ANNEX VI
Structures Research Projects

CONTENTS

VI.1 SUMMARY OF PROJECTS

This section of the report provides a summary of some significant recent research initiatives and challenges particular to the offshore production platforms and structures, namely:

- Explosive Removal of Offshore Structures (EROS) (safe removal of fixed offshore platforms);
- Assessment of Offshore Platforms in Hurricanes (review of structural design codes, data collected on platforms, and design recommendations against the hurricanes);
- Wave Action Modeling on Offshore Structures (simulation and testing of sloshing and green water effect, which ultimately leads to safe and better design of offshore structures).

VI.1.1 EXPLOSIVE REMOVAL OF PLATFORM STRUCTURES (EROS)

Efficient and environmental friendly removal of fixed offshore structures is important to the overall subsea infrastructure growth. As such, MMS TA&R Program has funded research into the technological development and field testing of engineered charges for the explosive removal of fixed offshore platforms, as represented by TA&R Projects No. 429 and 570 below. Detailed summaries of these projects are provided in a later section of this Annex.

Figure VI.1: Removal of a Fixed Structure after Explosive Severing onto the Pile

VI.1.1.1 Project No. 429 – Oil Platform Removal Using Engineered Charges: In-Situ Comparison of Engineered and Bulk Explosive Charges

SNC TEC Corporation team was awarded a contract in the fall of 2001 to develop an explosive charge system that would require less explosive to sever offshore structures through the use of an engineered charge and to obtain data to evaluate its impact on marine life. The aim for the engineered explosive charge total system weight was to be below 10 pounds and, if possible, below 5 pounds. The project team was led by SNC TEC. The team was comprised of Explosive Service International (ESI), Defense Research and Development Canada Suffield (DRDC Suffield) and Sonalysts. The team members were involved in different tasks related to charge development and its set-up on the ESI developed Scorpion delivery system as well as the different aspects of testing, including blast measurements during final tests in the Gulf of Mexico.

VI.1.1.2 Project No. 570 – Measurement of the Effect of Depth below Mudline of Charge Placement during EROS

In 2001, SNC TEC of Le Gardeur, Quebéc was originally contracted under MMS's Technology Assessment and Research (TA&R) Project No. 429 (Contract No. 1435-01-01-CT-31136) to develop an engineered charge of less than 5 lbs net explosive weight (NEW) that would be capable of severing piles typically severed with 50 lbs bulk charges. The project was later modified to allow for in-situ measurement and the comparison of the pressure wave and acoustic energy released from the detonated engineered and bulk charges. SNC's study was a success and the data suggested that use of an engineered charge of < 5 lbs NEW can reduce the impact zone to Marine Protected Species (MPS) by as much as 50% over the standard 50 lbs charges. However, the amount of data generated on this contract was quite limited, and it was evident after the conclusion of this effort that similar studies should be performed to generate more in-situ data.

To this end, Explosive Services International (ESI) was awarded a contract (1435-01-06-CT-39658) under TA&R Project No. 570 in March 2006 to perform similar testing and measurement of in-situ explosive detonation effects. The Scope of Work (SOW) for this new project had as a primary goal the generation of in-situ data, but in a much larger volume than TA&R Project No. 429 (at least 16 shots). However, instead of making all cuts at 15 ft below mudline (BML), as was done on the SNC TEC contract, TA&R Project No. 570 would evaluate the effect of placing charges at 15-ft, 20-ft, 25-ft, and 30-ft BML;

gathering blast effect data to compare the difference that depth would make in peak pressure, impulse, and acoustic energy.

VI.1.2 INTEGRITY MANAGEMENT OF OFFSHORE STRUCTURES

The research projects outline detailed modeling, simulation and experimental verification of complex, nonlinear wave behaviors on offshore structures, as well as the integrity management strategies. The repair materials and procedures for the offshore platforms with respect to integrity assessment are also discussed. The potential application of the research projects in this category is in the safe design, maintenance, and monitoring of offshore structures. Detailed summary of the research projects are provided in a later section of this Annex.

VI.1.2.1 Project No. 441 – Mitigating Green Water Damage through Design

Green water damage to floating structures occurs when high pressure and loads from wave crests engulf structures far above the waterline in areas that are not designed to withstand such pressures.

The study was carried out to develop a numerical model for predicting greenwater velocities and provide design guidance to avoid or minimize greenwater damage. A fixed but simplified 2D rectangular structure based on the dimensions of a typical TLP was tested in a laboratory 2D wave tank using extreme waves breaking and impinging on the structure with green water. A new non-intrusive image based technique called bubble image velocimetry (BIV) was also developed and used to measure the velocity of the multiphase flow. An equation for predicting green water profile based on measured velocity field was then developed.

Figure VI.2: Green water incident at the side of Selkirk Settler

VI.1.2.2 Project No. 482 – Spar Vortex Induced Motions

Spar Vortex-Induced Motions (VIM) responses under current flow is an important consideration for the design of the mooring and riser system. The offshore energy industry has not had the opportunity to share and review the collective data/knowledge on spar VIM in order to establish a common understanding of the problem and an industry consensus on how to deal with Spar VIM during design.

Based on these considerations and funding from the US Mineral Management Service, OTRC organized and hosted an industry workshop including Technical Steering Group representing major industry stakeholders to establish a shared vision for an effective path forward on Spar VIM.

VI.1.2.3 Project No. 488 – Global Analysis of FPSO and Shuttle Tanker during Offloading

The growing need for energy, met in part by an increase in oil and gas production has driven exploration into deeper water depths. Some of the field development solutions that were unattractive or un-economical are beginning to receive attention. One such field development with multiple floating platforms is an FPSO and a shuttle tanker. The response of each structure in the system can be influenced by interactions with the other structure(s) and the relative motion between the structures during operation needs to be considered during design. This study was carried out to analyze the motions and interactions of an FPSO (or LNG Carrier) and a shuttle tanker during both side-by-side and tandem offloading scenarios.

Nowadays, the offshore energy industry analyze the relative motions between two vessels connected by lines using two approximated methods: (i) NHI: iteration method between two vessels without considering hydrodynamic interaction between the two vessels (ii) SMM: iteration method between two vessels with partial consideration of the hydrodynamic interaction (ignoring the off-diagonal cross-coupling terms in 12 x12 hydrodynamic coefficient matrix).

In this study the hydrodynamic interaction and mechanical coupling of two floating platforms connected by elastic lines were investigated using a time-domain, multi-hull/mooring/riser coupled dynamic analysis program.

