DEVELOPMENT OF AN INTEGRATED STRUCTURAL INTEGRITY MANAGEMENT (SIM) FRAMEWORK FOR MALAYSIA FIXED OFFSHORE STRUCTURE

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DISSERTATION TITLE: DEVELOPMENT OF AN INTEGRATED STRUCTURAL INTEGRITY MANAGEMENT (SIM) FRAMEWORK FOR MALAYSIA FIXED OFFSHORE STRUCTURE

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I MOHAMMAD KABIR BIN MOHD AKRAM,

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The opinions expressed in this document are those of the authors, and they should not be construed as reflecting the views of PETRONAS or UTP.

ABSTRACT

Malaysia currently has approximately 200 fixed offshore structures, some of which have been in operation for over 40 years, which is well beyond its design life. In order for these ageing fixed structures to continue in service or extend its operation, the current structural integrity condition of these assets needs to be identified, addressed, prioritized and the appropriate mitigation that should be implemented planned, which is the topic of the current research.

This research has acquired the actual fixed offshore structure data, which comprises of design, assessment and inspection records and evaluated them to identify the gaps in the design, the assessment and the inspection programs. The need for developing an integrated framework for Structural Integrity Management (SIM) of Malaysia's fixed offshore platforms was also identified. Four important components of this framework were identified as 1) Classification of Malaysia's offshore platforms 2) Developing the Statement of requirement for design of fixed offshore structure and case study, 3) Developing the data handover guideline for green field and Brownfield projects and case study, and 4) Development of a Risk Based Underwater Inspection (RBUI) program and case study.

The classification of the platforms showed that many of the structures have exceeded the design life of 30 years. The baseline risk of the 186 platforms was also evaluated. Fifty five (55) platforms were identified to be in "very high risk" category. The components of "Statement of Requirement for Design of Offshore Structure" were identified. The framework for developing a proper "Statement of Requirement for Design of Offshore Structure" has been developed and the same illustrated through a case study. A proper guideline for data handover for Greenfield and Brown field projects has been developed and illustrated through a case study. A risk based underwater inspection guideline was also developed based on the Amoco system and the local

conditions. A case study was done to illustrate how it affects the inspection planning of the offshore structures.

ABSTRAK

Malaysia kini mempunyai kira-kira 200 struktur luar pesisir pantai, ada yang telah beroperasi selama lebih 40 tahun, yang berada di luar jangka hayat reka bentuk. Dalam usaha untuk memastikan struktur ini meneruskan perkhidmatan atau melanjutkan operasinya, keadaan integriti struktur aset-aset ini perlu dikenal pasti, ditangani, dan langkah-langkah menambah baik yang sesuai perlu dilaksanakan.

Kajian ini telah memperolehi data sebenar struktur luar pesisir pantai, yang terdiri daripada reka bentuk, penilaian dan pemeriksaan rekod dan ini dinilai untuk mengenal pasti jurang dalam reka bentuk, penilaian dan program pemeriksaan. Keperluan untuk membangunkan satu rangka kerja bersepadu bagi Pengurusan Integriti Struktur (SIM) pelantar luar pesisir pantai Malaysia juga telah dikenal pasti. Empat komponen penting rangka kerja ini dikenal pasti sebagai 1) Pengelasan struktur luar pesisir Malaysia 2) Membangunkan penyata keperluan untuk reka bentuk struktur luar pesisir pantai dan kajian kes, 3) membangun data penyerahan garis panduan bagi projek dan kajian kes, dan 4) Pembangunan program pemeriksaan struktur pesisir pantai berdasarkan risiko (RBUI) dan kajian kes.

Pengelasan struktur menunjukkan bahawa banyak struktur telah melebihi hayat reka bentuk 30 tahun. Risiko asas daripada 186 struktur itu juga dinilai. Lima puluh lima (55) struktur telah dikenal pasti untuk berada di dalam "berisiko tinggi" kategori. Komponen "Penyata Kehendak bagi Rekabentuk Struktur Luar Pesisir" telah dikenal pasti dan digambarkan melalui kajian kes. Garis panduan yang sesuai untuk data penyerahan untuk projek telah dibangunkan dan digambarkan melalui kajian kes. Garis panduan pemeriksaan berasaskan risiko dalam air juga telah dibangunkan. Satu kajian kes telah dilakukan untuk menggambarkan bagaimana ia mempengaruhi perancangan pemeriksaan struktur luar pesisir.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Initial considerations for this research are discussed, with particular focus on the following items:

- Background of project
- Problem statement
- Project objectives
- Scope of study
- Organization of the thesis
- Chapter summary

1.2 Background of project

Structural Integrity Management (SIM) is a continuous assessment process applied throughout design, construction, operations, and maintenance and decommissioning to assure that the structures are managed safely. The objective of the SIM process is to confirm that the structures are fit for purpose and maintain structural integrity throughout its life cycle and maybe longer. The SIM strategy will reflect the risk associated with the decrease the ability of structures to withstand overload due to wave and current loading. Furthermore, several offshore fields are experiencing subsidence as a result of petroleum production. Subsidence results in a decreased safety margin towards wave in deck loading, being the worst hazard for many of the offshore structures of jacket type. Also, improvements in knowledge about the wave conditions can result in a similar decrease of safety margin towards wave in deck loading (Ersdal, 2005).

Finally, lack of knowledge of the structure (e.g. drawings, steel type, welding procedures, inspection results and details about earlier repairs etc.) may result in a high uncertainty about the structures ability to withstand wave and current loading, compared to the uncertainty at the design stage of the structure. In contrast, a well-managed structure with relevant data may have significantly lower uncertainty compared to the uncertainty at the design stage of the structure. A well-managed structural integrity management (SIM) approach in this context would mean that the operator has detailed knowledge about the structure, inspection and repair results. Measurements and experience from structural behavior in extreme wave and current loading will also reduce this uncertainty (Ersdal, 2005).

The major task in this thesis is to develop an integrated SIM strategy for Malaysian offshore platforms in solving the above mentioned issues.

1.4 Project objectives

The main objective of this research is to develop an Integrated SIM strategy for Malaysian offshore platforms. The sub-objectives can be listed as below:

- Classify Malaysia's fixed offshore structure based on as-built characteristic of platforms.
- Develop a statement of requirement for design of new offshore fixed structure.
- Develop a data handover guideline for green field and brownfield projects.
- Develop Risk Based Underwater Inspection (RBUI) program.
- Develop and prepare case studies for each objective above.

1.5 Scope of research

This thesis addresses the jacket structure of offshore fixed platforms only. Other structural parts such as foundations are not in the scope of study. Besides that, other major hazards such as earthquake, boat impact and corrosion rate are outside of the scope of this thesis. Earthquake loading and boat impact loading may be governing for some structures. However, earthquake loading and boat impact are not studied and definite conclusions on such hazards cannot be made based upon this thesis. Corrosion will definitely be an important hazard for the structure but this aspect would need a specific investigation to evaluate the impact it has on the structural integrity of a platform.

