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Structural Integrity Management (SIM) of Offshore Facilities

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Abstract

The paper discusses the history and development of the Structural Integrity Management (SIM) process. A recap is provided of the significant industry initiatives and technological developments that have punctuated the passage towards the creation of the first stand-alone API recommended practice for the structural integrity management of existing offshore structures. The paper explores relevant SIM issues associated with the life cycle of an offshore structure. It looks at where risk-based SIM strategies have been applied, the benefits that have been delivered and where risk-based SIM strategies may lead in the future. Examples are provided of recent BP initiatives in the Gulf of Mexico and offshore Trinidad and Tobago.

Introduction

Structural Integrity Management (SIM) is an ongoing life-cycle process for ensuring the continued fitness-for-purpose of offshore structures. The SIM process has evolved over the last 25 years to provide industry and regulatory authorities a means to ensure the continued safe and reliable operation of the aging fleet of offshore platforms around the world.

The four phases of the SIM process: Data – Evaluation – Strategy - Program, as described in ISO (ISO/DIS/19902, 2004) are illustrated in Figure 1.

Data and Evaluation

As new SIM data is collected it is evaluated to determine whether it increases operating risk, i.e. either the consequence or likelihood of platform failure. Data may emanate from in-service inspections, platform modifications or other sources such as new technology or industry learning. If the operating risk has increased significantly then some level of assessment engineering is required to determine whether the platform remains fit-for-purpose or whether risk reduction or mitigation measures are required. The role of assessment engineering within the SIM process is illustrated in Figure 2.

Risk reduction measures include options to decrease the likelihood of failure of the structure e.g. strengthening, modification or repair. Risk mitigation options include operational changes to reduce consequences of failure e.g. demanning or removal of storage facilities. Reduction and mitigation alternatives will have financial and operational implications. For that reason it is usually cost-effective to use appropriate assessment engineering techniques to determine the fitness-for-purpose of the facility. A clear distinction between design and assessment engineering is recognized in the SIM process.

Strategy and Program

The SIM strategy will define the planning of the inspection program. The plan for the inspection program includes the frequency of inspections and the scope of work. It also includes the survey tools/techniques to be used and the deployment method e.g. diver, ROV or combination of these and/or other alternative methods. In addition to the inspections, the program may include implementation of risk reduction or mitigation measures in accordance with the SIM strategy.

Increasingly, operators are adopting risk-based strategies for integrity management (Craig et. al. 1994 and DeFranco et. al. 1999) to optimize the focus of valuable resources whilst ensuring HSE risks are maintained as low as reasonably practical. Amoco, in the North Sea, had a risk-based underwater inspection program approved by the certifying authorities in the mid eighties. BP, in the Gulf of Mexico, has had a risk based SIM strategy approved by the US regulatory authority, the Minerals Management Service (MMS), in 2003.

Historic Overview and Future Opportunity

This paper looks at the historic development of SIM and the underpinning technologies and in-service performance experience. BP continues to develop the SIM strategy in the Gulf of Mexico through integration of the SIM process within the wider operations of the Business Unit (BU). Applications include data sharing, field development planning, hurricane emergency response planning and field exit planning. The Trinidad and Tobago BU (bpTT) has adopted the same SIM model and is extending its application to incident driven inspection planning and performance based design.

Historical Overview

The traditional component-based approach to fixed platform design has seen gradual historical development (HSE OTO, 1999) since the installation of the first platform in shallow water off the coast of Louisiana more than fifty years ago. The design evolution process is illustrated in Figure 3.

The approach has served society well; indeed, experience from in-service performance suggests that well-maintained platforms are more robust and damage tolerant than a component-based design approach would indicate. As a result of this inherent 'reserve-strength', large numbers of fixed platforms are seeing safe service well beyond their intended design lives. The growth of the fixed platform fleet around the world is shown in Figure 4. The worldwide fleet now exceeds 9,000 platforms, infrastructure integral to the energy supply of nations large and small around the world.

Structural optimization is clearly one objective in design but there are many conflicting factors that influence the process, e.g. material availability, the need for standardization, ease of fabrication, and demands of temporary conditions including construction, load-out, transportation and installation. These factors together with schedule and other project constraints, which encourage the use of simple but generally conservative design procedures, collectively lead to a degree of over design, which is nevertheless cost-effective in total project terms.

By their very nature design codes are conservative and produce structures with reserves of strength. A design code check greater than unity does not imply structural failure. The codes contain an explicit safety factor and an additional implicit margin between the code check equation and mean values from test data.

Over the last twenty or so years offshore engineers have needed an alternative to the traditional component-based design checks in order to warrant the continued safe operation of the aging platform fleet. This need led to the development of assessment guidelines, allowing engineers to better exploit the full capacity of offshore structures not accounted for in traditional design using codified component-based methods.

Assessment guidelines adopt a pseudo risk-based approach by consideration of platform 'failure consequence' in the establishment of their acceptance criteria. Catalytic to the creation of assessment guidelines was the industry-wide effort to develop technologies necessary to gain the required confidence in the reliability of the assessment practice. This led to an improved understanding of platform behavior in the harsh offshore environment and a gradual ability to better explain observed in-service performance. Parallel advances in computing capabilities provided the means for engineers to economically implement these improved technologies.

In the early 1980s Amoco pioneered assessment engineering for their Southern North Sea (SNS) platform fleet and their Central North Sea (CNS) platform Montrose Alpha. Many of the key methodologies and early assessment practices were derived from other industries including the railway and bridge industries. These industries were faced with similar challenges for the assessment of fitness-for-purpose of aging infrastructure. Railway bridge-assessment became well established through technology research and testing, resulting in technical guidance notes to assist engineers in their departure from design standards.