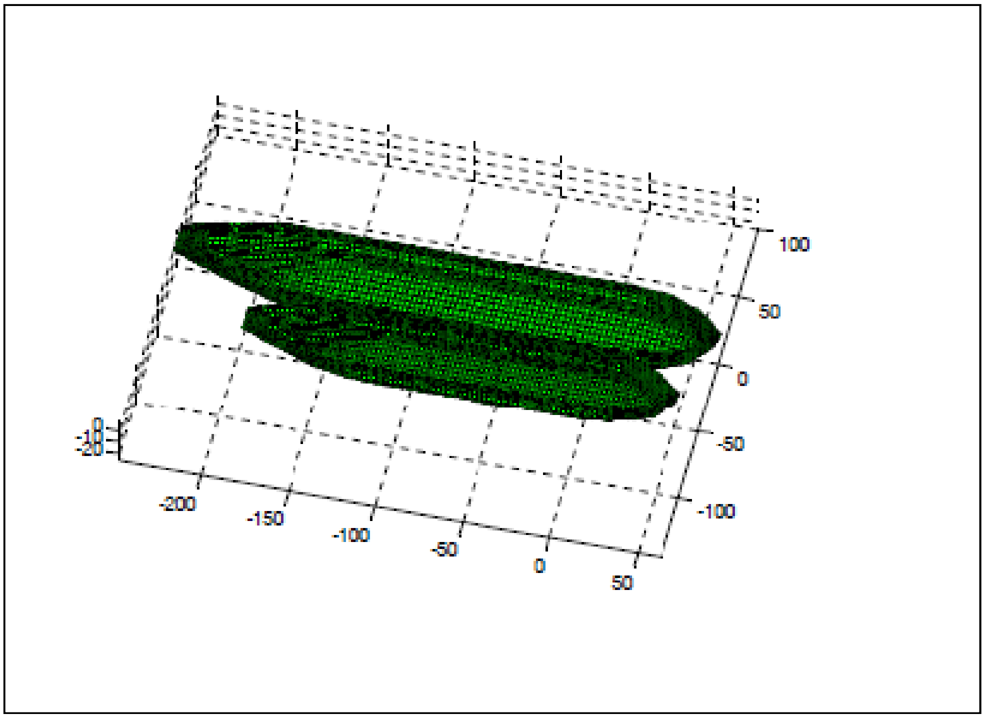


Figure VI.3: Mesh Generation of Side-by-Side Moored FPSO and Shuttle Tanker

VI.1.2.4 Project No. 502 – Assessment of New Repair Techniques for Ageing or Damaged Structures

Strengthening Modification and Repair (SMR) operations tend to be highly engineered for moderate and major works to minimize the high costs associated with offshore works. The continuing requirement for conducting Strengthening, Modification and Repair (SMR) of existing installations is an important and integral part of offshore engineering practice. The reappraisal of existing installations or the presence of damage may lead to a requirement for more strengthening or repair.

This study was funded by the Minerals Management Service (MMS) to develop guidance to offshore asset owners, practicing engineers charged with installation's integrity management, approval/certifying agencies and regulatory authorities.

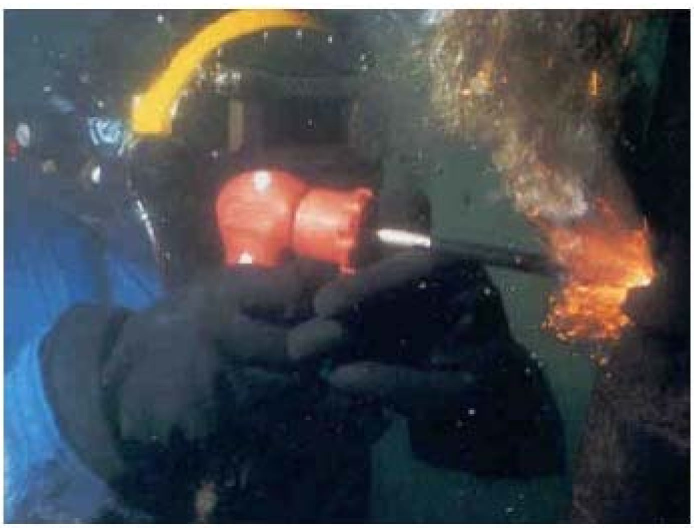


Figure VI.4: Example of wet welding repair

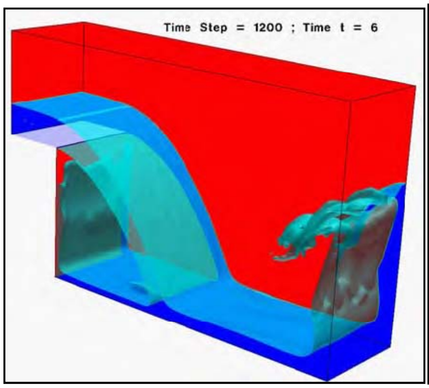
VI.1.2.5 Project No. 543 – Recommended Practice for the Structural Integrity Management of Fixed Offshore Platforms

When compared with earlier designs, platforms installed since the late 1970's provide a much more uniform design basis and have incorporated many of the lessons learned during the design, installation and operation of earlier generation platforms. As structures age, the original safety margin may be altered due to damage, deterioration or changes in used from the intended design.

This recommended practice was written to provide guidance to owners, operators and engineers on the implementation and delivery of a process to manage the structural integrity of fixed offshore platforms.

VI.1.2.6 Project No.571- Loads Due to Extreme Wave Crests

This research project was undertaken to understand, experiment and simulate numerically the mechanics of sloshing flow (in a Liquefied Natural Gas tank) and green water waves and extreme waves over an offshore structure, whose mechanics so far are not well understood. This research is applied to an offshore platform, in a model testing.



