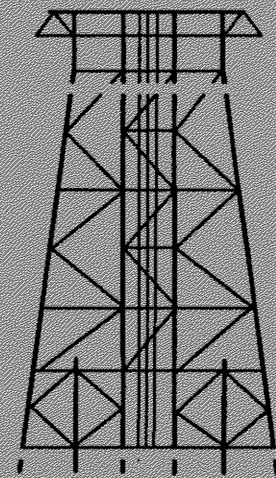
PROJECT 202 AH

MARINE TECHNOLOGY
DEVELOPMENT GROUP
PROJECT



Screening Methodologies for Use in Platform Assessments and Requalifications

Ultimate Limit State Limit Equilibrium Analyses ULSLEA

Professor Robert Bea

Doctoral Graduate Student Researcher Mehrdad Mortazavi

Department of Civil Engineering

UNIVERSITY OF CALIFORNIA AT BERKELEY

June 2, 1995

AGENDA

9:00 INTRODUCTIONS *(Bob Bea)*
9:15 PROJECT REVIEW *(Bob Bea)*

10:00 COFFEE / STRETCH BREAK

10:15 VERIFICATION CASE STUDIES
(Ken Loch , Mehrdad Mortazavi)
11:00 PARAMETER STUDIES *(Ken Loch)*
11:30 DISCUSSION

12:00 LUNCH

1:00 ULSLEA - FINAL IMPROVEMENTS
(Mehrdad Mortazavi)
1:30 ULSLEA - SOFTWARE DEMONSTRATION
(Mehrdad Mortazavi)
2:00 WRAP UP / CONCLUSIONS / DISCUSSION

2:45 BREAK

3:00 FUTURE WORK
(Bob Bea, Mehrdad Mortazavi, Ken Loch, Jim Stear)
4:00 DISCUSSION / SPONSORS INPUT
4:30 ADJOURN

PROJECT SPONSORS

Arco Exploration and Production Technology

California State Lands Commission

Exxon Production Research Company

Mobil Research and Development Company

Shell Oil Company

Unocal Corporation

U. S. Minerals Management Service

PROJECT ASSISTANCE

Amoco Production Company

Chevron Petroleum Technology Company

Phillips Petroleum Company

Screening Methodologies for Use in Platform Assessments and Requalifications

PROJECT OBJECTIVE

Further develop simplified quantitative screening methodology for Level 2 platform assessments so they can be used in practice

SCHEDULE

1 June 1993 - 31 May 1995

DELIVERABLES

Level 2 formulation, implementation, verification

"Screening Methodlogies for Use in Platform Assessments and Requalifications"

ULSLEA program and documentation

"Appendix C - ULSLEA...."

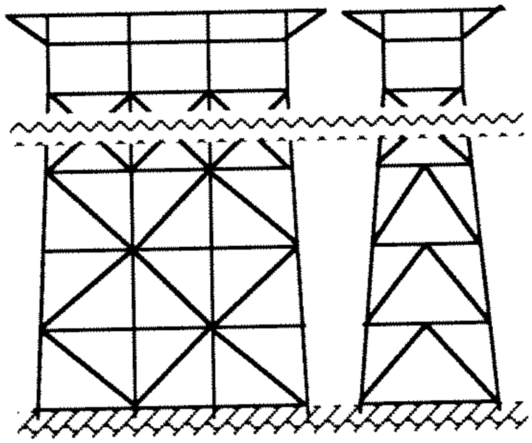
BUDGET

$ 150,000 (5 sponsors @ $15,000 per year)

Expended: GSR $ 80,000, PI $ 40,000, Expenses $ 30,000 = $150,000

Σ : project on scope, budget, and schedule

Determination of the Ultimate Limit States of Fixed Steel-Frame Offshore Platforms Using Static Pushover Analyses



by

Kenneth J. Loch

and

Professor Robert G. Bea

Report to

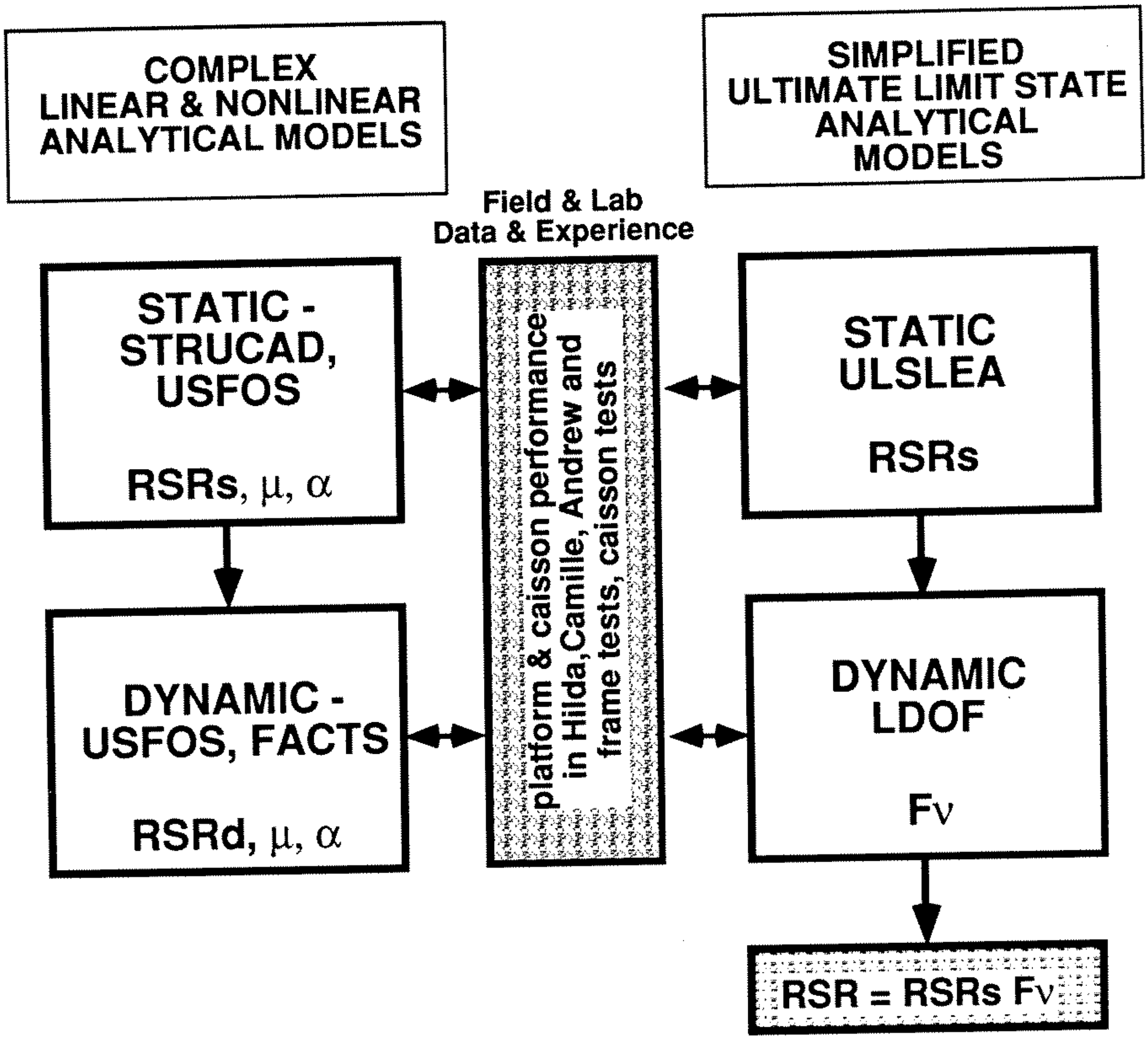
U. S. Minerals Management Service
and
Joint Industry Project Sponsors

Marine Technology Development Group
Department of Civil Engineering

UNIVERSITY OF CALIFORNIA AT BERKELEY

May 1995

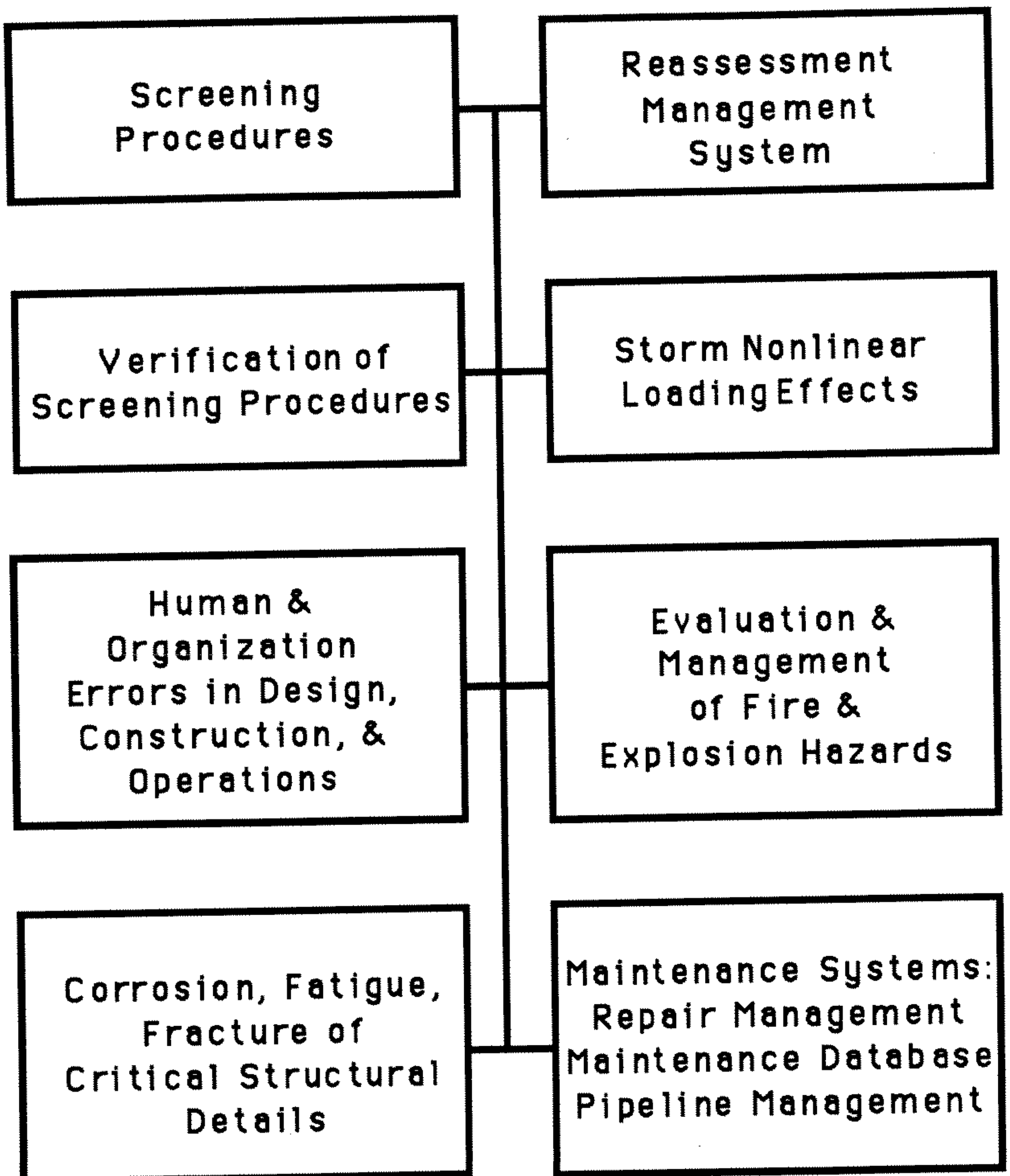
Platform Performance Research



ULSLEA PROJECT SCOPE

- Aero and hydrodynamic loadings
- Deck legs capacity
- Jacket capacity (legs, braces, joints)
- Foundation capacity
- Deterministic ULS analysis
- Probabilistic ULS analysis
- Damaged and repaired members
- Verification case studies (5)
- ULSLEA program and documentation

MTDG PROJECTS



Marine Technology Development Group - University of California at Berkeley

Verification of Screening Methodologies for Use in Gulf of Mexico Platform Requalifications

Kenneth J. Loch

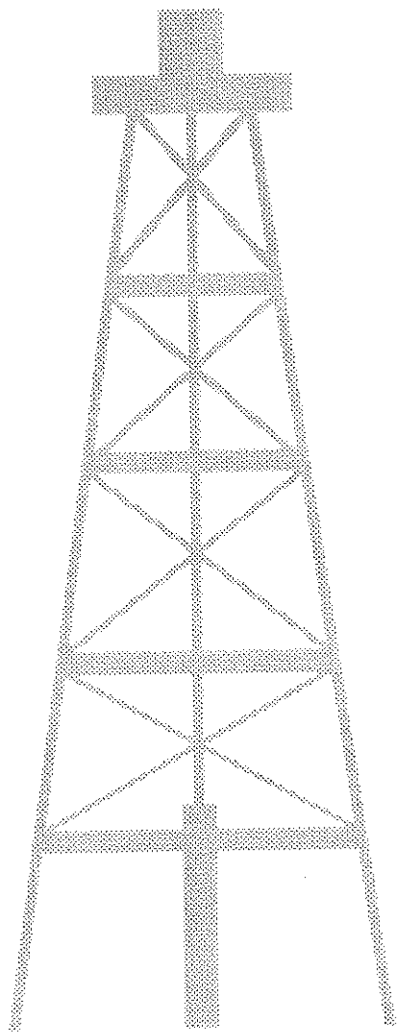
Project Scope
Jan. 94 - May 95

- Chevron ST 151H
- Chevron ST 151K
- Chevron ST 151H
- Chevron ST 151K
- Report

Verification Case Study Status

- Chevron ST 151H - completed
- Chevron ST 151K - completed
- Kerr McGee ST 34-2,3 - completed
- Kerr McGee ST 34-4 - completed
- Chevron ST 151H - completed
- Chevron 151K - completed
- Shell SP 62 - data available
- Shell SS 274 - data available
- Phillips SMI 76B - data available
- Phillips NCI - A - data available
- others (Mobil, Unocal, Exxon)

Chevron ST 151H



General Description

- Eight leg drilling and production platform
- Installed in 137 ft of water in 1964
- Eleven 30 in. conductors
- Broadside and end-on framing battered at 1:12
- Cellar and main decks at +35 ft and +46 ft respectively

Platform Details

- Ungrouted legs with thickened joint sections
- F_y = 43 ksi
- 30 in. piles penetrate 180 ft of firm to very stiff clay
- Vertical braces range in size from 16 in. in the fourth (upper) bay to 18 in. in the first bay

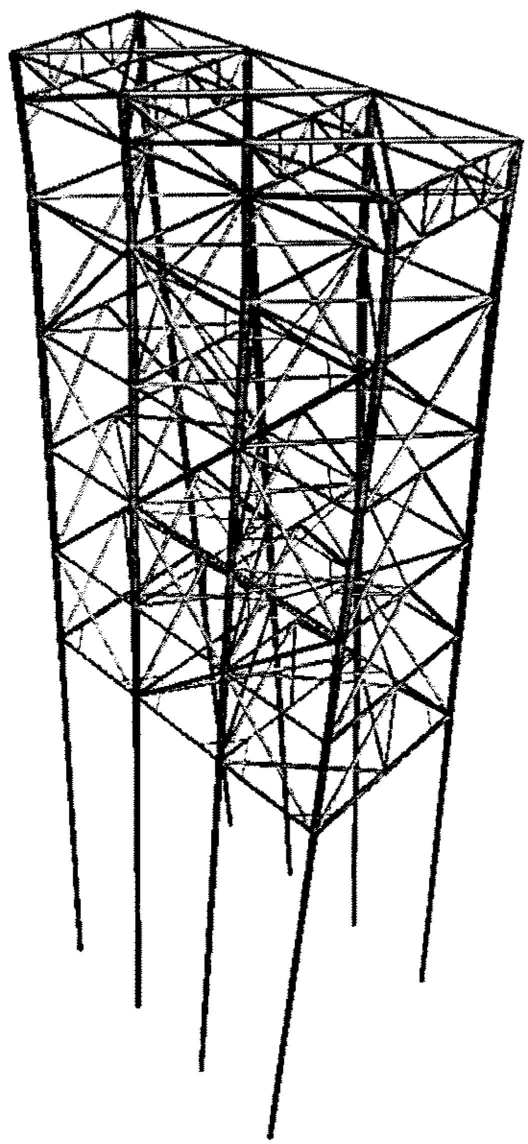
Level 4 Analysis

- Static pushover analysis
- WAJAC generated hydrodynamic loads
- Broadside and end-on analyzed separately to match Level 2 approach

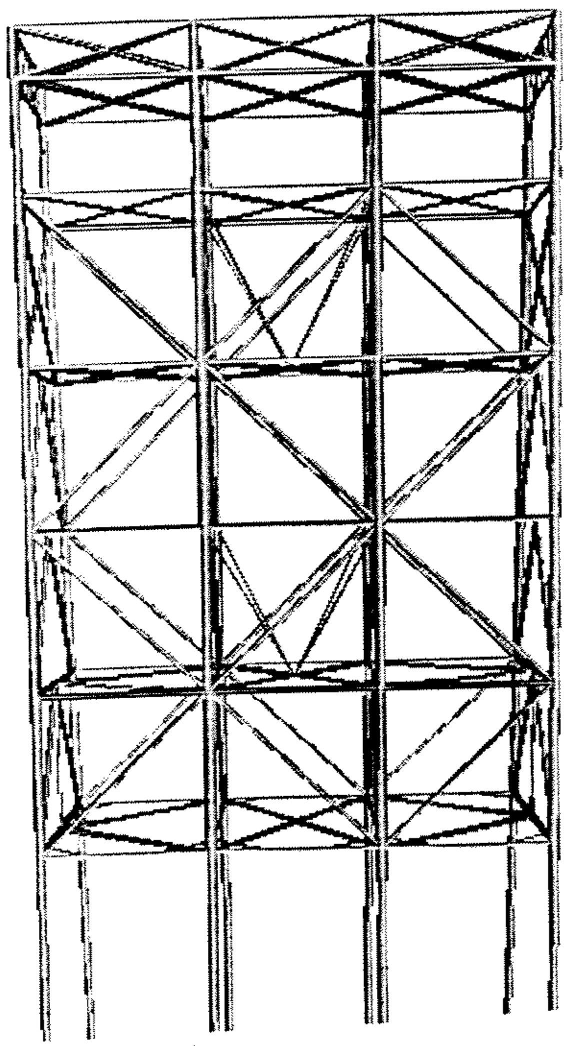
USFOS Model

- Only major structural members modeled
- Initial imperfection taken as 0.003 for all members
- Used API RP 2A spring models with strength increased by 3.28
- Rigid joints assumed