In the SNS, a noteworthy development was metocean hind-cast technology, which provided the means to back-predict maximum wave height from measured environmental and climatic data. This led to a reversal of the upward trend in wave loading for SNS platforms, as illustrated in Figure 5. Joint probabilities of metocean events were also established.

Similarly, during the mid-1980s in the U.S., the Assessment, Inspection and Maintenance (AIM) Joint Industry Projects (JIP) were conducted for a variety of operators as well as the MMS (Bea, et. al., 1988). These projects, which totaled four phases over 5 years, established a framework for assessing and maintaining older platforms. In the later 1980's it became evident that an API process was required for assessing the structural integrity of existing jacket platforms. The approach would be different from the design of new platforms and as such required a new section of API RP2A. The offshore community then established an API working group that developed the assessment approach and released it in the mid 1990s as "API RP 2A, Section 17 – Assessment of Existing Platforms."

Section 17 was developed using technology taken from the AIM projects, specialist contractor studies, work at several academic institutions and from operator experiences. Interestingly, some of the key strategies in Section 17, such as the use of reduced criteria for assessment of existing structures, came from work associated with the aftermath of the 1989 Loma Prieta earthquake. This was a devastating earthquake centered near San Francisco and resulted in considerable damage to the onshore highway infrastructure that was constructed in the region in the 1960's and 1970's. This was also the timeframe of expansive growth in the U.S. offshore with much of the same types of onshore civil engineering approaches applied to the design of offshore structures. The concern was that this type of significant damage could happen to existing offshore platforms in an extreme event, such as an earthquake offshore Southern California or a large hurricane in the Gulf of Mexico. API therefore established an expert panel of eminent earthquake engineers to review the state-of-the-art practices in seismic assessment and acceptable performance for existing onshore facilities in order to develop consistent criteria for offshore structures (Iwan, et. al., 1992). This work established a foundation for not only assessment of structures in seismic areas but also for the subsequent API work that culminated in Section 17.

Since then, Section 17 has become the worldwide recognized process for assessing existing platforms. The process has been used many times particularly in the Gulf of Mexico where the reduced metocean criteria are applicable. In August 2003, the MMS released an NTL requiring Gulf of Mexico platform owners to assess their platforms to Section 17 requirements (NTL, 2003). Further detailed description of the historical background of Section 17 is provided in Wisch, et. al. (2004).

Technology Developments

Many important technology developments have been instigated that have lead to an improved understanding of the strength of components and importantly the reserve strength provided by the redundancy and robustness of typical space frame jacket structures.

Analysis Methods

System strength is not addressed in detail in codes and guidance documents. It has been demonstrated through large scale testing and via field observations that, for all frame types, there is additional system capacity available over and above that defined by the failure of the first component. In other words, the whole is stronger than the sum of the parts. The 2D, and later 3D, frames testing JIPs (Bolt, 2000) in the 1990s provided important confirmation of frame behavior and data for calibration of analysis tools for offshore platforms.

Comparison of the process for the use of elastic and non-linear analysis for structural analysis is illustrated in Figure 6. In elastic methods consideration of the failure response of components is only introduced within the code check. In non-linear analysis the characteristics are allowed for in the structural modeling, so that the stiffness analysis reflects the true response and the capacity of the system can be assessed. To achieve this, the software must be capable of capturing material non-linearity (i.e. yield) and geometric changes, locally and globally.

Today a range of validated software tools exists for elastic analysis, non-linear system analysis and reliability analysis to support advanced assessment engineering. However, in certain respects the techniques and underlying theories are more complex than many engineers and analysts will have been exposed to. It is therefore essential that, despite the slick interface provided by many software packages, suitably experienced engineers should use the tools with the ability to test and validate the analytical conclusions

Tubular Joints

Over the last three decades considerable effort has been expended by the offshore industry and research organizations to understand the behavior of tubular joints. Whilst most of these efforts have been directed towards fatigue behavior, a considerable body of knowledge has been gained on the capacity of tubular joints to resist static loads (Pecknold et. al., 2005). There now exists an extensive database of tubular joint test data and modern day joint strength formulations reflect the findings of rigorous assessment of the database.

Tubular joint formulations exist to satisfactorily and demonstrably capture the ultimate strength of a wide range of joint geometries and combined load effects. Conventional design analysis for offshore structures assumes rigid joint behavior and this has proved to be a satisfactory approximation based on past experience. As a result of recent joint industry efforts software has been developed to capture the flexibility of joints, and the associated load re-distribution that occurs during platform collapse. This provides the opportunity for more accurate determination of the ultimate strength of offshore structures.

In addition there is increasing recognition that local joint flexibility plays an important role in the bending moment distribution in a frame, which has significant implications for fatigue life estimates.

Structural Framing

In traditional component-based design, the practicalities are no different whether the structure has X-braced, K-braced or single diagonal framing. However, during the life-cycle of the structure the operational costs and risk levels can be significantly influenced by the framing configuration adopted at the outset. For example, a minimally braced structure may not have alternative load paths to redistribute forces if a component is damaged or if applied loads are higher than initially anticipated. As a consequence, failure of a single component may be critical to overall integrity – relatively intense inspection activity may be required to monitor the structural condition of key load paths and there may be little scope to modify the installation for enhanced facilities at a later stage without adversely affecting safety levels. Conversely, a robust structure with alternative load paths through the jacket may be more tolerant of damage or increased loads, offering greater operational flexibility and a much-reduced need for inspection activity to provide the same assurance of safety.