1.6 Organization of the thesis

The thesis is presented in six chapters. Figure 1.1 shows the organisation and content of the chapters of the chapters.

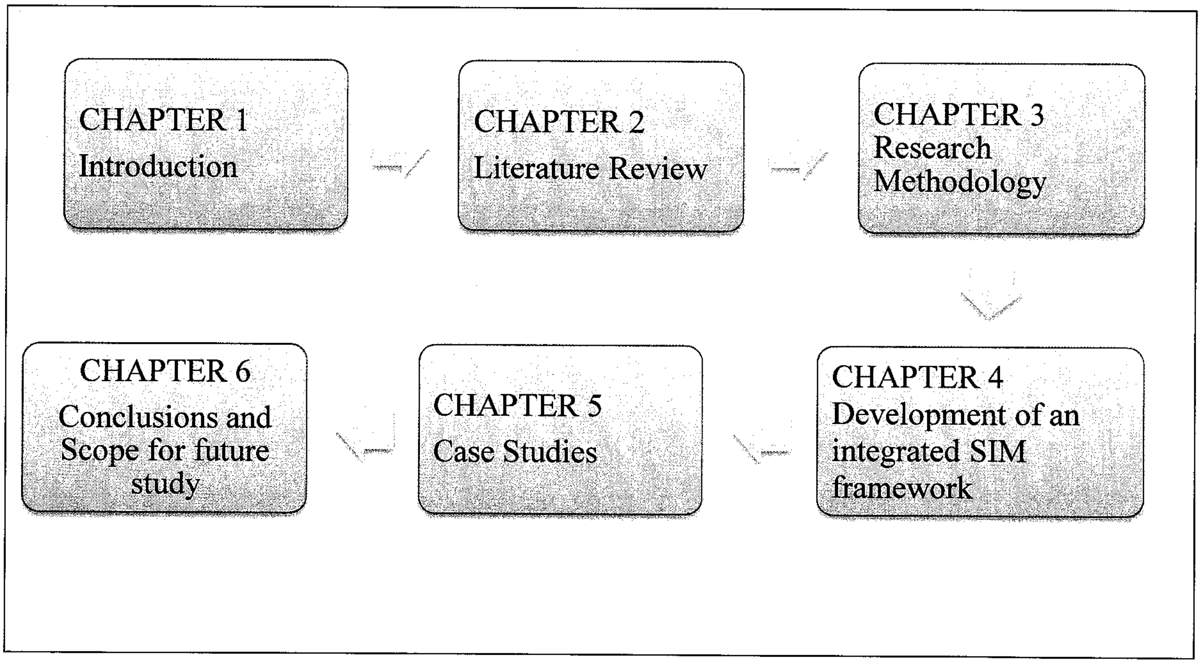

Figure 1.1: Organization of the thesis

In Chapter 1, a brief introduction to the thesis is presented. The chapter provides information on the project background, problem statement, the project objectives and scope of this research. The chapter ends with information on the organization of the thesis and chapter summary.

In Chapter 2, the review of past works on SIM is presented. An overview is provided on the area of Oil and Gas with respect to overseas and also Malaysia. A brief review of the evolution of the design codes is also presented. The impact of hurricanes on code provisions has also been described. Brief review of SIM practices worldwide is also provided. The development of RBUI by AMOCO is discussed. The current SIM practices in Malaysia, and data hand over and SOR practices worldwide are reviewed and gaps in the practices identified.

In Chapter 3, the research methodology is discussed. The methodology to develop an integrated SIM framework for offshore platform is presented and each of the objectives is discussed. The methodology consists of site investigation to gather data on platform, evaluation of baseline risk and RBUI, developing of SOR guideline, developing of Data handover guideline and consolidation of all the research study into an integrated SIM framework for offshore platform.

In Chapter 4, the development of an integrated SIM framework for fixed offshore structure was discussed and presented. The chapter addressed all the objectives of this research. Various recommendations and suggestions were put forward with supporting arguments, with the specific purpose of solving the problem statement mentioned above.

In Chapter 5, four (4) case studies were presented, one for each objective mentioned, using actual data obtained from various local O & G operators. The case studies provide an understanding of the results in Chapter 4 by executing detailed analysis to support the recommendation and suggestions provided in this research.

In Chapter 6, the conclusions and recommendations of areas for future studies are presented.

1.7 Chapter summary

The chapter has discussed the significance of having an integrated Structural Integrity Management (SIM) framework for Malaysia fixed offshore structures. SIM is a continuous assessment process applied throughout design, construction, operations, and maintenance and decommissioning to assure that the structures are managed throughout its design life or beyond.

The main challenges to the O & G industry now are the increase of ageing fixed offshore structures. These in return, create various problems to the oil operators. The major problems are:

- No firm basis for relating traditional component based design approaches to structural system performance.

- Degradation of the fixed offshore structure due to its extended design life.

- Subsidence, which results in a decreased safety margin towards wave in deck loading.

- Lack of knowledge of the structure (e.g. drawings, steel type, welding procedures, inspection results and details about earlier repairs etc.).

This in return, results high uncertainty about the structures ability to withstand additional loading, compared to the uncertainty at the design stage of the structure. Therefore, a well-managed integrated structural integrity management (SIM) approach in this context would mean that the operator has detailed knowledge about the structure, inspection and repair results.

CHAPTER 2:

LITERATURE REVIEW

2.1 Introduction

Past research and advances made in Structural Integrity Management (SIM) are reviewed, summarized and commented. This helps to identify the knowledge gap in this particular topic and the problem statement for this master's project.

This literature review is organized into twelve (12) sub topics given below:

- General overview of the Oil and Gas (O&G) industry
- Analysis of United Kingdom Continental Shelf (UKCS) and North Sea oil production
- Analysis of oil production in Malaysia
- Evolution of American Petroleum Institute (API) design codes in the Gulf of Mexico (GOM)
- Impact of hurricanes to the existing fixed offshore platforms in the GOM
- Current SIM practices worldwide (mainly in the GOM and the North Sea)
- Risk based inspection (RBI)
- Risk based Underwater inspection (RBUI)
- Current SIM practices in Malaysia
- Review of data handover practices in the O&G industry
- Review of current SOR practices in the O&G industry
- Chapter summary

2.2 General overview of the O&G Industry

The offshore structure design adopted the component based design approach, yielding an end product that is a structural system. These individual components cannot be optimized in isolation without considering the overall impact on the system and the wide range of structures from shallow to deep water facilities. This design approach has been implemented from the first installed platform in the shallow waters offshore Louisiana some 60 years ago until now (P.E O'Connor, 2005).The estimated deep-water oil reserves for selected regions including West Africa, U.S., Brazil, West of Shetlands, and Norway exceed 40 billion barrels (Asia Classification Society), 2012

By considering the recent discoveries in deep-water areas such as South East Asia, West of Ireland, The Caspian Sea, Falkland Islands, Alaska and Canada's Arctic waters, Sakhalin Island waters, and Norway's and Russia's Barents Sea, the total deep-water oil reserves will be about 200 billion barrels. Since the other oil reserves are declining rapidly, these deep-water oil reserves can be expected to play an important role in the future of the world oil and gas energy. Although deepwater exploration is the way forward, the development and continuous production of shallow fields throughout the world is essential in maintaining the energy consumption of the world. Pulsipher et al (2001) forecasts a trend of 29% decline in the number of operating offshore structures in GOM over the period 1999-2023.

