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IMPACT OF MARINE GROWTH ON PIPELINE RISERS FOR FLOATING PRODUCTION FACILITIES

Summary of Marine Growth Impact on Riser Systems

Prepared for

MMS

MMS TAR&P

Reference No. 4-1-4-333/SR01

Rev. 2

May 2009

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EXECUTIVE SUMMARY

The Mineral Management Services (MMS) has contracted MCS to study the impact of marine growth (fouling) on the performance of deepwater risers for floating facilities. MCS is responsible for the delivery of the following four tasks:

Task 1: Perform a literature and industry survey to develop comprehensive information regarding the level of marine growth experienced on facility risers in the Gulf of Mexico

Task 2: Analytically assess the impact of marine growth on the global riser response (stress and fatigue) for an SCR assuming no VIV suppression (no strakes)

Task 3: Analytically assess the impact of marine growth on the global riser response (stress and fatigue) for an SCR assuming VIV suppression (strakes)

Task 4: Investigate what technologies are available for marine growth inspection, removal and mitigation.

Marine Growth Profile Survey Results

Soft marine growth has been observed down to 2000 ft salt water. Hard marine growth has been observed on the floating facility hulls and support structures, also at depths greater than anticipated. The observed marine growth did not exceed the thickness limits set forth in API RP 2RD [2].

Survey response was limited; five (5) responses were received from the twenty-four (24) Gulf of Mexico operators surveyed. These responses were predominately from operators of spars, with steel catenary riser (SCR), top-tensioned riser (TTR), or unspecified riser systems. The marine growth profiles reflected at most 5 years of growth.

Analysis Results

The analytical assessment was conducted with two marine growth profiles on both a straked and unstraked 20 inch steel catenary riser (SCR), hung off a semi-submersible vessel. The system particulars selected were representative of a Gulf of Mexico deepwater system. As of 2009, SCRs make up approximately 70% of the risers installed in the Gulf of Mexico deepwater (depths > 5000 ft). Approximately 50% of the facilities in these water depths are semi-submersibles.

The API RP 2A [1] marine growth profile was selected in lieu of the API RP 2RD [2] profile. The other profile analyzed was a slightly more conservative profile (i.e. larger amounts of marine growth to an increased water depth), based on previous MCS project data. The results of the assessment showed that the marine growth had little effect on the overall stress (static loading as well as dynamic) and on the fatigue life of the riser. This is because the marine growth mainly affects the upper portion of the riser systems, while the peak stress for SCRs is typically generated in the lower portion.

Marine Growth Inspection, Removal, & Mitigation

The primary focus in industry is the development of anti-fouling coatings without tributyl tin (TBT), such as self polishing copolymer (SPC) biocidal coatings. The most information on these coatings is proprietary and region specific. The available data on the effectiveness of the current anti-fouling coatings varies. Some operators deem that the coatings are invaluable, while others find no real benefit.

There has been little development in removal techniques in the last 15 years. Remote operated vehicles (ROVs) deployed high pressure water jets or scrubbers are typically used for localized marine growth removal. Inspections are typically visual, with measurements estimated from visual marine growth density.

Recommendations

MCS recommends development of a marine growth profile, extending beyond the API RP 2RD 150 ft water depth to a depth on the order of 2000 ft. The limited survey responses received indicated that marine growth can be found at water depths significantly beyond 150 ft. The primary data for this profile would be measurements taken during visual inspections. Ideally, these inspection reports would include a measure of the change in marine growth between inspections.

We recommend further analytical studies using this new profile to assess the impact of marine growth on various riser systems (e.g. SCRs, TTRs, and flexibles). The deeper marine growth profile may have more significant impact on weight-sensitive systems (such as TTRs) or systems that are fatigue-critical in the hang-off region (flexibles).

It is also recommended that performance of anti-fouling coatings over the installed life be assessed, through collection and analysis of in-field data.

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1 INTRODUCTION

1.1 BACKGROUND

The Mineral Management Services (MMS) has contracted MCS to study the impact of marine growth (fouling) on the performance of deepwater risers for floating facilities.

For riser design, the API RP 2RD [2] standard states that only equipment in the first 150ft of the water column should be subjected to marine growth. Marine growth will occur in the euphotic zone, the region in which photosynthesis is able to occur (approximately up to 660ft water depth). The current regime, water temperature and the distribution of essential nutrients in the water column effect the depth marine growth will reach. Evidence from ROV inspections show that marine growth may extend much deeper in the water column than originally believed in the Gulf of Mexico (GoM). One operator reported marine growth down to 2000ft below the water surface.

For riser analysis, the effect of marine growth is normally accounted for as an increase in the drag diameter and mass for the affected riser region. The riser system hydrodynamic inertia, added mass, drag and damping are then calculated with the additional drag diameter and mass. The addition of marine growth to a riser system is considered detrimental due to the additional mass and hydrodynamic loading. This disadvantage may translate into increased stresses in the system, decreases in fatigue performance and additional tension requirements. In the MCS performed analysis of an SCR, the marine growth had little effect on the overall stresses, both static and dynamic.

A typical periodic riser inspection includes some type of marine growth assessment. The assessment will normally include a close visual inspection of the upper portion of the system performed by divers or remotely operated vehicle (ROV). During the inspection, measurements of the marine growth thickness are taken along the structure.

In order to mitigate against marine growth in the splash zone and in the upper portion of the riser, anti-fouling coatings or sleeves may be applied to the riser system. The coatings are also sometimes applied to vortex induced vibration (VIV) suppression devices (e.g. strakes or fairings) attached to the riser. Around the strakes, the marine growth can cause bridging between the fins and have a detrimental effect on suppression. The survey responses confirmed this, some operators responded that they coat both the riser and the strakes with an anti-fouling coating, and saw little marine growth. Other operators witnessed no real benefit of anti-fouling coatings.

1.2 OBJECTIVES

The objective of this study is to conduct an investigation into the marine growth and how it affects pipeline riser performance in terms of stress and fatigue. The results will include research results and establish technologies available for marine growth inspection, removal and mitigation.

1.3 SCOPE

The scope of work is shown below:

Task 1: A literature and industry survey to assess the level of marine growth experienced on facility risers in the Gulf of Mexico. This task will include a comparative assessment of the design versus actual observed marine growth in the GoM. In addition, this task will address the levels of inspection being performed, inspection techniques and anti-fouling employed for GoM facility risers.

Task 2: Based on the industry experience gathered in Task 1, apply the approach adopted by the relevant facility riser design code (API RP 2RD [2]) and assess the impact of marine growth on the global riser response (stress and fatigue) for a an SCR assuming no VIV suppression.

Task 3: Based on Task 2 continue the performance assessment assuming strakes and fairings are applied to the riser system for VIV suppression and establish what the effect of adding marine growth would be on the global fatigue performance of each riser system. In addition make a comparative assessment of research that has already been performed with regard to marine growth and VIV suppression devices by companies such as AIMS and Shell Global Solutions.

Task 4: Based on Task 1, establish what technologies are available for marine growth inspection, removal and mitigation.

Task 5: Final Report

1.4 REVISION HISTORY

This is Rev. 02, issued as the final report and close-out of MMS comments.

1.5 UNITS

The Imperial system of units has been used for this study.

