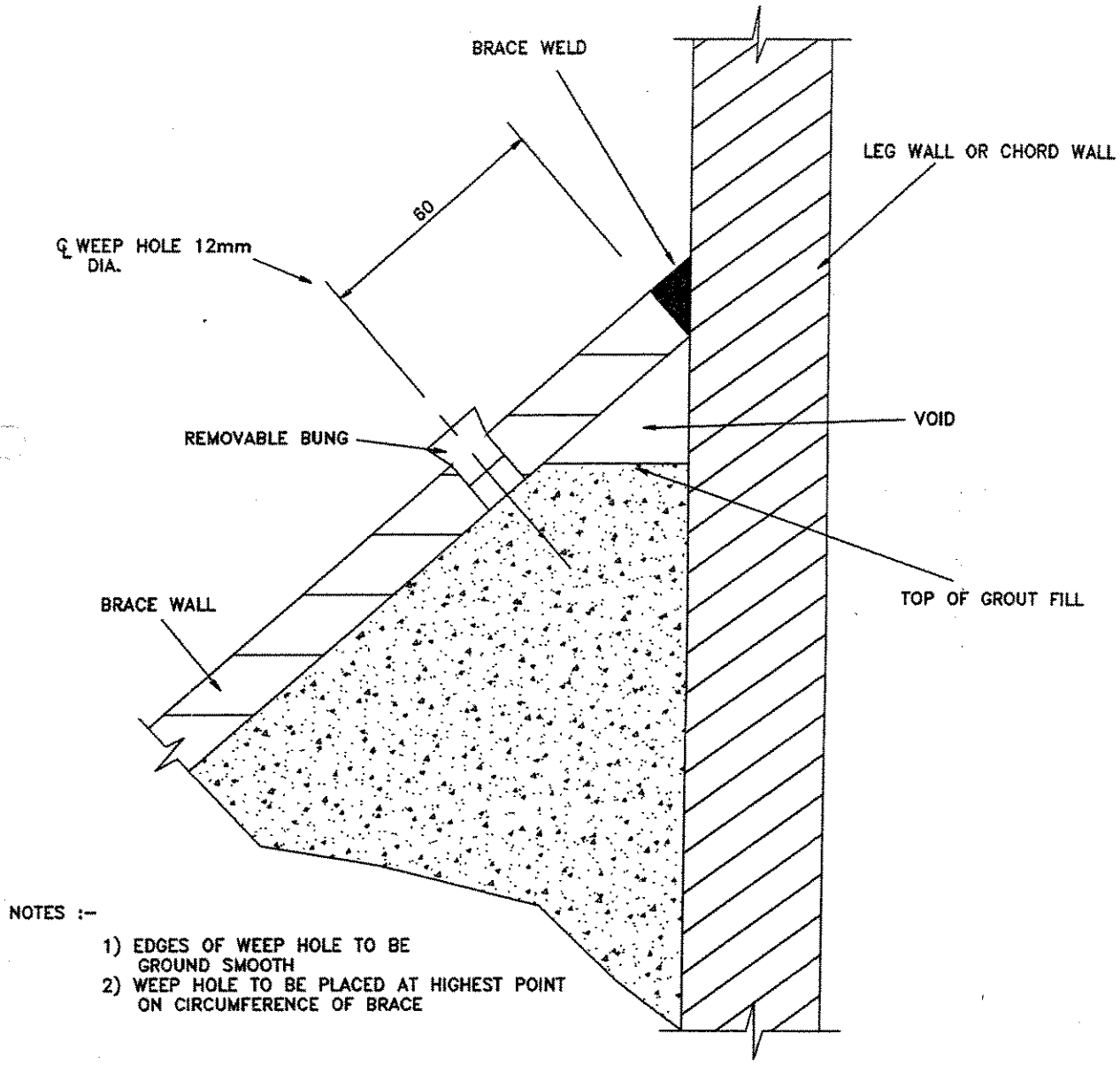
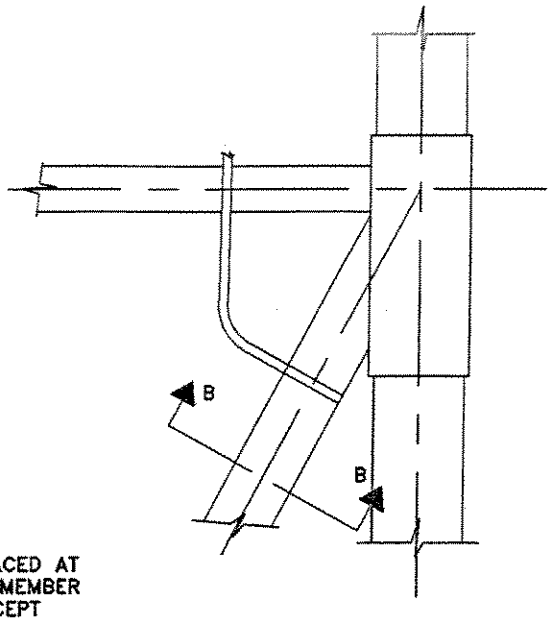