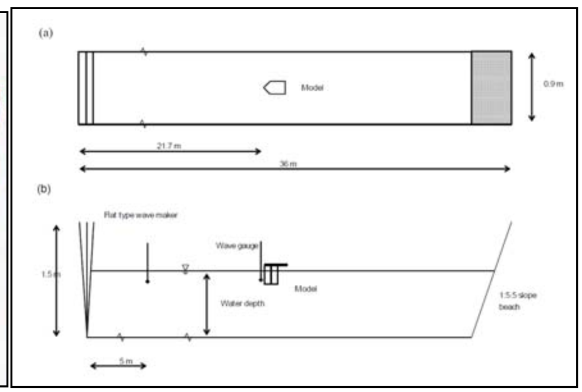


Figure (a) Figure (b)

Figure VI.5: (a) Simulation of Green Water Effect (b) Experimental Setup for Wave Tank

VI.1.2.7 Project No. 609 – Reliability vs. Consequence of Failure for API RP 2A Platforms Using API Bulletin 2INT-MET

In the past fifteen year, there have been several large hurricanes that have damaged or destroyed fixed platforms and caissons. The American Petroleum Institute (API) in May of 2007 issued Bulletin 2INT-MET (2MET) - Interim Guidance on Hurricane Conditions in the Gulf of Mexico. The new guidance which divided the Gulf of Mexico (GOM) into East, Central, West Central and West regions showed some increase in metocean conditions for some of these regions. This study was carried out to determine the reliability of typical Gulf of Mexico fixed platforms designed using the API RP 2A vs. the new 2MET guideline. The two reliability methods used for the study were: The Generic Method – which uses the Reserve Strength Ratio (RSR) of a platform along with wave height to determine probability of failure (pf) in a hurricane and the Detailed Method, which includes the effect of deck elevation, a critical factor for determining platform survival during extreme waves if the wave crest impacts the deck.

Figure VI.6: Wave-in Deck (WID) Damage to GOM platforms from Hurricane Ike 2008

VI.2 EXPLOSIVE REMOVAL OF OFFSHORE STRUCTURES

VI.2.1 PROJECT NO. 429 – OIL PLATFORM REMOVAL USING ENGINEERED CHARGES: IN-SITU COMPARISON OF ENGINEERED AND BULK EXPLOSIVE CHARGES

VI.2.1.1 Introduction

VI.2.1.1.1 Background

Part of the mission of the Minerals Management Service (MMS) of the US Department of the Interior (DOI) is to "manage the mineral resources of the Outer Continental Shelf in an environmentally sound and safe manner". This includes the oil platform decommissioning practices in the Gulf of Mexico. While different methods can be used for this task, Explosive Removal of Offshore Structures (EROS) present some cost advantages on shallow water removals. However, a number of alternative removal technologies exist and are used regularly. EROS is also frequently used in deep water where there are significant risks to divers while inspecting the results of removal operations. The current maximum explosive weight authorized by MMS for explosive structure removal is 50 pounds, which is also the upper limit of charge covered by a generic Endangered Species Act (ESA) consultation. A limit value of 5 pounds was determined to be at a "de minimus" level set by another ESA consultation. The blast characteristics of explosive charges and their impact on wildlife have not been completely assessed. Data on current weight limits have been obtained through modeling and extrapolation, hence the MMS expressed a need to obtain data from actual tests, which could later be used to confirm and validate the weight characteristics.

SNC TEC Corporation team was awarded a contract in the fall of 2001 to develop an explosive charge system that would require less explosive to sever offshore structures through the use of an engineered charge and to obtain data to evaluate its impact on marine life. The aim for the engineered explosive charge total system weight was to be below 10 pounds and, if possible, below 5 pounds. The project team was led by SNC TEC. The team was comprised of Explosive Service International (ESI), Defense Research and Development Canada Suffield (DRDC Suffield) and Sonalysts. The team members were involved in different tasks related to charge development and its set-up on the ESI developed Scorpion delivery system as well as the different aspects of testing, including blast measurements during final tests in the Gulf of Mexico.

VI.2.1.1.2 Technical Scope

This research project describes the design and development, along with deployment and testing on test ranges and actual Gulf of Mexico locations, of engineered charges which were intended to be less than 10 pounds. The linear –shaped charges described in this research project are 4.05 pounds and 6.58 pounds, for severing 30-inch and 48-inch platform piles, respectively. The research project describes the efficiency of using engineered charges as compared to the bulk charges through the testing and modeling, for their more desirable effect with respect to the marine life.

VI.2.1.1.3 Study Limitations

The study has the following limitations:

- Marine life impact has not been quantified.
- Cost comparison of engineered and bulk charges is not developed.
- Engineered charges of only linear-shapes are investigated. Other charge shapes and deployment systems have not been considered.
- The method of removal is applicable only at the piles. The method is not applicable for deployment outside the pile, so that it could be employed to remove the structure from some intermediate position, resulting in relative ease of deployment.

VI.2.1.2 Project Conclusions

VI.2.1.2.1 Key Conclusions and Results

In summary, the conclusions were:

- The research project shows that the linear-shaped engineered charges with full water proof casing can achieve similar effectiveness as compared to the conventional bulk charges;
- With distance required to achieve the overpressure of 12 psi as half compared to the conventional bulk charges, the engineered charges can be more environmental and marine-life friendly;

- The research project also broadens the design of the deployment system, Scorpion, and concludes from the study that more accurate deployment techniques with design modifications will be required in the actual field platform piles removal.

VI.2.1.2.2 OSER Goals

This project has led to the TA&R Project No. 570, "Effect of Depth below Mudline of Charge Placement during EROS".

VI.2.1.2.3 Recommendations

The following are the recommendations of this research project:

- The research project recommends to understand in more detail the relative ineffectiveness of Scorpion deployed engineered charge on 30-inch pile in Gulf of Mexico, where it severed only about 1/3 of the circumference of the pile;
- Improve the design of Scorpion or any other deployment method for effectiveness of the charge under shallow and deepwater conditions.

VI.2.1.3 Current State of Knowledge

The research opens up the possibility of using explosives, specifically engineered charges, for the removal of offshore structures. Currently, the explosives used are conventional bulk charges, which are around 50 pounds (upper limit allowed). The marine life effect is susceptible, and with the new explosive design and development technologies, it is possible to achieve efficiency and cost effectiveness in the removal procedures.

VI.2.2 PROJECT NO. 570 – MEASUREMENT OF THE EFFECT OF DEPTH BELOW MUDLINE OF CHARGE PLACEMENT DURING EROS

VI.2.2.1 Introduction

VI.2.2.1.1 Background

Superstructure sea spray icing and atmospheric icing from various sources reduce the safety of offshore platforms and supply boat operations. These sources originate from snow, freezing rain, freezing drizzle, rime, sleet, and frost. Platforms operating in cold regions are protected primarily by designs that reduce ice accretion, coupled with the selective use of heat. A variety of deicing and anti-icing technologies had been tested on offshore platforms and boats, but with little overall success. This research puts forward the proposal to use new technologies and modern versions of old technologies, now used successfully in aviation, the electric power industry, and on transportation systems in general, on offshore platforms for performing the deicing. The presented technologies are the population from which new marine ice protection systems may be selected.