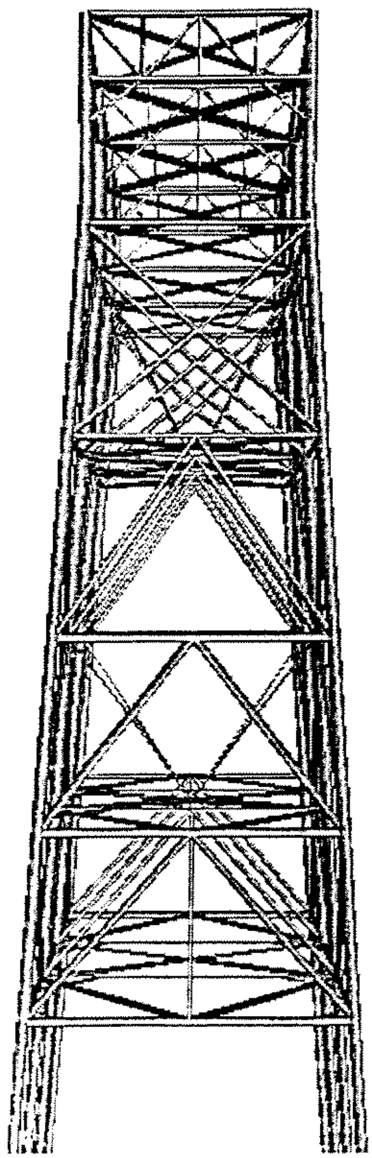
Isometric



Broadside Elevation



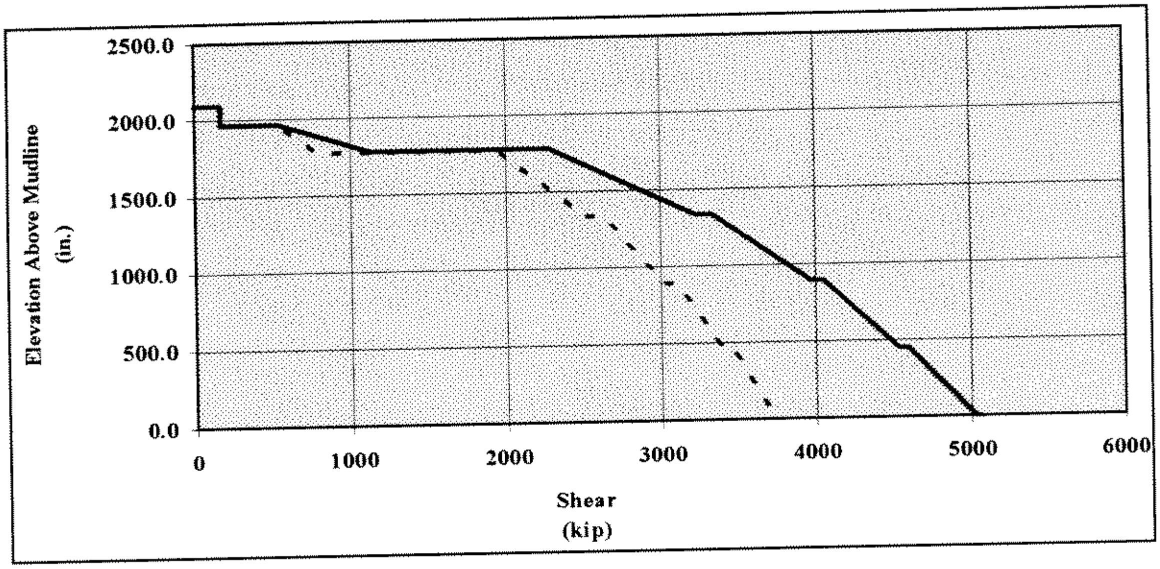
End-on Elevation



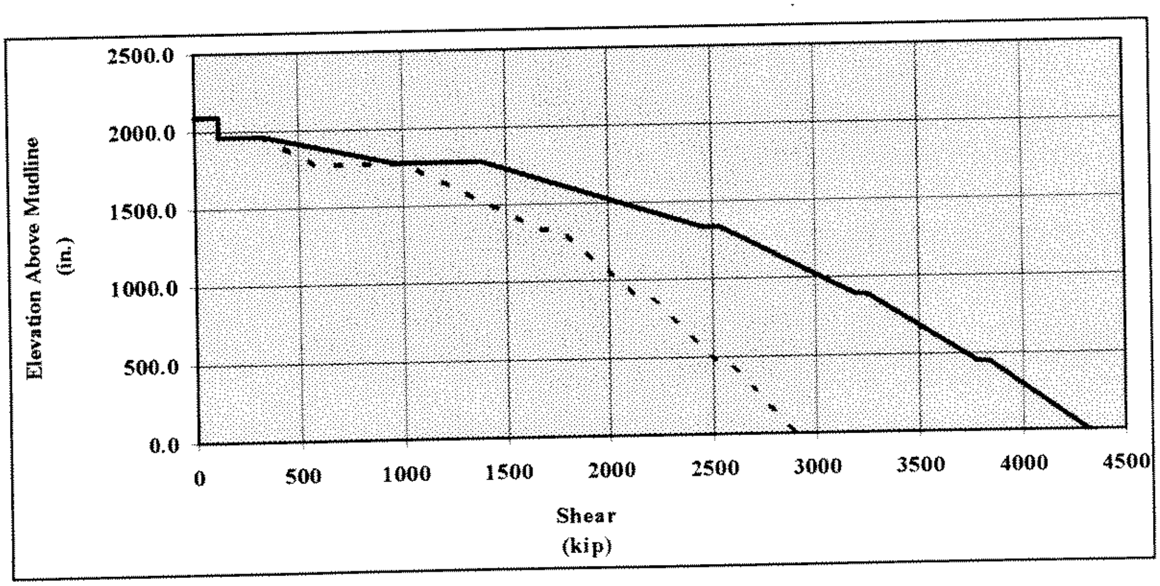
Loading Information

- Assumed marine growth = 1.5 in.
- Cd = 1.2
- Cm = 1.2
- wkf = 0.88
- Broadside loading
  - H = 56 ft, T = 13 sec.
  - In-line current = 46.5 in/sec, cbf = 0.80
- End-on loading
  - H = 60 ft, T = 13 sec
  - In-line current = 46.5 in/sec, cbf = 0.70

Loading Profiles
(with and without conductor loads)