An analysis of Europe's oil production shows that both the United Kingdom (UK) and Norway oil and gas discoveries and production is declining. For the UK, the larger fields were evidently discovered in the early phases of exploration and were brought on stream first as shown in Figure 2.1. As these old fields' peak and head into decline, their place has to be taken by an increasing number of smaller fields which can sustain overall production for a limited period of time.

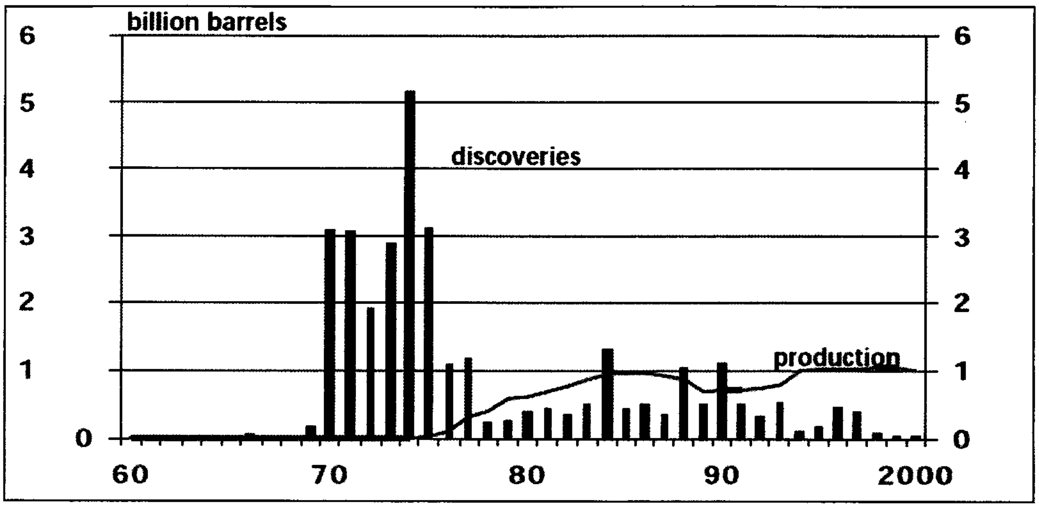

Figure 2.1: Oil discovery and production by year in UK
(PEPS, 2000; Zittel, 2001)

However the rate of new discovery of ever smaller fields cannot be maintained indefinitely and it is evident that the UK passed its peak in 1999, and that production is set to fall by about 60% over the next ten years (Zittel, 2001). The example of the UK demonstrates a pattern that sooner or later applies to all oil producing countries, given the finite nature of the resource. Figure 2.2 shows the average size of new fields discovered in the UK from the early 1960s.

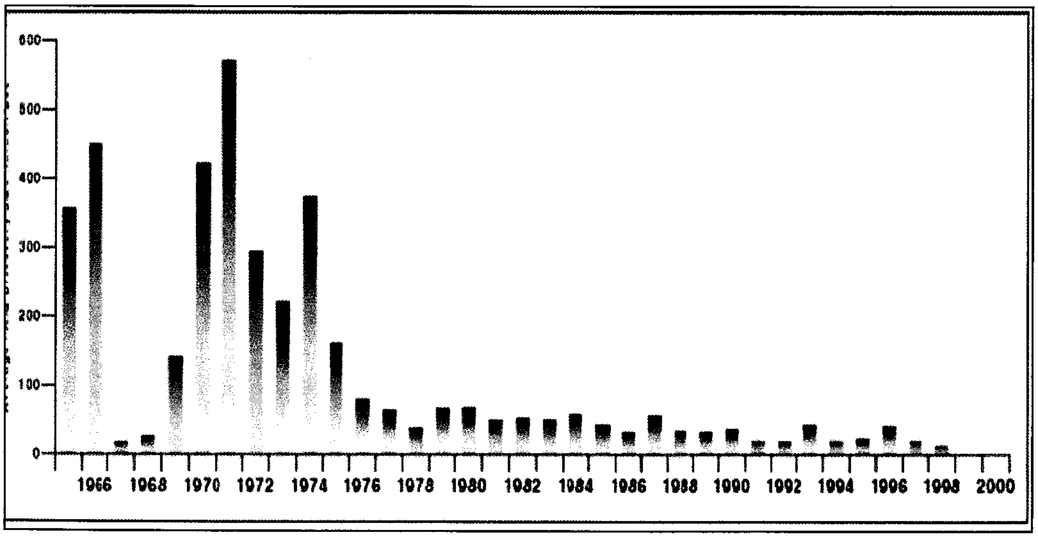

Figure 2.2: Average size of new field discoveries in the UK
(UKOOA Annual Report, 2000; Zittel, 2001)

2.3 Analysis of UKCS and North Sea Oil Production

An analysis of the total North Sea production shows that the general pattern mentioned above of depletion is to be found in every oil province, although there are naturally quantitative differences. It is also important to note that the pattern offshore differs from that of onshore. It follows that Norway will follow the UK example closely. It is likely to have an imminent peak, having been spared the effects of the Piper accident which distorted the UK profile, thanks in part to a more stringent safety regime (Zittel, 2001).

The present world situation differs markedly from the experience over the past century. Further production increases (if indeed they are possible) would consume huge efforts in bringing large numbers of small new fields on stream. Further production increases would be even counter-productive in the sense that they increase the oil dependence once again at the cost of increasing future depletion rate. But even to keep the present production level constant will need increasing efforts, year by year. It is only a matter of a short period until the increasing efforts are no longer followed by increasing new field developments. The analysis of Europe oil and gas production also highlights a significant finding. For each of the aging offshore field that is being exhaustively explored and producing, the aging of the offshore fleet itself is alarming. A study by the Norwegian Technical Institute (NTI) showed that the existing jackets in the North Sea area have typically been designed for a life of around 20 years (Ersdal, 2005).

Improvements in the possible oil recovery from several fields as mentioned above have increased the interest for using these structures well beyond their initial design life. Even if rather large reconstructions, repairs and inspections have to be performed, using existing installations beyond their design life will in many cases be economically preferable. A major concern in this regard is that requirements regarding safety should not be compromised.

Figure 2.3 shows the age distribution for installations in the UK continental shelf (UKCS) and the Norwegian continental shelf (NCS). It shows that a relatively large number of installations have passed 20 years (Ersdal, 2005).