1.6 ABBREVIATIONS

BMSL	Below Mean Sea Level
FEA	Finite Element Analysis
FHC	Free Hanging Catenary
FSO	Floating Storage and Offloading unit
GoM	Gulf of Mexico
HO	Hang-Off
MG	Marine Growth/Fouling
MSL	Mean Sea Level
SCF	Stress Concentration Factor
SCR	Steel Catenary Riser
TDP	Touchdown Point
TDZ	Touchdown Zone
VIV	Vortex Induced Vibrations
WD	Water Depth

2 CONCLUSION

2.1 GENERAL

2.1.1 Task 1: Industry Survey

Soft marine growth has been observed down to 2000 ft salt water. Hard marine growth has been observed on the floating facility hulls and support structures, also at depths greater than anticipated. The observed marine growth did not exceed the thickness limits set forth in API RP 2RD [2].

Survey response was limited; five (5) responses were received from the twenty-four (24) Gulf of Mexico operators surveyed. These responses were predominately from operators of spars, with steel catenary riser (SCR), top-tensioned riser (TTR), or unspecified riser systems. The marine growth profiles reflected at most 5 years of growth.

2.1.2 Tasks 2 & 3: Deepwater Riser Case Study

The analytical assessment was conducted with two marine growth profiles on both a straked and unstraked 20 inch steel catenary riser (SCR), hung off a semi-submersible type vessel. The system particulars selected were representative of a Gulf of Mexico deepwater system. Load cases were based on internal review of MCS projects. The API RP 2A marine growth profile and a more conservative profile with soft marine growth extending to 1000 ft below MSL were applied to the systems.

Marine fouling had limited impact on SCR strength and fatigue response. The soft marine growth applied for the deepwater profiles was close to neutrally buoyant and the increased in drag load was relatively small. The addition of strakes did cause significant variance in the riser response, primarily due to the increase in drag loading.

2.1.3 Task 4: Marine Growth Inspection, Removal, & Mitigation

The primary focus in industry is the development of anti-fouling coatings without tributyl tin (TBT), such as self polishing copolymer (SPC) biocidal coatings. The most information on these coatings is proprietary and region specific. The available data on the effectiveness of the current anti-fouling coatings varies. Some operators deem that the coatings are invaluable, while others find no real benefit.

There has been little development in removal techniques in the last 15 years. Remote operated vehicles (ROVs) deployed high pressure water jets or scrubbers are typically used for localized marine growth removal. Inspections are typically visual, with measurements estimated from visual marine growth density.

2.2 RECOMMENDATIONS

MCS recommends development of a marine growth profile, extending beyond the API RP 2RD 150 ft water depth to a depth on the order of 2000 ft. The limited survey responses received indicated that marine growth can be found at water depths significantly beyond 150 ft. The primary data for this profile would be measurements taken during visual inspections. Ideally, these inspection reports would include a measure of the change in marine growth between inspections.

We recommend further analytical studies using this new profile to assess the impact of marine growth on various riser systems (e.g. SCRs, TTRs, and flexibles). The deeper marine growth profile may have more significant impact on weight-sensitive systems (such as TTRs) or systems that are fatigue-critical in the hang-off region (flexibles).

It is also recommended that performance of anti-fouling coatings over the installed life be assessed, through collection and analysis of in-field data.

3 STATE OF THE ART MANAGEMENT OF RISER/PIPELINE MARINE GROWTH FOULING

3.1 GENERAL

MCS contacted twenty-four (24) facilities in the Gulf of Mexico to determine the observed marine growth levels. Appendix A and Appendix B show the survey (revision 1 and 2 respectively) that was sent to the operators. Specific riser types were not provided by the operators and were not requested by MCS.

3.2 SURVEY RESULTS

In the Survey 1 response from Mississippi Canyon 773, the operator responded with a Level II inspection report dated 12/21/05. For this spar facility the risers are installed within the spar, and are not visible for inspection until 535 ft below the water line. Below are the comments from the inspection report on marine growth.

> "No reportable excessive marine growth was reported. Marine growth was moderate to light at the hard tank down to -191 fsw with hard growth covering 90% to 100% of the members to an average thickness of ½". The marine growth consisted primarily of barnacles and incrusting corals. The [marine growth] was light [and] spotty hard and soft marine growth on all components from -191 fsw down to -2000 fsw with less than 40% coverage and ½" thick or less. The hard marine growth consisted primarily of barnacles and incrusting corals."[5]

Survey 2 response from Mississippi Canyon 127 reported that an ROV visual inspection showed some "heavy marine growth." According the operator, "the details of the strakes were not visible in the inspection." There were no available marine growth measurements. The operator is using 16D strakes. The operator has other experience treating the risers with marine growth inhibitors, but believed that there was not much benefit. In Mississippi Canyon, 25% of the operators surveyed used a marine growth inhibitor.

Survey 3 response from Mississippi Canyon 582 reported operating at 2200 ft water depth, and reported minimal marine growth. The facility is a spar facility with the risers installed within the spar, and is not visible for inspection until 535 ft below the water line. The riser system was treated with a marine growth inhibitor.

Survey 4 response from Green Canyon 338 reported operating at 3300 ft water depth, and reported minimal marine growth. The facility is a spar facility with the risers installed within the spar, and is not visible for inspection until 535 ft below the water line. The riser system was treated with a marine growth inhibitor.

Survey 5 response from Garden Banks 250 reported no substantial marine growth on the upper portion of the riser. The operator has treated the riser system with an anti-fouling coating, and believes this is why there is minimal growth. The operator did witness excessive marine growth below 1000ft.

The completed operator surveys address facilities that have been installed for less than five years.