Where design practices have been based on the results of isolated laboratory tests of planar components, no account has been taken of the continuity and constraint in a real structure or of the more complex force interactions generated in a 3D frame. Large scale testing of jacket frame structures (Bolt, 1995) has improved understanding of these influences. When assessing existing structures, which fail to satisfy present day design criteria, this new knowledge has enabled adequate safety margins to be demonstrated without the need for strengthening.

Fatigue

With the growth of platform operating experience over time, it has become clear that the number of occurrences of fatigue cracks discovered in existing structures is not as high as would be expected. The reason for the lack of correlation is the degree of conservatism in the conventional fatigue design procedure. It should be noted that, for design, the conservatism has served industry well, allowing many platforms to continue to operate safely well past their initial design lives.

There are various sources of conservatism in the fatigue design process and implicit conservatisms in the S-N curves. It is not unusual to apply a factor of safety on fatigue life, sometimes dependant on the consequence of failure and/or ease of inspection of the joints and in the treatment of corrosion allowances. However, these conservatisms do not explain the lack of fatigue defects detected during underwater inspections in comparison to the population of joints in service.

Recent studies indicate that the structural analysis is the principal cause of this conservatism. It has been usual practice to assume that tubular joints are rigid when performing fatigue analyses, usually due to a lack of knowledge on how to better represent the true flexibility of joints that is observed in large-scale component and frame tests. The technology now exists to address the question of local joint flexibility and reflect it in the fatigue analysis with a high degree of reliability and in a cost-effective manner.

These conclusions are supported by in-service performance data and a case study on a bpTT platform that highlighted the influence of joint flexibility in a fatigue life assessment, as described later in this paper.

Foundation Capacity

Small-scale centrifuge geotechnical tests by a major operator in the early 1990’s indicated that the ultimate lateral capacity of pile foundations is higher than expected. The tests used a small-scale pile in clay soils typical of the Gulf of Mexico. These tests indicated that the pile ultimate capacity was not equal to the “degraded” capacity, as used in design, but instead to the “un-degraded” capacity.

The conclusion of this work was that for design level loading the degraded soil strength is correct. However, for ultimate capacity loading, where the pile will see large deformations, the un-degraded strength is more correct. Note that ultimate capacity is typically used as the reference level for platform assessments.

The conclusions from this study are consistent with observations from in-service performance history where there have been few observations of platform foundation failures.

In-Service Performance History

Parallel to the many technology development studies other joint-industry initiatives were established to examine in-service performance of structures. In particular, valuable lessons have been learnt from the behavior of platforms subjected to extreme loading, most significantly from hurricanes, as illustrated in Figure 3, but also from accidental events including blast and vessel impact.

Hurricane Andrew

In August of 1992, Hurricane Andrew appeared in the Gulf of Mexico after causing significant devastation in Southern Florida. The storm was a Category 4 hurricane with sustained winds reaching 140 mph and maximum wave heights near 75 ft. The storm moved west from Florida and then veered north below the Mississippi Delta before making landfall near Morgan City. Table 1 summarizes the impact of Andrew on the offshore structures in the Gulf of Mexico.

Andrew provided an opportunity to validate offshore platform design standards and advanced analytical techniques against known platform failures and platform survivals (Puskar et. al. 1994). The failures provided an opportunity to verify if they could have been predicted analytically and to benchmark many of the assessment technologies being developed at the time.

Significant findings from the work with application to integrity management and assessment engineering are as follows:

- All platforms that were damaged or failed were early vintage platforms of pre-1980 era. Platforms designed to RP2A standards in this era or to other standards (pre RP2A) are known to have certain design deficiencies, such as low decks, weak joints or poor framing configurations.
- There was no extensive damage or failures of platforms designed to modern (post 1980) RP2A guidelines. The one platform of this vintage that failed was determined to be the result of a construction error where the deck was not correctly connected to the jacket.
- All of the observed damage or failures appeared to be in the jacket. There appeared to be no foundation related failures.
- Poor framing schemes such as K and single diagonal bracing without joint cans contributed to many of the platform failures. On the contrary well designed X braced structures did not experience any platform failures.
- Probabilistic assessment indicated that platforms designed to RP2A standards, no matter which era, tend to have an “unknown bias” in capacity of about 20% above the capacity that is a “best estimate.” In simple terms – even when engineers use their best approaches to estimate the platform strength, the Andrew study demonstrated that there is an additional 20% reserve strength within the platform system (deck/jacket/piles).
- The probabilistic assessment also showed that a significant proportion of the bias appears to be in the foundation. This is confirmed by the lack of observed foundation failures in Andrew.

Inspection Data

Operating experience gained in widely separated parts of the world consistently shows that provided corrosion protection systems are adequately maintained structural reliability does not degrade significantly even for exposure periods well in excess of originally intended design lives.

Recent projects looking at both Gulf of Mexico and North Sea (Bucknell et. al, 2000) have examined the results of over 3,200 underwater inspections. The data shows that the largest proportion of damage to offshore structures is mechanical damage resulting from boat impact and/or dropped objects. Mechanical damage typically accounts for 80% of total damage whilst corrosion defects and weld/joint defects, in particular, are far less common. The consistency in the nature and causes of damage to offshore platforms in the Gulf of Mexico and the Southern and Central North Sea is illustrated in Figure 7. Data from around the world shows that fatigue damage that exists is largely confined to known susceptible details.