VI.2.2.1.2 Technical Scope

The research project delineates various classes of de-icing and anti-icing technologies and proposes investigation for their use on cold regions fixed offshore platforms. The research project identifies chemical and numerous other modern day technologies that had been used successfully in other industries, and proposes their use for offshore cold regions.

VI.2.2.1.3 Study Limitations

The key limitation is that the use of various presented technologies (total of fifteen) was not demonstrated to be applied on fixed marine offshore platforms. The idea of using de-icing techniques from other industries was strongly advocated, with each method having their own advantages and limitations. However, there still is a need to see the applicability if these methods in, say, an offshore drilling rig or platform to deice these structures, to change from hazard to an inconvenience.

VI.2.2.2 Project Conclusions

VI.2.2.2.1 Key Conclusions and Results

A number of transportation and aviation de-icing technologies were presented, with industrial contacts. In addition, advantages and limitations of each of the method were highlighted. The research study should provide an optimistic practical step towards usage of technology for de-icing the offshore fixed platforms.

In summary, the results were:

- Engineering information available from manufacturers, developers, vendors, patents, literature and experience was used to obtain an assessment of the capabilities of ice protection technologies that can be used in the marine environment. In addition, technology readiness level for each of the technology as can be applied to the marine environment was described.

- Ice protection technologies from other disciplines experiencing icing, especially from the highway, aviation, and electric power transmission industries, were summarized and matched to specific marine needs.

VI.2.2.2.2 OSER Goals

The project aligns with the second goal of OSER, in terms of assessment of fifteen classes of de-icing and ice removal technologies, to retain or restore the integrity of fixed marine platforms, in order to reduce the hazard and make the offshore operations more accessible in cold regions.

VI.2.2.2.3 Recommendations

Apply the recommended technologies to simulated or actual arctic structures and assess the results. In addition, perform more research on refining the technologies.

VI.2.2.3 Current State of Knowledge

The research outlined current emerging and renovated technologies for ice cooling in various industries, such as Chemicals, Coatings, and Electrical Techniques. No significant development was noted in these technologies since the study was conducted.

VI.3 INTEGRITY MANAGEMENT OF OFFSHORE PLATFORMS

VI.3.1 PROJECT NO. 441 – MITIGATING GREEN WATER DAMAGE THROUGH DESIGN

VI.3.1.1 Introduction

VI.3.1.1.1 Background

Extreme waves have in the past, caused significant damages to offshore structures due to the tremendous forces created by the wave impingement. A number of offshore structures were damaged by major hurricanes in the Gulf of Mexico between 2004 and 2005. These hurricanes usually result in large waves that result in greenwater occurring on decks of some structure causing damage that range from equipment on the deck being moved or damaged to the loss of older platforms designed to lower criteria.

Green water problem has been investigated experimentally and numerically in the past. Attempts have also been made to correlate greenwater with a dam break flow. In a typical design procedure for green water load, the standard approach to estimate the velocity of a green water incident is to use the dam break solution. More advanced approaches based on Reynolds averaged Navier-Stokes equations (RANS) or large eddy simulations (LES) that feature turbulent model have provided more physical insight into the problem.

Very few experimental approaches to the problem have been non-intrusive quantitative measurements of breaking waves impinging on structures. The PIV technique has been successfully used to measure bubble velocity by correlating bubbles or tracking each bubble in the recorded image that were taken.

The study was carried out to develop a model for predicting greenwater velocities so as to provide design guidance to avoid or minimize greenwater damage. A fixed and simplified 2D rectangular structure based on the dimensions of a typical TLP was tested in a laboratory 2D wave tank using extreme waves breaking and impinging on the structure with green water. A new non-intrusive image based technique called bubble image velocimetry (BIV) was developed and to measure the velocity of the multiphase flow. An equation for predicting green water profile based on the measured velocity field was then developed.

VI.3.1.1.2 Technical Scope

The study was carried out under following work scope:

- Literature review of green water incidents and studies
- Experimental study of the subject matter
- Formulation of numerical models and,
- Validation of numerical models

VI.3.1.1.3 Study Limitations

The following are some of the identified study limitations:

- 3D effects were not covered in the current study.
- Numerical model from the test has not were not validated with any laboratory or field experiments

VI.3.1.2 Project Conclusions

VI.3.1.2.1 Key Conclusions and Results

In summary, the key conclusions and results from the research project are as follows:

- A numerical model for predicting the horizontal velocity distribution of green water along the deck and was formulated.
- The formulated equation is valid throughout the entire period when the front of the green water is on deck and after the front falls back into the sea.
- If the initial water depth is carefully selected, the widely used dam breaking solution works reasonably well. Although it fails to predict the shape of the velocity distributions of the green water flow.
- The maximum horizontal velocity reached is 1.5C, with C being the wave phase speed before overturning jet of the breaking wave impinging on the structure.
- The front velocity of green water on the deck was approximately constant and equal to 1.1C to 1.2C along the deck.
- The turbulence level of green water was between 40% and 50% of the maximum velocity at the particular given moment during the entire period when the front of green water was on the deck.

- The maximum velocity of the upward moving splashing water right after impinging of the breaking wave occurs at the front of the structure and reached a maximum value of 2.8C.
- The numerical model was compared with other models and was found to be flexible and accurate.

VI.3.1.2.2 OSER Goals

The study was carried out to develop a model for predicting greenwater velocities so as to provide design guidance to avoid or minimize greenwater damage to offshore structures. This is in line with the OSER goal of evaluating technological challenges associated with the entire life cycle of offshore energy operations.

VI.3.1.2.3 Recommendations

The authors recommended:

- Laboratory experiments using 3D models to investigate the 3D effects of the green water process.
- Validation of the 2D numerical model with laboratory measurements.
- Extension of the present numerical model to 3D and validation with laboratory measurements.

VI.3.1.3 Current State of Knowledge

Another TA&R Project (No. 571, presented in this report) researched the advanced modeling and model testing of green water and wave sloshing effects on offshore structures.

VI.3.2 PROJECT NO. 482 – SPAR VORTEX-INDUCED MOTIONS

VI.3.2.1 Introduction

VI.3.2.1.1 Background

On top of the eight Spar-based floating production systems that have been installed in the Gulf of Mexico since 1996, another five Spar based production systems are slated for installation in the next two years. In the past decade, many operators and engineering firms have made substantial investment in technology related to spar VIM, whether it be sophisticated model tests, advanced computer models, or full scale performance data.