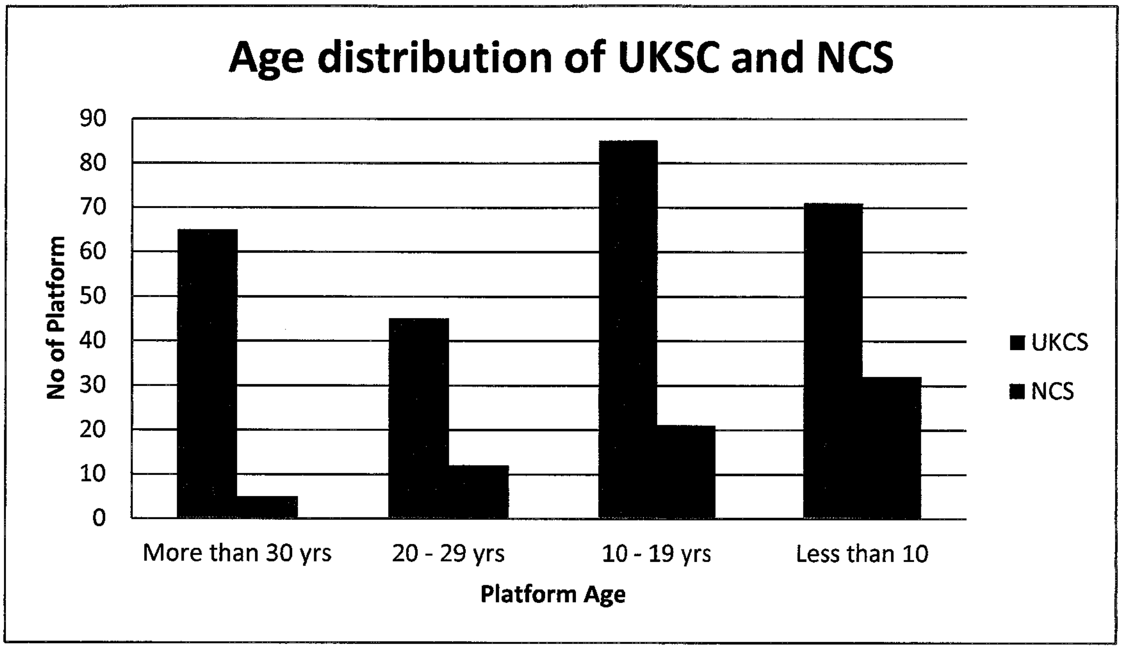

Figure 2.3: Age distribution of existing installations in UKCS and NCS (Ersdal, 2005)

2.4 Analysis of Malaysia oil production

There are about 200 platforms at present in Malaysia operated by various operators; hence there is a critical need for a systematic structural integrity management (SIM). Figure 2.4 shows the time line in the development of Malaysian O&G Industry. The first PSC contract was awarded to ESSO in 1976 and subsequently many fixed offshore structures were installed in Malaysia.

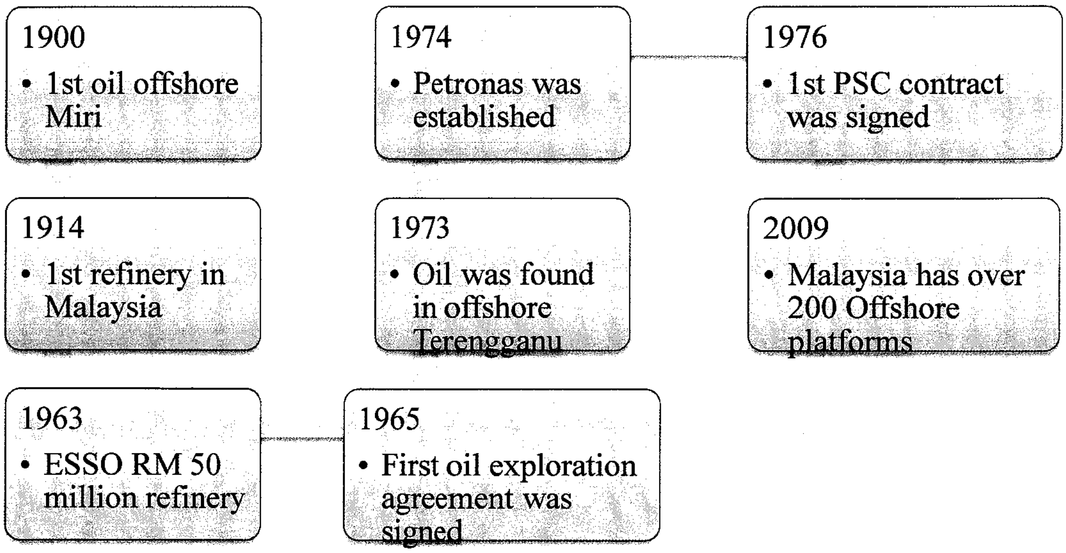

Figure 2.4: Timeline in the development of Malaysia's oil and gas (O&G) industry (Potty and Akram, 2009)

An analysis of total Malaysia's oil production shows that Malaysia is also facing a decline in oil production rate, where aging oilfields are still being exhaustively explored. Figure 2.5 shows the Malaysia crude oil production by year. The figure clearly shows that the crude oil production had peaked in 2004, and currently has been in decline for the past 8 years.

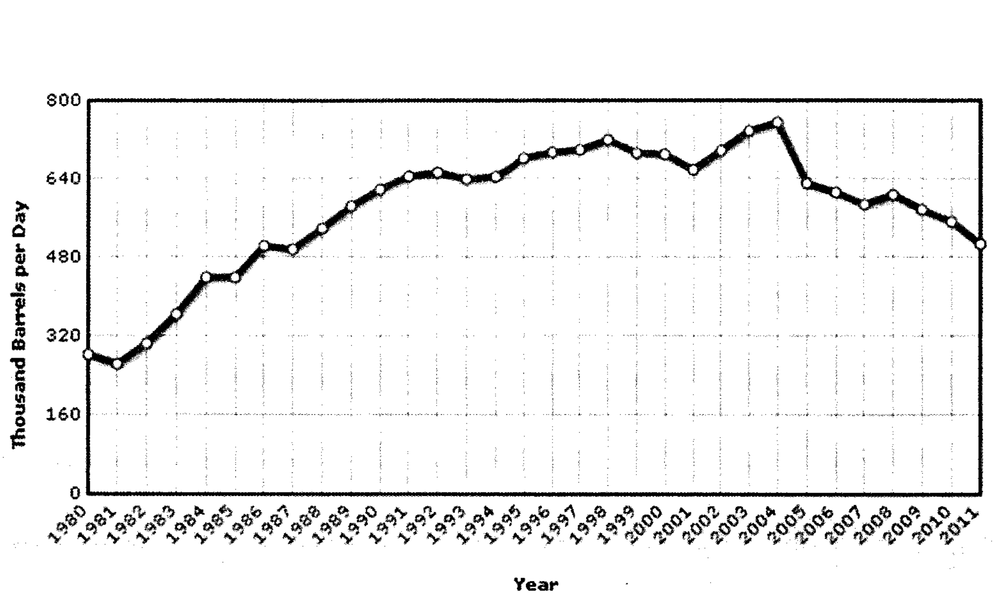

Figure 2.5: Malaysia's crude oil production by year (United States Energy Information Administration and indexmundi, 2012)

Furthermore, the daily production rate for Malaysia is in constant decline. Figure 2.6 shows that since year 2004, there has been a steady decline in oil production with the lowest daily production rate less than 700,000 barrels per day. This however, is not favorable as the demand for oil continues to grow rapidly in Malaysia and internationally. Figure 2.6 shows that the consumption rate for Malaysia has been increasing since 2001 and in future it is predicted that Malaysia will utilize all its oil production for domestic use.