Recent studies have isolated some of the elements of this over-design for both strength and fatigue of offshore structures. These allow more accurate fatigue life predictions better correlated to in-service performance data. As a result, industry has generally moved away from fatigue and corrosion (time dependant phenomena) driven inspection strategies to incident driven approaches with inspections targeted to identify damage to which the platform type is most susceptible.

Through the analysis of existing data, industry efforts has identified differences in the susceptibility to damage of different platforms. This has resulted in a move away from the present Level II, Level III, Level IV approach (increasing intensity and localization) to inspections designed to locate and quantify defects to which the platform has a known susceptibility. As part of an overall SIM strategy, traditional Level III/IV surveys, in many cases, may be reliably limited to post-incident inspections (Special Inspections) and, therefore, accurately targeted.

Understanding and Managing Risk

A risk-based SIM strategy requires an understanding of the in-service performance of the structure and the establishment of performance objectives. Existing codes and standards provide some guidance on minimum performance standards for platforms, usually based on the consideration of the consequence of failure of the platform. API RP2A and ISO 19902 use the concept of platform ‘exposure category’ to categorize platforms by life-safety or environmental consequence of failure.

A risk-based approach introduces the additional parameter of platform likelihood of failure. Understanding of assessment engineering and associated technologies and performance data is required to assign likelihood of failure categories for platforms. Although these technologies are relatively mature with proven track records, they are outside of existing codified guidance and unfamiliar to many design contractors. The technologies, therefore, bring with them a level of additional competency over and above the competency associated with a conventional design approach. It is important that these risks are understood to allow Owners to make informed decisions in the consideration of a risk reduction and mitigation alternatives. Experience indicates that an increased level of competency is usually necessary to manage a risk-based strategy and assessment engineering technologies and data.

A useful means to understand the need for, and the appropriate level of competence is provided in UKOOA, as reproduced in Figure 8. Three ‘decision context’ types are identified, A, B and C. The conventional engineering design engineering approaches to fixed offshore platforms typically reside in the A-category; the engineering is not usually new or unusual, risks are understood and practice well established. The ‘means of calibration’ to the left of the figure can be thought of as an indication of the level of competency required. In the case of conventional design this is essentially handled by compliance with Codes and Standards, sometimes supported with independent verification as the risk of failure increases.

A risk-based SIM strategy, however, may have life-cycle implications and/or require trade-offs in performance and/or introduce uncertainty associated with deviation from standard practice: shifting the ‘decision context’ to type B. In this case the level of competency required increases and need for specialist expertise and experience also increases.

The SIM process should assist in preventing, controlling or mitigating risk and ensure that, in addition to code and regulatory compliance, best practice is followed to align with the Owners own minimum HSE requirements.

Hurricane Lili – A Test of the Assessment Process

Hurricane Lili provided the first true test of the Section 17 assessment process when it passed through the Gulf of Mexico in 2002. A total of 19 platforms were seriously damaged or destroyed (Puskar, et. al, 2004). Two particular platforms that were in the path of the hurricane had undergone the assessment process, with each having a different approach and outcome, as described below.

Eugene Island Platform – Collapse Case: This platform was toppled by hurricane Lili, even though it had passed the assessment process that was triggered by damage found in the platform during an underwater survey in 1997. The operator and the MMS knew the platform would not withstand storm forces much greater than that expected during a Sudden Hurricane event. Hurricane Lili imposed forces on the platform much greater than Sudden Hurricane forces and, as a result, the platform collapsed. Due to the assessment process, the operator was able to sustain production for an additional 5 years, taking the risk of higher removal cost should the platform be destroyed prior to production ceasing and normal removal operations being completed.

Eugene Island Platform – Survival Case: This platform survived hurricane Lili. The operator was considering expanding production capacity through the addition of new conductors and wells. The addition of new conductors to this system required an assessment following the Section 17 guidelines. The assessment showed that adding the new conductors would not be acceptable without additional strengthening of the platform or by reducing the loads. Rather than use a new platform and leave the original platform as-is, the operator decided the best solution was to install a new platform that allows increased production for the field and at the same time provides additional strength to the existing platform so that it can withstand greater storm loads. This new four-leg platform was connected to the existing facility both above the water line and at the mudline in order to improve load sharing between the two systems. Hurricane Lili passed very close to these two joined platforms. Based on hindcast information, the original structure would not be expected to withstand the Lili loading. However, the combined system performed well and no significant damage was noted on either the old or the new platform.

These examples demonstrate that the assessment process does indeed work, even though in one case the platform failed (as expected). Assessment utilizes reduced criteria and owners must consider this risk into their operations. In the first case, the economics and field development plan did not warrant significant strengthening of the platform. In the second case, the economics and field development plan did warrant strengthening and the platform survived Lili.

API SIM Recommended Practice

API Sub Committee 2 recently established a Task Group to develop a stand-alone Recommended Practice (RP) (O’Connor et. al., 2005) for the integrity management of fixed offshore platforms. The work is being executed as a Joint Industry Project (JIP) with sponsorship from API, BP, Bureau Veritas, ChevronTexaco, Devon Energy, ExxonMobil, MMS and Shell.

The new RP will draw on the experience gained from many years of operational experience data and technological developments. It is intended to provide guidance to Owners, Operators and Engineers in the implementation and delivery of the SIM process. The process is being developed around existing industry standards and guidance documents.

Specifically, the RP will describe the SIM Process and offer specific recommendations for in-service inspections, damage evaluation, structural assessment, assessment criteria, risk reduction and mitigation alternatives and, for the first time in API, decommissioning of fixed offshore platforms.