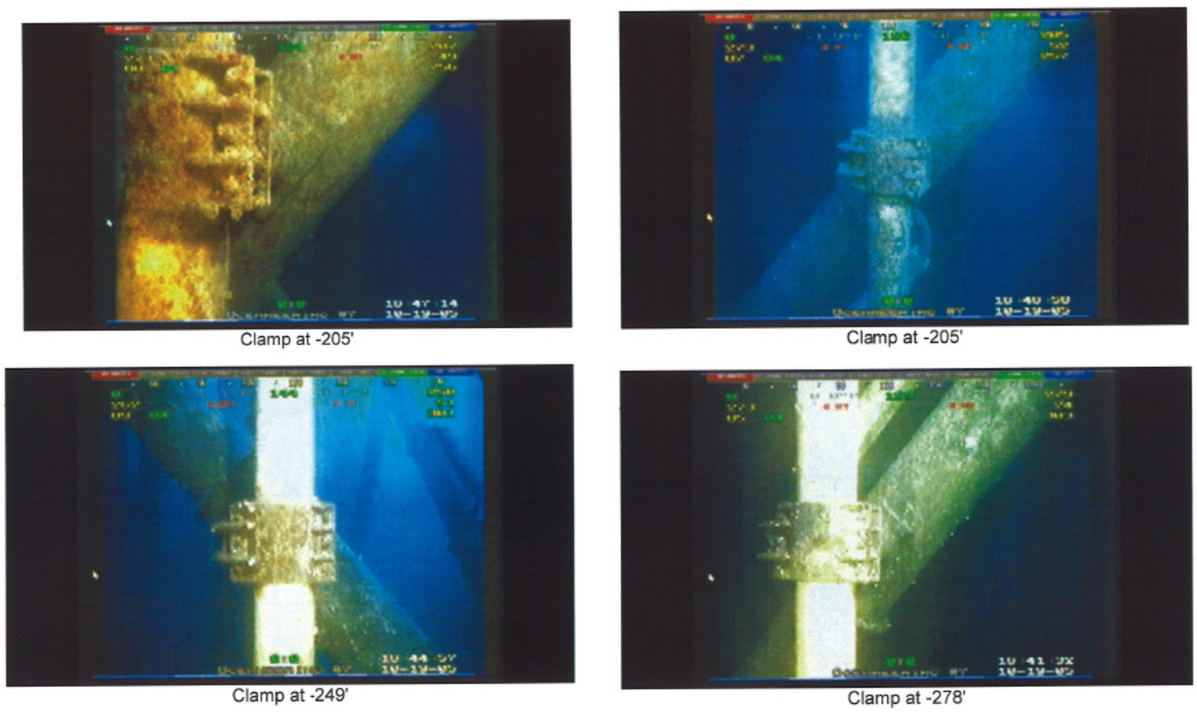

Figure 3-1 Mississippi Canyon 773 Marine Growth Pictures Below 150ft

3.3 LITERATURE RESULTS

A literature study was initiated in which the MMS reports, OTC papers, industry publication, and in house papers were surveyed for information on marine growth. Most of the information found was not relevant to this study. A previous study conducted by the MMS, "Rationalization and Optimization of Underwater Inspection Planning Consistent with API

RP2A Section 14" [4], gathered all the inspection data on facilities in the GoM from 1950 to 2001, including marine growth measurements.

4 PERFORMANCE ASSESSMENT BASIS

4.1 GENERAL

This section presents the metocean data and the riser configuration (both straked and unstraked) used in the global riser response analysis. The field development scenario for the case study is for 6,000 ft water depth, in the Gulf of Mexico. A deepwater gas export steel catenary riser (SCR) system was selected for evaluation of marine fouling on riser performance.

The system particulars selected were representative of a Gulf of Mexico deepwater system. As of 2009, SCRs make up approximately 70% of the risers installed in the Gulf of Mexico deepwater (water depths > 5000 ft). Similarly, approximately 50% of the facilities in these water depths are semi-submersibles.

4.2 RISER CONFIGURATION

Table 4-1 presents the basic SCR configuration considered.

Table 4-1 SCR Configuration

Parameter	Unit	Value
General		
Nominal Size		20
Nominal Diameter	inch	20
Nominal Wall Thickness	inch	1.2
Line pipe Type	-	DSAW
Design Pressure	psi	4,000
Wall Thickness Tolerance	-	-5% - +19%
Hang-off Arrangement	-	Flexible Joint
Hang Off Angle	°	15
Normal Drag Coefficient (C_d)	-	1.2 (unstraked)
Normal Inertia Coefficient (C_I)	-	2.0 (unstraked)

The objective of the case study is to determine the effect of marine fouling on the strength and wave-induced fatigue performance of the 20-inch SCR. To do this, the case study adopted a parametric technique to identify performance trends. The benchmark for the study is a 20-inch SCR which is unstraked and void of marine growth, while combinations of marine fouling and strake coverage were considered. Table **4-2** shows the suspended riser length (ft), the horizontal distance to touch down point (ft), the percentage of strake coverage, and the marine growth profile used (see Table 4-4 for marine growth profiles).

Table 4-2 SCR Configurations for Case Study

Riser Configuration	Suspended Length (ft)	Horizontal Distance to TDP (ft)	% Strake Coverage	MG Profile
RC#1 (Benchmark)	7693	4168	-	-
RC#2	7693	4168	-	MG1
RC#3	7714	4189	80%	-
RC#4	7714	4189	80%	MG1
RC#5	7705	4180	-	MG2

Notes: 1) Refer to Table 3 4 & Figure 3 1 for details on Marine Fouling Profiles

Generic 16D strakes have been assumed in this study, the characteristics of which are presented in Table 4-3.

Table 4-3 Generic 16D Strake Particulars for 20-inch SCR

Parameter	Units	Value
Weight in Air	lbs/ft	48.4
Submerged Weight	lbs/ft	5.3
Barrel Outside Diameter	inch	22.36
Normal Drag Coefficient (C_d)	-	2.5
Normal Inertia Coefficient (C_I)	-	2.5

4.3 MARINE GROWTH PROFILES

The particulars of the marine fouling profiles are presented in Table 4-4 and plotted in Figure 4-1. Marine Fouling Profile MG1 is based on MCS GoM project data, and is typical of the design profiles currently employed by operators and riser designers for GoM designs. Marine Fouling Profile MG2 is an additional profile which is substantially more onerous and has been considered as a sensitivity analysis for the Case Study. A specific gravity of 1.2 was assumed for marine fouling.

Marine Fouling Profile MG1 is quite similar to the generic profile recommended by the industry code API RP 2A [1]. API RP 2A suggests a profile of 1.5-inch in thickness from MSL to a depth of 150 ft, unless a smaller or larger value of thickness is appropriate from site specific studies.

Table 4-4 Marine Growth Profiles

Depth Below MSL (ft)	Thickness (in)		
	API RP 2RD	MG1	MG2
0	1.5	1.5	0.75
150	1.5	1.5	0.75
150	1.5	0.75	0.75
175	0	0.75	0.75
175	0	0	0.75
1000	0	0	0.75
1000 plus	0	0	0