This in return will result in Malaysia being a net importer unless current fields are maintained properly and new fields are explored and developed. Due to this and an increase in consumption of oil in Malaysia, the interest for using existing structures well beyond their initial design life has never been greater. Even if rather large reconstructions, repairs and inspections have to be performed, using existing installations beyond their design life will in many cases be economically preferable.

Knowing the importance of managing aging platforms, this study has undertaken the structural integrity review covering all the platforms in Peninsular Malaysia, Sabah and Sarawak. The types of platforms range from drilling, wellhead, production, gas compression, living quarter, vent and riser.

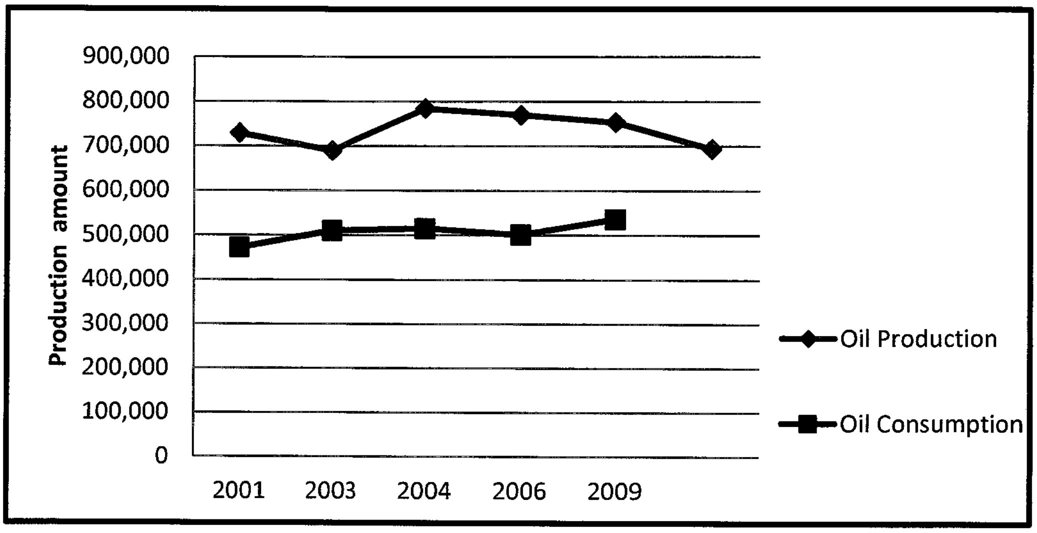

Figure 2.6: Malaysia oil production and consumption (bbl/day) (indexmundi, 2012)

2.5 Evolution of API design codes in the GOM

To better understand these aging structures, it is important to know the codes used to design the structures. Figure 2.7 shows the percentage wise distribution of the fixed platforms in the GOM at different periods of code development. Figure 2.8 shows the number of existing platforms including Caissons by age. Figure 2.9 and 2.10 shows the detailed evolution of API design codes.

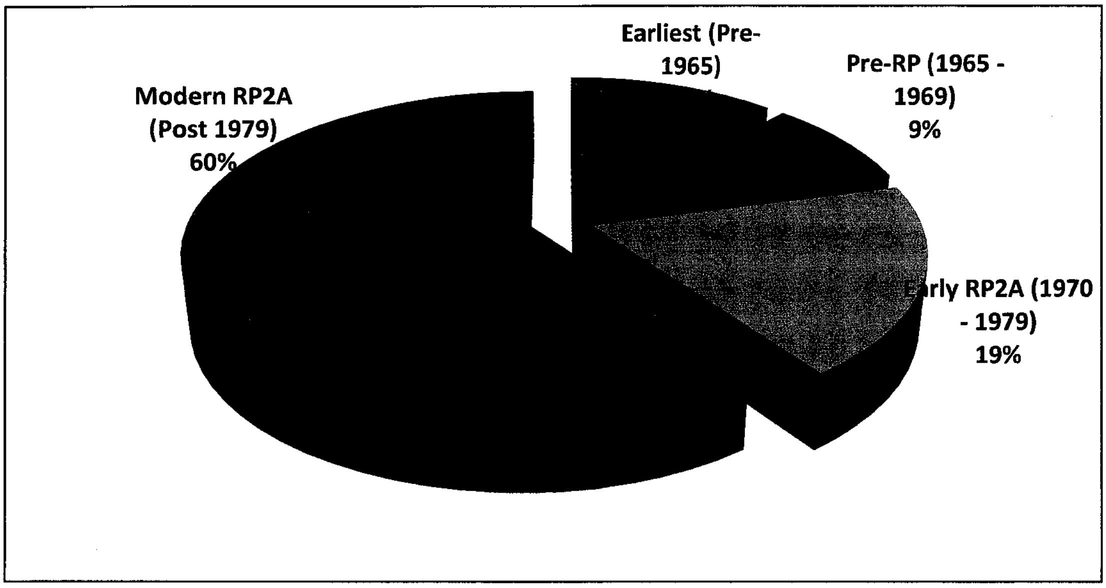

Figure 2.7: Percentage wise Distribution for Gulf of Mexico Fixed Structures at different periods of code development (Sadhu, 2006)

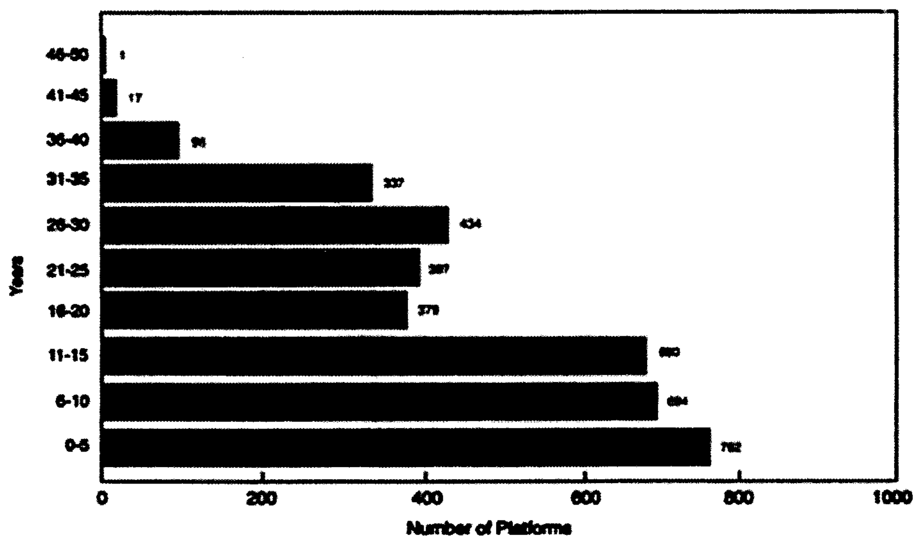

Figure 2.8 Number of existing platforms, including Caissons by age (Source: MMS and Committee, 1996)