The draft contains a number of elements relevant to a risk-based strategy for the SIM of offshore structures. The development of a risk-based strategy is encouraged and rewarded by the dispensation from more onerous default inspection program requirements, which apply in the absence of a risk-based approach.

The new RP is being developed specifically for platforms operating in the United States; however, the SIM process will have application to platforms at any location worldwide. In developing the RP it will also be necessary to prepare an updated RP2A exclusively for the design of new Fixed Offshore Platforms.

Case Study

BP has documented numerous examples of cost-effective assessment engineering within a risk-based SIM strategy. One such case study has been selected to emphasize some of the distinctions between design level and assessment level engineering. The study includes both strength and fatigue assessments and was conducted for the bpTT Cassia A drilling and production platform. A summary results from the study and conclusions are provided in order to highlight the benefits that the assessment approach, within a risk-based SIM strategy, delivers for the BU.

In 2002 bpTT installed the Cassia B riser platform offshore Trinidad. The platform was bridge-linked to the existing Cassia A platform, which was installed in 1982. The Cassia A topsides is supported on a conventional eight leg fixed steel jacket structure which is X-braced in both the transverse and longitudinal directions. The platform stands in 220-feet of water and presently operates with twenty conductors and seven risers. Figure 9 shows a recent photograph of the Cassia A platform.

During the detailed design of the new platform the project carried out an “assessment” of the existing platform to determine whether it was a candidate for the anticipated life extension. The project adopted a conventional design approach, which may be considered the industry norm, for the ‘assessment’ of the platform, which included both strength and fatigue analyses.

The difference in the results and conclusions made from the design approach adopted by the project compared to the assessment approach carried out by a specialist consultant under the supervision of BP EPTG Group are discussed.

Strength Results and Conclusions

Since the modifications to the platform were relatively minor and the structure is a modern, robust design the strength was determined to be adequate even using the conservative design approach. The conclusions from the design level approach, however, were limited to confirmation that all components met the allowable stress requirements of the API recommended practice.

The assessment approach also concluded that the platform was fit-for-purpose for the proposed modifications. In addition, an ultimate strength analysis showed that the platform has an unusually high safety factor (reserve strength) against failure with a capacity of over 5 times the design extreme load. A typical minimum acceptable value is 1.6. Robustness studies also showed that the platform is highly tolerant of damage; i.e. it can tolerate the loss of multiple primary bracing members before the reserve strength is reduced to close to the minimum acceptable value; the intact Reserve Strength Ratio (RSR) and the reduction after the removal of over twenty vertical diagonal braces is illustrated in Figure 10.

Fatigue Results and Conclusions

The design level fatigue analysis concluded that the platform had numerous joints with low fatigue lives requiring a costly underwater inspection of the low life joints and casting doubt as to the viability of the platform for life extension.

In contrast the assessment level approach demonstrated that the platform has good fatigue performance, well in excess of the intended life extension of the facility. Table 2 shows a comparison of results from the assessment and design approaches. The Table shows the design approach identifies 11 joints with fatigue lives less than the target life of 80-years (2 x required platform life extension). The shortest fatigue life determined from the design analysis was 0.3-years (bear in mind that the platform has already been in the water over twenty years). The more advanced techniques applied in the assessment engineering approach, including exploitation of joint flexibility in the analysis along with other technologies, indicated the lowest life to be 106-years.

Implications for the SIM Strategy

The results of the strength and fatigue analysis of the bpTT Cassia A provided clear evidence that the structure is highly redundant and has a robust configuration. It was also apparent through the more detailed assessment level fatigue analysis that the structure is relatively fatigue insensitive.

In accordance with the SIM process the assessment engineering work was used to update the SIM strategy to increase the interval between inspections: reducing operating costs. Due to its robustness it was demonstrated to be a suitable candidate for remote visual inspection without the use of divers consistent with the BU’s long-term strategy. Another benefit of the ultimate strength analysis was identifying the failure paths. This allowed the scope of work for the routine periodic inspection to be targeted at the most safety critical elements of the platform.

Interestingly, the cost of the assessment engineering was less than the cost of the design approach. The additional value provided by the assessment approach to the project and to the BU was measured in the millions of dollars.

Opportunities for the Future

BP is continuing to develop a number of initiatives relating to the logical extension of the risk-based SIM strategy.

Integrated Planning Environment

BP is developing an integrated planning environment (IPE) that uses recent GIS technology to graphically communicate SIM data residing in the BP data management and SIM delivery system, bpFMS. The IPE provides simultaneous links to any of BPs other data management systems or external web-based systems within the single graphical interface. Initial applications of the tool include:

Hurricane Emergency Response Planning

Hurricane location and intensity can be tracked real time, as can the locations of mobile drilling units. Real time metocean data, including wind speeds and wave heights, can be received from weather buoys and monitoring systems. Asset capacity to withstand the event can be displayed to determine risk to BP assets. Strategies for remediation of potential lost production can be developed at an early stage. Post event inspection programs can be accurately targeted and resources budgeted and allocated.

Development Planning

The IPE provides a visual means to share and communicate data between disciplines to assist field development planning and field exit planning. Operational risk can be compared to asset value to assist exit planning considering alternatives such as sale, reuse or decommissioning.