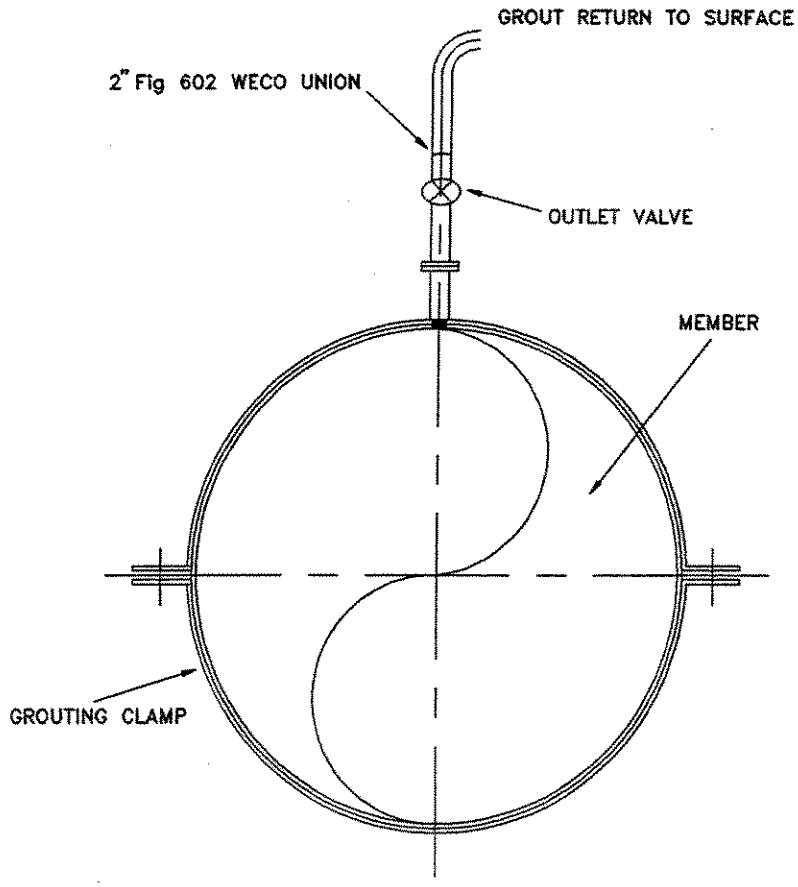

Figure 4.5 – WEEP HOLE DETAILS




ELEVATION

NOTE

OUTLETS TO BE PLACED AT HIGHEST POINT ON MEMBER CIRCUMFERENCE EXCEPT THAT OUTLETS TO BE AT LEAST 300mm FROM ANY GIRTH WELD AND 75 mm FROM ANY LONGITUDINAL WELD