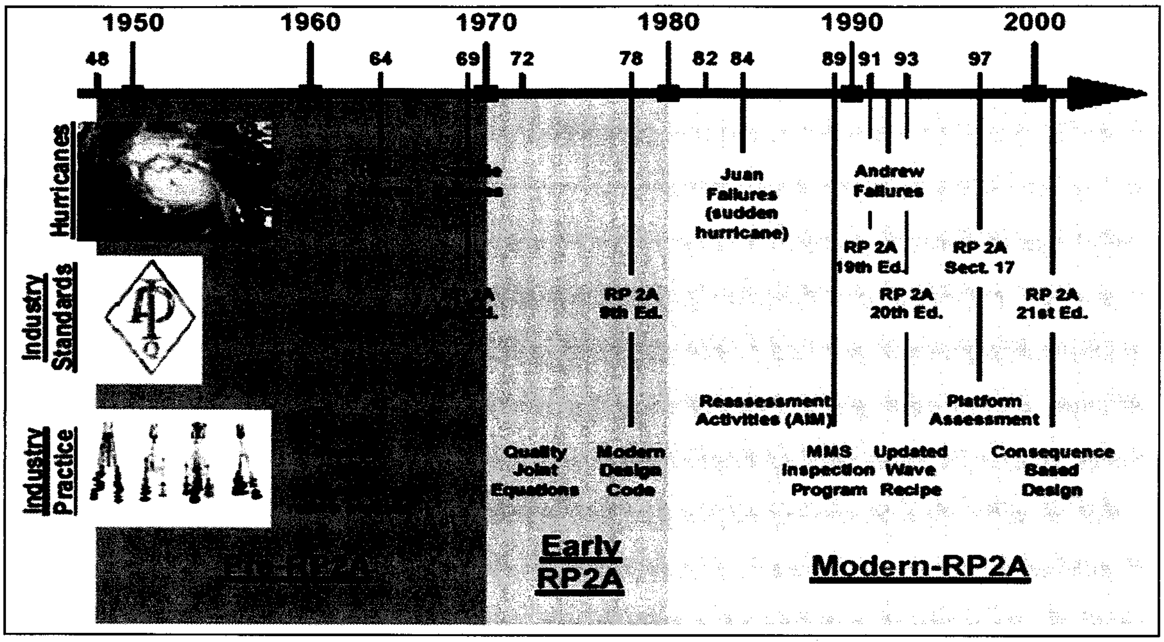

Figure 2.9: Evolution of API Design Codes (O Connor et al, 2005a; Puskar et al, 2006)

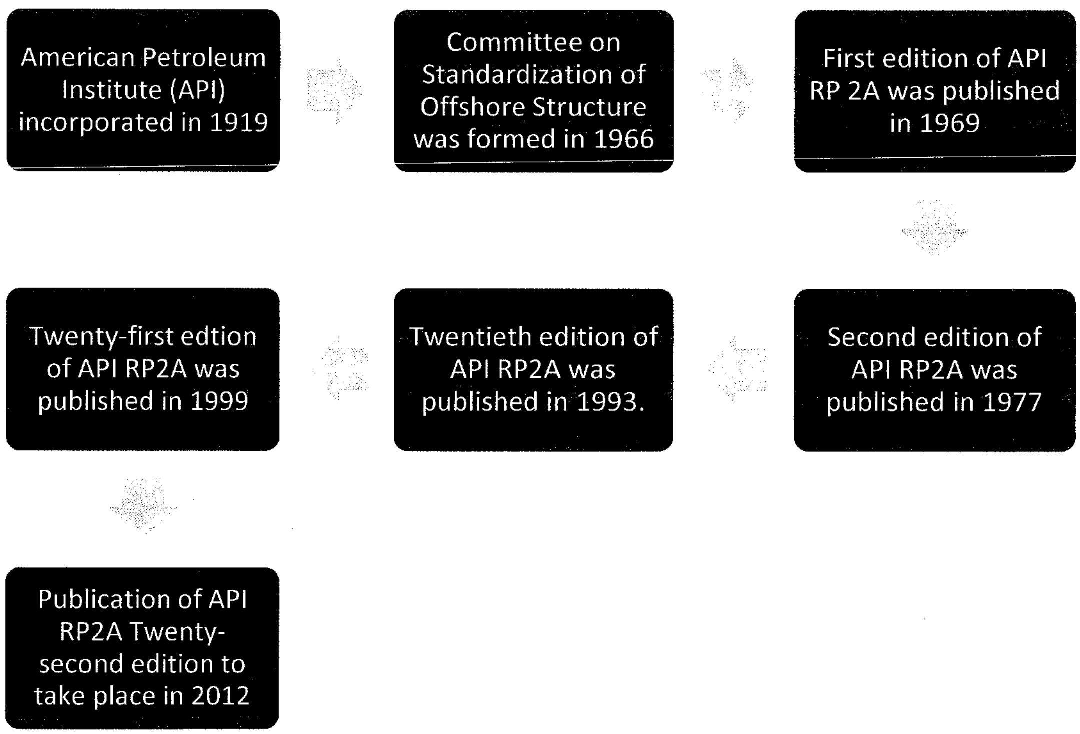

Figure 2.10: Detailed Evolution of API Design Codes

Thus it can be said that many of the GOM structures were designed using the earliest (12%) and Pre-RP American Petroleum Institute (API) design codes and practices (9%).

The differences between the Pre- RP2A codes and the current API RP2A code 21st edition are significant.

Drilling and production operations over waters started well over 100 years ago, usually carried out from decks supported by wooden piles, connected to shore by long piers. This solution was successfully replicated in diverse locations such as the coast of Louisiana, the Caspian Sea, and Venezuela's Lake Maracaibo (Andrea Mangiavacchi, 2005). The installation in 20 feet (6 m) of water off the coast Louisiana of a steel platform owned by Kerr-McGee and designed by Brown & Root in 1947, is generally accepted as the official birth of the offshore industry (Andrea Mangiavacchi, 2005). Today, production facilities in 6,000 feet (2,000 m) of depth have been developed. This proves that how technology and the industry have evolved since the 1950s.

The API, which was incorporated in 1919, was involved in all aspects of the oil and gas industry including exploration, production, transportation, refining and marketing. API's active involvement in offshore structures was in part prompted by Hurricane Carla (1961), Hilda (1964) and Betsy (1965), which caused varying degrees of damage to several offshore platforms (Andrea Mangiavacchi, 2005). Hilda exacted more damage on the offshore industry than any storm before it.