Usually, the information and knowledge from these technology development efforts is proprietary and has understandably been kept confidential. It is clear that the industry needs widely accepted and consistent practices for addressing Spar VIM in order to ensure the integrity of existing and future Spar designs. Such practices must be based on verifiable data if they are to be credible and must allow for any perceived uncertainties.

It is these considerations and funding provided from the US Minerals Management Service (MMS) that the OTRC has organized and hosted an industry workshop on spar VIM to establish a shared vision for an effective path forward.

VI.3.2.1.2 Technical Scope

The first part of the workshop was devoted to invited presentations organized so as to review:

- The regulatory perspective on current issues associated with spar VIM
- The state-of-the art of fundamental understanding of the mechanics of vortex-induced-vibrations as applicable to spar platforms.
- Current design and model test practices among the organizations engaged in the design of spars and
- Field and model test data and experiences for existing or planned Gulf of Mexico spars, as relevant to validation of modeling and design practices
- The second part of the workshop was devoted to structured discussion among the workshop participants in order to:
- Identify and prioritize technical uncertainties and gaps on the basis of design impact and,
- Recommend new initiatives to resolve the identified gaps and advance Spar VIM design practice.

VI.3.2.1.3 Study Limitations

- The following are the identified uncertainties and technology gaps in Spar VIM:
- The existing metocean data base on Loop eddy currents cover only the past 25 years at best.

- Fully dynamic numerical models are not ready for use in developing loop eddy current criteria through hind casting or providing insight on the iteration of hurricanes and loop current eddies
- Model tests are used to develop prototype VIM design criteria, however the inability to preserve Reynolds number similitude between full and models scales results in distortion of the boundary layer flow around the spar at model scale, which introduces fundamental uncertainties in the design and interpretation of Spar VIM model tests.
- Procedures for quantifying damping at full and model scale or for controlling damping at model scale are not well established. Other important effects that need to be considered include the shear in the current profile, and non linear, asymmetric stiffness effects due to the mooring and risers.

VI.3.2.2 Project Conclusions

VI.3.2.2.1 Key Conclusions and Results

The Spar VIM Workshop was successful in achieving its objectives of establishing a shared vision for an effective path forward on Spar VIM.

In summary, the results are:

- There is a need for oceanographers and designers to work more closely together in understanding the uncertainties associated with: (1) metocean data and criteria (2) modeling and prediction of Spar VIM.
- There is a need for better understanding of the uncertainties associated with existing model testing and data interpretation practice and to validate these practices using benchmark field data.
- There is a need for broader access to existing benchmark field and model test data and to ongoing field monitoring programs in order to share costs and leverage future opportunities for advancing the state-of-the art;
- There is a need for test data on high stress/low cycle fatigue behavior of mooring chains and industry consensus design criteria for strength design of mooring and risers under repeated high stress fatigue loading associated with Spar VIM.

VI.3.2.2.2 OSER Goals

The workshop was conducted to establish a shared vision for an effective path forward on Spar design for VIM. This inline with the OSER goal of evaluating the technological challenges associated with the entire life cycle of offshore energy operation.

VI.3.2.2.3 Recommendations

The following were recommended from the workshop:

- A need for oceanographers and designers to work more closely together in understanding the uncertainties associated with metocean and Spar modeling for VIM
- More study into understanding the uncertainties associated with existing model testing and data interpretation practices.
- A broader access to existing benchmark field and model test data and to on-going filed monitoring programs.
- Further study to generate test data on high stress/low cycle fatigue behavior of mooring chain

An industry consensus design criteria for strength design of mooring and risers under repeated high stress fatigue loading associated with spar VIM.

VI.3.2.3 Current State of Knowledge

The oceanographic community has a couple of long term JIP in place (CASE, EJIP) that in combination with results from the workshop will be better focused to address the identified technology gaps.

Most spars deployed in the Gulf of Mexico are equipped with metocean and structural monitoring system; the primary need is for sharing mechanism that allows broader access to the field data for those engaged in spar design.

A broader access to existing benchmark models test data is of substantial interest as it would enable independent interpretation of test results and serve as a basis for leveraging follow-on-studies to advance the state-of –the art in spar model testing, data interpretation and design analysis procedures.

VI.3.3 PROJECT NO. 488 – GLOBAL ANALYSIS OF FPSO AND SHUTTLE TANKER DURING OFFLOADING

VI.3.3.1 Introduction

VI.3.3.1.1 Background

Studies to investigate hydrodynamic interactions between multiple bodies have been carried out in the past. An example of such study is the 'Analysis of Hydrodynamic Interactions using 2-D like Strip Theory' by Ohkushu, Kodan, and Fang and Kim carried out in 1974, 1984 and 1986 respectively.

As demand for oil and gas increases, field development with multiple floating platforms which was considered very challenging in the past has become more attractive. An example is an FPSO (Floating Production Storage and Offloading Unit) offloading operation to shuttle tankers. An FPSO production system that offloads oil to shuttle tankers can be much cheaper than installing new underwater pipelines in a remote deepwater oil and gas field. For an LNG offloading carrier offloading into an LNG terminal, great care needs to be taken since the flow lines have to overcome extremely low temperature, and the arrangement gap distance is restricted by the arm-length of LNG off-loading lines. As a result of this, the study of hydrodynamic interaction effects between the two large-volume floating bodies in close proximity is an important element of the development, operation and downtime analysis of floating-LNG terminal system.

In this study the hydrodynamic interaction and mechanical coupling of two floating platforms connected by elastic lines were investigated using a time-domain, multi-hull/mooring/riser coupled dynamic analysis program.

VI.3.3.1.2 Technical Scope

The technical scope of the research project is as follows:

- Literature review of hydrodynamic interactions between multiple bodies
- Formulation of a numerical hydrodynamic model based on complex matrix method (CMM)
- Compare the results from the Coupled Matrix Model (CMM) model predictions with the results from other industry models (i.e. Separated Matrix Method (SMM)) and No Hydrodynamic Interaction Method (NHI).

- Verification of the developed numerical model with large-scale experiments.

VI.3.3.1.3 Study Limitations

The key limitations of the study are as follows:

- The effects of tangential drag on the mooring lines and coulomb friction from seabed were not considered in the study.
- Only the collinear wind-wave-current environmental conditions from the head direction were considered.
- The 'Newman's approximations used for calculating the effect of slowly varying wave forces may not be very reliable in the case of shallow water. The approximation is valid when the natural frequencies of slowly-varying motions are small.
- Wave drift damping is expected to be small compared to the other drag component and was not included in the study.