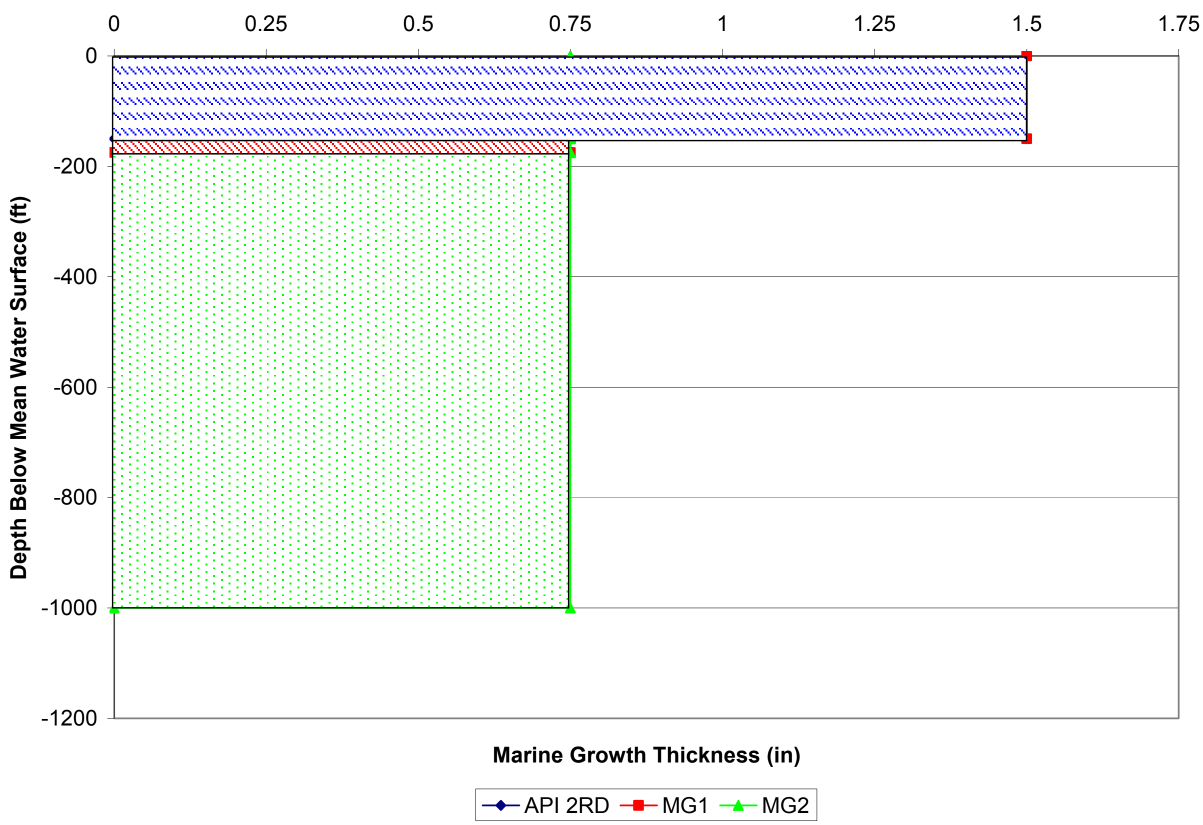

Figure 4-1 Marine Fouling Profiles

4.4 METOCEAN DATA

4.4.1 Extreme Seastates

The 20-inch Gas Export SCR was assessed for extreme (strength) performance using the generic GoM 100-year hurricane and the 100-year loop current design events. The particulars of the hurricane and loop current events are presented in Table 4-5 and Table 4-6, respectively.

Time domain dynamic Flexcom analysis of the SCR for five configurations was performed for the extreme analysis. A deterministic (regular) design wave approach was used. This would not be typically employed for detailed SCR design in the GoM, but was considered sufficient for the purposes of the marine fouling parametric study.

Analyses were completed for near and far loading directions, albeit with the floating production facility located at the nominal position for both cases. Near loading considered the design event (hurricane or loop current) to arrive at the facility in the plane of the SCR, with wave & current propagating from deep draft semi-submersible towards the SCR touchdown. Far loading analysis was in the opposite direction, i.e. in SCR plane, but wave & current propagating from SCR touchdown towards semi-submersible.

Table 4-5 Generic GoM 100 Year Hurricane Design Condition

Parameter	Symbol	Units	Value
Waves			
Significant Wave Height	H_s	ft	46.92
Peak Spectral Period	T_p	s	15.0
JONSWAP Parameters			
Peakedness Parameter	γ	-	2.6
Current			
Current Speed at 0ft BMSL	V_{0ft}	ft/s	6.23
Current Speed at 13ft BMSL	V_{-13ft}	ft/s	5.58
Current Speed at 56ft BMSL	V_{-56ft}	ft/s	4.59
Current Speed at 121ft BMSL	V_{-121ft}	ft/s	3.28
Current Speed at 144ft BMSL	V_{-144ft}	ft/s	2.30
Current Speed at 171ft BMSL	V_{-171ft}	ft/s	0.33
Direction (°relative, toward)			+15° from wave

Table 4-6 Generic GoM 100 Year Loop Current Design Condition

Parameter	Symbol	Units	Value
Waves			
Significant Wave Height	H_s	ft	4.92
Peak Spectral Period	T_p	s	6.0
JONSWAP Parameters			
Peakedness Parameter	γ	-	1.0
Current			
Current Speed at 0ft BMSL	V_{0ft}	ft/s	6.56
Current Speed at 164ft BMSL	V_{-164ft}	ft/s	6.56
Current Speed at 492ft BMSL	V_{-492ft}	ft/s	4.76
Current Speed at 984ft BMSL	V_{-984ft}	ft/s	2.79
Current Speed at 1476ft BMSL	$V_{-1476ft}$	ft/s	1.48
Current Speed at 2461ft BMSL	$V_{-2461ft}$	ft/s	0.82
Current Speed at 3937ft BMSL	$V_{-3937ft}$	ft/s	0.33
Direction (°relative, toward)			0

4.4.2 Fatigue Seastates

The various SCR configurations were analyzed for five seastates critical to wave-induced fatigue performance. The characteristics of the five seastates are presented in Table 4-7.

Table 4-7 Wave-induced Fatigue – Critical Seastates

Seastate Number	H_s [ft]	T_p [sec]	Spectra Peakedness [γ]	Annualized % of Occurrence
#01	4.50	5.50	1.0	2.4
#02	5.52	5.50	1.0	1.1
#03	6.93	6.59	1.0	1.5
#04	8.90	7.43	1.0	1.0
#05	11.60	8.19	1.0	1.3
			Total	**7.3**

These five seastates were chosen based on experience of design driver for large diameter GoM deepwater SCRs, generating approximately 30% of total SCR hang-off and touchdown zone wave-induced fatigue damage. The case study SCR was assumed to have an azimuth bearing of approximately NNW, which is considered reasonable for a deepwater development in the GoM. For this layout, the five critical seastates will arrive at the facility from the SSE and propagate towards NNW. Therefore, the wave loading is analogous to near case loading considered in the extreme analysis.

The fatigue damage accumulation was calculated using 1 hour time domain irregular wave analysis. The stress cycling along the SCR was assessed using standard Rainflow Counting practices.

A global stress concentration factor (SCF) of 1.2 has been assumed for all girth welds. The E S-N Curve was used to assess fatigue performance of the riser [3]

5 ANALYSIS APPROACH – RISER PERFORMANCE WITHOUT VIV SUPRESSION

A finite element analysis (FEA) technique using Flexcom was employed to evaluate the impact of marine fouling on the deepwater SCR case study. Flexcom is a general purpose, non-linear, three-dimensional finite element package for the analysis of a wide range of offshore structures. The SCR system was analyzed in Flexcom using a time domain approach.

The performance of the SCR is evaluated in terms of tension and stress response along the riser joints and also the maximum predicted rotation of the flexible joint assembly.

5.1 SCR UNSTRAKED STATIC/FUCTIONAL LOAD RESULTS

Table 5-1 presents the static (functional) loads and results along the unstraked SCR system for the three different riser configurations considered. It is evident from the results that the inclusion of marine fouling has little or no impact on the static loads along the SCR system. This is because as both the marine fouling and strake material are close to neutrally buoyant and will not significantly affect the tension distribution along the SCR.

Table 5-1 Static/Functional SCR Results

Riser Configuration	SCR Suspended Length (ft)	Horizontal Distance to mean TDP (ft)	Mean Flex Joint Angle [°]	Maximum API RP 2RD Stress [ksi]	Maximum Effective Tension [kips]
RC#1	7693	4168	0.0	28.7	1147
RC#2	7693	4168	0.0	28.7	1144
RC#5	7705	4180	0.3	28.8	1108

Figure 5-1 shows that the inclusion of marine fouling has little or no impact on the static loads along the unstraked SCR system.