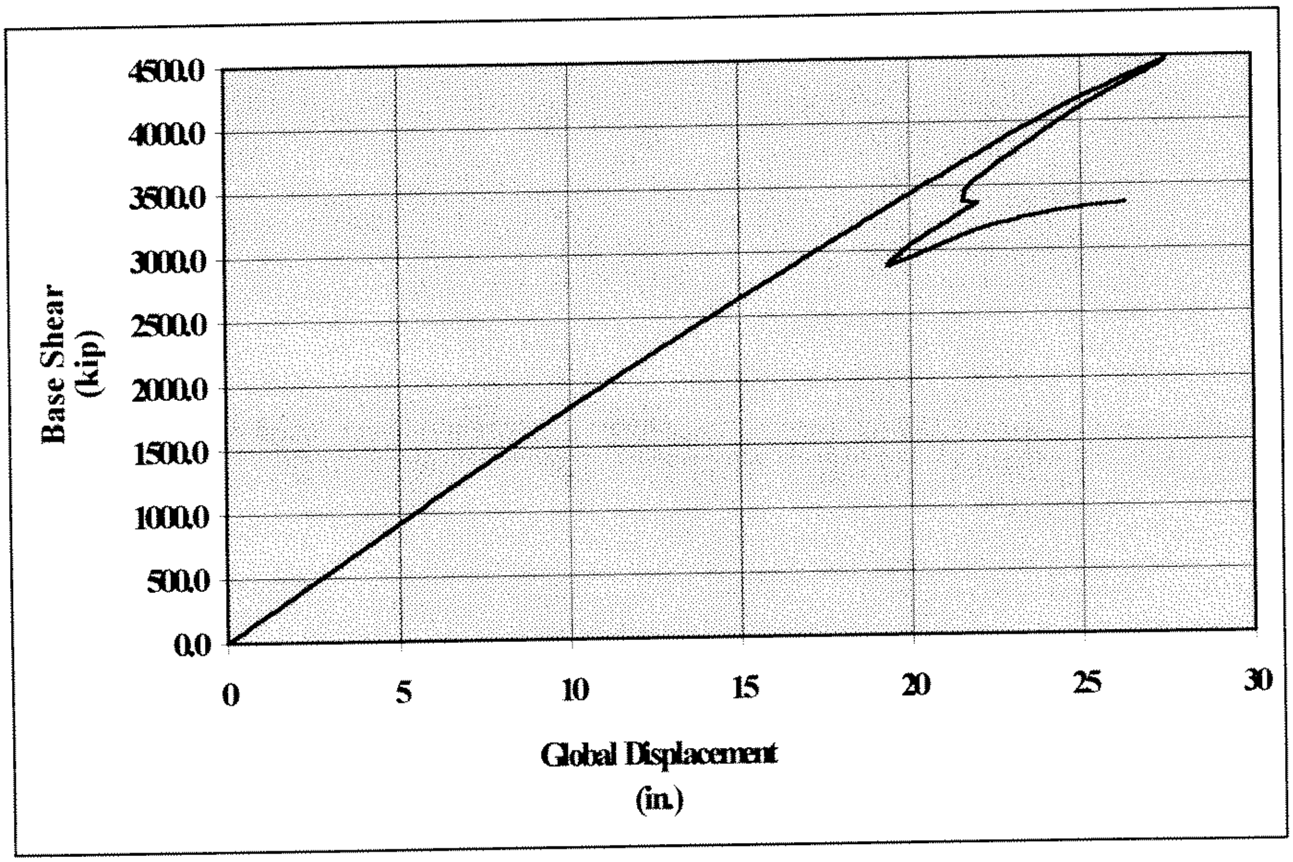


Broadside Loading



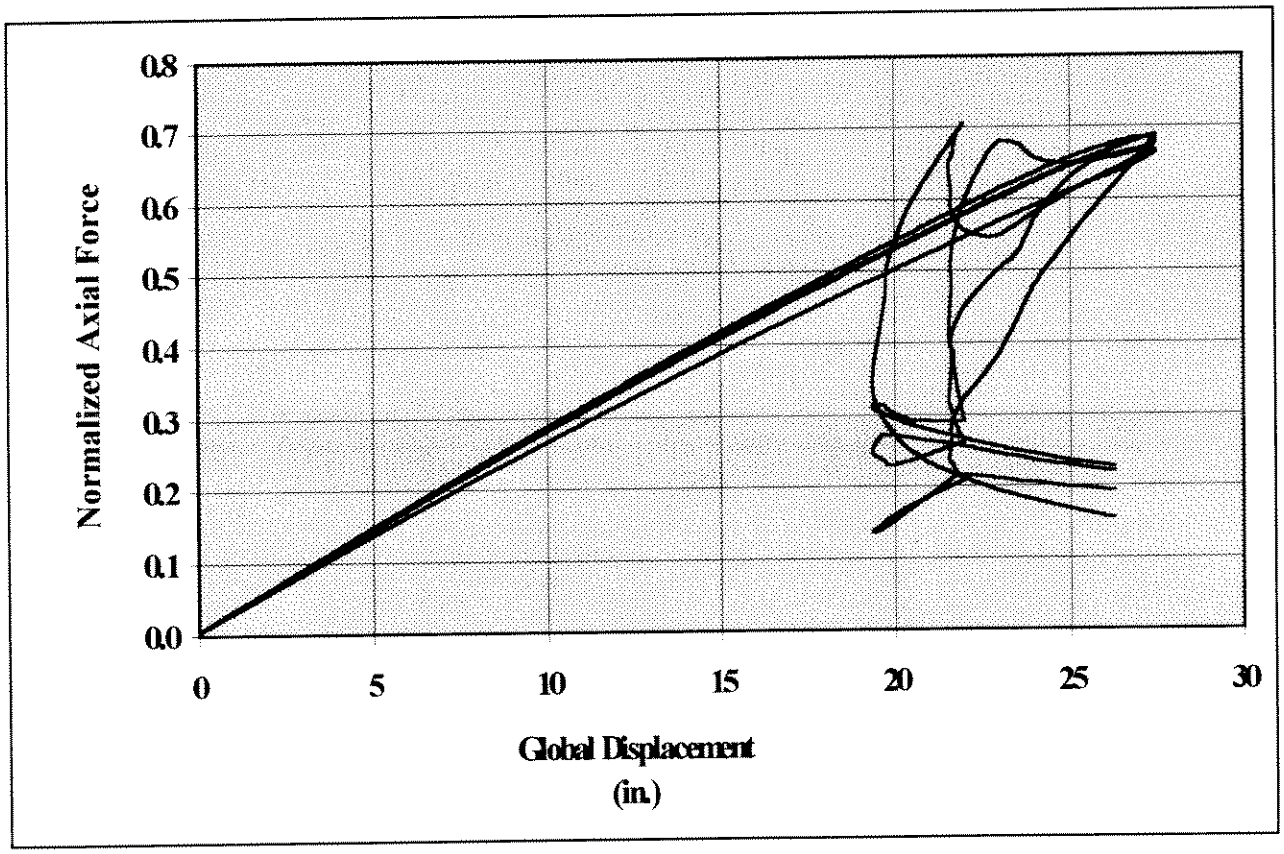
Endon Loading

Broadside Force-Displacement History



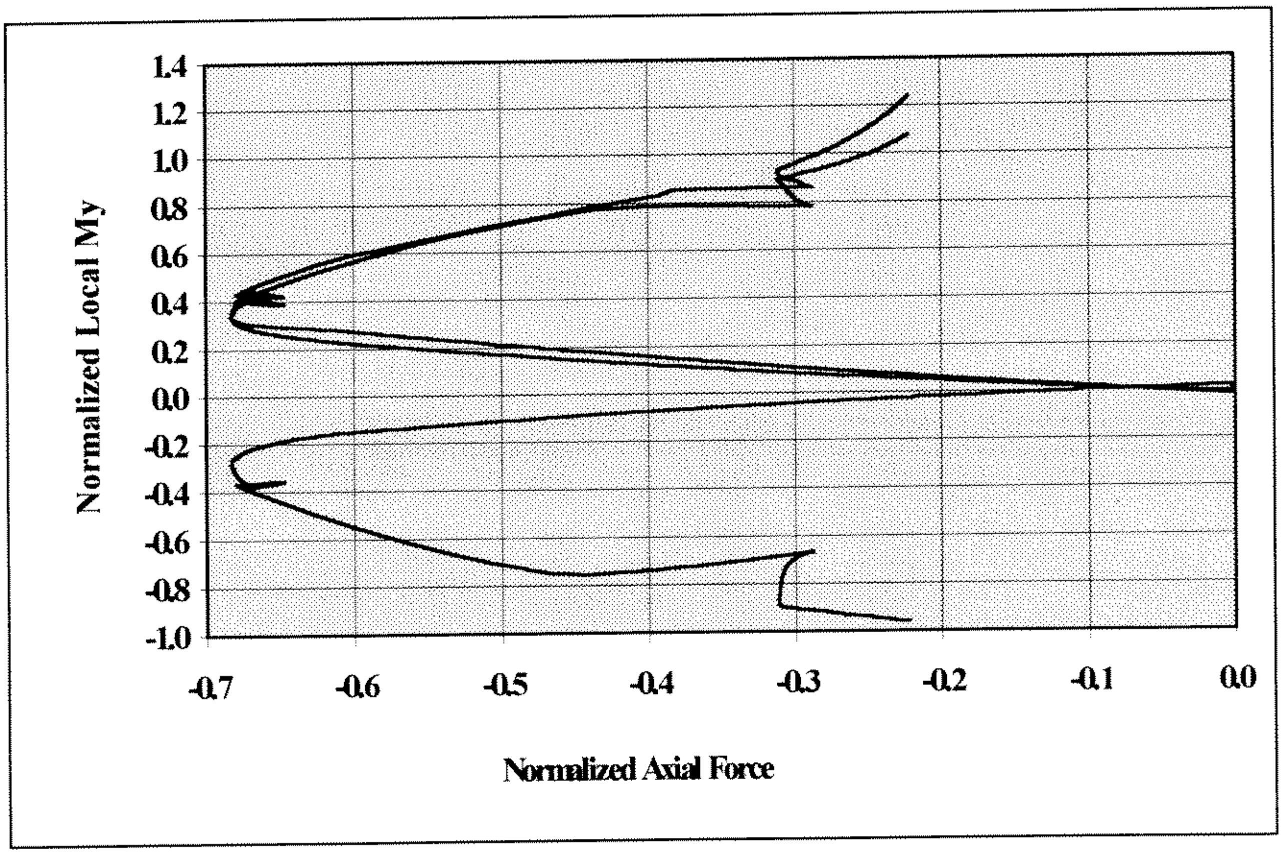
Maximum base shear = 4,475 kips

Broadside Critical Brace Axial Force History



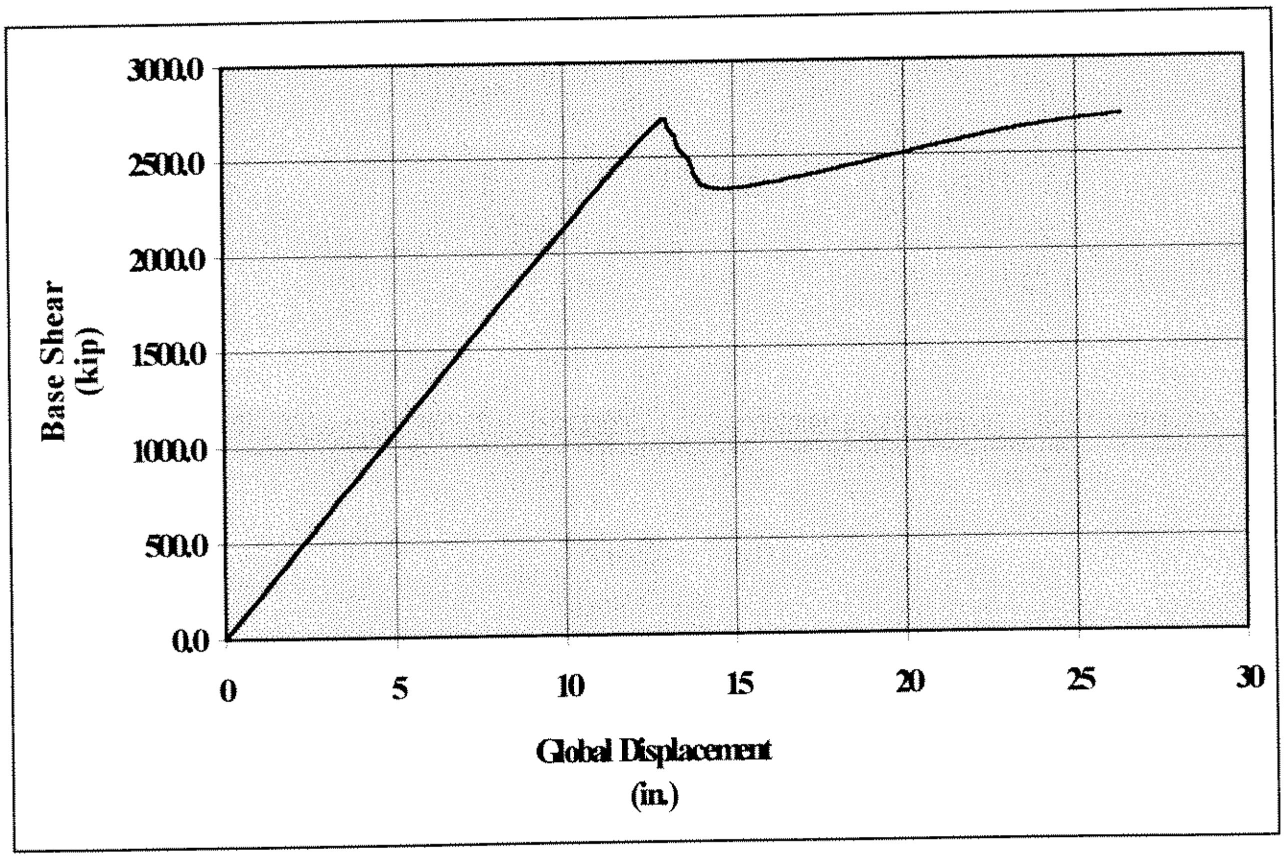
Values normalized by plastic capacity

Broadside Critical Brace P-M Interaction



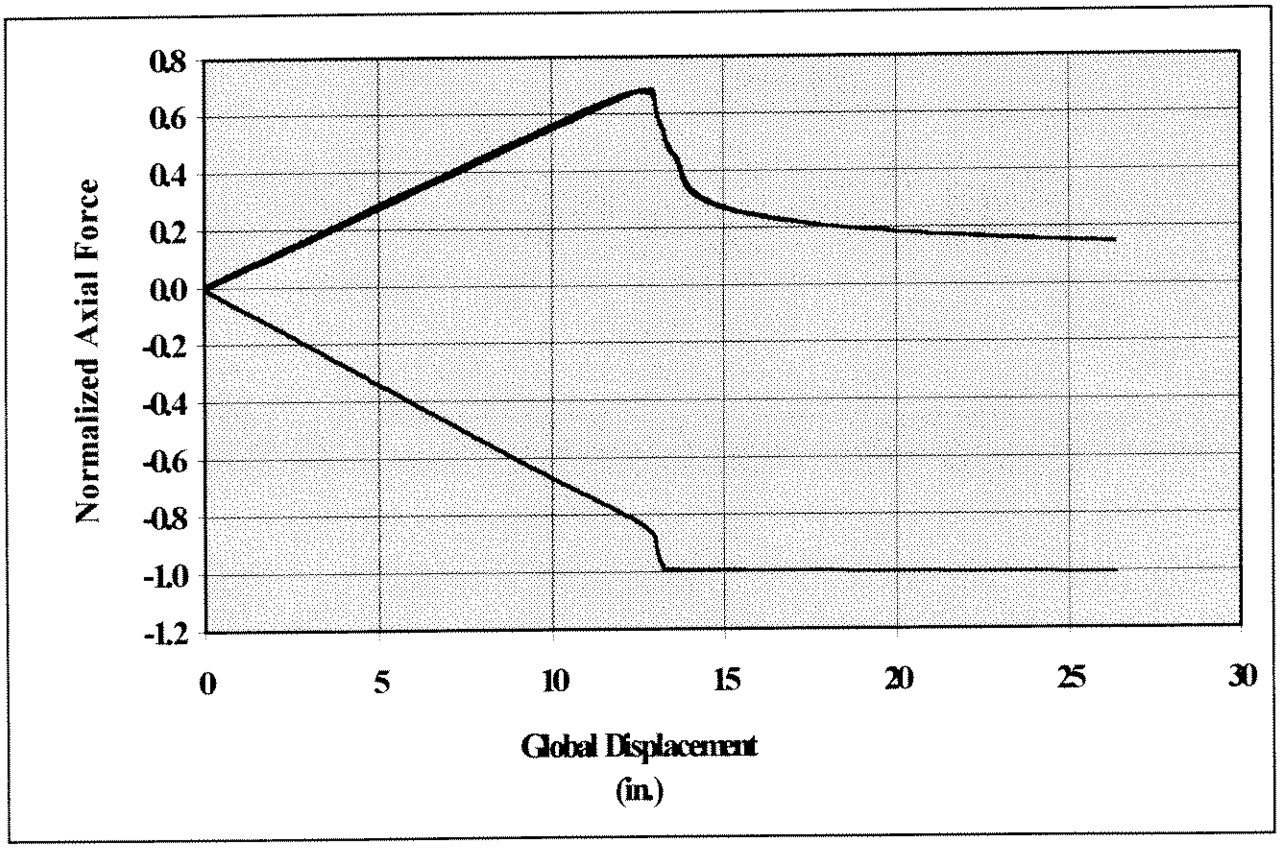
Values normalized by plastic capacity

End-on Force-Displacement History



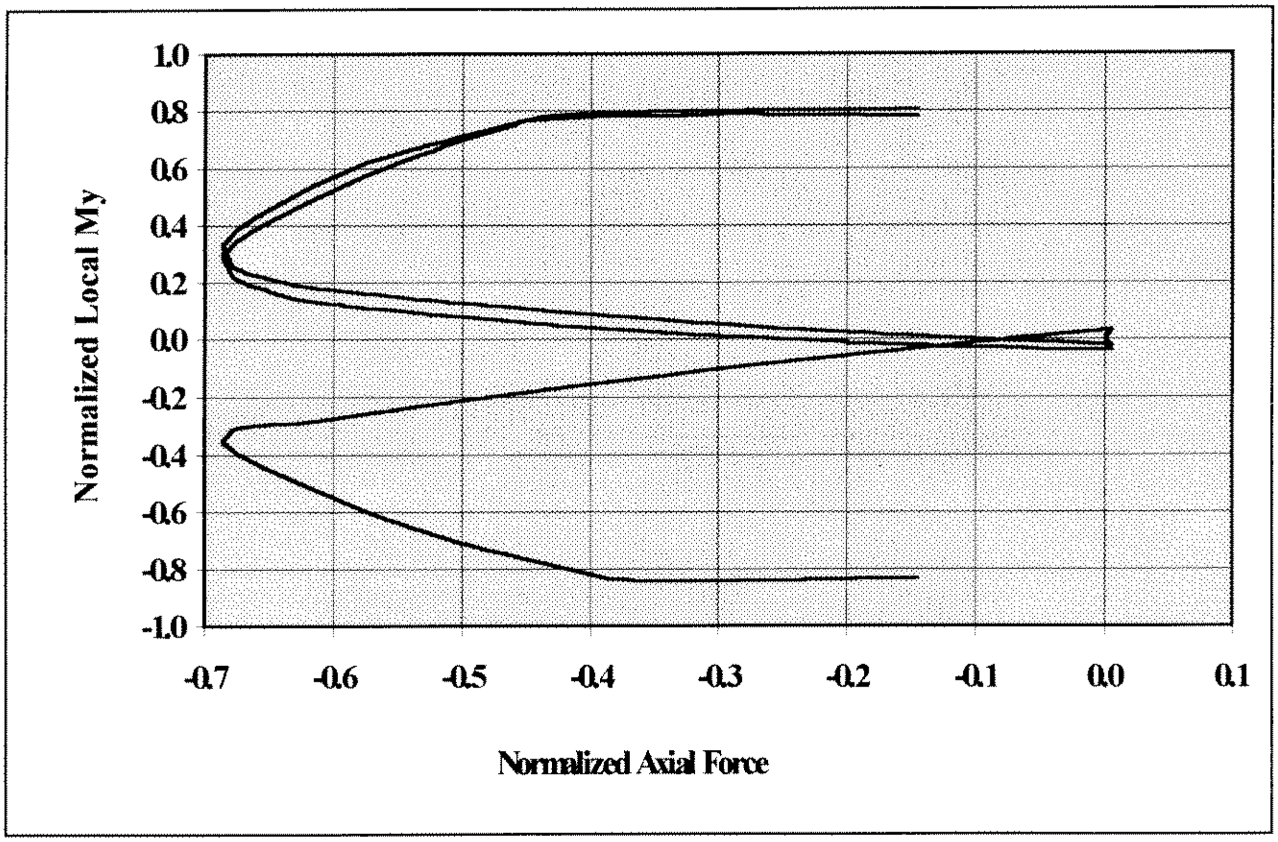
Maximum base shear = 2,697 kips

End-on Critical Brace Axial Force History



Values normalized by plastic capacity

End-on Critical Brace P-M Interaction



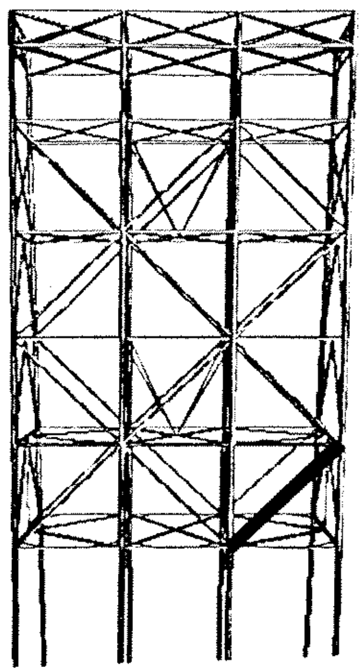
Values normalized by plastic capacity

Comparison with Observed Andrew Performance

- Chevron ST 151H experienced approximately 60 ft waves between end-on and diagonal directions
- Platform appeared to have failed in the end-on direction
- USFOS model predicted failure at 62 percent of 60 ft end-on storm load
- Imperfection and member orientation combination is realistic but conservative

- **Conclusion:** USFOS model would predict failure during likely Andrew loading

Platform "D" End-on Loading
MLTF Member

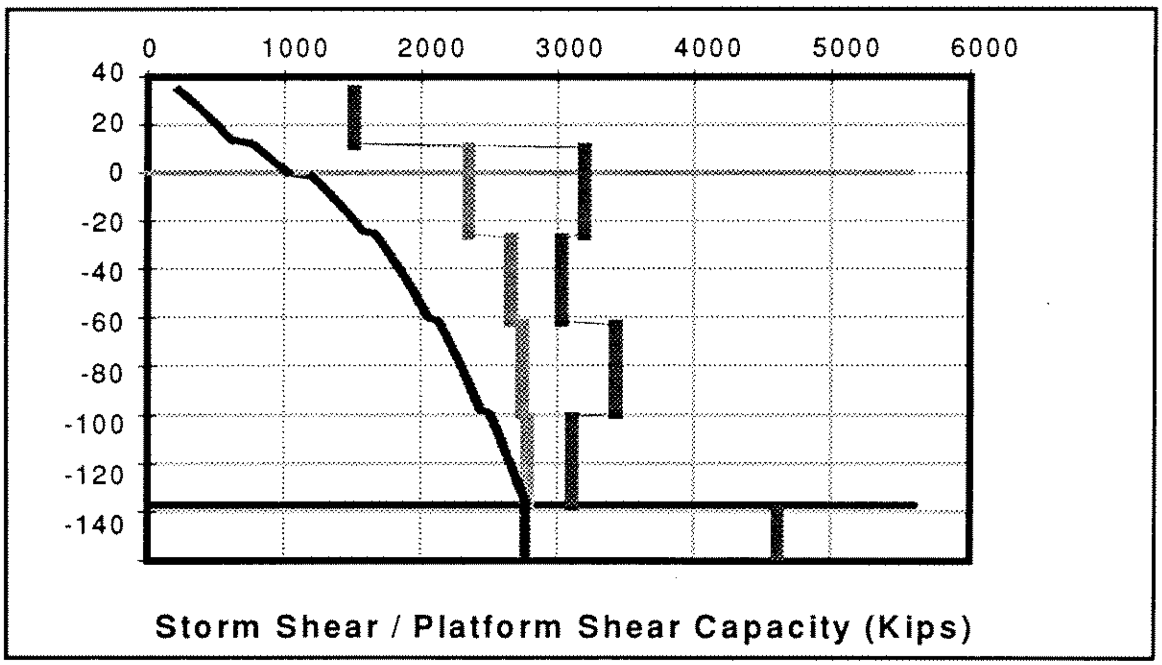


	K-factor	Δ/L (%)	$P_{ULTIMATE}$ (kips)
USFOS	-	0.15	620
	-	0.30	590
ULSLEA	0.55	-	670
	0.65	-	630

Platform "D" End-on Loading (ULSLEA)

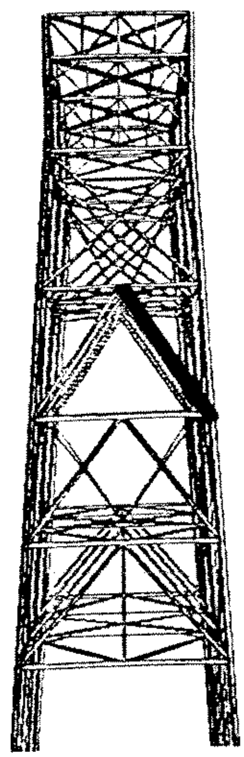
LOAD PATTERN

H = 60 ft, T = 13 sec, Uc = 3.2 ft/sec (constant)



USFOS	2,700 Kips
ULSLEA	2,800 Kips

Platform "D" Broadside Loading
MLTF Member

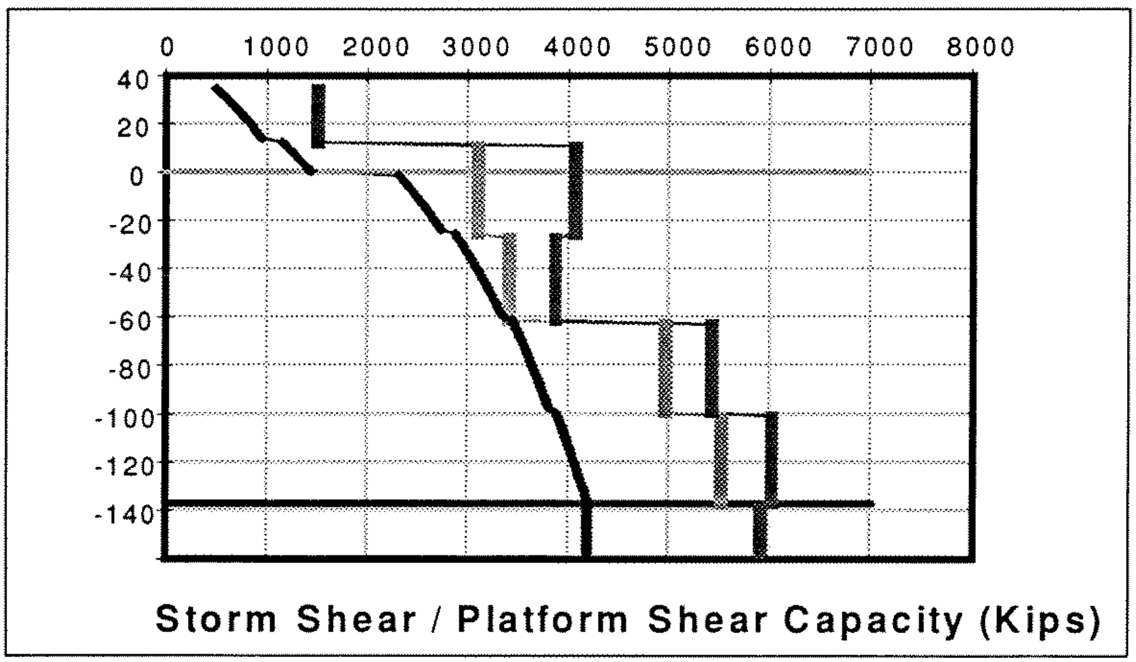


	K-factor	Δ/L (%)	$P_{ULTIMATE}$ (kips)
USFOS	-	0.15	600
	-	0.30	570
ULSLEA	0.65	-	650

Platform "D" Broadside Loading (ULSLEA)

LOAD PATTERN

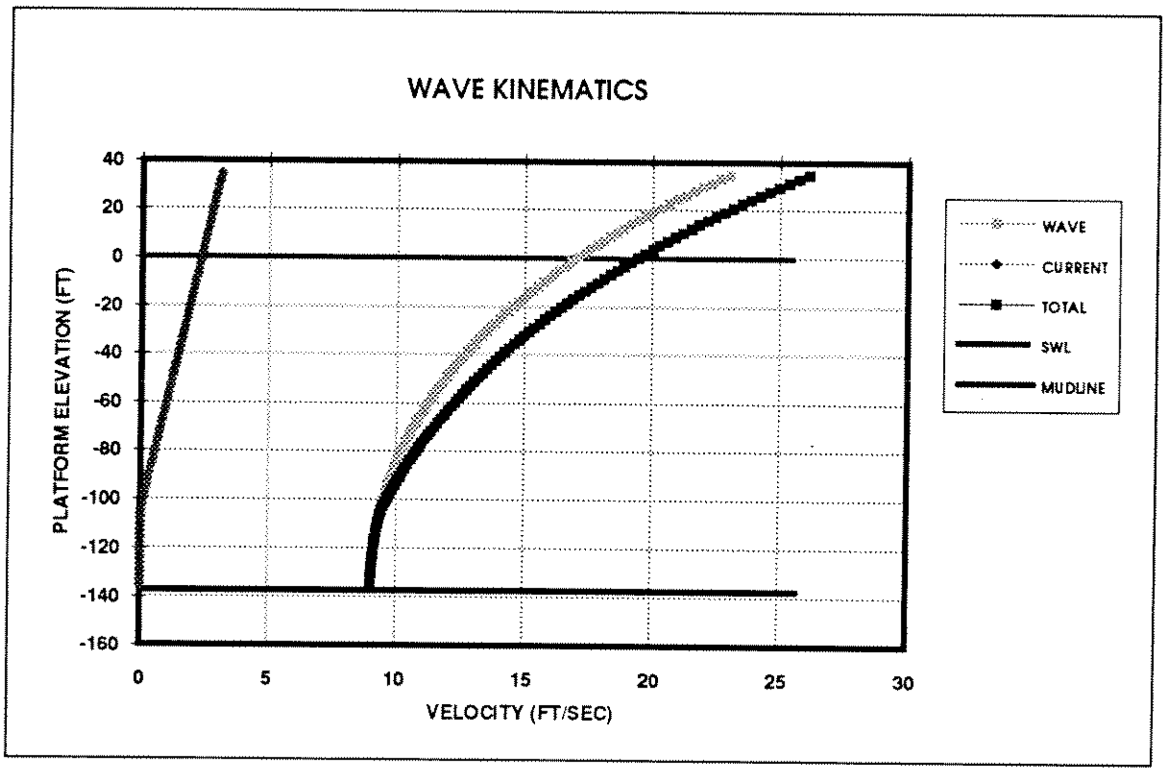
H = 56 ft, T = 13 sec, Uc = 3.2 ft/sec (constant)



USFOS	4,500 Kips
ULSLEA	4,200 Kips

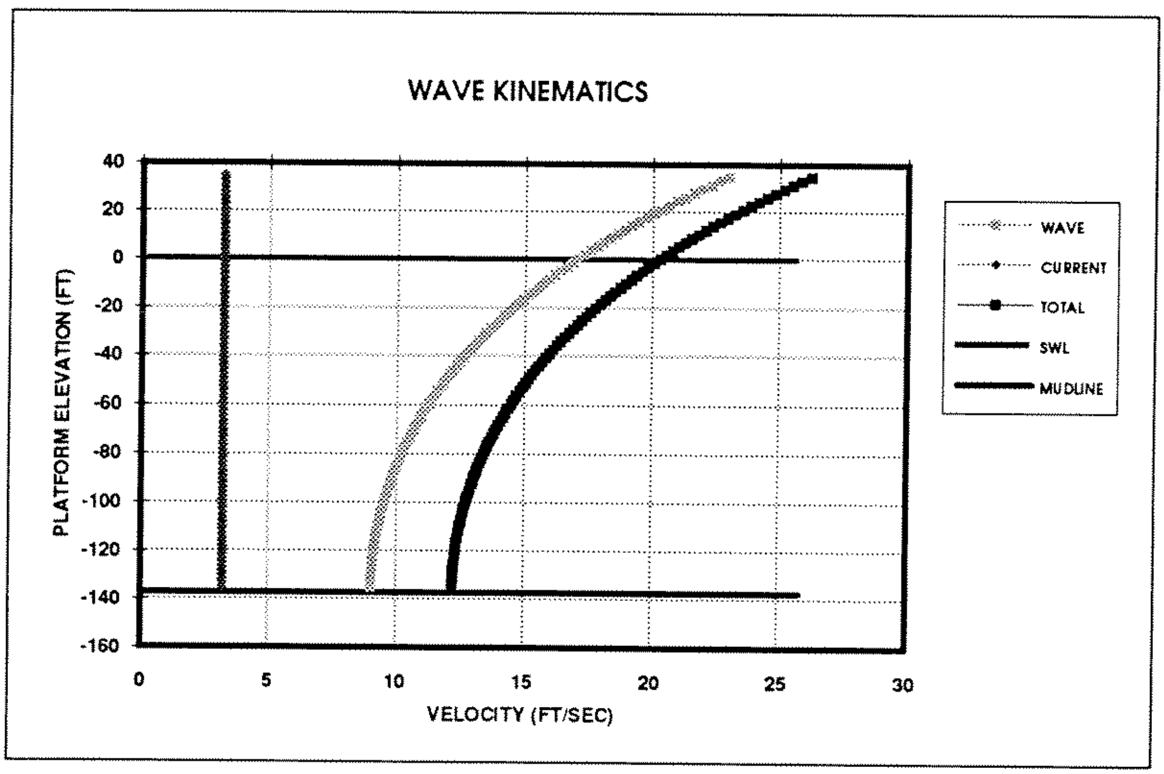
Platform "D" Kinematics (ULSLEA)