VIEW B–B

Figure 4.6 DETAIL OF OUTLET

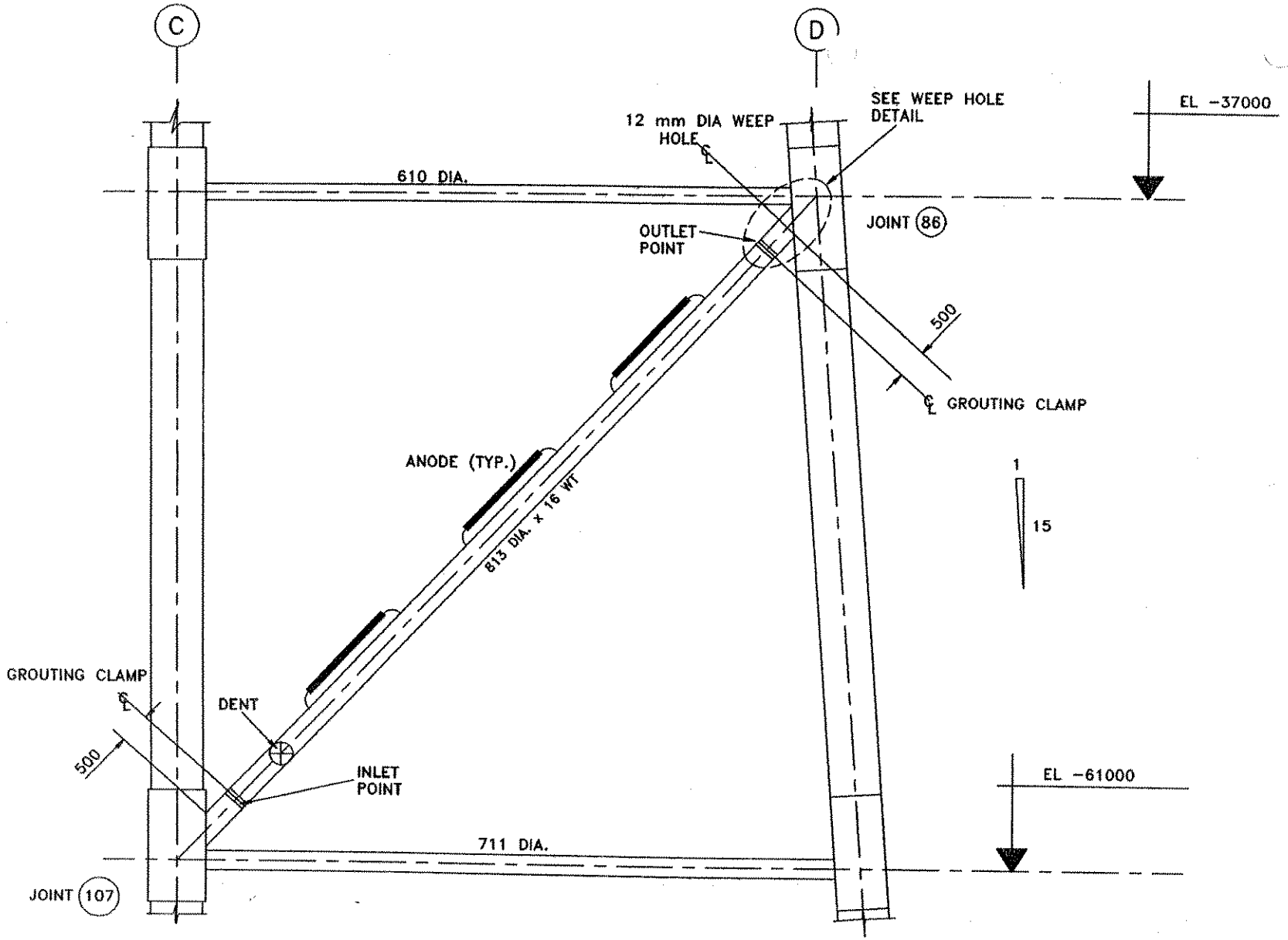



Figure 4.7 ELEVATION ON MEMBER 1

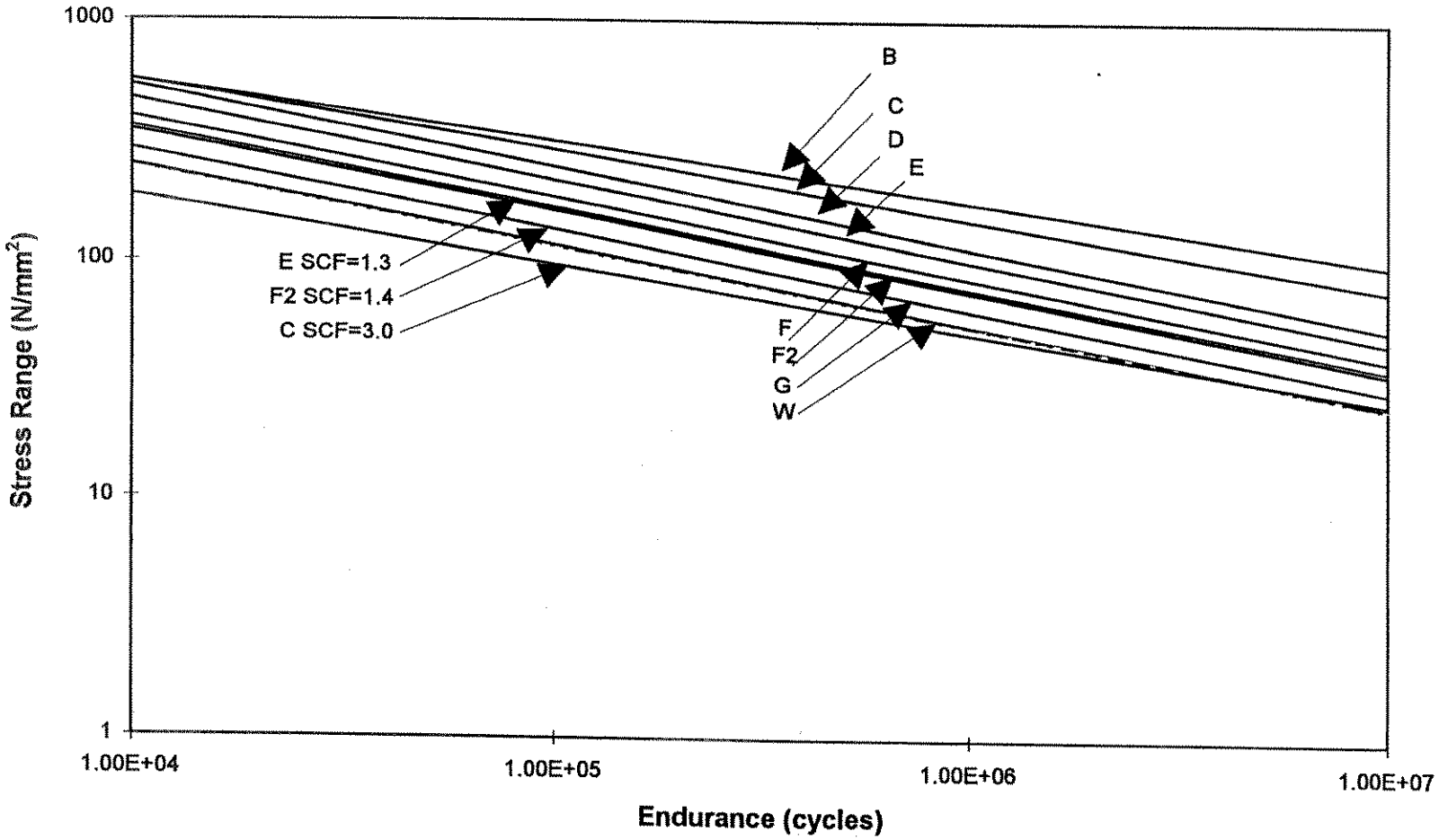



Figure 4.8 FATIGUE LIVES FOR HOLES AND BUTTWELDS IN MEMBERS

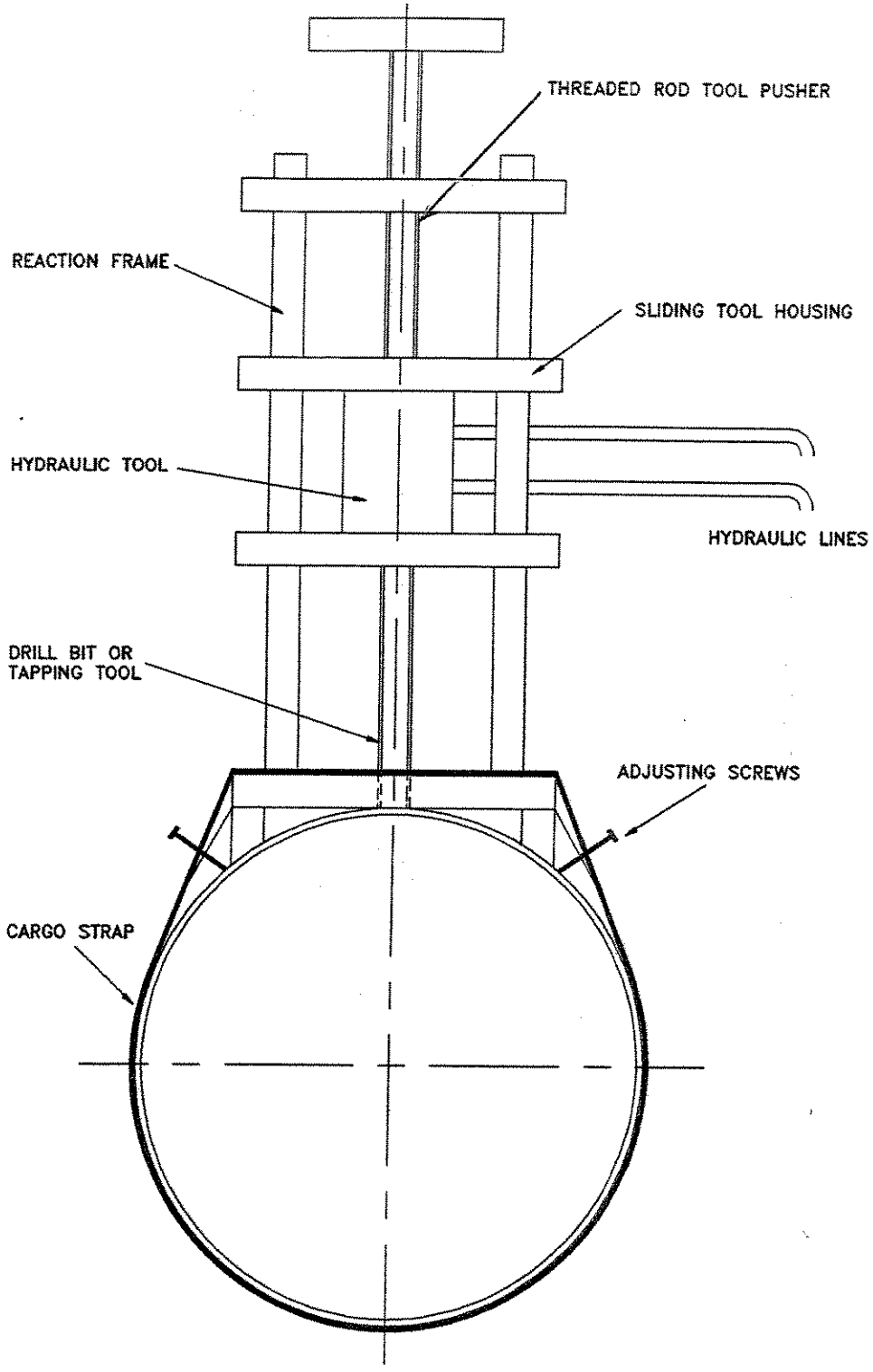



Figure 4.9 GENERAL ARRANGEMENT OF UNDERWATER DRILLING / TAPPING TOOL

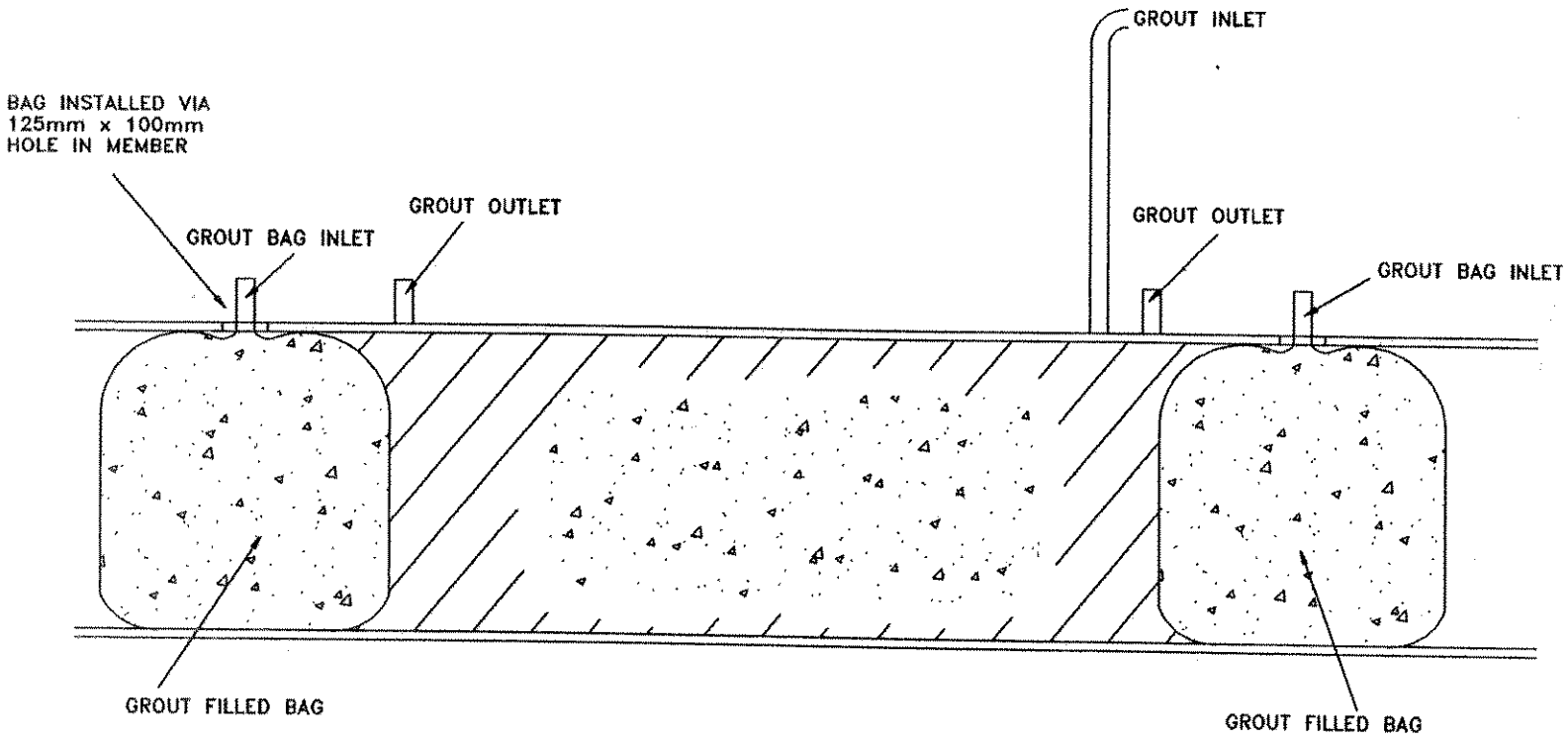



Figure 4.10 APPLICATION OF GROUT BAGS IN MEMBER FILLING

15 minutes using the inlet point to pump seawater. Do not stop flushing until grout has ceased to issue.

(iv) Inspect all valves and 'rake out' where necessary.