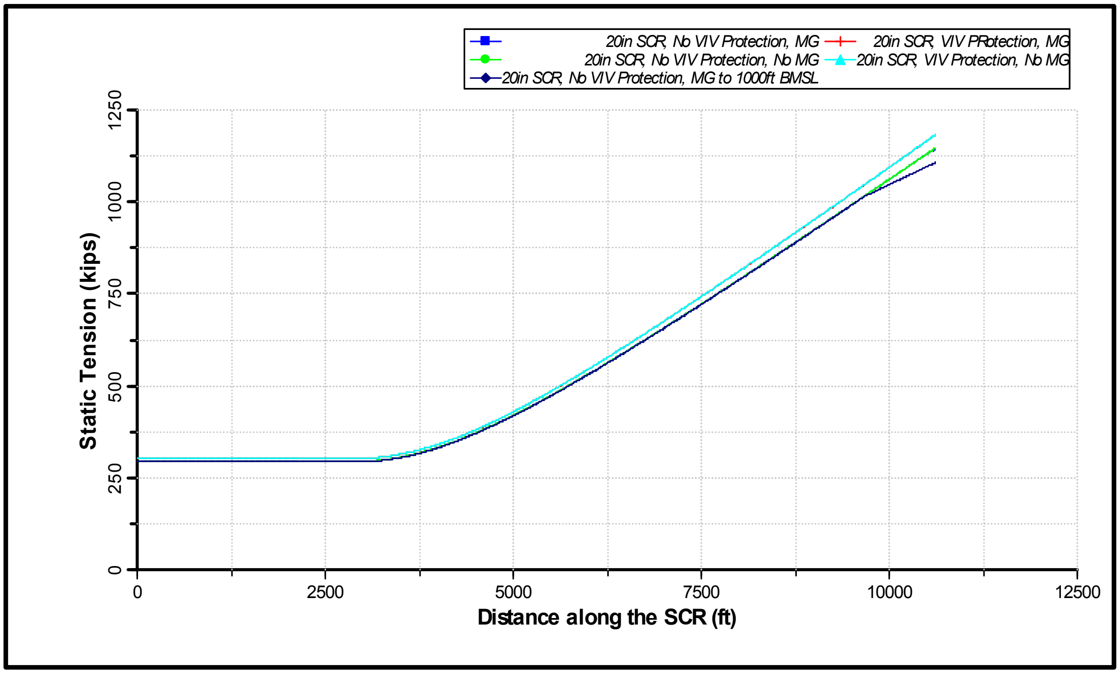

Figure 5-1 Static Tension in Unstraked SCR

5.2 SCR UNSTRAKED STATIC EXTREME LOAD RESULTS

Table 5-2 and Table 5-3 present the extreme dynamic unstraked SCR results for the 100-year hurricane and 100-year loop current design load cases respectively.

Marine fouling profile MG1 (typical of current industry practices) has little or no affect on the deepwater SCR extreme response. This is primarily because the fouled region of the SCR for MG1 is such a small percentage of the total riser suspended length that the local increase in weight & hydrodynamic loading does not affect global riser response, i.e. SCR stresses, tension and flexible joint rotations are within 0.5% of the benchmark riser configuration.

The sensitivity analysis (RC#5) considering the very onerous marine fouling profile (from MSL to 1,000 ft) does not significantly alter the tension or stress response of the SCR. It does however increase maximum flexible joint rotations by up to 10% over the benchmark configuration.

Table 5-2 Unstraked SCR Extreme Results – 100-year Hurricane Event

Riser Configuration	Loading Direction	Maximum Flex Joint Angle [°]	Maximum API RP 2RD Stress [ksi]	Effective Tension [kips]	
				Min	Max
RC#1	Near	4.2	36.8	13	1464
RC#2		4.1	36.8	14	1462
RC#5		4.6	37.3	17	1427
RC#1	Far	5.7	38.5	36	1480
RC#2		5.7	38.4	36	1477
RC#5		5.9	37.8	31	1447

Table 5-3 Unstraked SCR Extreme Results – 100-year Loop Current Event

Riser Configuration	Loading Direction	Maximum Flex Joint Angle [°]	Maximum API RP 2RD Stress [ksi]	Effective Tension [kips]	
				Min	Max
RC#1	Near	1.4	30.3	272	1187
RC#2		1.4	30.3	272	1184
RC#5		1.9	30.7	271	1150
RC#1	Far	1.5	30.3	282	1186
RC#2		1.5	30.2	282	1183
RC#5		1.2	29.6	281	1148

5.2.1 Unstraked SCR Wave-Induced Fatigue Load Results

Table 5-4 presents the wave-induced fatigue results for the 20-inch unstraked SCR case study. Figure 5-2 presents the distribution of damage along the SCR for RC#1 & RC#2; it is evident that damage is concentrated just below the flexible joint and at the touchdown location.

From the dynamic fatigue analysis, it can be concluded that the presence of marine growth on deepwater SCRs is not significantly detrimental to riser performance. In general, from current industry practices, marine growth has little impact on wave-induced fatigue performance, for similar reasons as results of the extreme analysis. The marine growth profile increases the level of drag loading experienced by a riser. For deepwater deployment, this has the effect of damping the riser response and correspondingly improve the fatigue performance in the touchdown region. The fatigue life decreases slightly (2 years; 0.005%) for RC#5 at the hang-off region due to the increased tension/weight from the marine growth. This decrease is not significant over the life of the SCR at the hang-off. The level of damping only becomes appreciable for significant levels of fouling and hence the trend cannot be observed for RC#2, but slight (5%) increase fatigue life over the benchmark is observed for RC#5 in the touchdown zone.

Table 5-4 Unstraked SCR Case Study Wave-induced Fatigue Results

Riser Configuration	Marine Growth Profile	Touchdown Zone		Hang-Off Region (1st Offshore Weld	
		Annualized Damage	Fatigue Life (years)	Annualized Damage	Fatigue Life (years)
RC#1	Benchmark (zero MG)	0.0277	36.1	0.0023	438
RC#2	MG1	0.0277	36.0	0.0023	438
RC #5	MG2	0.0263	38.0	0.0023	436

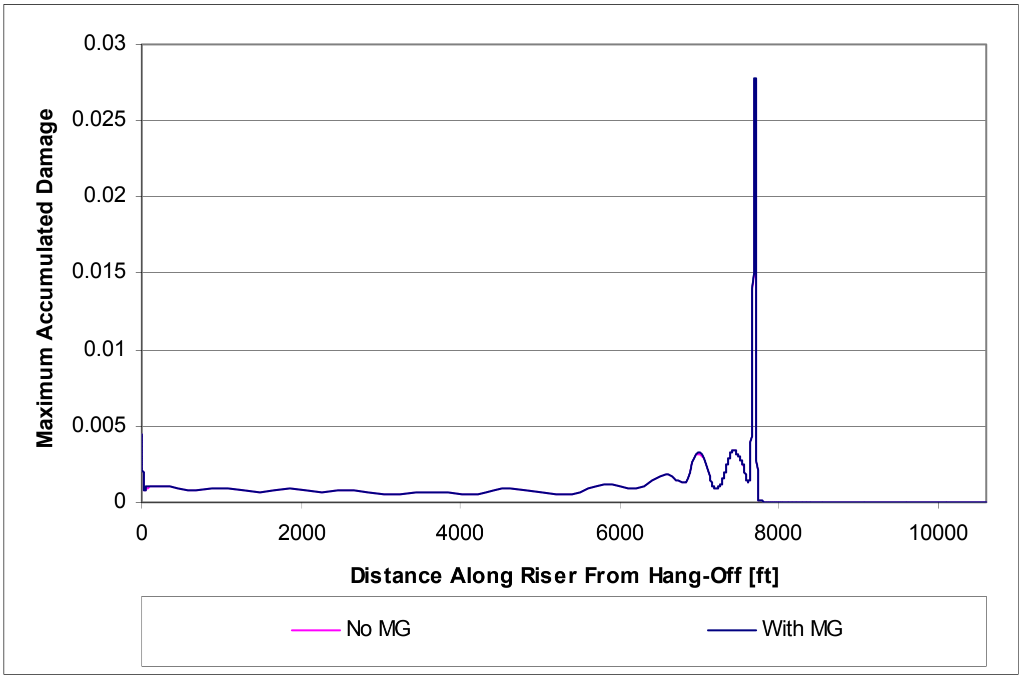

Figure 5-2 Unstraked SCR Fatigue Damage Distribution for RC#1 & RC#2

6 ANALYSIS APPROACH – RISER PERFORMANCE WITH VIV SUPPRESSION

6.1 GENERAL

A finite element analysis (FEA) technique using Flexcom was employed to evaluate the impact of marine fouling on the deepwater SCR with VIV suppression. Flexcom is a general purpose, non-linear, three-dimensional finite element package for the analysis of a wide range of offshore structures. The SCR system was analyzed in Flexcom using a time domain approach.