Linear Depth Stretched Current Profile

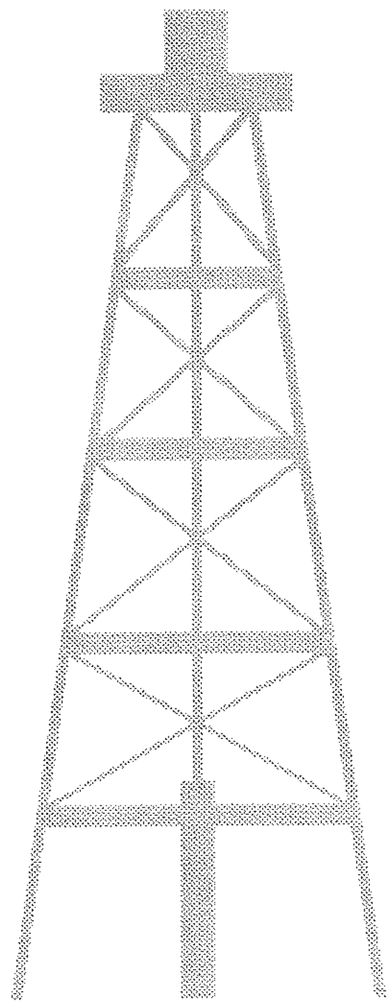


Platform "D" Kinematics (ULSLEA)

Constant Current Profile



Chevron ST 151K Platform



General Description

- Eight leg drilling and production platform
- Installed in 137 ft of water in 1964
- Sixteen 30 in. conductors
- Broadside and end-on framing battered at 1:10
- Cellar and main decks at +35 ft and +46 ft respectively

Platform Details

- Ungrouted legs with thickened joint sections
- F_y = 43 ksi
- 30 in. piles penetrate 180 ft of firm to very stiff clay
- Vertical braces range in size from 16 in. in the fourth (upper) bay to 20 in. in the first bay

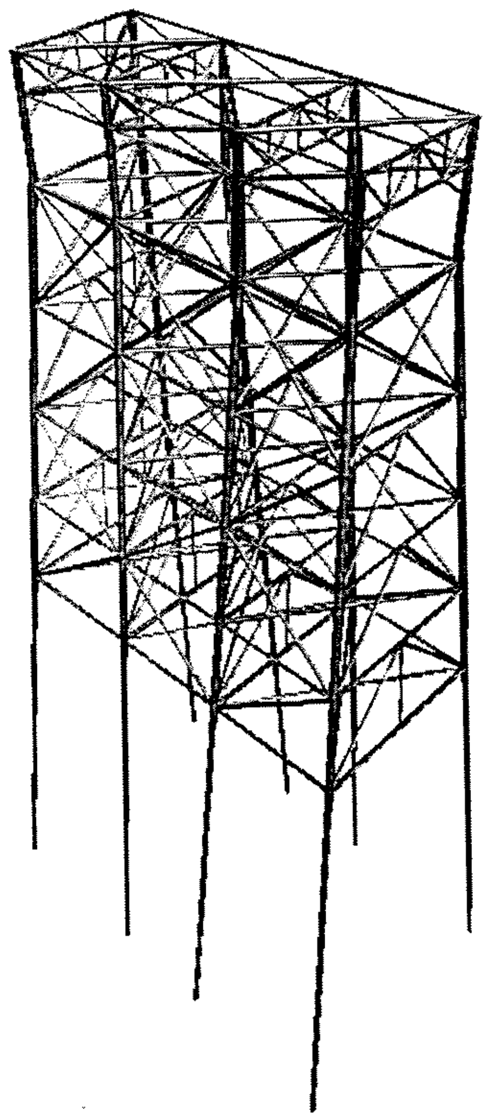
Level 4 Analysis

- Static pushover analysis
- WAJAC generated hydrodynamic loads
- Rigid and flexible foundation assumptions both analyzed

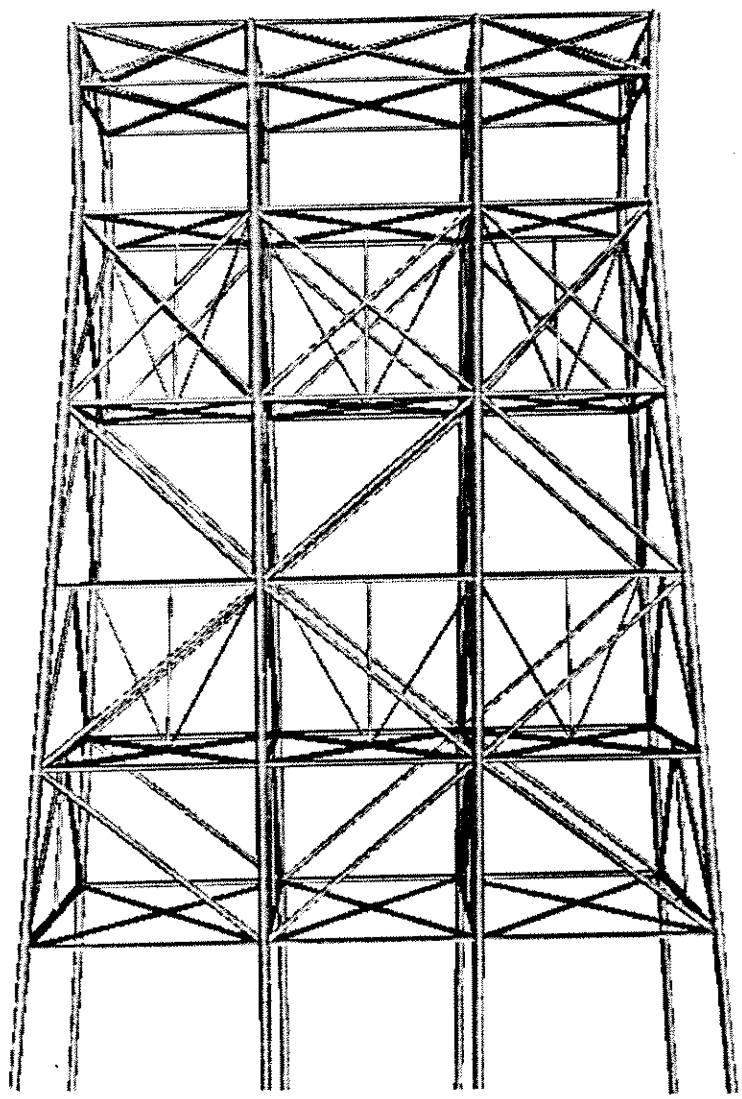
USFOS Model

- Only major structural members modeled
- Initial imperfection taken as 0.003 for all members
- Used API RP 2A spring models with strength increased by 3.28
- Rigid joints assumed

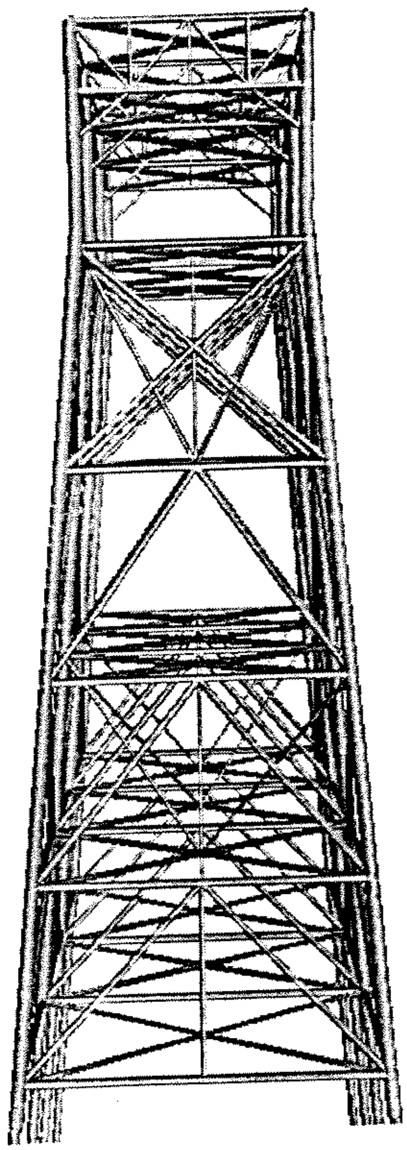
Isometric



Broadside Elevation



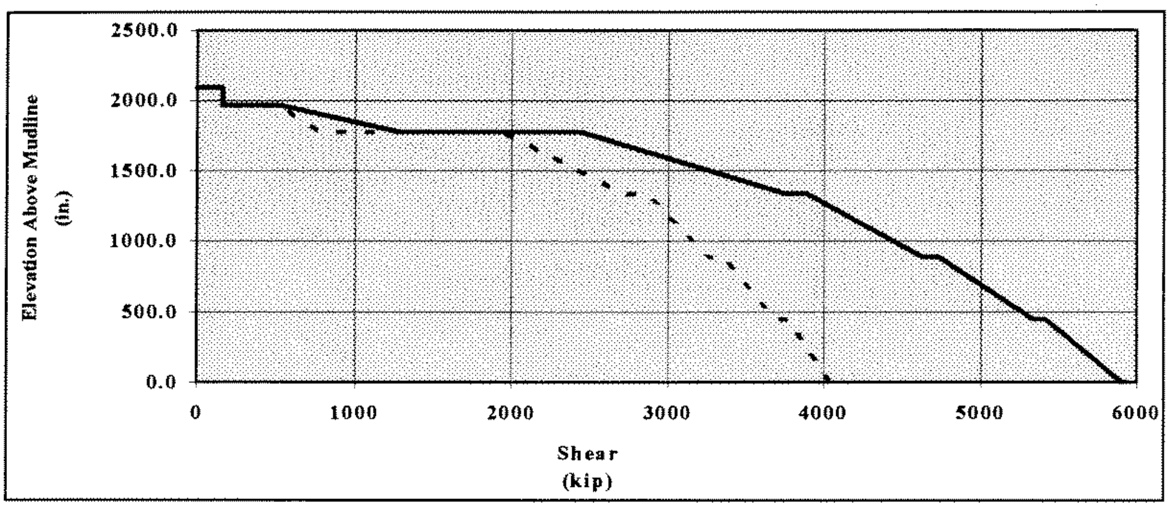
End-on Elevation



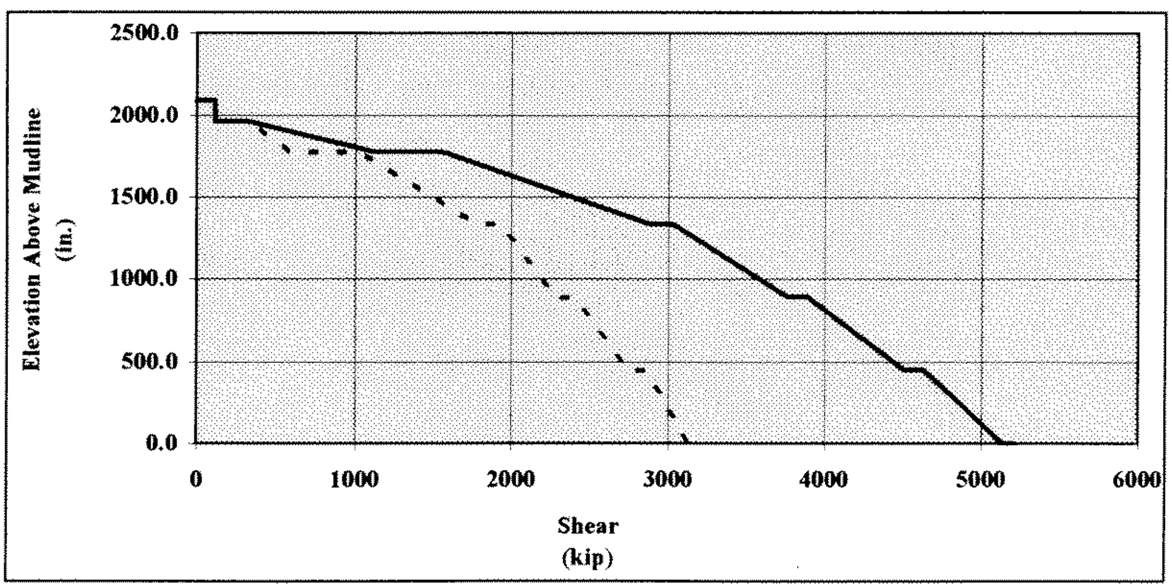
Loading Information

- Assumed marine growth = 1.5 in.
- Cd = 1.2
- Cm = 1.2
- wkf = 0.88
- Broadside loading
  - H = 56 ft, T = 13 sec.
  - In-line current = 46.5 in/sec, cbf = 0.80
- End-on loading
  - H = 60 ft, T = 13 sec
  - In-line current = 46.5 in/sec, cbf = 0.70

Loading Profiles
(with and without conductor loads)