(v) If, as a result of stoppage, the inlet hole becomes permanently blocked by grout, a new inlet hole should be cut in the member as close to the existing hole as possible but avoiding any solid grout. The location of solid grout can be determined by using ultrasonic techniques or, alternatively, by tapping the member with a hammer (a grouted section will sound more solid than an ungrouted flooded section). The new hole should be placed using the same procedures as the original hole.

4.2.2.13 Post Grouting Procedure

**Flush Grout Lines**

Immediately after satisfactory grouting, close inlet and outlet valves and flush the grout inlet lines (via bypass) and retrieve to surface.

**'Feed Hose'**

The 'feed' hose at the outlet point shall be attached to the leg using lashing material. Underwater tape will be wrapped around exposed inlets/outlets and weep holes to prevent ingress of seawater. The 'feed' hose may be removed after 24 hours if required.

## 4.3 Fatigue Details

At completion of the work the inlets and outlets which remain form stress raisers which must be checked against fatigue. Assuming that the holes have been cut in parent plate (not weld metal) in the brace, then a type 'C' S-N curve applies and a hole gives rise to a stress concentration factor of 3.0. At single sided closure welds without thickness transitions a SCF of 1.4 applies with a type 'F2' S-N curve. At double sided butt welds without thickness transitions a SCF of 1.3 applies with a type 'E' S-N curve.