The performance of the SCR is evaluated in terms of tension and stress response along the riser joints and also the maximum predicted rotation of the flexible joint assembly.

6.1.1 SCR Static/Functional Load Results

Table 6-1 presents the static (functional) loads and results along the straked SCR (RC# 1 shown for benchmark comparison) system for two different riser configurations considered. It is evident from these results that the inclusion of marine fouling has little or no impact on the static loads along the SCR system. This is because as both the marine fouling and strake material are close to neutrally buoyant, and will not significantly affect the tension distribution along the SCR

Table 6-1 Static/Functional SCR Results

Riser Configuration	SCR Suspended Length (ft)	Horizontal Distance to mean TDP (ft)	Mean Flex Joint Angle [°]	Maximum API RP 2RD Stress [ksi]	Maximum Effective Tension [kips]
RC#1	7693	4168	0.0	28.7	1147
RC#3	7714	4189	0.1	29.0	1183
RC#4	7714	4189	0.1	30.1	1183

Figure 6-1 shows that the inclusion of marine fouling has little or no impact on the static loads along the SCR system.

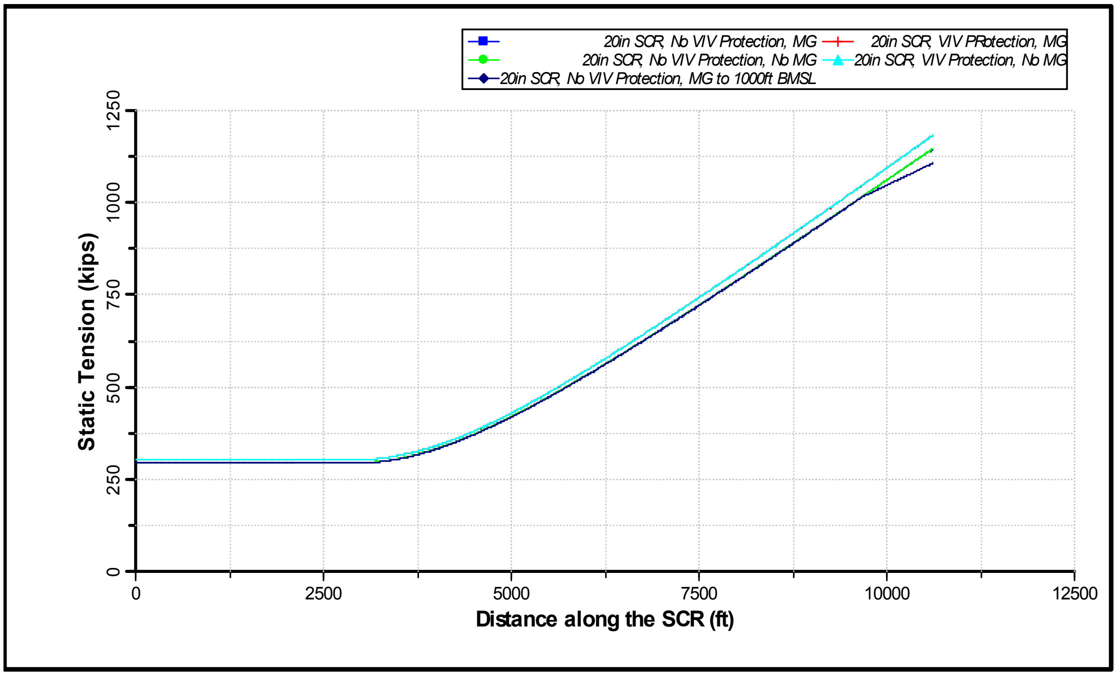

Figure 6-1 Static Tension in SCR

6.1.2 SCR Extreme Load Results

Table 6-2 and Table 6-3 present the extreme dynamic straked SCR (RC#1 is shown for benchmark comparison) results for the 100-year hurricane and 100-year loop current design load cases respectively.

Marine fouling profile MG1 (typical of current industry practices) has little or no affect on the deepwater straked SCR extreme response. This is primarily because the fouled region of the straked SCR for MG1 is such a small percentage of the total riser suspended length, that the local increase in weight & hydrodynamic loading does not affect global riser response, i.e. SCR stresses, tension and flexible joint rotations are within 0.5% of the benchmark riser configuration.

Attaching strakes to the SCR (80% coverage) significantly changes the response characteristics of the SCR. This is partly because of the increase in weight of the SCR, but primarily because of the larger hydrodynamic coefficients of the strakes. Typically, strakes will have a drag coefficient of close to twice that of an unstraked riser. For the level of coverage assumed in this Case Study, which is not unusual for deepwater GoM project, the increase in riser drag will increase maximum flexible joint rotations by 25% – 40%. If strakes (or general increase in drag coefficient) are attached to a catenary riser (SCR, etc.) in the lower water column, close to the seabed, it is possible that the strakes will generate a touchdown zone effective compression for the SCR during environmental conditions that create large platform and riser displacements on the water surface. RC#3 & RC4 are expected to witness some level of touchdown zone effective compression during the 100-year hurricane. During instances of effective compression there is potential for a riser system to experience large curvature and possible local overstressing

Table 6-2 Straked SCR Extreme Results – 100-year Hurricane Event

Riser Configuration	Loading Direction	Maximum Flex Joint Angle [°]	Maximum API RP 2RD Stress [ksi]	Effective Tension [kips]	
				Min	Max
RC#1	Near	4.2	36.8	13	1464
RC#3		4.9	40.1	-50	1558
RC#4		4.9	40.5	-49	1556
RC#1	Far	5.7	38.5	36	1480
RC#3		7.2	41.3	-30	1601
RC#4		7.3	42.0	-31	1602

Table 6-3 Straked SCR Extreme Results – 100-year Loop Current Event

Riser Configuration	Loading Direction	Maximum Flex Joint Angle [°]	Maximum API RP 2RD Stress [ksi]	Effective Tension [kips]	
				Min	Max
RC#1	Near	1.4	30.3	272	1187
RC#3		2.8	32.3	271	1227
RC#4		2.8	33.2	272	1228
RC#1	Far	1.5	30.3	282	1186
RC#3		3.0	32.5	293	1229
RC#4		3.1	33.5	293	1230

6.1.3 Straked SCR Wave-Induced Fatigue Load Results

Table 6-4 presents the wave-induced fatigue results for the 20-inch straked SCR case study (RC#1 is shown for benchmark comparison).