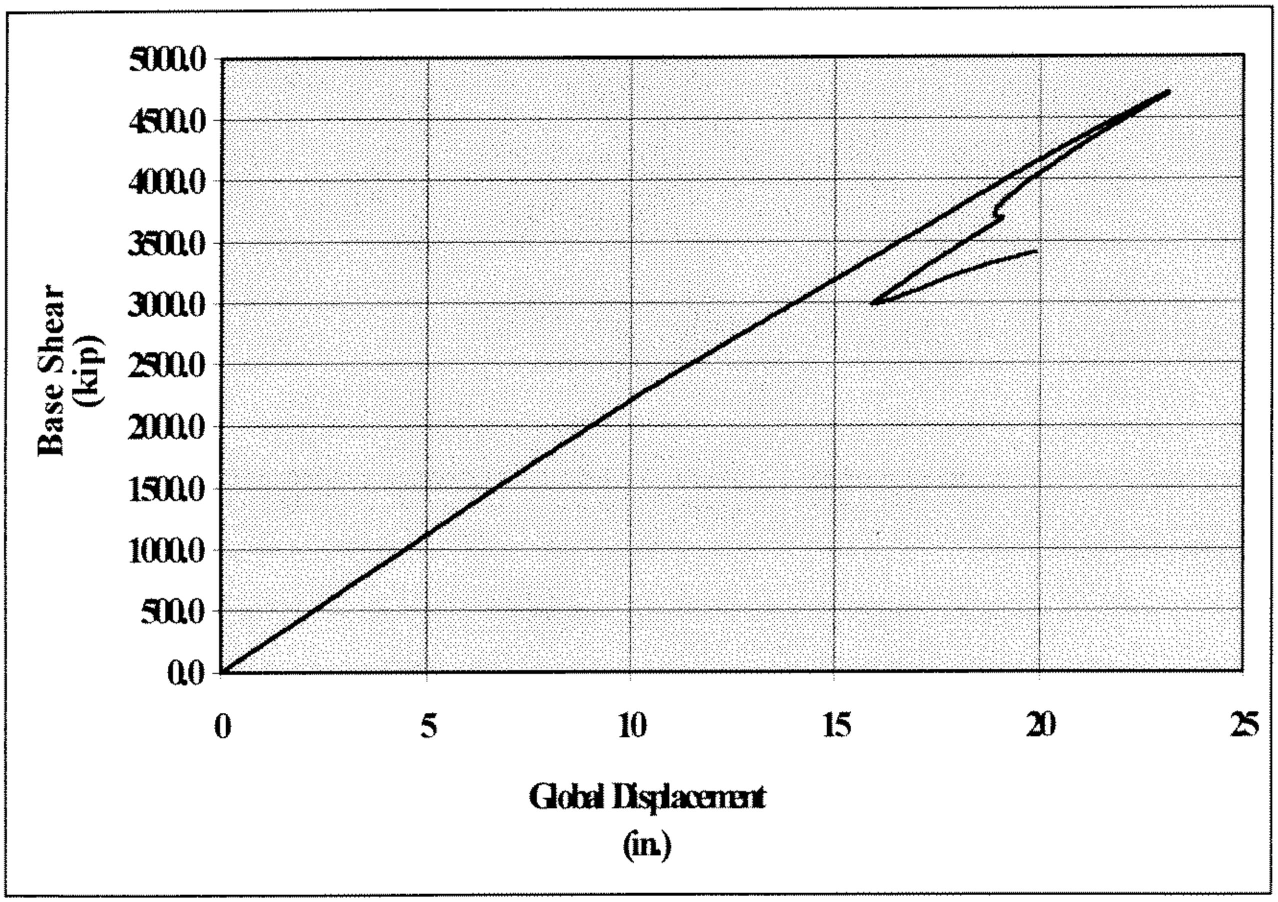


Broadside loading



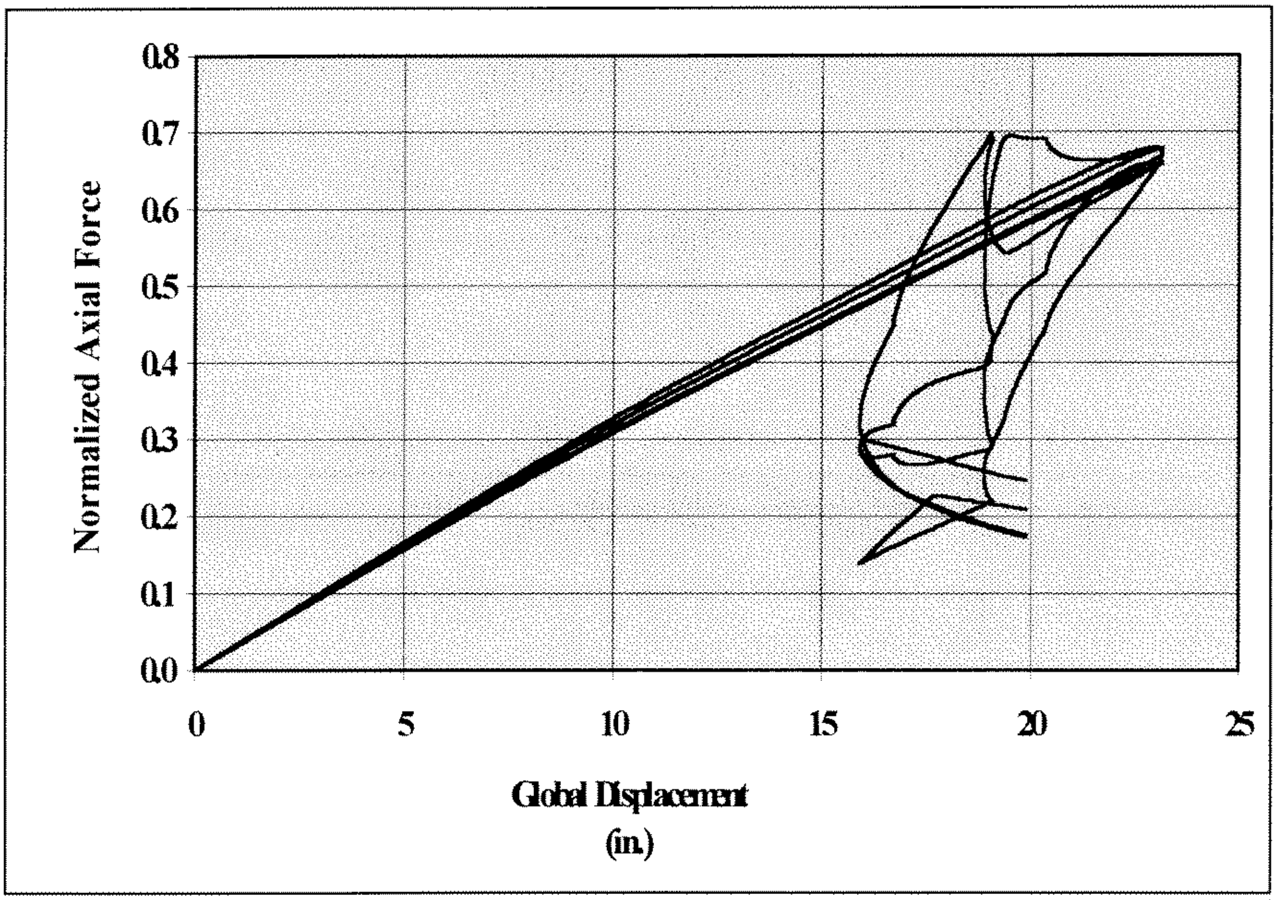
Endon loading

Broadside Force-Displacement History



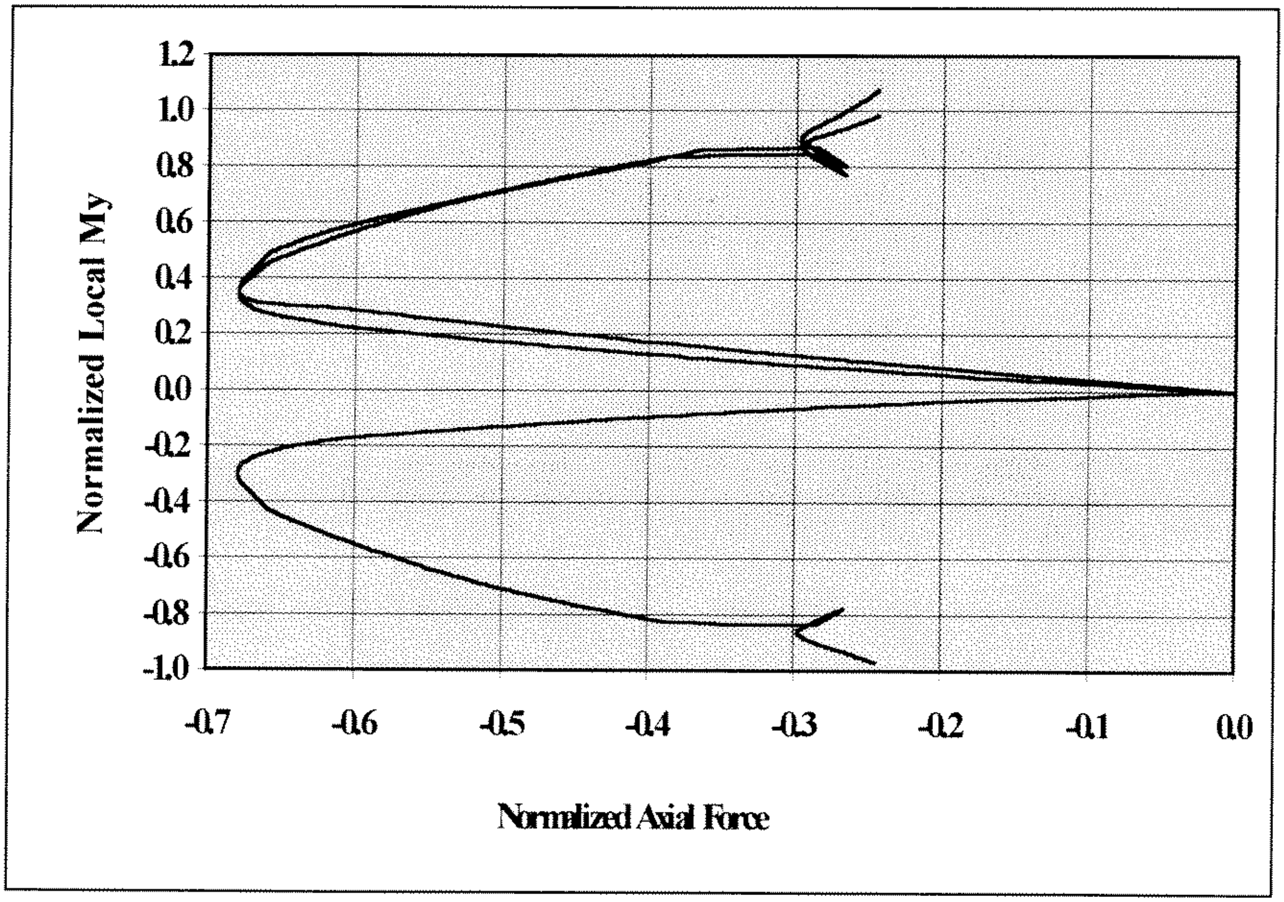
Maximum base shear = 4,709 kips

Broadside Critical Brace Axial Force History



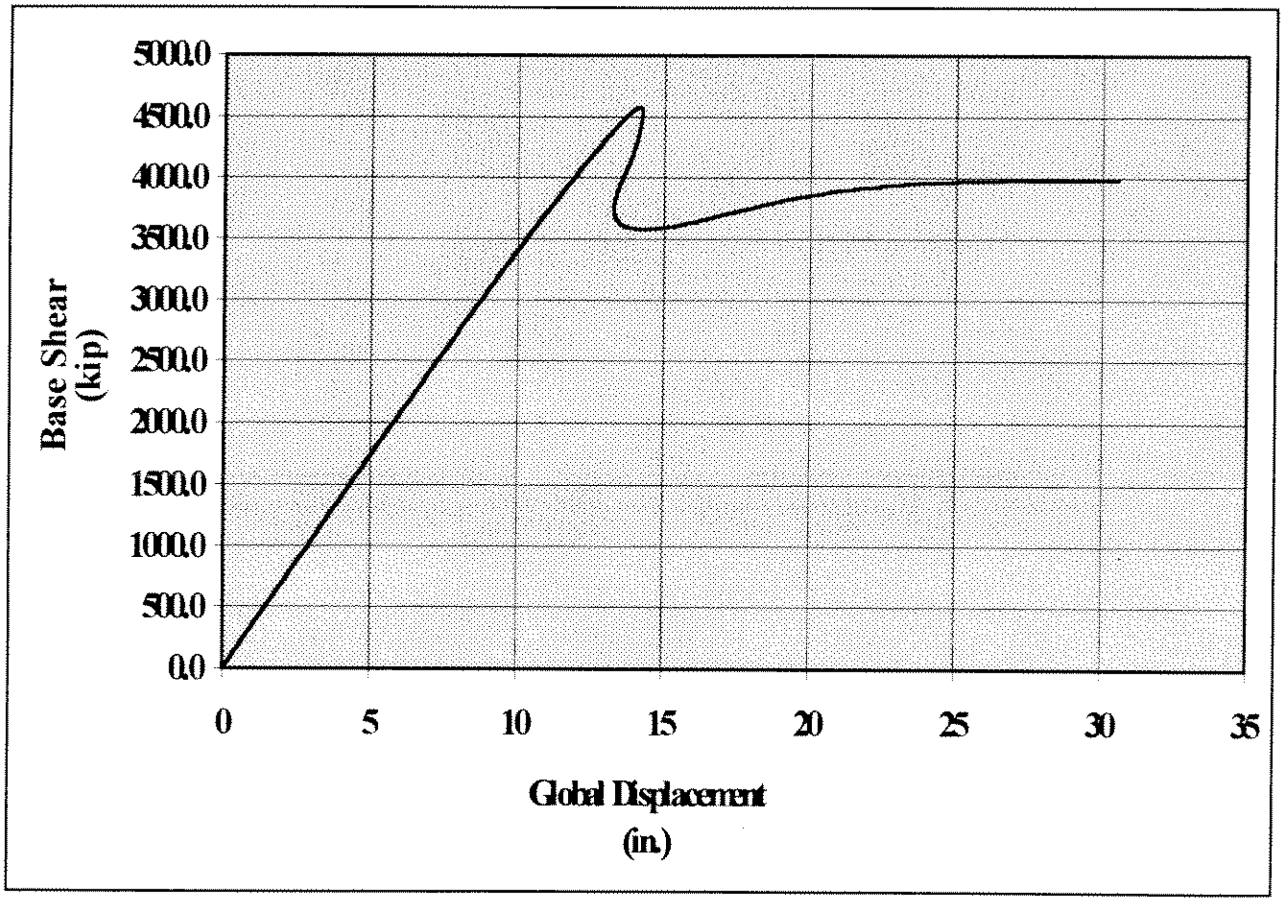
Values normalized by plastic capacity

Broadside Critical Brace P-M Interaction



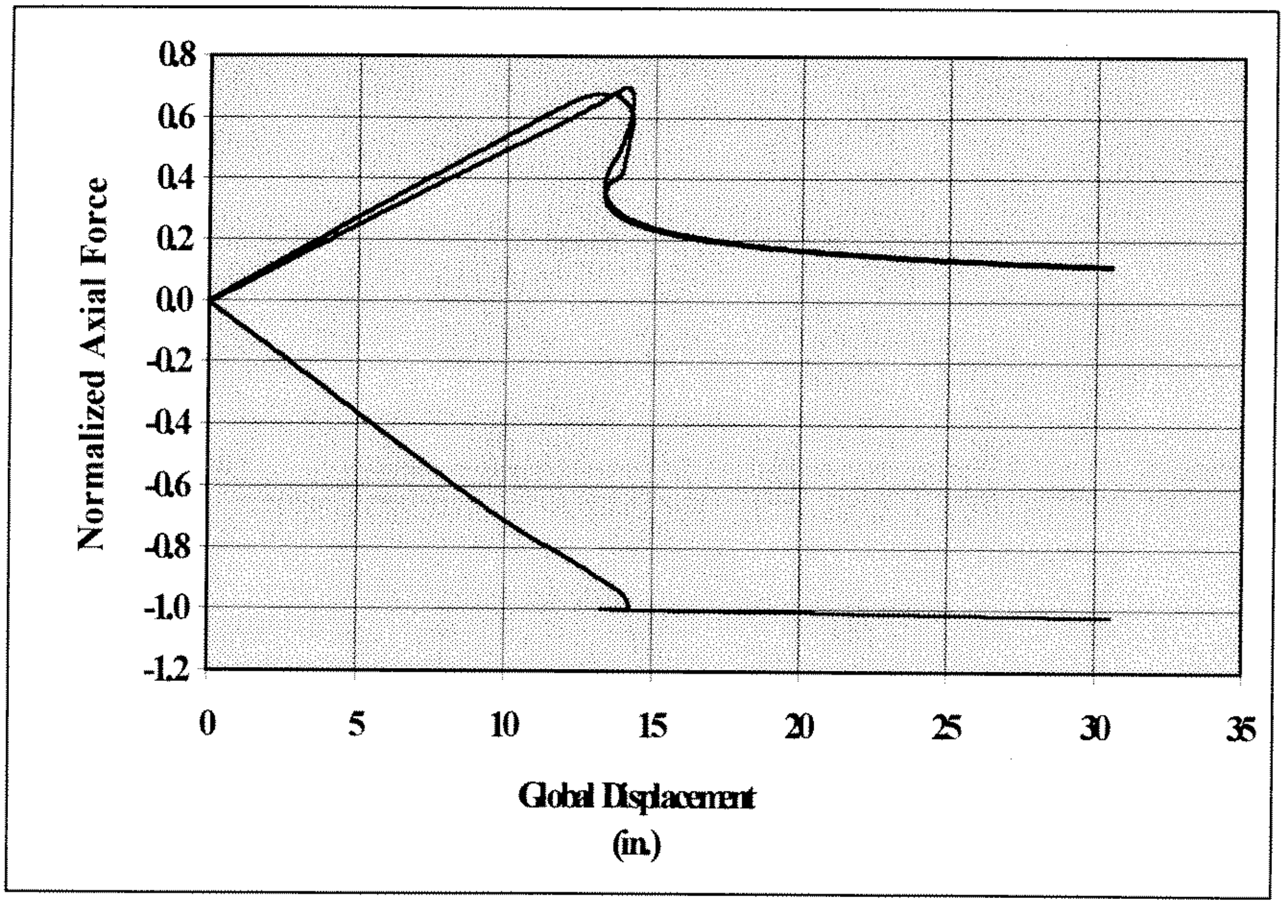
Values normalized by plastic capacity

End-on Force-Displacement History



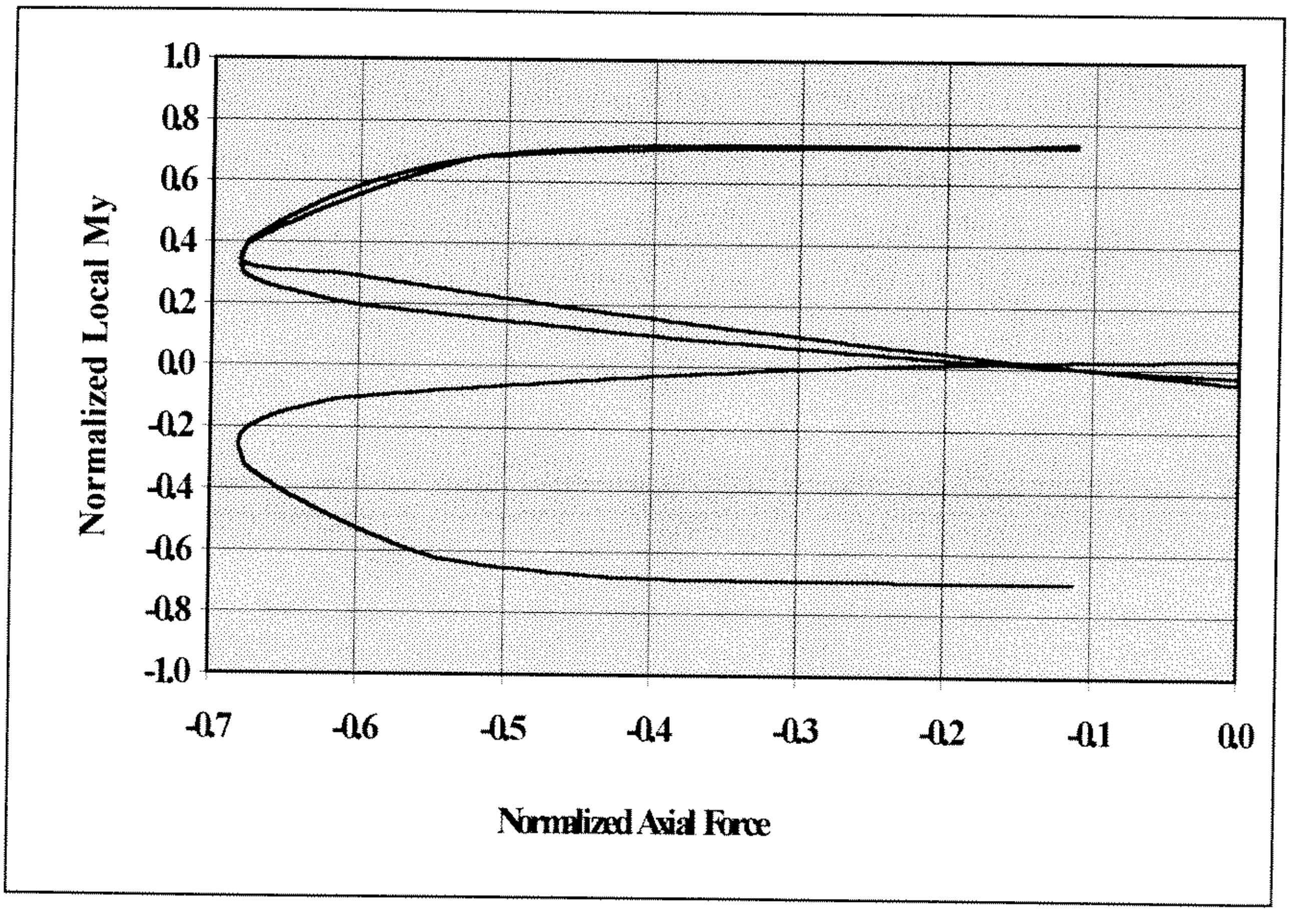
Maximum base shear = 4,577 kips

End-on Critical Brace Axial Force History



Values normalized by plastic capacity

End-on Critical Brace P-M Interaction



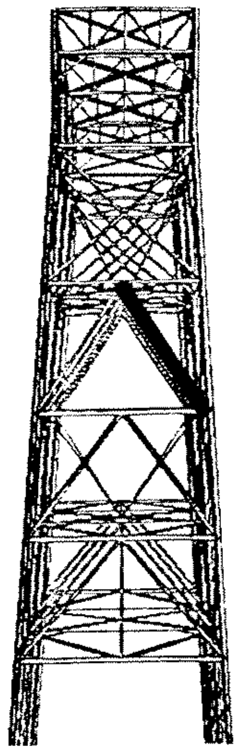
Values normalized by plastic capacity

Comparison with Observed Andrew Performance

- Chevron ST 151K experienced approximately 60 ft waves between end-on and diagonal directions
- Platform appeared to have experienced minor damage
- USFOS model predicted failure at 88 percent of 60 ft storm load
- Imperfection and member orientation combination is realistic but conservative

Conclusion: USFOS model would predict failure during likely Andrew loading. However, USFOS model would predict higher chance of survival than 151H for end-on loading.

Platform "E" Broadside Loading
MLTF Member

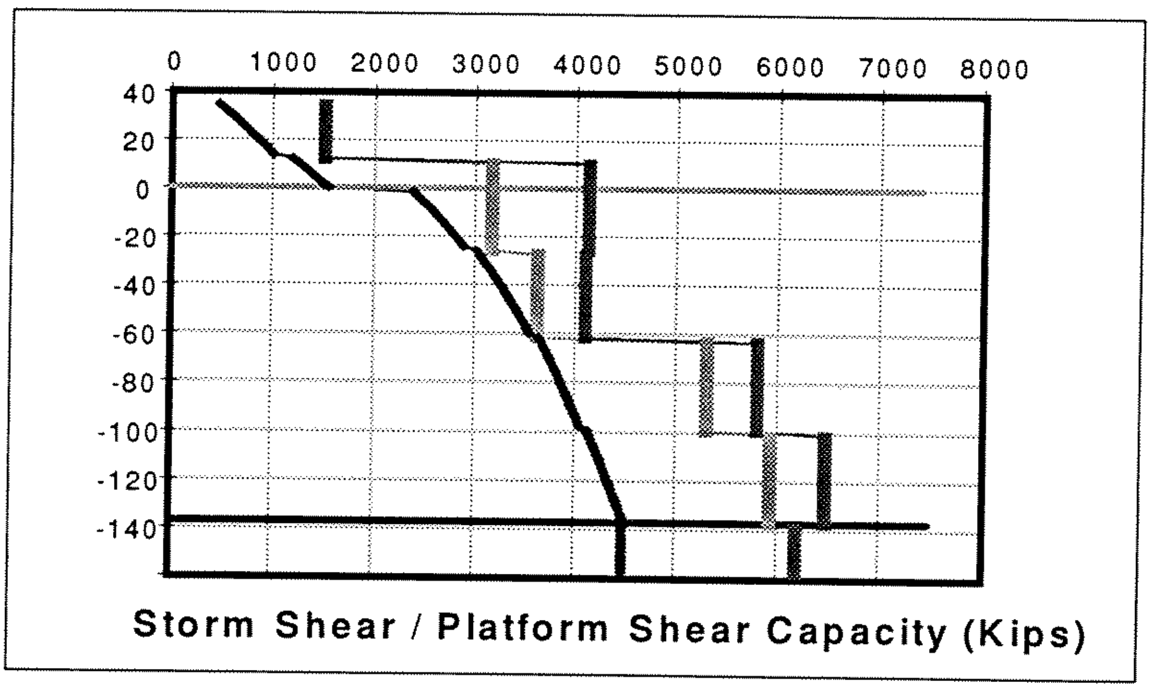


	K-factor	Δ/L (%)	$P_{ULTIMATE}$ (kips)
USFOS	-	0.30	580
ULSLEA	0.65	-	650

Platform "E" Broadside Loading (ULSLEA)

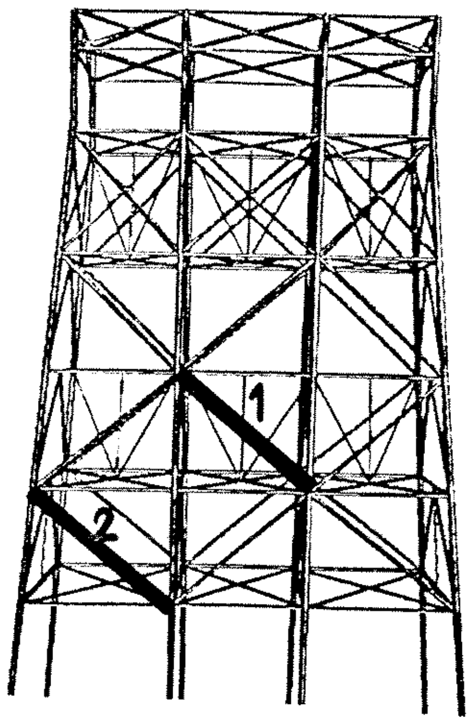
LOAD PATTERN

H = 56 ft, T = 13 sec, Uc = 3.2 ft/sec (constant)