Figure 4.8 illustrates the relative endurance of each of the three details described. It is clear that the grout inlet/outlets represent the worst case. The single sided and doubled sided weld cases will have been checked in detailed design, it is, therefore, necessary to additionally check the brace member for fatigue at the inlet/outlet points.

## 4.4 Construction Details

### 4.4.1 Grout Inlets/Outlets

A typical arrangement of a jig used to drill and tap holes in members on an offshore structure is depicted in Figure 4.9. This particular jig is intended to be held in place and react the drilling force by being strapped to the member. However, the jig could equally be held in place by a simple hydraulic grabber arm arrangement. The drill and tap are held against the member by turning the handle at the end of the threaded bar using either a diver or a ROV. It is possible to carry out the drilling and tapping with a single tool in a single operation.

### 4.4.2 Grout Bags

It is conceivable, in certain circumstances, that it may not be desirable to grout the whole length of the member. Such an occasion would be where additional weight of fill grout would distress the member. In such an event it is necessary to locally confine the grout and this is achieved by the use of grout bags.

Figure 4.10 illustrates the general arrangement of such an application which consists of the following stages:-

1. Cut 125mm x 100mm holes in member.
2. Dress holes to remove sharp edges, burrs etc.
3. Insert grout bags and tie off inlets.
4. Inflate grout bags with 'standard' grout mix.
5. Maintain recommended pressure whilst grout sets.
6. Wait 24 hours after grouting of bags before grouting the void created in the member

The grout bag producers have now developed a standard specification for the material as follows:-

The material is manufactured from yellow woven polypropylene with the following characteristics in a standard tensile test

Warp 310 Kgf per 5 cm width
Weft 175 Kgf per 5 cm width
Weight = 300 g/m$^2$

The material is inert and is non degradable.

The material shall be protected at all times from prolonged exposure to direct sunlight.

All cutting of the material shall be by the 'hot-knife' method to prevent fraying of the seams and edges. Sewing thread shall be Polyamid Zwylon.

## 5. GROUT MIXES

This section describes the minimum technical requirements necessary for the grout constituent materials, mix design and quality control for grout filling of tubular members.

### 5.1 Design Requirements

All grouts to be used shall achieve a minimum compressive strength of 41.4 $N/mm^2$ at 28 days.

### 5.2 Grout Mix Proportions

All procedures in Section 4 are based on the grout mix given in Section 5.2.1. However the mix in Section 5.2.2 is equally acceptable, but produces a slightly less dense mix.

#### 5.2.1 Oilwell Cement

The grout mix shall be as follows:-

| | |
|---|---|
| Class 'B' or 'G' oilwell cement to API Specification 10 or equivalent | 100 parts by weight |
| Water | 34 parts by weight |

Alternatively, sulphate resisting Portland Cement to specification ASTM C150 Type II may be submitted in the same proportions.

No admixtures shall be permitted.

The mix will produce a slurry with a theoretical specific gravity of 2.05 and a yield of 0.65 $m^3$ per tonne of cement.

#### 5.2.2 Dutch Encillite

The grout mix shall be as follows:-

| | |
|---|---|
| Dutch Encillite (Dutch Portland Class B) | 100 parts by weight |
| Water | 39 parts by weight |

No admixtures shall be permitted.

The mix will produce a slurry with theoretical specific gravity of 1.98 and a yield of 0.7 $m^3$ per tonne of cement.

## 5.3 Materials

Manufacturer's Certificates of Quality with respect to the materials shall be obtained before use.

The cement shall be stored and transported in accordance with the manufacturer's instructions. The cement shall be kept free from moisture at all times and a careful inspection of all materials shall be made prior to their use to ensure their suitability for the work.

Potable water shall be used in preference to seawater if readily available on the platform. Seawater shall be clean, if used, and should be taken from the hydrant ringmain no earlier than one hour before mixing. The temperature of the water shall be in the range 4°C to 8°C.

All measures shall be taken to keep the cement and water cool prior to mixing. The measures proposed shall be subject to Client approval.

## 5.4 Grout Mixing

The grout shall be mixed using a continuous recirculating jet type mixer. The mixer type specified shall be subject to Client approval. An initial mix shall be made to line the mixer. This mix shall be discarded. Subsequent batches shall be used to grout the members. All batches shall be mixed for a minimum of two minutes.

## 5.5 Quality Control Requirements

### 5.5.1 Equipment

Calibration certificates are to be supplied for all relevant equipment.

### 5.5.2 Slurry Density Measurements

Measurement of slurry densities shall be made using a pressurised slurry density balance in the manner described in API Specification 10. Particular attention shall be paid to ensure that the external surfaces of the balance are cleaned and dried after filling and prior to balancing.

Grout mixes in accordance with Section 5.2.1 shall not be pumped until a specific gravity of 2.00 or greater is achieved. Grout mixes in accordance with section 5.2.2 shall achieve a specific gravity of 1.96. Slurry densities shall be checked immediately prior to pumping and throughout the grouting operations, sampling every batch mixed.

5.5.3 Cube Manufacture, Curing and Testing

Cubes shall be manufactured in accordance with Specification BS 1881 Part 108: 1970, or equivalent, with the exception that 75mm cubes shall be used.