From the dynamic fatigue analysis, it can be concluded that the presence of marine fouling on deepwater SCRs is not significantly detrimental to riser performance. In general, from current industry practices, marine growth has little impact on wave-induced fatigue performance, for similar reasons as the extreme analysis. The marine fouling profile increases the level of drag loading experienced by a riser. For deepwater deployment, this has the effect of damping the riser response and correspondingly improve fatigue performance in the touchdown region, but challenge it in the hang-off region. However, due to the higher fatigue life at the hang-off region, the marine growth impact may be considered insignificant. The level of damping only becomes appreciable for significant levels fouling. It is seen from the Table 6-4 that the two marine growth profiles considered did not have any significant impact.

A similar observation and conclusion is made regarding the strakes. However, on a dramatic trend, because of the significant portion of strake coverage and the large associated drag coefficient. SCR touchdown wave-induced fatigue performance is observed to increase by almost 70% over the benchmark (RC#1) result due to straking, while the hang-off performance reduces by approximately 15%, as flexible joint rotations increase resulting in larger bending moment cycling in the SCR close to hang-off.

Table 6-4 Straked SCR Case Study Wave-induced Fatigue Results

Riser Configuration	Touchdown Zone		Hang-off Region (1st offshore weld)	
	Annualized Damage	Fatigue Life (years)	Annualized Damage	Fatigue Life (years)
RC#1	0.0277	36.1	0.0023	438
RC#3	0.0170	58.8	0.0027	375
RC#4	0.0170	58.7	0.0027	374

7 NEW TECHNOLOGIES AND INDUSTRY INITIATIVE FOR IMPROVED MANAGEMENT OF MARINE GROWTH FOULING

7.1 TECHNIQUES FOR MARINE GROWTH INPECTION

Excessive marine growth prevents effective detailed inspection; this section outlines the procedures and techniques used for marine growth inspection.

7.1.1 Marine Growth Survey Techniques

The types of survey generally required are:

General Marine Growth Survey – A general marine growth survey is usually undertaken concurrent with routine structural survey. This survey assesses general fouling levels and assists in determining the requirement for further detailed marine growth survey.

Detailed Marine Growth Survey – A detailed marine growth survey is carried out when more representative survey results are required. This survey allows marine growth profiles and trends to be plotted and assists in determining when critical levels of marine growth will be reached, aiding in programming of remedial works.

Pi-tape Measurement – Pi-tape measurements measure the compressed marine growth thickness by passing a graduate tape around the circumference on the component. Pi-tape measurements are carried out when more accurate detailed marine growth surveys are required. This allows assessment of the static and dynamic loading factors attributable to marine growth to be calculated and assists in determining when critical levels of marine growth will be reached.

Marine Growth Sampling – Marine growth sampling facilitates a more accurate estimate of the marine growth weight. This is also used for determining the structural and dynamic loading attributable by marine growth. This activity requires detailed laboratory analyses of samples for positive species identification and future growth predictions. The method of removal depends on the location and type of growth being removed, but may be removed by diver or ROV.

7.2 LOCATION OF MARINE GROWTH SURVEY

Four locations are to be inspected on deepwater risers, each location having four sites.

Location numbers identify the areas to be inspected on each component. There can be as many as eight locations on each component depending on its type. Locations are identified numerically starting from one, with one being the uppermost, north or east end of a particular component.

Site numbers identify the areas to be inspected at each location and are numbered on horizontally components as: one = Top; two = Bottom; three = Inner; and four = Outer. Vertical components as: five = North; six = South; seven = East; and eight = West.

Regarding Pi-tape measurement, it normally requires only one reading at each location.

Figure 7-1 illustrates the locations to be surveyed in a riser.

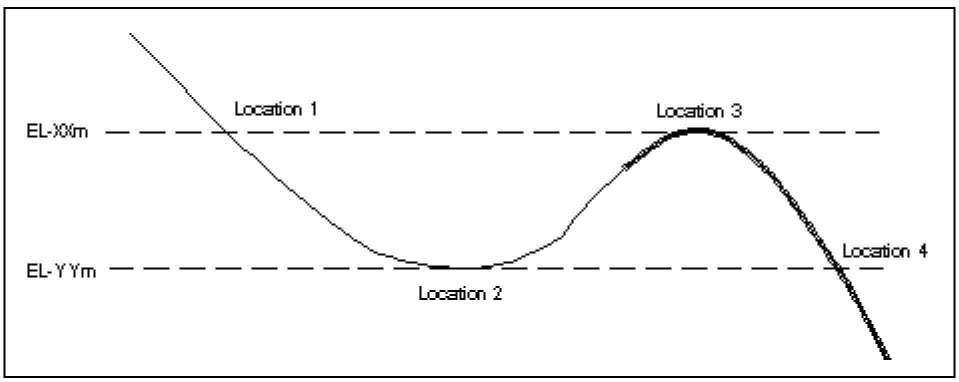

Figure 7-1 Locations to be surveyed in a riser.

7.3 SURVEY EQUIPMENT

Equipment supplied usually comprises the following

7.3.1 General Marine Growth Inspection

- An underwater colour video camera system;
- An underwater photographic camera system; and
- Scales or other measurement aids to facilitate accurate marine fouling measurement.

7.3.2 Detailed Marine Growth Inspection

- Equipment capable of spot cleaning hard marine growth on the component back to bare metal or component coating, at all specified locations, without damaging the material surface;

- An underwater color video camera system;
- An underwater photographic camera system; and
- A graduated, colour scale, capable of being positioned on the cleaned area and adjacent undisturbed growth, and being directly read by diver or ROV to allow accurate assessment of thicknesses.

7.3.3 Pi-Tape Measurement

- A pi-tape with a minimum width of 100mm and capable of conveniently fitting around the component being inspected shall be used. The pi-tape will also be scaled such that the member diameter, plus compressed marine growth thickness, can be read directly. The pi-tape should also be capable of remaining in place with the measurement visible, while photographic and video recordings are undertaken;
- An underwater color video camera system; and
- An underwater photographic camera system

7.3.4 Marine Growth Sampling

- An underwater color video camera system;
- An underwater photographic camera system;
- Equipment capable of removing the marine growth such that all growth removed can be placed in a recovery container with growth lost to ambient seawater being kept to an absolute minimum;
- A container which will hold all marine growth, gathered from any site during the recovery operation. The container should be large enough to hold marine growth removed from an area of one square metre;
- Equipment for determining accurately, the dimensions of the removal area of marine growth;
- Equipment capable of weighting, in a container of seawater, the marine growth gathered from any one site, after it has been recovered to deck;
- A topside photographic camera system;
- Screw top containers for sending samples of recovered marine growth ashore;
- Industrial alcohol (or other approved preservative) for use as a storage agent when

holding marine growth in screw top containers; and

- Labels which can be securely attached to the screw top containers, and will allow identification of contents as specified in the Work Instruction.

7.4 MARINE GROWTH CLEANING

7.4.1 General

Cleaning is carried out at locations where inspection activities require clarification of further evaluation of findings.

The standards of cleaning are as follows:

7.4.2 Level I

Level I requires removal of all marine growth and surface coatings such that the parent material is exposed to a standard equivalent to SA 2.5 (Bare metal finish, no surface deposits of any kind, preferably matt type texture). This standard of cleaning is intended to facilitate close visual inspection (CVI) and non-destructive testing (NDT).