USFOS	4,700 Kips
ULSLEA	4,500 Kips

Platform "E" End-on Loading
MLTF Member

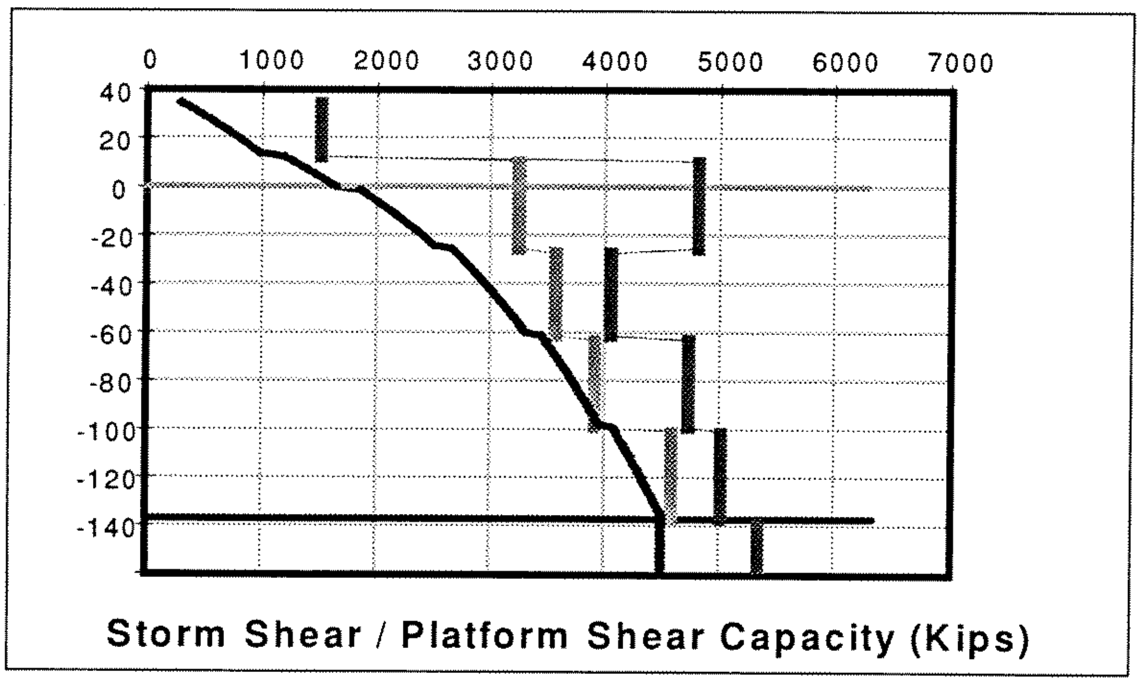


		K-factor	Δ/L (%)	$P_{ULTIMATE}$ (kips)
USFOS	Member 1	-	0.30	710
	Member 2	-	0.30	810
ULSLEA	Member 1	0.65	-	770
	Member 2	0.65	-	910

Platform "E" End-on Loading (ULSLEA)

LOAD PATTERN

H = 60 ft, T = 13 sec, Uc = 3.2 ft/sec (constant)

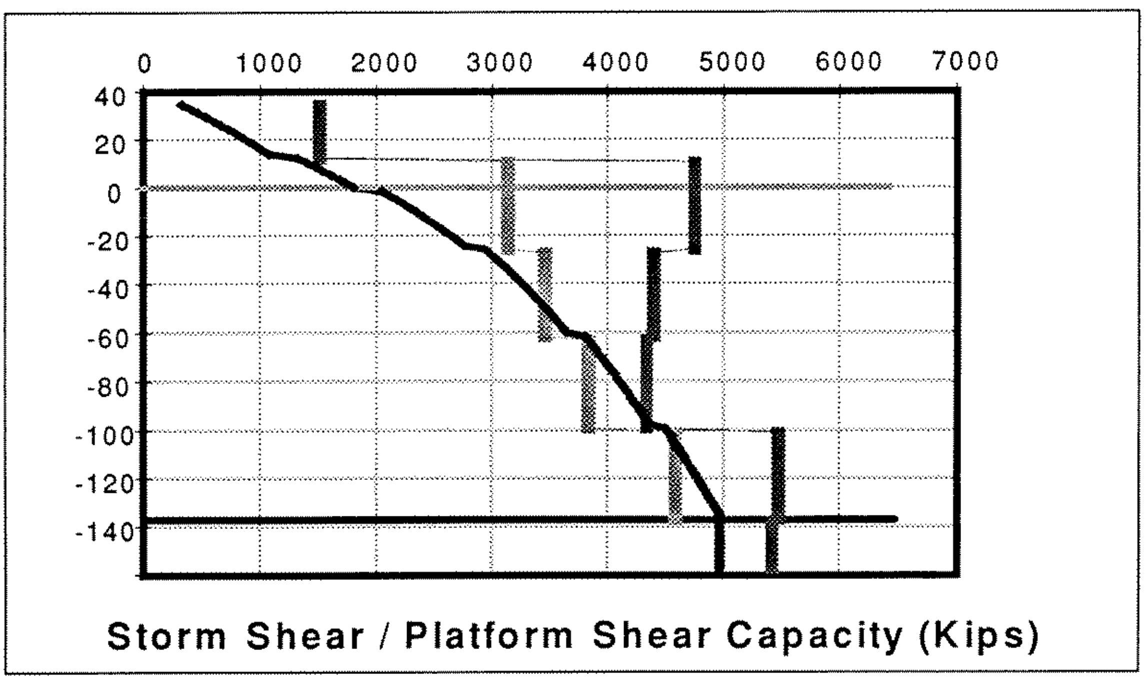


USFOS	4,400 Kips
ULSLEA	4,500 Kips

Platform "E" End-on Loading (ULSLEA)

LOAD PATTERN

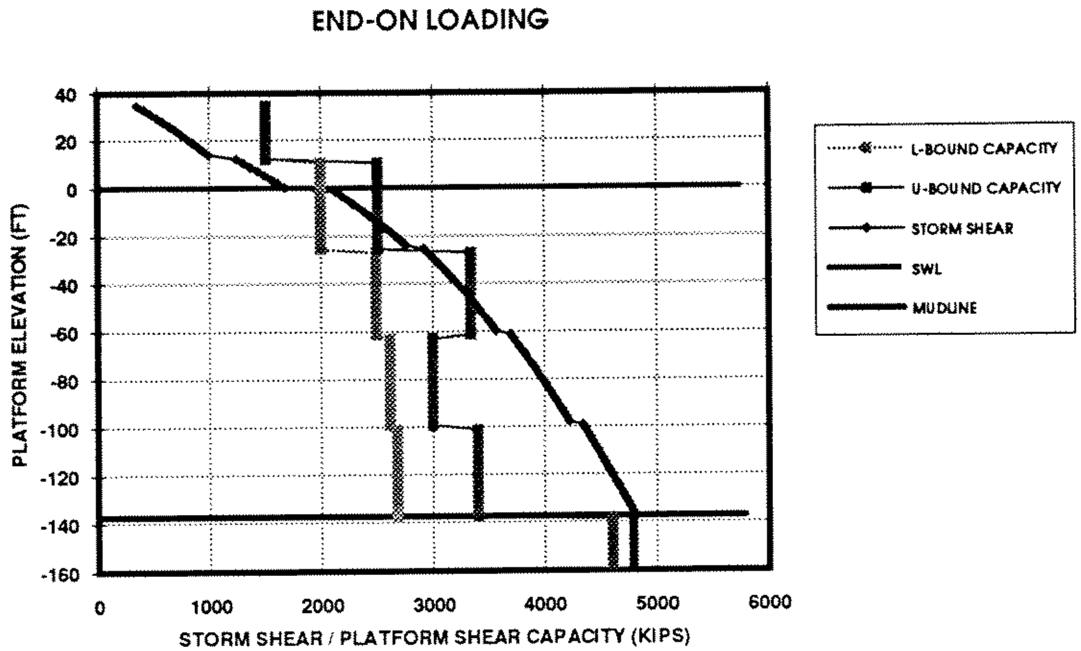
H = 60 ft, T = 13 sec, Uc = 3.2 ft/sec (constant)



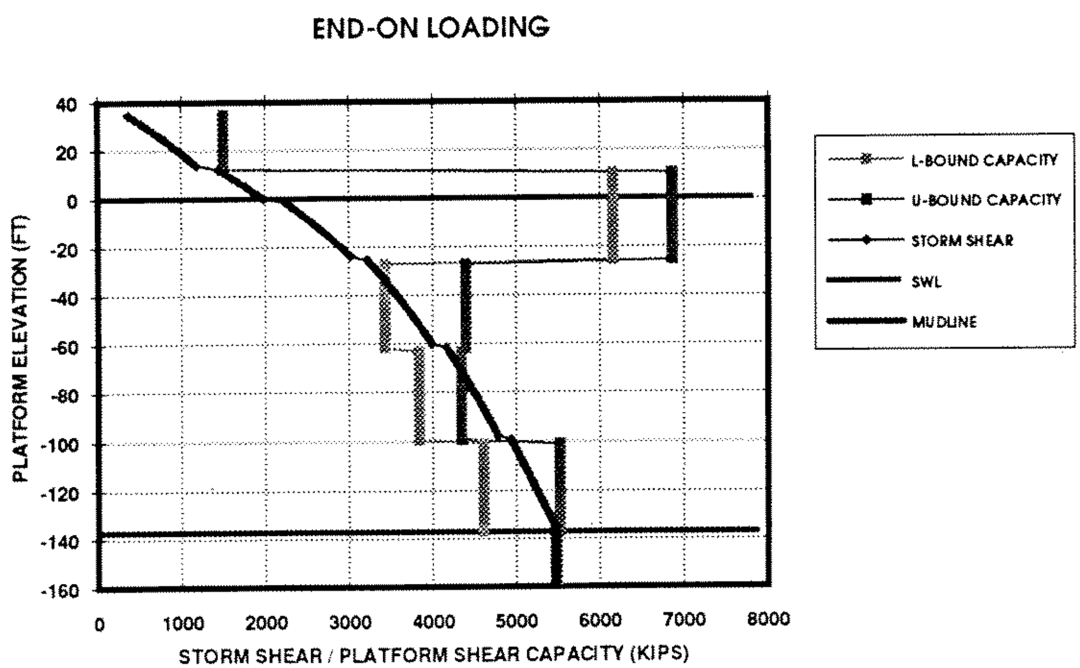
Hurricane Andrew Experience

- Hindcast Wave Height = 60.8 ft
- Hindcast Current Velocity = 3.44 ft/sec
- Platform "D" failed in end-on direction
- Platform "E" survived

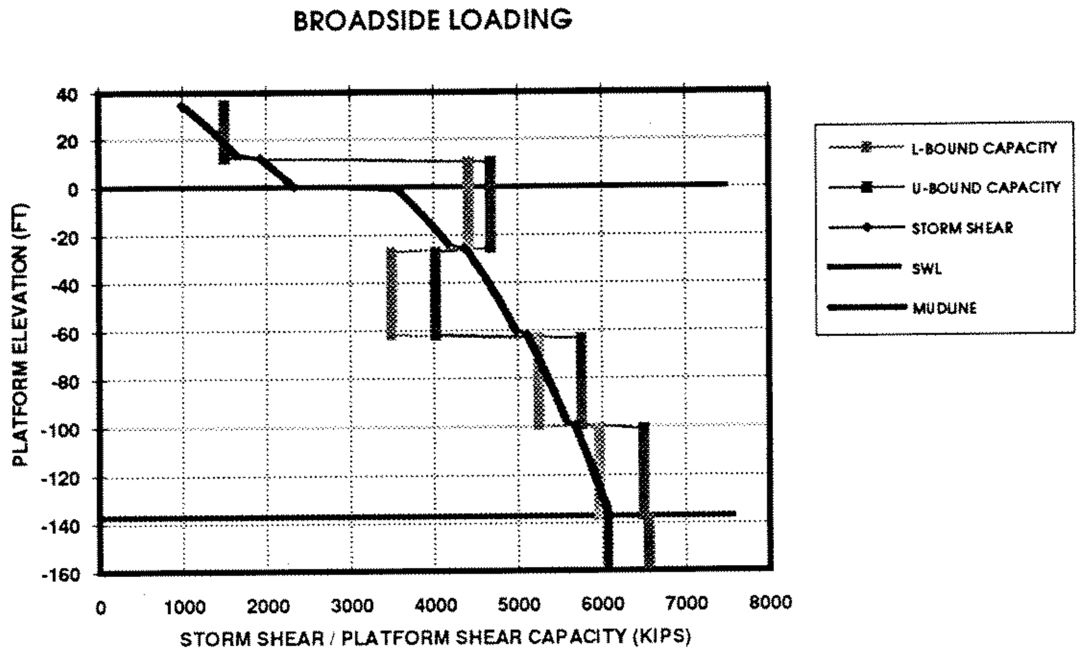
Platform "D" (failed)



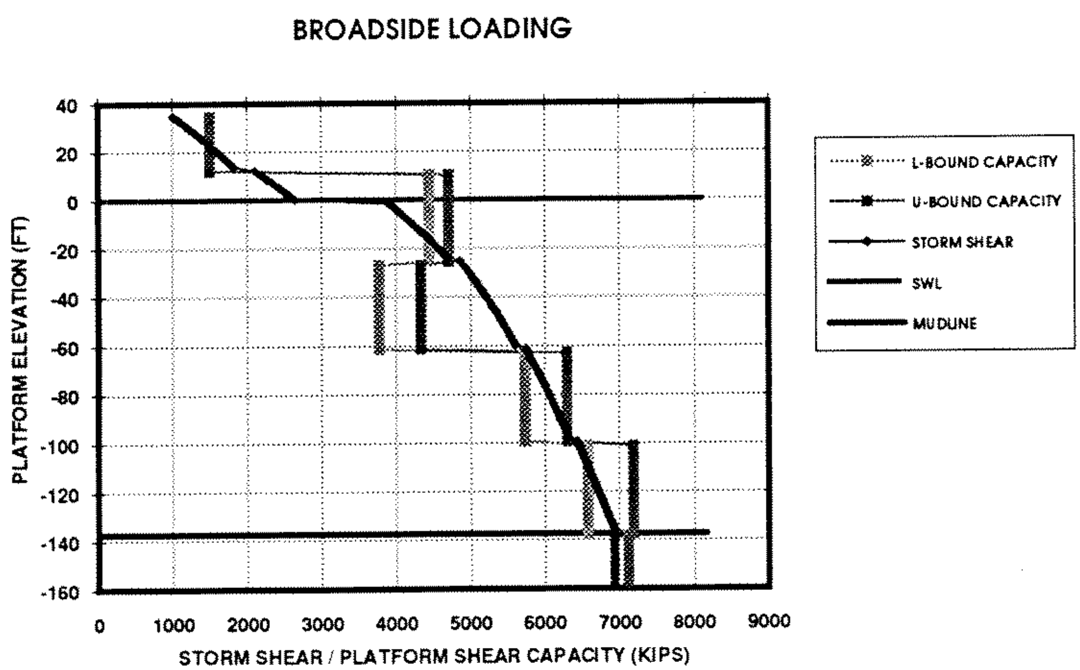
Platform "E" (survived)



Platform "D" (failed)



Platform "E" (survived)



VERIFICATION CASE STUDIES
Summary

Platform	Configuration	Wave Direction	ULSLEA		USFOS / SEASTAR		Ratio of USFOS/ULSLEA Base Shears
			Failure Mode	Base Shear (kips)	Failure Mode	Base Shear (kips)	
A	8 leg double battered K-braced	End-on Broadside	1st jacket bay 2nd jacket bay	2,900 3,400	1st jacket bay 2nd jacket bay	2,600 2,900	0.90 0.85
B	8 leg double battered K-braced	End-on Broadside	1st jacket bay 1st jacket bay	3,100 3,700	1st jacket bay 1st jacket bay	3,900 3,900	1.26 1.05
C	4 leg double battered K-braced	End-on End-on	4th , 5th and 6th jacket bays Foundation	3,200 1,900 (1,700)	5th and 6th jacket bays Foundation	3,400 1,700	1.06 0.90 (1.00)*
D	8 leg single battered K-braced	End-on Broadside	4th jacket bay 2nd jacket bay	2,800 4,200	4th jacket bay 2nd jacket bay	2,700 4,500	0.96 1.07
E	8leg double battered K-braced	End-on Broadside	3rd and 4th jacket bays 3rd jacket bay	4,500 4,500	4th jacket bay 3rd jacket bay	4,400 4,700	0.98 1.04

*) Including the platform selfweight

VERIFICATION CASE STUDIES
Summary (Cont.)

- In all verification cases, ULSLEA was able to predict the collapse mechanism and a reasonable estimate of ultimate load

<u>Bias = USFOS / ULSLEA</u>

- Mean Bias = 1.02

- Bias Range = 0.85 - 1.26

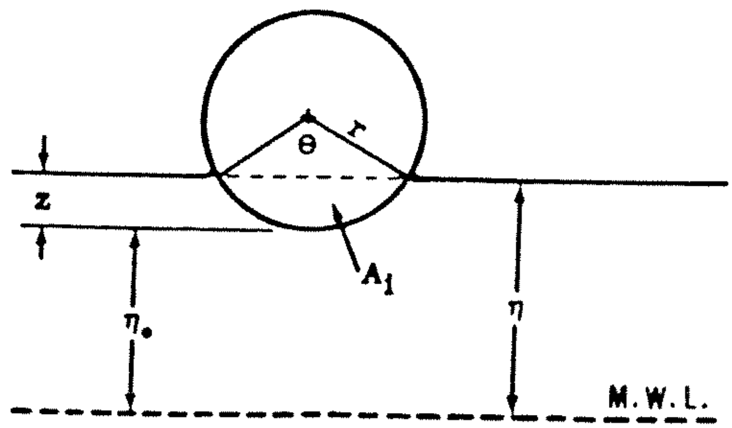
Level 4 Analysis Parameter Studies

- Wave induced Vertical Deck Loads
- Initial Member Imperfection
- Soil Strength and Soil Spring Modeling

Waved Induced Vertical Deck Loads

- Vertical deck loads usually ignored in design and assessment
- Potentially important loads, especially for older platforms with small air gaps
- Waves can induce positive (upward slamming) vertical loads as well as negative (downward suction) vertical loads
- Platforms with solid plate flooring have greatest potential for significant vertical deck loads

Surface Impact of a Horizontal Cylinder



Surface Impact of a Horizontal Cylinder

Total vertical force per unit length is given as:

$$F_v = \rho g A_i + (m_3 + \rho A_i)\ddot{\eta} + \frac{\delta(m_3)}{\delta z}\dot{\eta}^2$$

$$m_3 = \frac{1}{2}\rho r^2 \left[\frac{2\pi^3}{3} \frac{(1-\cos(\theta))}{(2\pi-\theta)^2} + \frac{\pi}{3}(1-\cos(\theta)) + (\sin(\theta)-\theta) \right]$$

$$\eta = A_{\max} \sin\left(\frac{2\pi t}{T}\right)$$

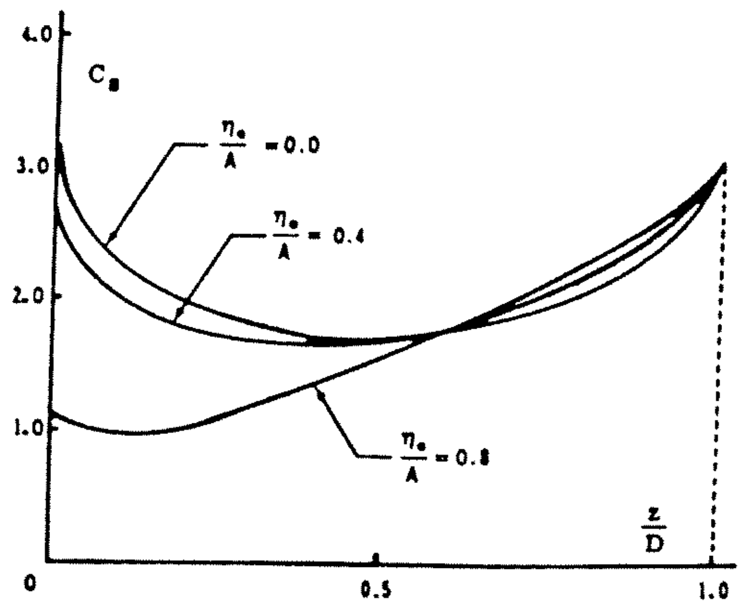
Slamming Coefficient

Total vertical force in terms of maximum particle velocity and slamming coefficient, C_s:

$$F = \frac{1}{2} \rho \, C_s D L U_{\max}^2$$

$$C_s = \overline{A}_i \frac{gr}{U_{\max}^2} - \left(\overline{m} - \overline{A}_i\right) \frac{r}{A} \sin\left(\frac{2\pi t}{T}\right) + \frac{\delta \overline{m}}{\delta \overline{z}} \cos\left(\frac{2\pi t}{T}\right)$$

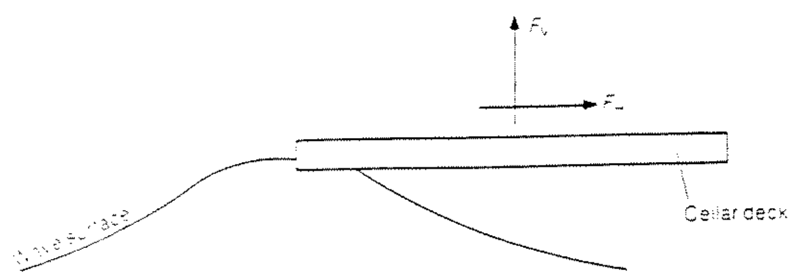
Theoretical Slamming Coefficient



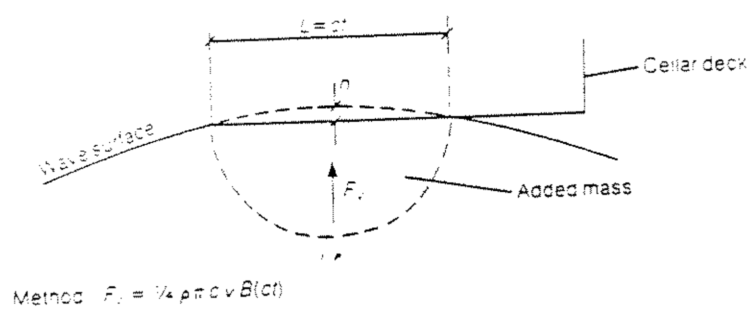
Empirically derived slamming coefficient could be 0.5 to 1.7 times the theoretical value of 3.14. Experiments shows values from 4.1 to 6.4.