Event Driven Inspection

A regional issue that affects the SIM strategy in the Trinidad and Tobago is the lack of marine operations support infrastructure. Mob/Demob of a suitable inspection vessel can be several millions of dollars. Due to the high cost of mobilization the bpTT BU is exploring the applicability of an event driven inspection strategy for selected platforms. This strategy does not require routine periodic underwater inspections. Instead Special Inspections are required when a significant 'event' is reported. Events may include occurrence of the extreme design event e.g. earthquake or hurricane, or accidental events e.g. vessel impact or dropped object. Event driven inspection strategies can only be employed as part of an integrated risk-based SIM process. The approach requires knowledge of the historical performance data for the platforms, the robustness of the structures and their susceptibility to damage.

An event driven strategy may be supplemented by 'spot checks' that involve general visual survey by ROV of higher risk platforms when a suitable vessel is already operating in the field. BP has also investigated the use of monitoring systems as a further assurance of an event driven underwater inspection strategy. Recent evaluation trials of a structural monitoring system by the Gulf of Mexico Shelf BU have validated the technical performance of the systems.

Performance Based Design

The objective of performance-based design is to facilitate the design of structures that have predictable performance in compliance with performance goals selected for the intended life. Emphasis is provided on the consideration of the entire life-cycle; from appraisal and selection to disposal, potentially after one or more change-of-use or reuse.

Many lessons arising from previous design and operational experience have application to future performance-based design. By making the design process open to the adoption of past service experience, and assessment engineering tools and technologies competent engineers are able to optimize facilities to better deliver the life-cycle performance goals most closely aligned with Owner financial targets and HSE expectations.

In the past 15 years the onshore industry has modified its approach for the seismic design of buildings to be Performance Based (FEMA 389, 2004). These changes were the result of observations of building performance in the 1989 Loma Prieta earthquake in Northern California and the 1994 Northridge earthquake in Southern California, which showed some of the inadequacies of the building design practices at the time. Figure 11 shows conceptually the Performance Based design levels for onshore buildings. Four levels are defined, with differing "performance" of the building during and after the earthquake. Building collapse is not allowed. The highest level of design is Operational, used for important structures like hospitals that must not only survive the earthquake, but must also function immediately after the earthquake (note how the lights are still on in the building following the earthquake). Industrial buildings can also use this criteria – provided the owner is prepared for the additional expenses associated with more robust design and construction, compared to design for one of the lower performance levels. But some owners may consider this as a viable option given the ability to stay in operation immediately following the earthquake and minimize business interruption.

There is some similarity to the onshore building approach and the API RP2A Section 17 assessment approach and Consequence Based Design approach for offshore structures, where reduced wave criteria can be used, for example where the consequence of failure is lower, e.g. minimal unmanned facilities. Whilst this is the first step, further work is required to make a true Performance Based design code, which modifies the overall design recipes (and not just loads). This is clearly the trend for onshore structures and a direction that BP may be leading the industry for future offshore design.

Conclusions

Structural Integrity Management (SIM) is an ongoing life cycle process for ensuring the continued fitness-for-purpose of offshore structures. The SIM process has evolved over the last 25 years to provide industry and regulatory authorities a means to ensure the continued safe and reliable operation of the aging fleet of offshore platforms around the world.

Technology developments have punctuated the development of the SIM process to provide improved understanding of the behavior of offshore structures in the harsh offshore environment. Experience of the failure and survival of structures during extreme events such as hurricanes has provided the opportunity to benchmark and further refine the assessment processes.

The SIM process for the fixed platform fleet has reached a level of maturity where API has recognized the need for a stand-alone RP for structural integrity management. The new RP will draw on the industry knowledge and experience and will provide guidance to Owners in the implementation and delivery of the SIM process. Specifically, the RP will describe the SIM Process and offer specific recommendations for in-service inspections, damage evaluation, structural assessment, assessment criteria, risk reduction and mitigation alternatives and, for the first time in API, decommissioning of fixed offshore platforms.

Increasingly, operators are adopting risk-based strategies for integrity management to optimize the focus of valuable resources whilst ensuring HSE risks are maintained as low as reasonably practical. Amoco was among the first company in the North Sea to get a risk based underwater inspection program approved by the certifying authorities in the mid eighties. BP was among the first operators in the Gulf of Mexico to have a risk-based SIM strategy approved by the US regulatory authority, the Minerals Management Service, in 2003.

BP continues to develop the SIM strategy in the Gulf of Mexico through integration of the SIM process within the wider operations of the Business Unit (BU). Applications include data sharing, field development planning, hurricane emergency response planning and field exit planning. The Trinidad and Tobago BU (bpTT) has adopted the same SIM model and is extending its application to incident driven inspection planning and performance based design.

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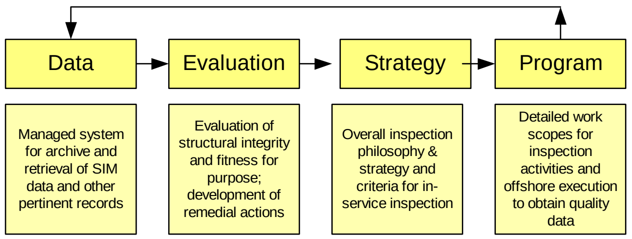