VI.3.3.2 Project Conclusions

VI.3.3.2.1 Key Conclusions and Results

In summary, the results are:

- An exact time-domain simulation method including the entire 12x12 hydro-dynamic coefficient in a hull-line combined matrix was developed and called CMM.
- For side-by-side loading, vessel interaction is more important and the full hydrodynamic coupling between the vessels, i.e. the CMM should be used. The simpler approximations, SMM and NHI can introduce appreciable errors and should be used with care.
- Separated Matrix Method (SMM) can introduce appreciable errors can introduce appreciable errors and should be used with care.
- In the case of tandem offloading, the difference between full coupling and the approximate methods are small.

VI.3.3.2.2 OSER Goals

The use of multiple floating structures is being considered for a variety of offshore oil and gas project. An FPSO production system that offloads oil to shuttle tankers can be much cheaper than installing new underwater pipelines in a remote deepwater oil and gas field.

The study was carried out to formulate a numerical model that predicts the hydrodynamic interaction of two floating large-volume in close proximity. This is in-line with the OSER goals of independent verification of emerging technologies (e.g. new materials and practices) in terms of reliability, operational safety and environmental protection.

VI.3.3.2.3 Recommendations

The authors recommended:

- Further study into hydrodynamic interaction in the non parallel or beam sea condition. The study was carried out based on potential theory which produces reasonable motion results except roll.

VI.3.3.3 Current State of Knowledge

Petrobras Cascade and Chinook, currently under installation in the US Gulf of Mexico is the first Floating Production Storage and Offloading (FPSO) unit to be installed in the Gulf of Mexico. The technology has been applied successfully in other parts of the world especially West of Africa and Brazil. This field development, when it goes into operation will represent first field application of the discussed technology in the US Gulf of Mexico.

VI.3.4 PROJECT NO. 502 – ASSESSMENT OF REPAIR TECHNIQUES FOR AGEING OR DAMAGED STRUCTURES

VI.3.4.1 Introduction

VI.3.4.1.1 Background

The need for platform Strengthening, Modification and Repair (SMR) is expected to increase due to platform ageing, refurbishment or field development. The continuing requirement for conducting strengthening, modification and repair of existing installations is an important and integral part of offshore engineering practice. Reappraisal of existing installation or the presence of damage may lead to a requirement for strengthening and/or repair, either at a local component level or at a global system level.

In August 2003, the Minerals Management Service (MMS) issued a Notice to Leases (NTL) requiring owners of all Gulf of Mexico OCS region offshore platforms that have been in service for more than 5 years to carry out Structural Integrity assessment (Section 17

Assessment of API-RP-2A). This is expected to result in some level of SMR for the continued safe operation of these platforms.

SMR operations tend to be highly engineered especially for moderate and major works. However in many situations, inappropriate, unnecessary or expensive SMR schemes have been deployed, primarily as a result of lack of readily available guidance, lack of understanding on the part of the designer of the advantages/disadvantages of the various SMR techniques that are available and insufficient effort during the assessment/analysis phase to work the perceived problem.

Based on the above reasons, the MMS commissioned MSL Engineering to undertake an assessment study of new and/or improved repair technique for ageing or damaged structures, including the use of ROVs in repair operations.

VI.3.4.1.2 Technical Scope

The study was carried out under the following work scope:

- Literature review, interviews and discussions with operators, design houses, research establishments and regulatory authorities to gather data and information on the use of different repair techniques for offshore components and systems.
- Undertake a review of present state-of-the art and state-of-practice for repair methods.
- Develop guidelines in this field, including the implementation of repair solutions using ROVs

VI.3.4.1.3 Study Limitations

The following are some of the limitations associated with the discussed SMR techniques:

- The quality of weld formed by wet welding is not as good as those formed by dry welding techniques.
- Stressed mechanical clamps require an extremely accurate survey of the contact zone and tight tolerances for the fabrication of the clamp.
- Formation of small voids close to tubular joints can limit the benefits from grouting and the added mass from grouting will need to be considered in seismically active regions.
- Toe grinding may not be possible in certain situations and shot peening is unsuitable for underwater application.

- Composites may be prone to impact damage if used in exposed situations.

VI.3.4.2 Project Conclusions

VI.3.4.2.1 Key Conclusions and Results

In summary, the results are:

- With the possible exception of carbon fiber and glass fiber reinforced composites review of literature written in the last decade did not identify any fundamentally new SMR technique. The most notable new SMR technique is the Fiber Reinforced Plastic (FRP) composites.
- Improvement to existing SMR techniques includes, the use of ultrasonic in peening, improvement in consumables for underwater welding, air cavity for under water wet welding, and the development of epoxy-based/cementitious grouts for structural member strengthening.
- The three approaches to effecting diverless repair includes remotely controlled deployment frame launched from the surface, ROV or robotic systems and use of manned submersible units.
- The quality of the input data has a significant bearing on the success of structural integrity assessment.
- For hyperbaric welding, the welding process has to be specially optimized for the welding environment, thus limiting the number of techniques that can be used to SMAW, GTAW, FCAW and GMAW.
- Except for friction welding, the quality of wet welds is adversely affected by poor visibility, high cooling rate and the dissociation of water within the weld.
- The main clamping techniques discussed include, stressed mechanical clamps, unstressed grouted clamps/sleeve connections, stressed grouted clamps and stressed elastomeric-lined clamps. For stressed clamps the capacity of the clamped member has to be sufficient to resist any crushing loads from the studbolts.
- Grout filling of tubular members and joints increases strength and provides resistance against buckling. Structural members can also be filled with grouts to provide strength against loads from the from the clamp studbolt loads.
- The weld improvement techniques include Toe grinding, Hammer, shot, needle and ultrasonic peeing, dressing, pre-straining and PWHT.
- Weld improvement techniques maybe ineffective where inaccessible root defects remain.

VI.3.4.2.2 OSER Goals

The need for platform strengthening, repair and modification (SMR) is expected to increase due to ageing platforms. SMR is an important aspect of offshore engineering that promotes continued safe operation of offshore installations. This is inline with the OSER goal of assessing, retaining or restoring the integrity of ageing offshore assets.

VI.3.4.2.3 Recommendations

- No recommendations into further study or qualification were made by the author.

VI.3.4.3 Current State of Knowledge

Growth in computing power has led to a commensurate increase in software sophistication and structural modeling techniques. Non-linear analyses including both geometric and material non-linearity can now be factored successfully at the design phase and during structural integrity assessments.