Ekofisk Momentum Based Force Equation

$$F_v = \frac{1}{4}\rho\,\pi\,cv\,B(ct)$$



(a)



(b)

Scale models tests of Ekofisk platform showed 66 percent of this value.

Test Case Loading Data

Load Component	Platform B 70 ft Wave (kip)	Platform D B.S. 56 ft Wave (kip)	Platform D E.O. 60 ft Wave (kip)
Jacket	2,359	4,426	4,607
Decks	393	527	330
Boatlanding	82	983	271
Total Horizontal Base Shear	2,834	5,936	5,208
Deck level 1 (pos. vertical)	230	-	-
Deck level 1 (neg. vertical)	-230	-486	-695

Global Analysis Results

Loading Scenario	Maximum Normalized Load	Displace. at Maximum Load (in)
Platform B		
70 ft Wave Base Case	1.16	8.7
70 ft Wave Positive Vertical Load	1.16	8.7
70 ft Wave Negative Vertical Load	1.20	8.8
Platform D Broadside Loading		
56 ft Wave Base Case	0.793	23.1
56 ft Wave Negative Vertical Load	0.824	24.3
Platform D End-On Loading		
60 ft Wave Base Case	0.879	14.2
60 ft Wave Negative Vertical Load	0.857	14.8

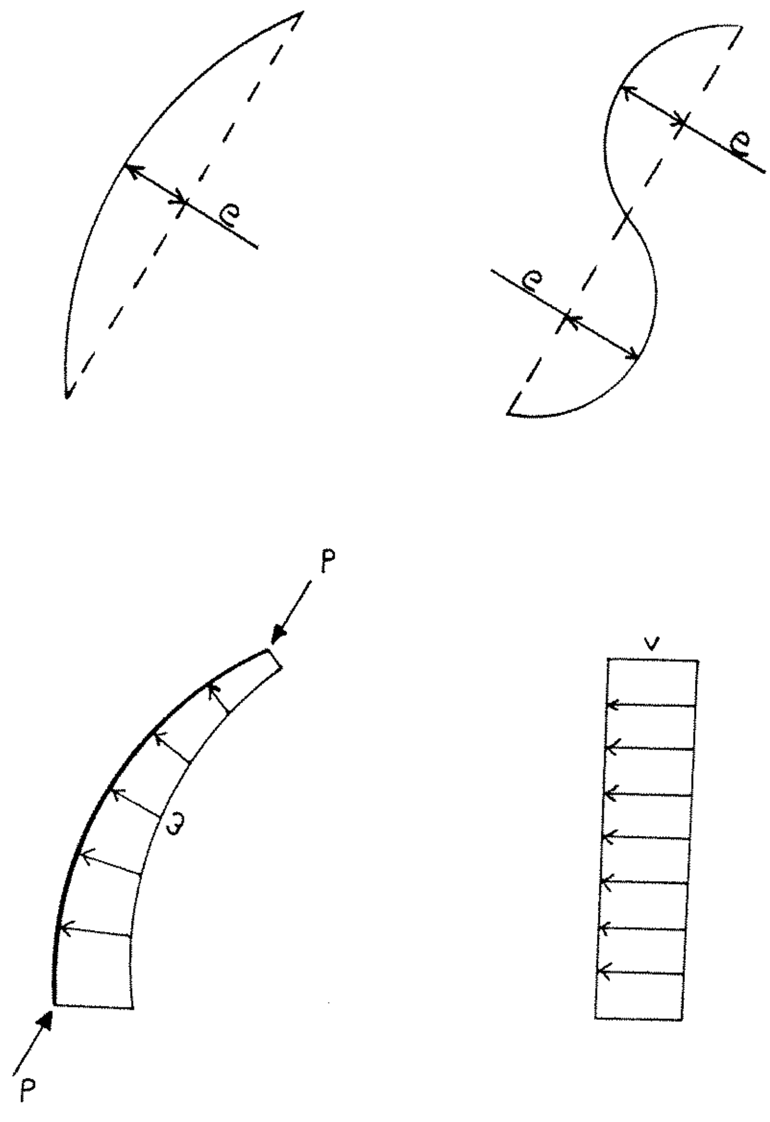
Conclusions

- Wave induced vertical deck forces can possibly be insignificant
- Dynamics could substantially increase the vertical slamming coefficient
- Local deck elements could suffer damage while overall superstructure is not affected
- More scale model test results could show larger slamming loads than Ekofisk experiments (small data set)

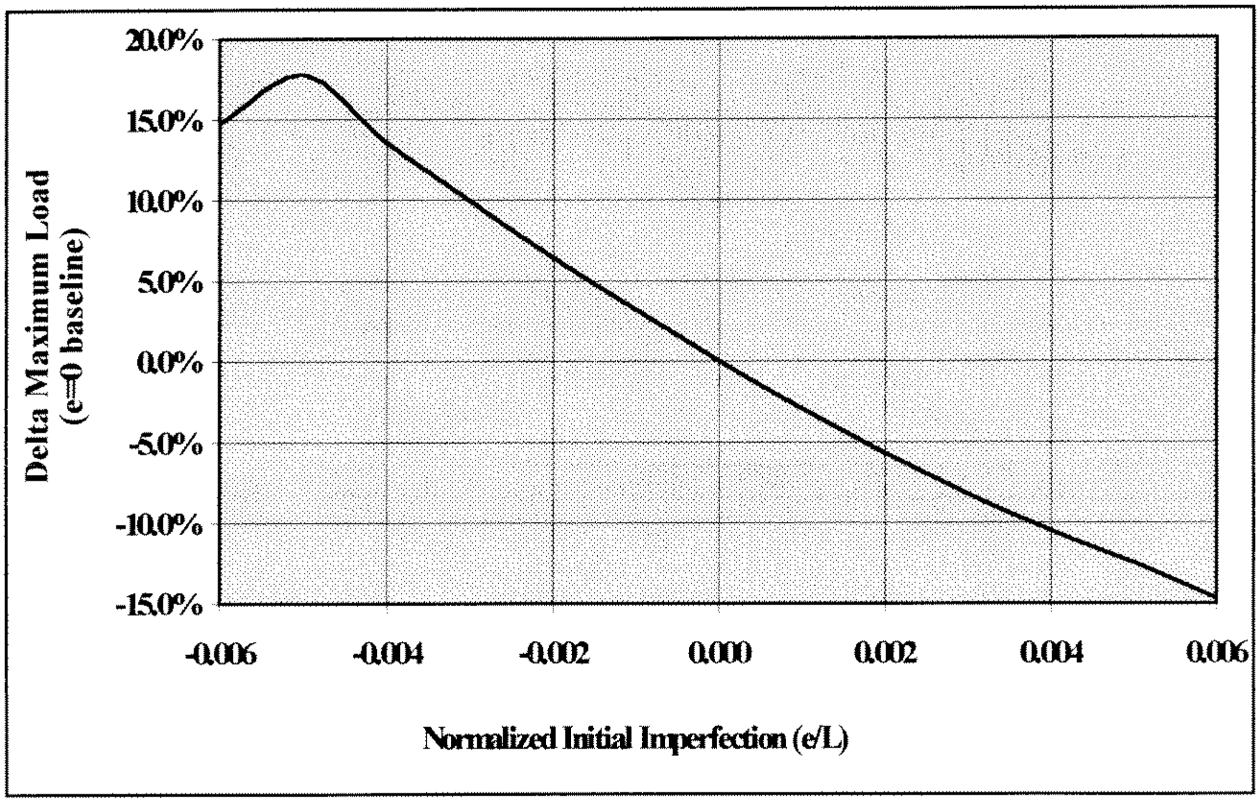
Initial Member Imperfection

- The interaction between local hydrodynamic loads and initial member imperfections can significantly affect the global capacity
- Many analysis programs do not consider local member forces or initial member imperfections

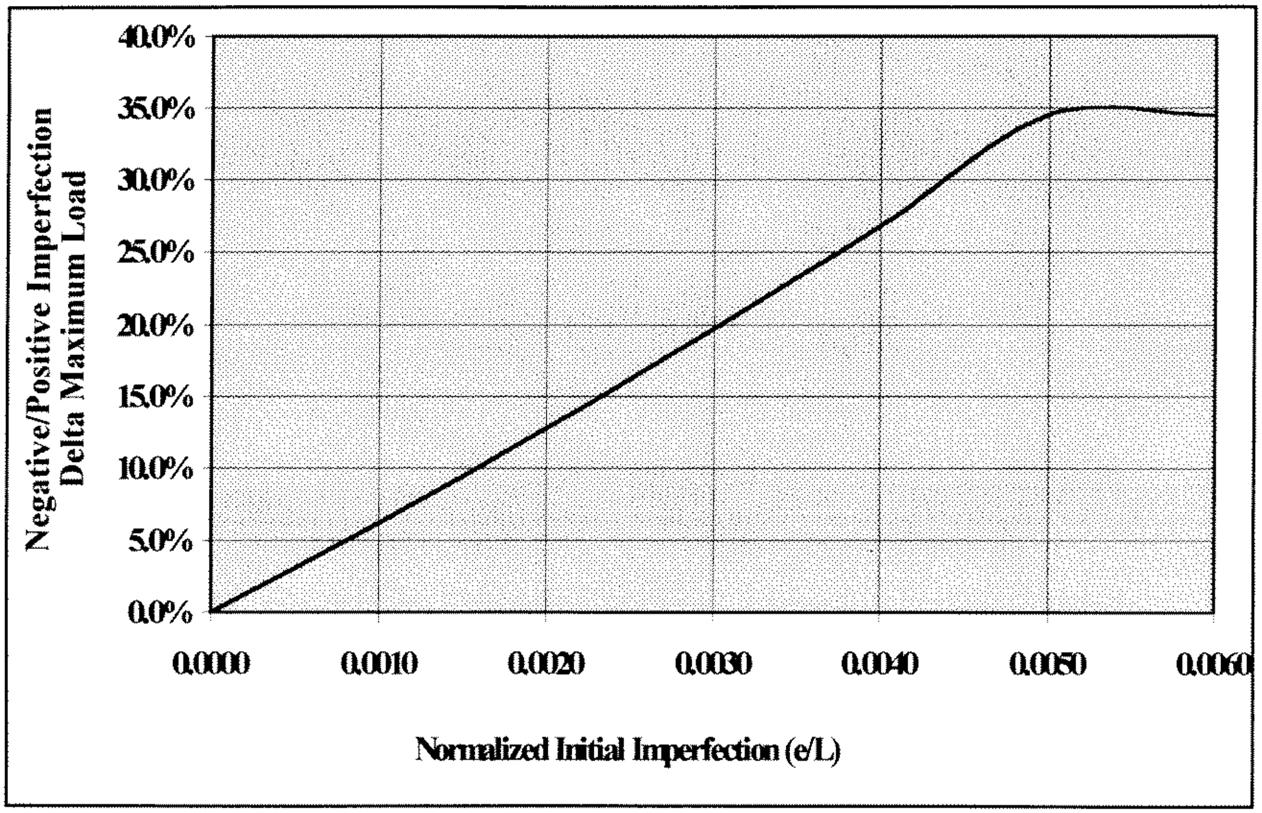
Local Forces and Initial Member Imperfections



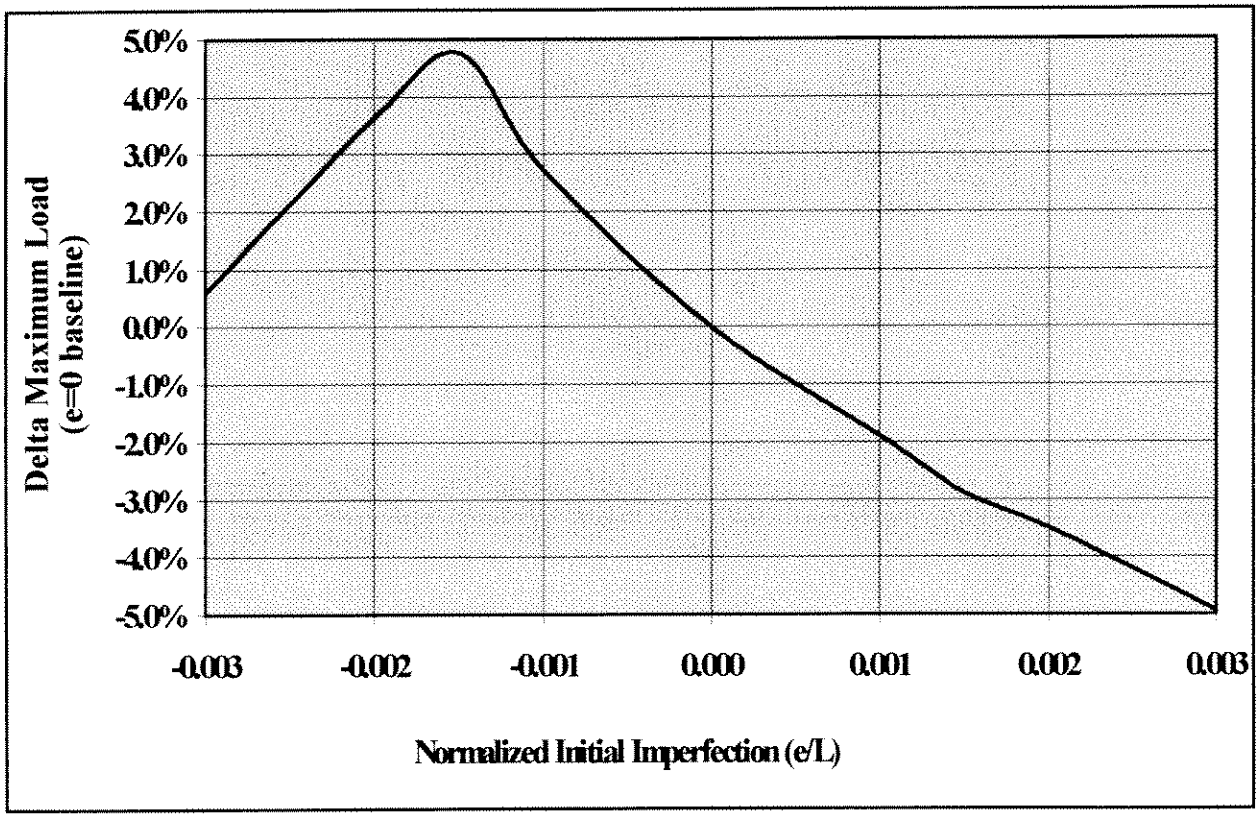
Platform A Results



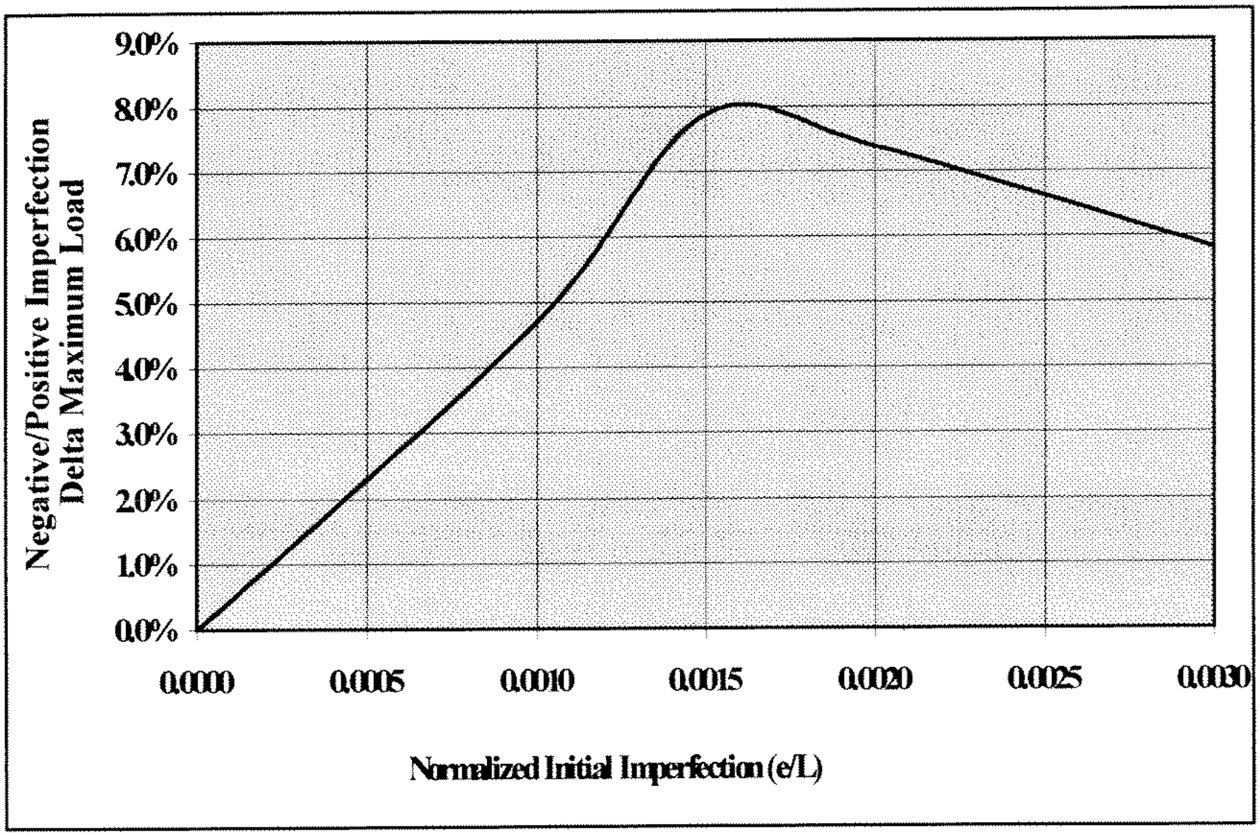
Platform A Results



Platform B Results



Platform B Results



Conclusions

- Exclusion of local forces and initial imperfections can cause significant overestimation of platform capacity
- In USFOS, increasing the initial imperfection can lead to increased capacity unless imperfection direction is specified t be in-line with wave direction