A category 4 hurricane, she made landfall near the center of the Louisiana coast. 13 platforms were destroyed, 5 more were damaged beyond repair, and losses were estimated at over USD100 million. From the post – Hilda investigation that was carried out, it was agreed that all except one of the platforms destroyed by Hilda had been designed to withstand a 25 year storm and it was recommended that operators use the 100 year storm design criteria as their standard design in future (Benfield , 2005). However, in 1965, during hurricane Betsy, eight more platforms were destroyed and many others were damaged (Benfield , 2005).

During the period 1946 – 48, GOM platforms typically had deck heights 6 to 12 meter above mean sea level. The consensus at that time was that a maximum wave height of 29 meter would occur every 40 – 50 years. This in turn indicated that the offshore platforms designed at that time were not fit for purpose since the design criteria could not withstand the maximum wave height. However, this estimation is without any guidelines and merely based on experience by the engineers at that time in the GOM.

In September 1948, Calco (another subsidiary of Standard Oil, which later became Chevron) nearly lost 50 men as a hurricane developed and intensified with minimal warning and their tender assisted drilling rig (TADR) was almost lost in high sea (Benfield , 2005). In October 1949, a platform off Freeport was damaged and post-mortem suggested that waves as high as 29 meters had occurred. Observed damage in others led to estimates of 6 to 9 meters of extreme wave height. This calls into question both the upper limit and frequency of occurrence of high waves in GOM.

The deck height designs for offshore platforms from 1950s onward varied from 9 to 10 meters above mean GOM level to higher than 15 meters. Not coincidently, those using higher values were companies directly impacted by storms either in terms of property or direct threat to employees. Conservatively, higher deck height designs meant safer and but more expensive platforms where each company placed a bet on the right combination of safety and cost. Hurricane Flossie, in 1956, caused widespread disruption to production in the GOM. A category 3 storm, she moved through facilities offshore on the western edge of Louisiana and caused the shut-down of several hundred producing wells and a halt in drilling operations (Benfield , 2005).

Nine months after Flossie, Hurricane Audrey gave a wakeup call, although despite being one of the worst storms in Gulf history she did relatively little damage offshore. Developing in June 1957 in the Bay of Campeche, she came ashore at Cameron, Louisiana: one (1) rig sank, four (4) were damaged and fortunately there was no loss of life (Benfield , 2005). After Flossie, three (3) more major hurricanes pounded the GOM; namely Carla (1961), Hilda (1964) and Betsy (1965).

Hilda and Betsy were both examples of 100 year storms (and were less than 12 months apart). API's active involvement in offshore structures was in part prompted by these 3 hurricanes (Andrea Mangiavacchi, 2005). These three hurricanes caused varying degree of damages to the GOM offshore platforms. Consultation with the industry at that time showed that the time was right to address the issue of consolidation and publishing adequate guidance and sound design criteria for the design of offshore platforms. The guidance and criteria was consolidated and published in 1965.

In 1966, API formed the "Committee on Standardization of Offshore Structures", which is responsible for developing the standards for the design and construction of offshore platforms, including standards for equipment packaging and arrangement (Andrea Mangiavacchi, 2005).

Since its inception, the original committee has seen many changes in its name, internal structure, responsibilities, composition, etc. Its size has varied from an initial 5 members to over 100, including various task force, work groups, resource groups and etc. The first task of this committee was to develop a recommended practice for design of fixed steel platforms. It took the committee three years to consolidate all the design practices for offshore platforms in the GOM and publish the 1st Edition of API RP2A in 1969. Important strategies outlined during the very beginning of the development effort were:

- To build on existing applicable engineering codes and guidelines, such as the American Institute of Steel Construction (AISC) and American Welding Society (AWS) specifications. API RP2A was intended to fill in the "gaps" where the two publications (namely AISC and AWS) primarily intended for conventional onshore structures, were not adequate for offshore platforms (Andrea Mangiavacchi, 2005).
- To use a Working Stress Design (WSD) approach, also referred to as Allowable Stress Design (ASD), reflecting the then prevalent US design practices (Andrea Mangiavacchi, 2005).

To fill in the "gaps" as mentioned above, three main areas of technology were identified to be included in the RP2A; environmental loads, foundations and tubular joints. In time and as technology evolved, other subjects such as fatigue, dynamics, material selection, welding, and grouted connections were deemed in need of special considerations for offshore platforms, and were progressively addressed in the API RP2A.

Changes were made to the design approach due to various incidents such as hurricanes which causes increased environmental loadings to the offshore platforms. Camille (1969) caused three (3) platforms to be destroyed and was one of the largest hurricanes to impact platforms in the GOM and contributed much to the development of API RP2A 1st edition (Puskar., 2007).

2.6 Impact of hurricanes to existing fixed offshore platforms in the GOM

It is important to note that the publication of API RP2A 1st Edition was no more than an auspicious beginning. Until the early mid 60-s, the offshore industry remained strongly focused on the U.S GOM. However, once API RP2A came into existence, the attention of the API committee was soon drawn towards the needs and special requirements of other domestic areas.

In the 1970's, RP2A further evolved and the platforms were tested by hurricanes Carmen (1974) and Frederic (1979). The 7th edition of RP2A was issued in November 1977 and contained the first industry accepted wave load "recipe" including the use of 100 year return period conditions and consistent hydrodynamic drag and inertia coefficients (Puskar., 2007). Table 2.1 shows the historical damage to offshore fixed platforms from hurricanes and the industry response until the 1970s.

Table 2.1: Historical damage to offshore fixed platforms from Hurricanes (Energo, 2006)

No.	Hurricane	Year	Platforms Destroyed	Industry Response
1	Grand Island	1948	2	Limited number of platforms in service
2	Carla	1961	3	No response from industry
3	Hilda	1964	14	Several operators start to use a 100 year return period design wave
4	Betsy	1965	8	No response from industry
5	Camille	1969	3	First API RP2A for fixed platform design
6	Carmen	1974	2	No response from industry
7	Frederic	1979	3	Wave load recipe provided in RP2A

However, after API RPA 7th edition, the API committee continued to evolve and in the 20th edition, published in 1993, presented a completely revised wave force formulation. These included additional terms in the traditional wave load formulation, and recommended using 100-year load conditions (rather than 100 year wave) as the basis for design (Andrea Mangiavacchi, 2005). In the same year, 1993, the 1st edition of the Load and Resistance Factor Design (LRFD) version of API RP2A made its long awaited appearance.

The API RP 2A WSD 21st Edition, issued in 1999, considered review of the ongoing process of globalization of the offshore structure industry standards. Hurricane Andrew tore through Florida and the Gulf of Mexico in 1992 and caused approximately USD 500 million of insured claims from offshore platforms and rigs – the losses were concentrated on structures in the shallow waters of Louisiana (Benfield , 2005). This presented a unique opportunity to “test” the API RP 2A design process by comparing platforms that survived, were damaged, or failed in hurricane Andrew against what API RP2A would have predicted.