In recent times system strength is now more commonly obtained by a pushover analysis rather than the component strength. Fracture mechanics is increasingly used to assess the effects of cracks and other defects on the structural integrity of members and joints.

Provision for damage and ageing of offshore structures is now being made in standard industry practice such as API RP 2A. It is expected that the future trend of drafting bodies will be to place more emphasis on the behavior of structures beyond the first yield, and to give more guidance on the residual strength of damaged components.

VI.3.5 PROJECT NO. 543 – STRUCTURAL INTEGRITY MANAGEMENT OF FIXED OFFSHORE PLATFORMS

VI.3.5.1 Introduction

VI.3.5.1.1 Background

Progressive evolution of platform design from when the first platforms were installed in the 1940's has resulted in a varied assortment of structures in the worldwide platform fleet. Platforms built prior to the late 1970's have diverse design criteria and fabrication techniques. Platforms installed since the late 1970's provide a much more uniform design basis and have incorporated many of the lessons learned from the design, installation and operation of earlier generation platforms.

The key objectives for design and operation of offshore platforms are preservation of life safety, environmental protection and economics. Due to maturity in the industry, the implicit level of risks associated with each of the areas has changed. Structures age over time and the original safety margins during design may have been altered due to damage, deterioration or changes in use from the intended design.

The recommended practice was written to provide guidance to Owners and Engineers on the implementation and delivery of a process to manage the structural integrity of fixed offshore platforms.

VI.3.5.1.2 Technical Scope

The study was carried out to provide guidance to those concerned with the Structural Integrity Management of fixed offshore structures used for drilling, development and storage of hydrocarbon in offshore areas. The following are the scopes covered under the study:

- Evaluation of structural damage
- Structural inspection
- Assessment and mitigation planning of fixed offshore platforms

VI.3.5.1.3 Study Limitations

- The recommended practice was developed specifically for platforms in the United States although the process as defined in the report is applicable at any worldwide location.
- Assessment of platforms designed in accordance with the provisions of the API RP2A 20th Edition and later is to be performed using environmental criteria originally used for the design of the structure unless a site specific study can justify alternative criteria or the consequence of failure.
- For damage evaluation, the derivation of the strength equation did not take into account the effects of external hydrostatic pressure and the presence of crack in a structure.

VI.3.5.2 Project Conclusions

VI.3.5.2.1 Key Conclusions and Results

In summary, the results are:

- To facilitate periodic "evaluation" and related update of the "inspection strategy", it is necessary that the owner / operator retain detailed records for the life of platform. It should also be ensured that during change of ownership that all platform data are transferred effectively.
- The recommended practice provides guidance for the consideration of life-safety and other consequence of platform failure. Life safety consequence considers the maximum anticipated metocean or other design event that would be expected to occur while personnel are on the platform. Other consequences of platform failure may include environmental impact, business disruption, public perception, impact to other operator and market supply disruption.
- A platform should undergo assessment process if one or more of the assessment initiators are triggered. Assessment initiators include addition of personnel, addition of Facilities, increased loading on Structure, inadequate deck height, and significant damage.
- Two contrasting periodic in-service inspection strategies can be used as part of the overall SIM Strategy. The first is a significant commitment to ongoing inspection with the goal of reducing the possibility of major repairs in the future and the second is the minimization of in-service inspection scope by assuming that adequate measures have been taken to reduce risk of damage that would require major repair in the future.
- The Structural Integrity Management (SIM) process is applicable to all components of the platform needed to operate the platform.
- In the event of platform damage, a damage evaluation is to be carried out to determine whether damage is potentially significant to the integrity and hence whether an engineering assessment is required.
- The methods used for platform structural assessment are the simple methods, design level method and the ultimate strength method.

VI.3.5.2.2 OSER Goals

The recommended practice was written to provide guidance to those concerned with the Structural Integrity Management of fixed offshore structures used for drilling, development and storage of hydrocarbon in offshore areas. This is in-line with the OSER goals of investigating techniques to best assess, retain or restore the integrity of ageing offshore assets.

VI.3.5.2.3 Recommendations

The report as a whole contains guidelines and recommendations for the structural integrity management of fixed offshore structures.

VI.3.5.3 Current State of Knowledge

Growth in computing power has led to a commensurate increase in software sophistication and structural modeling techniques. Non-linear analyses including both geometric and material non-linearity can now be factored successfully at the design phase and during structural integrity assessments.

In recent times system strength is now more commonly obtained by a pushover analysis rather than the component strength. Fracture mechanics is increasingly used to assess the effects of cracks and other defects on the structural integrity of members and joints.

Provision for damage and ageing of offshore structures is now being made in standard industry practice such as API RP 2A. It is expected that the future trend of drafting bodies will be to place more emphasis on the behavior of structures beyond the first yield, and to give more guidance on the residual strength of damaged components.

VI.3.6 PROJECT NO. 571 – LOADS DUE TO EXTREME WAVE CRESTS

VI.3.6.1 Introduction

VI.3.6.1.1 Background

In approximately one year from September 2004 to September 2005, three Category 5 hurricanes (Ivan, Katrina, Rita) hit the Gulf of Mexico. Well over 80% of the 4,000 oil and gas production platforms in the Gulf were directly impacted by the hurricanes. The hurricanes destroyed or caused extensive damage to 190 platforms. In most cases the platform damage was caused by green water wave loading on the deck. Green water damage to floating structures results from high pressures and dynamic loads that occur when wave crests inundate the structure far above the waterline in areas not designed to withstand such pressures. In situations where one must consider the possibility of wave overtopping and green water rushing onto the deck, the mechanics of wave loading become very complex and are poorly understood. One of the major sources of uncertainty is the velocity field of the green water flow itself.

VI.3.6.1.2 Technical Scope

The objective of this research is to develop a robust procedure to estimate local and global green water loads on structures due to extreme wave crests. Through the combined efforts of laboratory measurements and numerical simulation, the results will allow designers to avoid or minimize the impact of green water on new floating structures through design, and help the industry and regulators to develop associated design guidance.

VI.3.6.1.1 Study Limitations

The project report does not describe any limitations of the research. The research meets its objectives for simulating the extremely complex wave mechanics of sloshing and green water effects. In that sense, the research does not have limitations within its scope of work.

VI.3.6.2 Project Conclusions

VI.3.6.2.1 Key Conclusions and Results

In summary, the results are:

- The study preformed laboratory measurements of void fraction and velocity for overtopping green water flow generated by breaking wave impingement.
- A numerical method that couples the interface-preserving level set method with chimera RANS (Reynolds Averaged Navier Stokes) was developed; this new method was then validated to some typical free surface flows.
- Simulations of green water over an offshore structure showed reasonably good agreement with experimental results on model scale tests of an offshore structure,

demonstrating that the Level-Set RANS method is a powerful and accurate CFD methodology for free surface flow simulations.