The cubes shall be placed in a thermostatically controlled curing tank immediately after manufacture and cured at a temperature of 8°C±1°C until removed for demolding or testing. Seawater shall be used in the cube curing/storage tanks.

Cubes may be demolded after 24 hours and returned to the curing tank. Cubes shall not spend more than 1 (one) hour out of the curing tank.

Cubes shall be prepared for testing, weighed, measured and crushed within 30 minutes of removal from the curing tank.

The cube age shall be measured from the time the cube enters the tank to the time it is crushed.

Each cube shall be crushed in accordance with the procedure given in API Specification 10, with the exception that the rate of loading will not exceed 14 N/mm² per minute.

Each cube shall be marked with a unique mark and this mark correlated with the jacket member number, time, date made and slurry density as measured by a pressurised slurry density balance.

5.5.4 Sampling and Testing Procedure for Each Member

Four (4 N°) 75mm cubes shall be cast from the grout in the grout mixer at the start of the grouting operation after the minimum specific gravity is achieved.

Grouting operations shall continue until the density of the vented grout from the member achieves the required specific gravity as measured using the method described in Section 5.5.2. Once the specified grout density has been achieved from all vents, four (4 N°) 75mm cubes shall be cast from the remainder of the grout in the mixer using the method described in Section 5.5.3.

In addition to the casting of eight cubes noted above, twenty two (22 N°) 75mm cubes shall be cast during the grouting operation. Sampling shall be carried out at approximately equal intervals throughout the grouting operation.

Cubes shall be tested in accordance with the method described in Section 5.5.3. Three good cubes shall be tested at each of the following intervals:-

- 3 days
- 7 days

- 14 days
- 21 days

The remaining cubes, of which at least six shall be good, shall be tested at 28 days. Any cubes to be tested onshore can be packed in insulated containers for shipment, provided always that the curing regime is maintained.

For each grouted member, the following information shall be collated for the final report:-

- Member identification reference.
- Cube number and position in grouting sequence (eg. beginning, middle, end).
- Time and date of casting the cube.
- Time and date of testing the cube.
- Fluid grout density at time of casting.
- Weight and density of the grout cube.
- Failure load and cube strength.
- Average strength for cubes tested at the same time.

5.5.5 Transportation of Test Cubes

A period of three days shall elapse before the cubes can be made ready for transportation ashore.

Cubes should be demolded and each cube must be individually wrapped in hessian sacking or cloth and placed in a polythene bag. Fresh water should then be added to keep the cube moist during transit. The polythene bag must be then sealed to entrain the water. A label identifying the cube should then be securely attached to the bag.

When all the cubes have been wrapped, they should be packed in a sturdy container. If possible, they should be further cushioned by placing rags, or a similar packing material between individual cubes and around the sides of the container. Any voids remaining after the cubes have been packed should be filled with rags, and finally, a lid should be firmly attached to the container. Attach 'Fragile' packing labels to container.

The cubes should be transported ashore by the fastest possible means. Notification to the consignee must be made in advance in order that the cubes can be uplifted from their location and taken to the testing laboratory for

storage. On arrival at the laboratory the cubes shall be immediately placed in a curing tank at a temperature of 8°C ± 1°C until removed for testing.

## 6. EQUIPMENT LISTS

Equipment requirements to install a grouted member repair are given below. Equipment related to diving support is not included.

Drilling and Tapping

- Drilling and Tapping Jig to cut 1½" - 2" diameter holes in tubulars underwater. (see Figure 4.10)

Grouting

- Continuous batching recirculating jet mixer able to deliver approximately 4 $m^3$/hour of mixed grout.
- grout holding tank
- grout pump
- cement silo(s)
- 2" grout hose
- 2" ball values and unions (quick connect/disconnect type).

Grout Laboratory

- Curing tank capable of sustaining 8°C + 1°C. Suitable for minimum 30 cubes.
- Pressurised mud balance to test grout slurry density in accordance with API Spec 10.
- 75 mm cube moulds in accordance with BS 1881 part 108:1970.
- Weighing scales
- Callipers for measuring cube dimensions
- Cube crushing machine, minimum 50 tonnes capacity.
- Crates and packing in which to transport cubes ashore.

## 7. ESTIMATED OFFSHORE DURATIONS

Offshore logs have been made available to MSL Engineering for a project involving grout filling of 2 horizontal members through drilled and tapped inlets and outlets. The following durations are based on this project and do not allow for weather downtime or mechanical breakdown.

Day 1

Setting up equipment.
Start drilling and tapping holes. (10 No total)
Make trial mix.

Day 2

Continue drill and tap.
Make up grout hoses.

Day 3

Complete drill and tap.
Deploy hoses to Member 1.
Leak test Member 1.

Day 4

Grout Member 1.
Recover hoses and fittings from Member 1.
Deploy hoses and fittings to Member 2.
Grout Member 2.

Day 5

Recover hoses and fittings from Member 2.
Demobilise dive team.

Day 6

Cube demoulding.
Demobilise grouting spread.