Soil Strength and Soil Spring Modeling

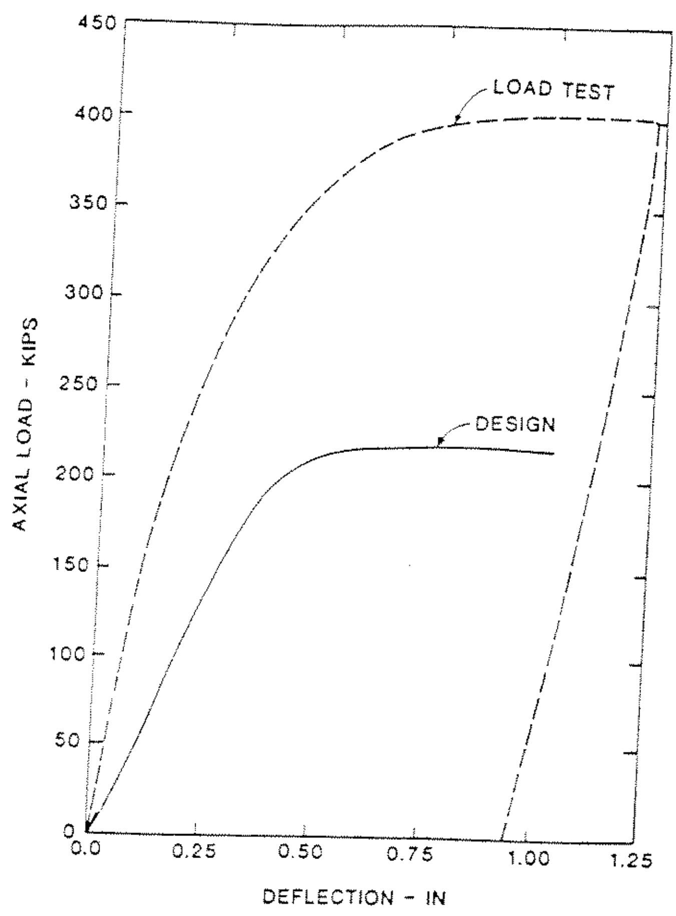
- Current code provisions can significantly underestimate foundation capacity
- Historically, very few platforms have experienced true foundation failure
- Much money is currently being wasted on conservative foundation designs instead of investing in good soil investigation data and research results

Areas of Over-Conservatism

- Code Bias
- Soil Sampling Methods
- Foundation Loading rates

Code Bias

Loading	Cohesive Soil	Cohesionless Soil
Axial	1.5 - 3.0	0.8 - 0.9
Lateral	1.1 - 1.2	0.8 - 0.9

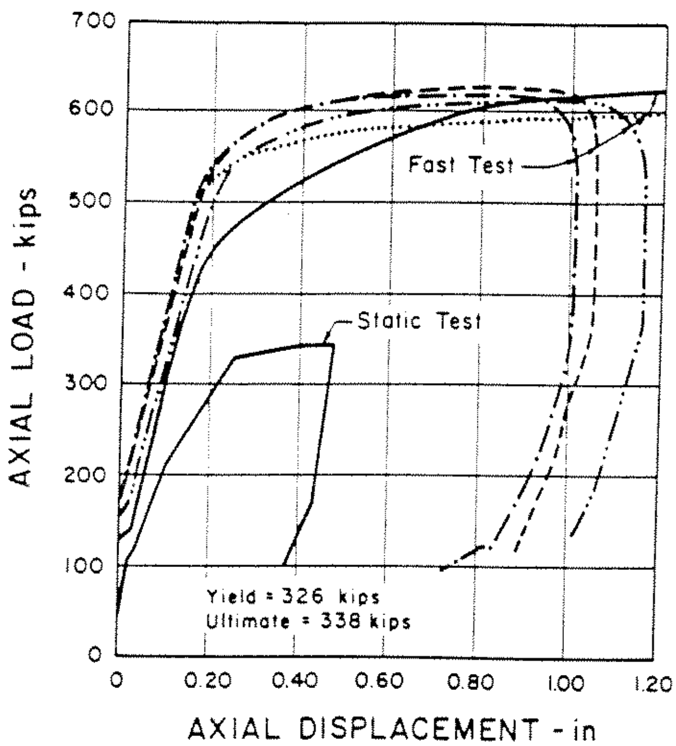


Soil Sampling Methods

Pushed vs. driven soil sampling data

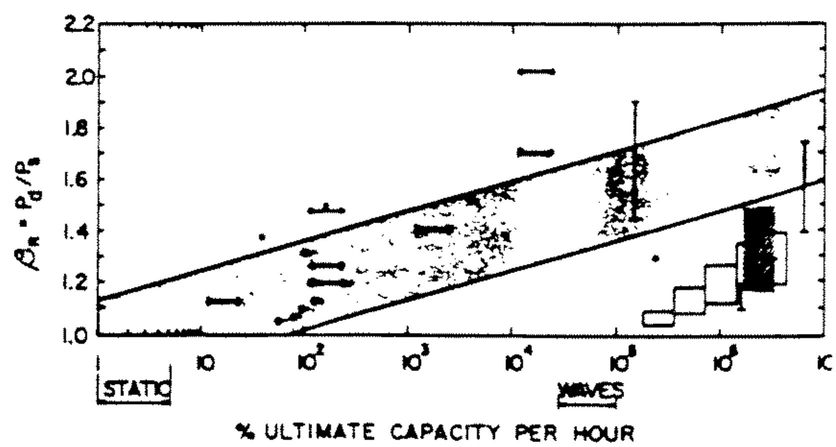
Test Type	Site 1	Site 2	Site 3	Average
UC	3.3	1.7	2.1	2.4
MV	1.4	1.5	2.0	1.6
UU	1.3	1.3	1.3	1.3
Average	2.0	1.5	1.8	1.8

Strain Rate Effects

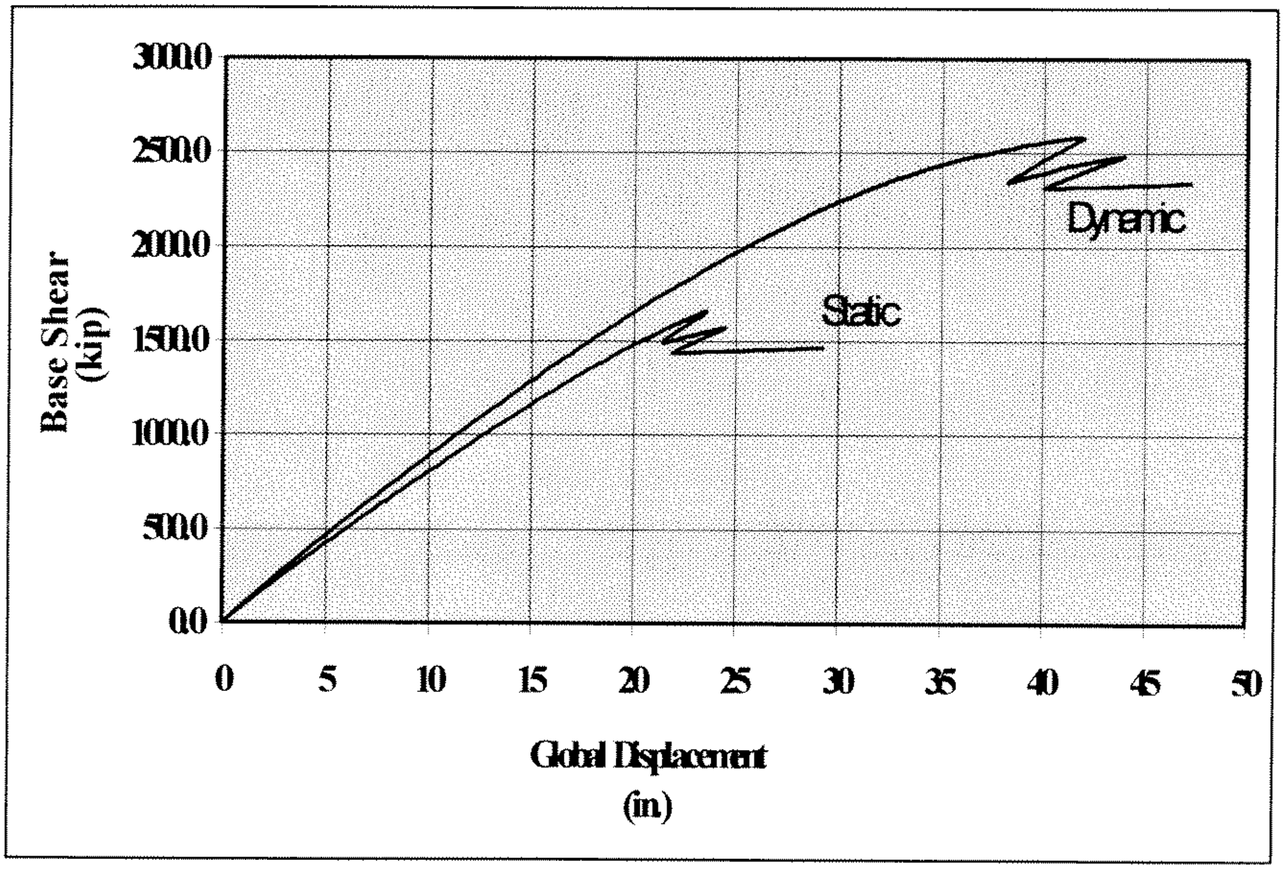


Strain Rate Effects

$$\beta_R = 1 + F \log \frac{t_r}{t_s} = \frac{R_{md}}{R_{ms}}$$



Analysis Results



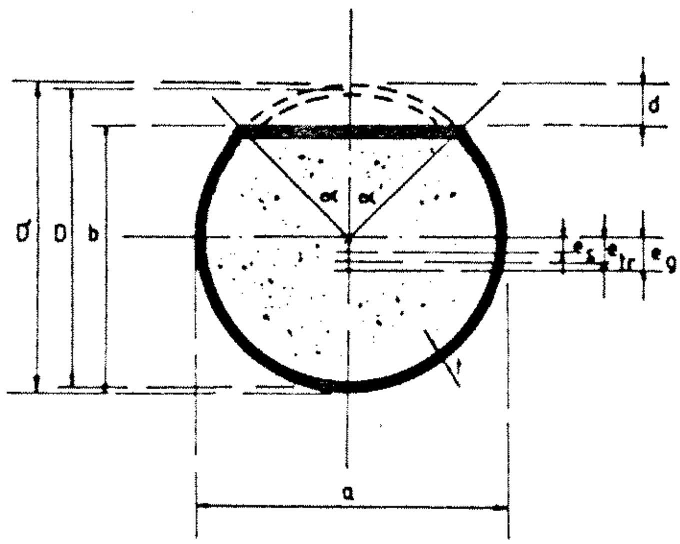
Conclusions

- Current foundation modeling procedures can be very over-conservative
- Reliable testing of pushed soil samples can produce much higher shear strengths than driven samples
- Past observation and recent research both indicate significant conservatism in foundation design

ULSLEA
Final Improvments

- Grout Repaired Tubular Braces
- Lateral Pile Capacity in Clay

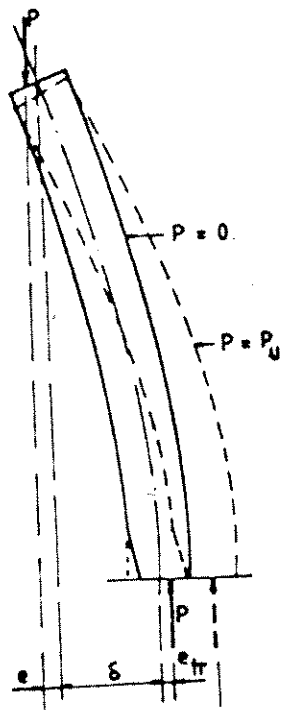
GROUT REPAIRED TUBULAR BRACES
Parsanejad's Formulation



Assumptions

- Full interaction between grout and tube
- Grout prevents premature local buckling
- First yield collapse criterion

GROUT REPAIRED TUBULAR BRACES
Parsanejad's Formulation



$$\left(\frac{\sigma_u}{\sigma_y}\right)^2 - \left(\frac{1+k}{\lambda^2} + m\right)\left(\frac{\sigma_u}{\sigma_y}\right) + \frac{m}{\lambda^2} = 0$$

$$\lambda = \sqrt{\frac{\sigma_y}{\sigma_e}} = \frac{1}{\pi}\frac{l}{r_{tr}}\sqrt{\frac{\sigma_y}{E_s}}$$

$$k = \frac{A_{tr}\, e_t}{Z_{tr}}$$

$$m = \frac{A_{tr}}{A^{*}_{tr}}$$

GROUT REPAIRED TUBULAR BRACES

Experimental Results

Parsanejad:

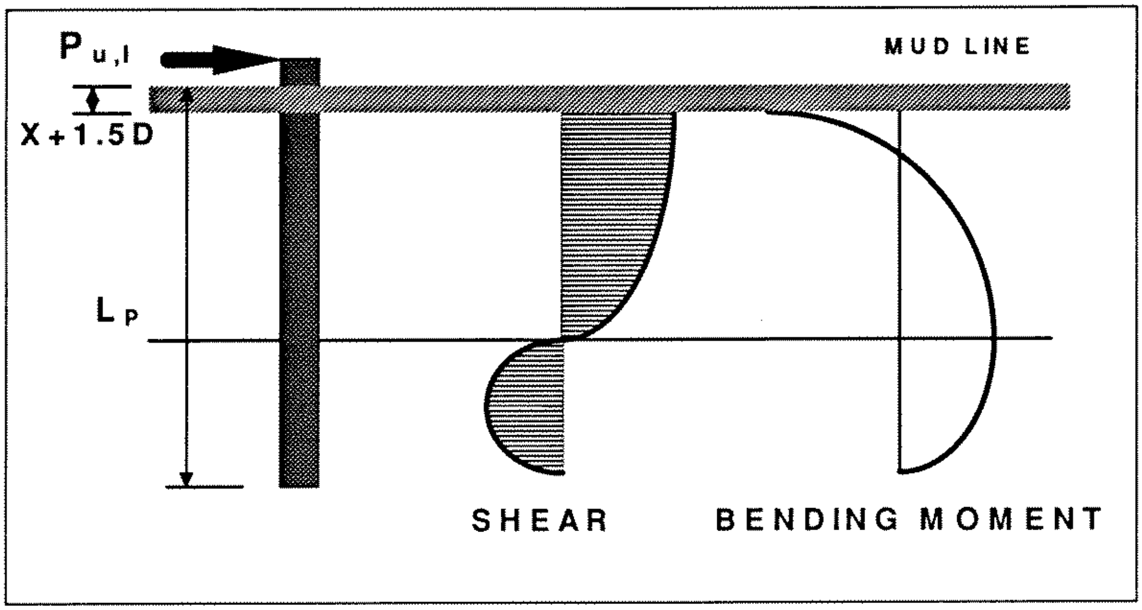
- The analytical results present a close lower bound estimates of test results

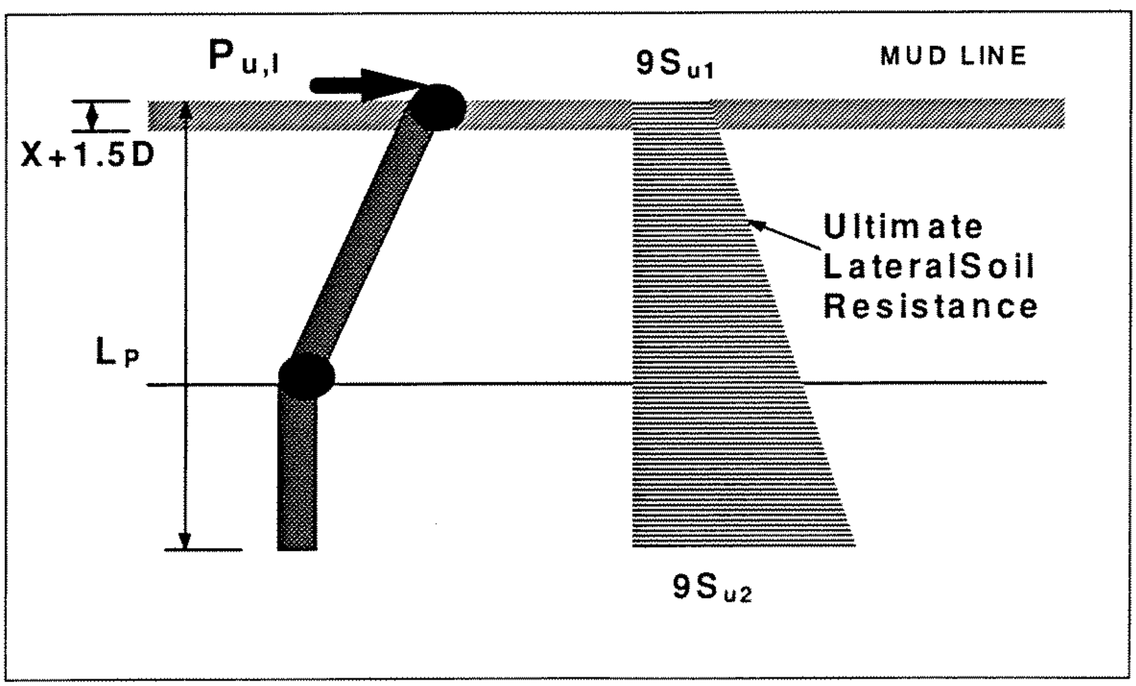
Ricles:

- Internal grout and grouted steel clamp repairs of a 0.1D dent damaged brace are successful in reinstating the original undamaged member's strength by arresting dent growth inwards

- The predicted strength of internally grout repaired members based on Parsanejad's method provide a close lower bound to experimental data.

Lateral Pile Capacity in Clay





ULSLEA
Lateral Pile Capacity in Clay

$$P_{u,l}\left(C+\xi\right)-2M_u-\left(A+\eta\xi\right)\frac{C^2}{2}-\left(\frac{\eta}{2}\right)\frac{C^3}{3}=0$$

$$C=\frac{1}{\eta}\left[\left(-A+\eta\xi\right)+\sqrt{\left(A+\eta\xi\right)^2+2\eta P_{u,l}}\right]$$

$$\eta=\frac{B-A}{L_p}$$

$$\xi=1.5D+X$$

$$A=9S_{u1}D\quad,\quad B=9S_{u2}D$$

FUTURE WORK

- Further verification and platform assessment studies
- Effect of horizontal framing on load redistribution
- Refine foundation capacity model

FUTURE WORK (Cont.)

- Further develop simplified reliability analysis procedures
- Apply ULSLEA to design and proportioning of jacket structures
- Additional features and improved user friendliness of ULSLEA

Future Work Recommendations

- Analyze 10 and 12 leg platforms and platforms with X-bracing failures
- Consider joint flexibility and joint capacity
- Consider stochastic failure modes such as tensile failure and crack rupture
- Consider dynamic effects on wave loading and platform capacity
- Consider cyclic capacity and/or damaged members
- Investigate effects of cyclic degradation of foundation capacity