VI.3.6.2.2 OSER Goals

The impingement of a large breaking wave on an offshore structure is of great concern to the safety of the offshore structure. This project presented the modeling and experimental studies of the sloshing, breaking waves and green water effects on offshore platforms and structures. This is inline with the OSER program goals part of which is to best assess, retain or restore the integrity of offshore energy assets.

VI.3.6.2.3 Recommendations

There are no general or specific recommendations specified in the project report.

VI.3.6.3 Current State of Knowledge

This research project leverages the techniques of the advanced computational fluid dynamics to simulate the complex sloshing waves and green water effects on offshore structures.

VI.3.7 PROJECT NO. 609 – RELIABILITY VS. CONSEQUENCE OF FAILURE FOR API RP 2A FIXED PLATFORMS USING API BULLETIN 2INT-MET

VI.3.7.1 Introduction

VI.3.7.1.1 Background

Major hurricane activity (hurricanes Category 4 or worse) crossing the central and western portion of the Gulf of Mexico's (GOM) offshore Oil and Gas developed region may result in significant damage or destruction to offshore oil and gas facilities and pipeline. Since its first issue in 1969, API RP 2A has provided reliable guidelines for platform designs against extreme metocean conditions. In May of 2007 API issued Bulletin 2INT-MET (2MET) an Interim Guidance on Hurricane Conditions in the Gulf of Mexico.

In the bulletin, GOM was divided into four regions i.e. the East, Central, West Central and West regions. For some of the regions like the central region, metocean criteria were found to have increased from prior API RP 2A recommendations. Metocean conditions in 2MET varied by water depth and changes in wave height, wind current and storm were not always consistent. When compared with the former RP2A, in some instances it was not clear if the new metocean resulted in larger or smaller resultant load on fixed platforms. Two bulletins (i.e. 2INT-EX (2EX) and 2INT-DG (2DG)) that provide guidance on assessment of existing offshore structures for hurricane conditions and guidance on the design of offshore structures for hurricane conditions respectively were also released. In summary the bulletins have resulted in the following changes in metocean conditions:

- Division of GOM into regions – East, Central, West Central and West
- Changes to water depth – Shallow (<75 ft), Intermediate (200 ft) and deep (400 ft+)
- Changes to API Exposure Category – High (100 yr), Medium (50yr) and Low (25 yr)
- 100 yr wave crest elevation to establish deck height.

This study was carried to determine the reliability of typical Gulf of Mexico fixed platforms for 2MET Vs RP2A. Additionally, platform reliability was also compared for each of the four 2MET regions. This was used to determine if platform reliability changes according to region.

VI.3.7.1.2 Technical Scope

The scope for the project is summarized below:

- Review of API guidelines on platform design for extreme conditions in the US Gulf of Mexico.
- Derivation of reliability assessment methodology.
- Carryout reliability assessment using both the generic and the detailed methods.
- Analyze and summarize the results from the study.

VI.3.7.1.3 Study Limitations

- The generic method which uses generic platform information, such as water depth, location and platform strength does not consider specific information like the wave – in-deck (WID) loading and currents
- Second order uncertainties from the C coefficients used to describe the metocean load acting on the platform were neglected in the base share calculation for the detailed reliability studies.

- Wave height data is limited to 400 ft in RP2A, as a result the plot was assumed to be the same for 800 ft WD.
- Only selected platforms were considered in the study.
- Statistical data for failure of new L1 design platforms were not available. Probability of failure was computed for the new L1 platforms designs.

VI.3.7.1.4 Project Conclusions

VI.3.7.1.5 Key Conclusions and Results

In summary, the results are:

- Comparison of the API-RP-2A with the 2MET criteria showed that the 2MET has equal or lower probability of failure (pf) across all of the 2MET regions.
- For new design high consequence platforms with Reserve Strength Ratio (RSR) of 1.7, the probability of failure was found to be the same for all four 2MET regions.
- For high consequence existing platforms with RSR of 1.2, probability of failure was found to be highest in the West Central when compared to other regions. The high pf in the region is driven by the steeper slope of the Hmax curve as a function of return period which can be seen as one of the factor responsible for the large number of destroyed platforms in the West Central regions.
- New design high consequence platforms have an increase in RSR value from 1.2 to 1.7. The new designs were assessed to have higher reliability than the minimum API standard for existing A1 platforms. This explains the reason for few recorded failures in hurricane conditions for these platforms.
- The 'old' RP2A L1 minimum deck elevation results in a higher pf when compared with the 'new' 2DG recommendations (i.e. wave crest + 5ft air gap + 15% of crest height).
- The pf of new design L1 high consequence platforms with RSR of 1.7, is about 7 x 10-4 while the probability of failure for existing A1 high consequence platform with RSR of 1.2 is about 3 to 6 x 10-3.
- Estimated probability of failures for existing L2, A2, L3 and A3 low and medium consequence existing platforms is in the range of 10-2 which explains the reason for many observed failures of platforms with low RSR.

VI.3.7.1.6 OSER Goals

In the past fifteen years, several large hurricanes that have damaged or destroyed multiple offshore platforms. The study was carried out to determine the reliability of typical Gulf of Mexico fixed platform for 2MET versus RP2A criteria. The result from the study showed that the 2MET design criterion has the same or slightly better reliability than the RP2A. This is in-line with the OSER goals of investigating techniques to best assess, retain or restore the integrity of aging offshore assets.

VI.3.7.1.7 Recommendations

- No recommendations were made by the authors. The study was carried out on generic platform. A separate assessment may be needed to determine the reliability of existing and new platforms.

VI.3.7.1.8 Current State of Knowledge

Growth in computing power has led to a commensurate increase in software sophistication and structural modeling techniques. Non-linear analyses including both geometric and material non-linearity can now be factored successfully at the design phase and during structural integrity assessments.

In recent times system strength is now more commonly obtained by a pushover analysis rather than the component strength. Fracture mechanics is increasingly used to assess the effects of cracks and other defects on the structural integrity of members and joints.

Provision for damage and ageing of offshore structures is now being made in standard industry practice such as API RP 2A. It is expected that the future trend of drafting bodies will be to place more emphasis on the behavior of structures beyond the first yield, and to give more guidance on the residual strength of damaged components.