Day 7

Crush 3 day cubes.

Day 8

Demobilise grout team.

Specific tasks have the following durations:

Drill and tap 10 NO 1½" inlets/outlets - 30 hours diving

Leak test and grout Member 1 (18.5 $m^3$ grout) and recover lines - 14½ hours diving

Leak test and grout Member 2 (11.2 $m^3$ grout) and recover lines - 8 hours diving

Work was executed by an air diving team with three divers in the water for a maximum of 180 minutes per dive.

For the two scenarios being addressed, time estimates have been developed using data derived from the reference offshore project.

Horizontal Member

Volume to be filled = $16m^3$

Day 1

Mobilise and set up equipment, make trial mix

Day2

Drill and tap 5 No inlets/outlets, 15 hours diving

Day 3

Deploy lines, grout member and recover lines, 15 hours diving

Day 4

Demobilise diving spread. Clean and service grouting spread. Demould cubes and prepare to transport ashore

Demobilise grouting spread

Day 6

Test 3 day cubes onshore

Day 10

Test 7 day cubes onshore

Day 31

Test 28 day cubes onshore

Inclined Member

Volume to be filled = 15 $m^3$

Day 1

Mobilise and set up equipment, make trail mix

Day 2

Drill and tap or drill and clamp 2 No inlets/outlets, 6 hours diving
Deploy lines, grout member and recover lines, 12 hours diving

Day 3

Demobilise diving spread
Clean and service grouting spread
Demould cubes and prepare to transport ashore
Demobilise grouting spread

Day 5

Test 3 day cubes onshore

Day 9

Test 7 day cubes onshore

Day 30

Test 28 day cubes onshore

**FIGURES**

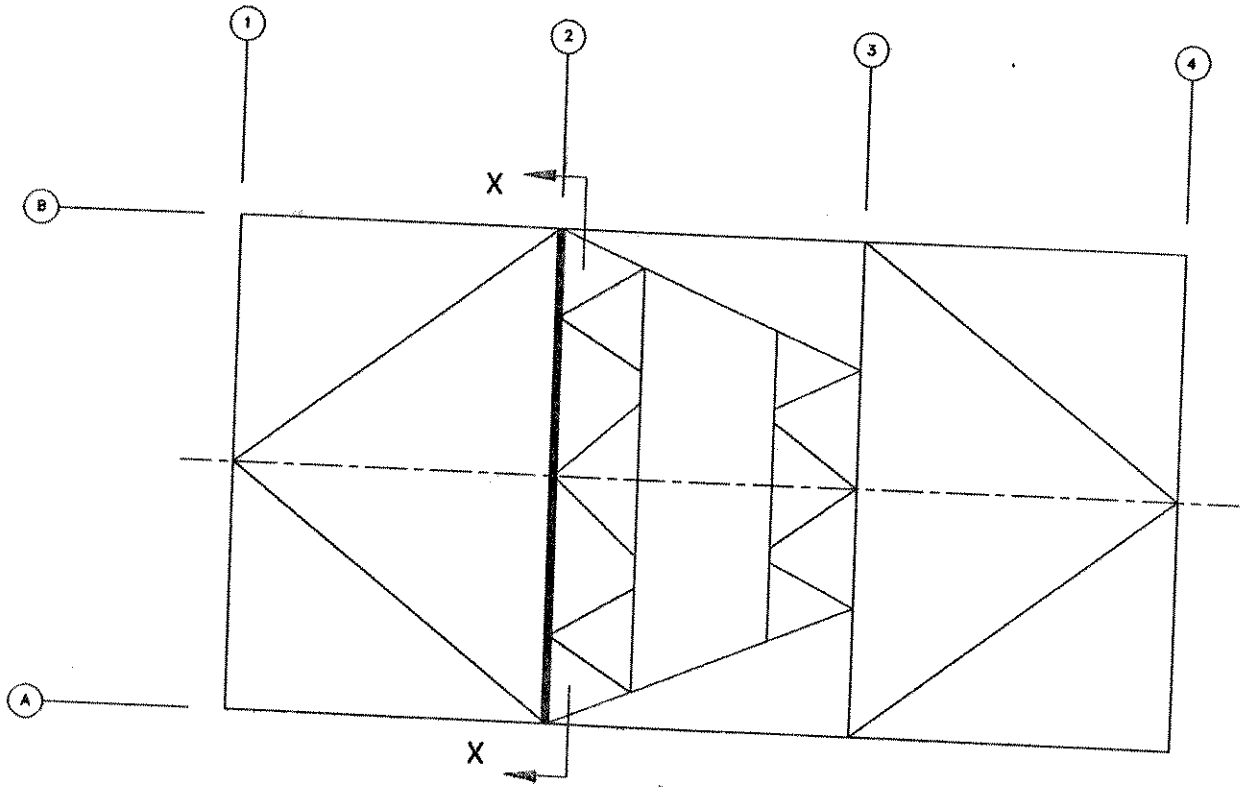



Figure 3.1 PLAN AT ELEVATION −12m LEVEL
SHOWING MEMBER TO BE GROUT−FILLED