Figure 1: SIM Process

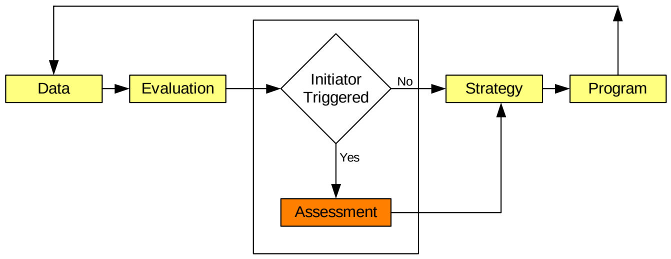

Figure 2: Assessment within the SIM Process

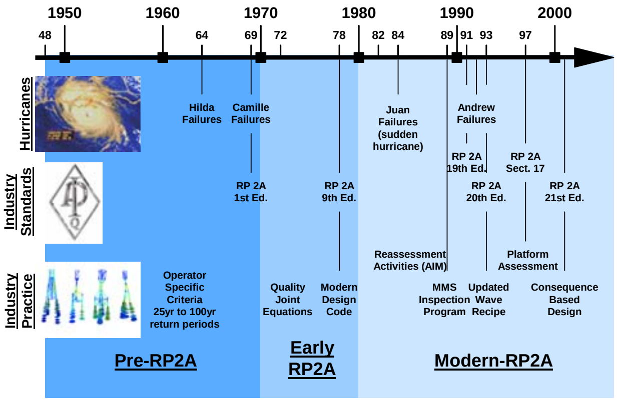

Figure 3: Evolution of Platform Design

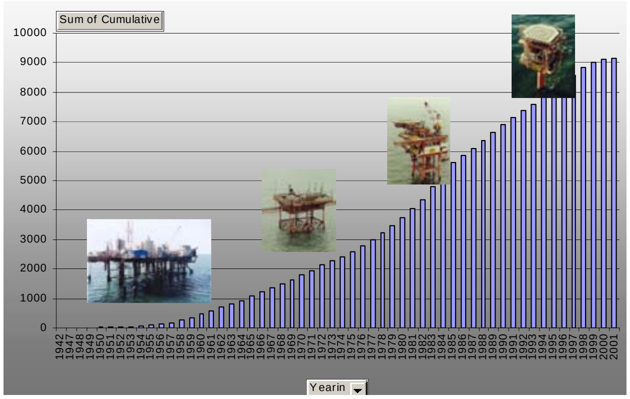

Figure 4: Growth of Worldwide Platform Fleet

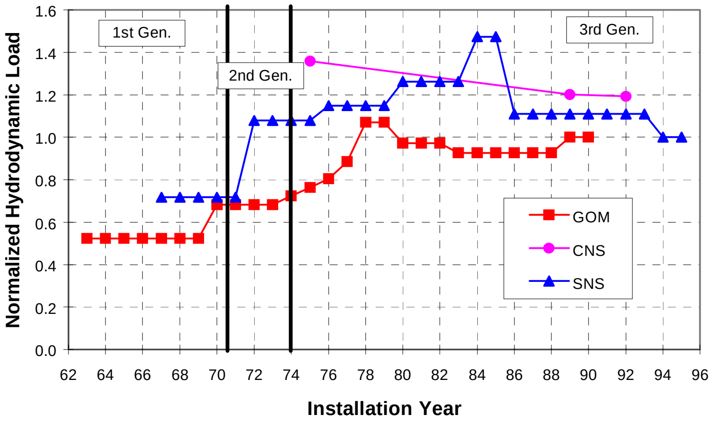

Figure 5: Reversal of the upward trend for design wave loading for SNS

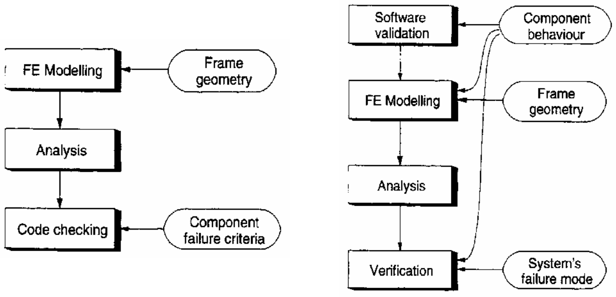

Figure 6: Conventional design analysis (left side) and non-linear analysis procedures (right side).

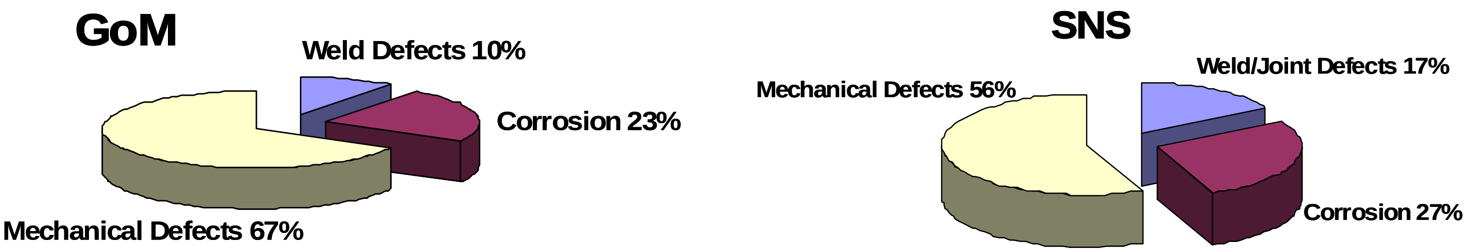

Figure 7: Comparison of Underwater Inspection Damage/Defects in Gulf of Mexico (GOM) and Southern North Sea (SNS)