7.4.3 Level II

Level II requires the removal of all marine growth and other loosely adhering deposits. This standard of cleaning is generally required to facilitate non-destructive testing by the electro-magnetic methods or other tasks where the removal of sound coatings is not required nor a pre-requisite.

7.4.4 Level III

Level III requires the removal of marine growth, deposits and loosely adhering coatings in excess of 80% of the surface area, but not sound coatings. This standard of cleaning is normally required where the standard of a coating is to be determined.

7.4.5 Level IV

Level IV requires the removal of bulk marine growth and loosely adhering materials such as mud etc. This standard of cleaning is normally required to confirm the identification of a component or component features, or to reduce the static and dynamic loading caused by excessive marine fouling.

7.4.6 Cleaning Equipment

Cleaning equipment would normally consist of one or more of the following:

- Hand scraper;
- Hand wire brush;
- Mechanical wire or nylon brush;
- Underwater high pressure water jet system;
- Underwater dry grit system; and
- Underwater wet grit/slurry system.

Note: Unless otherwise agreed, needle guns shall not be used where close visual inspection or non-destructive testing are to be carried out.

Cleaning can be performed by ROV or by diver

7.4.7 New Marine Growth Cleaning Technologies

There does not appear to be many new technologies for marine growth removal, the last U.S. patent was issued in the early 1990's. It appears that the industry is looking for new types of anti-fouling coatings as opposed to removal measures. The survey results indicated that the majority of the industry is using high pressure water jet techniques or physical scraping for marine growth removal.

A literature survey revealed that there is another type of high pressure system that is currently/was in development. This revolves around using water cavitation to remove the marine growth. The initial results were promising, with high levels of marine growth being removed quickly. However, there are some problems with the technology being heavy and hard for a diver to operate. There is also a tool that "walks" down the riser and scrape the surface with rotating brushes. The problem is this tool was prone to get stuck and require retrieval.

7.5 TECHNIQUES FOR MARINE GROWTH MITIGATION

Another mechanical technique used to mitigate marine growth is to create a slick surface that the marine growth can not adhere to. Copper coatings when used, kill the marine growth, but due to new environmental laws these coatings are being outlawed. There is currently ongoing research into the slick coatings and their effectiveness. These coatings have been used on large transportation vessels as well as risers and strakes. The results show that if soft marine growth forms on risers and strakes, it may be washed off in as little as a high current situation. This is only true for some regions, since the levels of marine growth are not constant in the GoM.

The industry has also begun incorporating integrity management (IM) strategies for their subsea infrastructure. The advantage of the IM procedures, with respect to marine growth, is that more monitoring of the riser systems and more/scheduled inspections are being performed by the operators. This will lead to more operational awareness of marine growth and its effects. Because of increased inspections, hopefully excessive marine growth will not be allowed to accumulate and significantly affect riser system performance.

8 REFERENCES

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3. DnV Classification Notes, "Fatigue Strength Analysis for Mobile Offshore Units", Note No. 30.2, August 1984;

4. MSL Services Corporation, Rationalization and Optimization of Underwater Inspection Planning Consistent with API RP2A Section 14, Doc. No CH104R006 Rev 0, November 2000

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APPENDIX A

MCS Marine Growth Survey

Revision 1

APPENDIX A MCS MARINE GROWTH SURVEY REVISION 1

1. How many facilities do you currently operate in the Gulf of Mexico that have been subject to marine growth inspection?

Facility Number

1. What is the Installation Date the facility

MM DD YYYY

Installation Date / /

2. What is the location of the facility in the Gulf of Mexico (Area, Block)?

3. What is the operational water depth of the facility

4. Was the API RP 2RD Marine Growth Profile used for design of the pipeline riser?

- Yes
- No

If "No" What Profile was used (depth, thickness)

5. What is the frequency of Level I inspections of the pipeline risers?

- Only After Storms
- 1 Inspection/year
- 2 Inspections/year
- 3 Inspections/year
- 4 Inspections/year
- Greater than 4 Inspections/year

6. During the latest Level I Inspection what was the Marine Growth Profile?

Date of Inspection (Month/Year)

Marine Growth Profile (Water Depth, Thickness)

Measurment Technique

Description of Marine Growth

7. What is the frequency of Level II inspections of the pipeline risers?

- Never
- 1 Inspection/year
- 2 Inspections/year
- 3 Inspections/year
- 4 Inspections/year
- Greater than 4 Inspections/year

8. How are the Level II Inspections performed?

	Method	depth (ft)
Diver		
ROV		

Other (please specify)

9. During the latest Level II Inspection what was the Marine Growth Profile?

Date of Inspection (Month/Year)

Marine Growth Profile (Water Depth, Thickness)

Measurment Technique

10. What is the frequency of Level III inspections of the pipeline risers?

- Never
- 1 Inspection/year
- 2 Inspections/year
- 3 Inspections/year
- 4 Inspections/year
- Greater than 4 Inspections/year

11. How are the Level III Inspections performed?

	Method	depth (ft)
Diver		
ROV		

Other (please specify)

12. During the latest Level III Inspection what was the Marine Growth Profile?

Date of Inspection (Month/Year)

Marine Growth Profile (Water Depth, Thickness)

Measurment Technique

13. During Inspections do you perform localized marine growth removal?

- Yes
- No

If "Yes" What Techinques are used

14. Is the Marine Growth ever completely removed from risers, tendons, mooring lines, or any other subsea structures?

◯ Yes

◯ No

If "Yes" How often is it removed, and by what method

15. Is all new equipment outfitted with anti-fouling coatings?

◯ Yes

◯ No

If "Yes" What anti-fouling method is being used?

16. What is the observed effectiveness of the anti-fouling methods?

	Poor	Mediocre	Average	Good	Excellent	N/A
Effectiveness	◯	◯	◯	◯	◯	◯

* **17. Do you have similiar information for other facilities?**

◯ Yes

◯ No

MCS would like to Thank You for your time in filling out this survey

1. Please Provide any additional comments or information

APPENDIX B

MCS Marine Growth Survey

Revision 2

APPENDIX B MCS MARINE GROWTH SURVEY REVISION 2

1. How many facilities do you currently operate in the Gulf of Mexico that have been subject to marine growth inspection?

Facility Number

1. What is the Installation Date of the facility?

MM DD YYYY

Installation Date / /

2. What is the location of the facility in the Gulf of Mexico (Area, Block)?

3. What is the water depth at the facility?

4. Was the API RP 2RD Marine Growth Profile used for design of the pipeline riser?

- Yes
- No

If "No" What Profile was used (depth, thickness)

5. How are subsea inspections of the riser system performed?

	Method	depth (ft)
Diver		
ROV		

Other (please specify)

6. During the latest subsea inspection what was the Marine Growth Profile?

Date of Inspection (Month/Year)

Marine Growth Profile (Water Depth, Thickness)

Measurment Technique

7. During Subsea Inspections are localized areas marine growth removed?

- Yes
- No

If "Yes" What Techinques are used

8. Is new riser equipment installed with anti-fouling coatings?

- Yes
- No

If "Yes" What anti-fouling method is being used?

9. What is the observed effectiveness of the anti-fouling methods?

	Poor	Mediocre	Average	Good	Excellent	N/A
Effectiveness	○	○	○	○	○	○

MCS would like to Thank You for your time in filling out this survey

1. Please Provide any additional comments or information