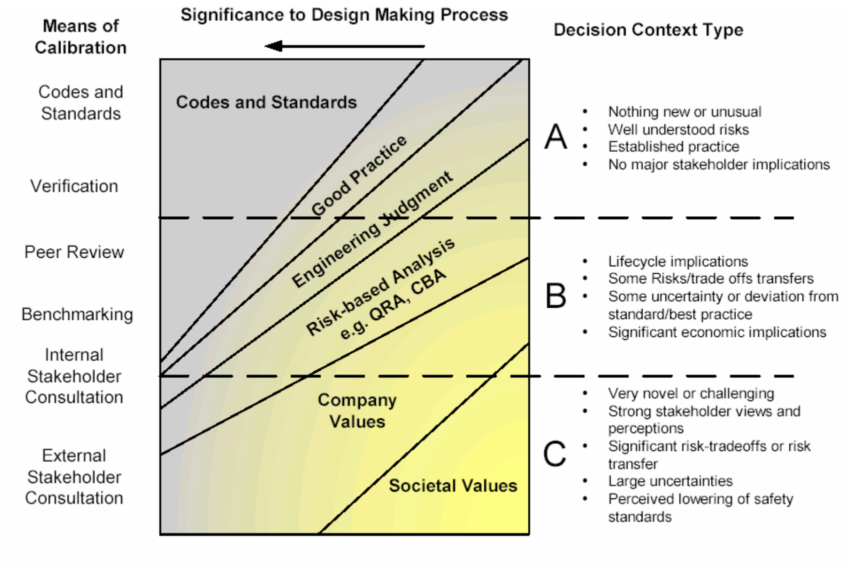

Figure 8: Risk-Based Decision Support (UKOOA)

Figure 9: bpTT Cassia A platform

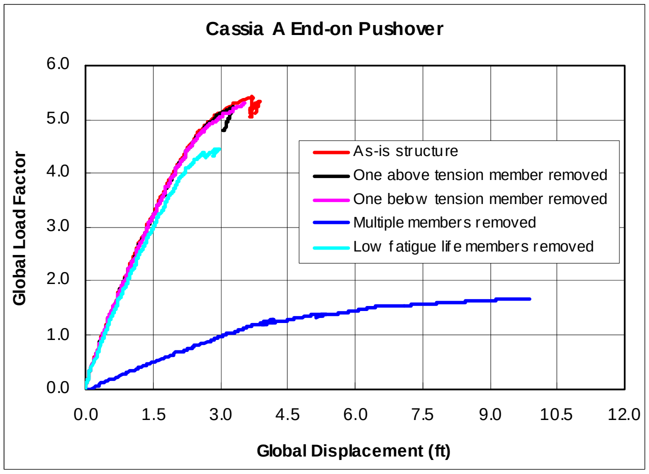

Figure 10: Load-Displacement Curve

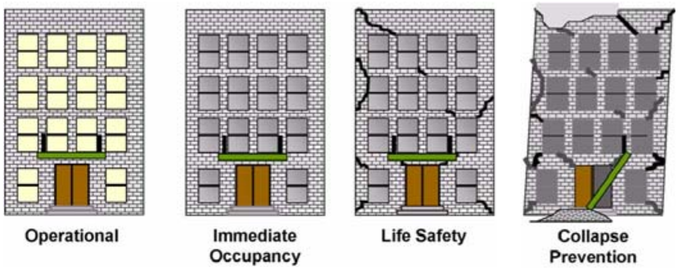

Figure 11 – Graphic Illustration of the FEMA Performance Based Design Levels for Onshore Buildings (FEMA 389, 2004)

Item	Value	Comment
Offshore structures impacted by Andrew	2000 total (635 platforms, 1365 caissons)	Platforms located in 85 mile swath deemed as most severe hurricane conditions per MMS
Platforms rendered unusable	36 (10 toppled, 26 severely damaged)	
Vintage of platforms rendered unusable	35 installed prior to 1980 1 installed post 1980	Later investigation indicated that the lone post 1980 platform failed due to a construction flaw where the deck was not properly attached to the jacket
Satellite wells rendered unusable	68 (25 toppled, 43 leaning more than 5 degrees)	Satellite well defined per MMS as a small protective structure around 1-3 wells

Table 1: Platforms Exposed to and Damaged during Hurricane Andrew

Joint Can	OD (in)	WT (in)	Joint Type	Member Type	Fatigue Lives (years)		
					Design Approach	Modified Approach	Assessment Approach
1643	16.00	0.500	Y	BRC	0.3	0.7	106.3
	58.50	1.000	Y	CHD	0.3	0.5	
1421	14.00	0.375	Y	BRC	1.8	394.0	6685.1
	19.50	0.562	Y	CHD	7.5	79.8	
6459	8.63	0.322	T	BRC	66.6	13627.0	311372
	10.75	0.365	T	CHD	23.2	3329.0	
407	20.00	0.812	K	BRC	30.2	149.2	25311
	60.50	2.000	K	CHD	25.4	38.4	
6469	8.63	0.322	T	BRC	84.6	19059.0	371483
	10.75	0.365	T	CHD	28.0	3773.7	
6479	10.75	0.365	T	BRC	28.4	212.4	3295
	18.00	1.000	T	CHD	28.4	123.1	
6468	8.63	0.322	T	BRC	133.5	17140.0	278422
	10.75	0.365	T	CHD	44.9	2879.0	
6458	8.63	0.322	T	BRC	158.1	24088.0	201219
	10.75	0.365	T	CHD	49.4	4754.0	
6424	8.63	0.322	T	BRC	166.7	153027	1280017
	10.75	0.365	T	CHD	51.5	25852.0	
1936	19.50	0.562		BRC	54.6	607.6	820.6
	19.50	0.562		CHD	52.3	606.4	763.3
419	22.00	0.375	K	BRC	54.6	115.8	605.3
	60.50	2.000	K	CHD	54.6	30.5	

Table 2: bpTT Cassia Comparison of Design and Assessment Fatigue Results