A Joint Industry Project (JIP) was initiated that developed and implemented a probabilistic comparison process based upon Bayesian updating. The process indicated that the API RP 2A design approach results in a conservative platform design with about 10 to 20 percent margin (Puskar K. S., 2004) Puskar et al, 1994)-- prior to the application of factors of safety. With the normal factors of safety included, the conservatism would be much higher. The Andrew JIP was funded by over 20 organizations including the MMS. Hurricane Andrew provided a unique opportunity for such a comparison process.

However, one of the limiting factors was that only 13 platforms were used in the comparison process. Also, many of the platforms were in the same vicinity (South Timbalier), and of similar design (old Gulf Oil). Also at that time, API was in the process of developing API RP 2A Section 17, which establishes a procedure for the assessment of existing platforms. Wisch et al (2004) provides the background, classification and proposed updates to the Section 17. The paper discusses the background and perspective on why and how section 17 was originally developed. The Andrew JIP was used by the API Section 17 Task Group to test and calibrate the Section 17 process for assessment of existing platforms (Puskar K. S., 2004). (O’Connor et al , 2005)

In 2002, Hurricane Lilly damaged several platforms, including a few that were a complete loss. This provided a similar opportunity as Hurricane Andrew had to further study the API process and update the Andrew comparison with new platforms – particularly those of different location and design. Table 2.2 shows the details of the 10 platforms that were identified from visual inspection to sustaining significant damage from Hurricane Lili.

Table 2.3 shows the 7 platforms that were identified as sustaining significant damage from underwater inspection programs after Hurricane Lili. The underwater inspection that was carried out and subsequent findings of structural damage to the offshore platforms validated the rational by API RP2A and the MMS to undertake underwater inspections soon after an extreme event.

Table 2.2: Platform with Significant Damage from Hurricane Lili based on Visual Inspection

(Puskar, Ku & Sheppard, 2004)

Area	Block	Description of Platform Damage
EI	215	Installed in 1983 in 98 feet of water. Damage includes a visible lateral deformation and the platform was removed.
EI	231a	Installed in 1968 in 111 feet of water. Damage includes a visible lateral deformation and the platform was removed.
EI	231b	Installed in 1971 in 106 feet of water. Heavy damage was visible without underwater survey
EI	273	Installed in 1970 in 191 feet of water. Underwater survey post-Lili identified four damaged k-nodes in the transverse framing rows. Also impact damage to a vertical diagonal was identified. Clamp repairs were planned for this structure
EI	275	Installed in 1964 in 172 feet of water. This platform was destroyed (toppled) by Hurricane Lili.

Table 2.2 – Continued

Area	Block	Description of Platform Damage
EI	295	Installed in 1972 in 211 feet of water. Evidence indicates a wave crest 5 feet above the cellar deck during Hurricane Lili. Damage to the jacket includes a severed leg, damaged k-node and three damaged vertical diagonals all in the same vertical row near El. (-) 33'. This platform has been abandoned.
EI	309	Installed in 1969 in 218 feet of water. This platform was destroyed by Hurricane Lili.
EI	314	Installed in 1973 in 235 feet of water. A boat landing became detached during the storm and its fall collapsed some vertical diagonal braces. This damage could only be detected by underwater survey.
EI	322	Installed in 1978 in 235 feet of water. A fabrication flaw led to the failure of a leg/pile connection weld. This led to severe damage to the platform which was stabilized, decommissioned and removed.
EI	324	Installed in 1990 in 260 feet of water. MMS indicates that the platform damage was severe enough to require removal

Table 2.3: Platform with Significant Damage from Hurricane Lili based on Underwater Inspection (Puskar, Ku & Sheppard, 2004)

Area	Block	Description of Platform Damage
EI	176	Installed in 1958 in 80 feet of water. Damage to skirt pile framing (cracks) necessitated the removal of this platform. This damage could only be detected by underwater survey.
EI	276	Installed in 1971 in 172 feet of water. Post-Lili underwater survey identified damage to a vertical diagonal through the splash zone and leg severance near El. (-) 22'. This damage was repaired by member replacement and leg grouting.
EI	330a	Installed in 1971 in 244 feet of water. Post-Lili underwater survey identified heavy damage.
EI	330b	Installed in 1971 in 248 feet of water. Post-Lili underwater survey identified heavy damage.
EI	337	Installed in 1982 in 268 feet of water. Post-Lili underwater survey identified heavy damage.
SS	204	Installed in 1968 in 100 feet of water. Post-Lili underwater survey identified crack indications in conductor guide framing members at the (-) 25' elevation
SS	269	Installed in 1965 in 170 feet of water. Post-Lili survey identified 8 broken or missing vertical diagonal members.

Hurricane Ivan was the strongest hurricane of the 2004 Atlantic hurricane season. Hurricane Ivan was formed on 2nd September 2004 and dissipated on 24th September 2004. The highest wind speed that was recorded during Hurricane Ivan was 270 km/hour. It passed on the north-northeast path striking the Florida-Alabama coast on Sept. 15, 2004. The hurricane smashed 150 platforms and 10,000 miles of pipelines.

At the peak of the storm, the data obtained by the National Data Buoy Centre recorded a significant wave height of 16 m. Given the duration of the storm and a significant wave height of 16 m, the maximum wave height was recorded at approximately 27 m. A total of seven structures were destroyed by Ivan, namely:

- Two braced caisson
- Four typical jacket structures in 76 m of water
- One typical jacket structure in 145 m of water

The details of the seven structures are shown in Table 2.4.

Table 2.4: Platform Damaged by Hurricane Ivan (modified from Puskar et al., 2006bgilbert)

No	Area	Block		Water Depth (m)	Year Installed	Exposure Category	Deck height	Structure Type	Damage Category
1	MC	20	A	142.5	1984	L1	15	8-P	Destroyed
2	MP	98	A	23.7	1985	L1	18	TRI	Destroyed
3	MP	293	A	74.1	1969	L2	14	8-P	Destroyed
4	MP	293	Sonat	69.6	1972	L2	13	4-P	Destroyed
5	MP	305	C	73.2	1969	L2	14	8-P	Destroyed
6	MP	306	E	76.5	1969	L2	14	8-P	Destroyed
7	VK	294	A	35.7	1988	L2	10	B-CAS	Destroyed

At least six additional platforms sustained major damage. Examples of major damage include bent structural supports, collapsed rig derricks, severely damaged production vessels and piping, overturned helicopter decks, and collapsed living quarters. The two braced caissons that were destroyed were installed in 1985 and 1988 respectively. The depth of one of the caisson was 80 ft and the other was 120 ft. Four of the platforms destroyed, installed between 1969 and 1972, were in water depths between 232 and 255 ft with deck heights between 40 ft and 46 ft. All these platforms were designed based on the requirements of earlier editions of API RP 2A.

API released the third edition of RP 2A in 1972. Analysts believed that the failure of the eight-pile fixed platform installed in 1984 in 479 ft of water was due to mudslide movement in conjunction with the direct effects of Ivan. The intensity of the soil movement during Ivan exceeded expectations. After Ivan, API set up a committee whose charge was to reorganize RP 2A. New platforms will continue to be addressed in API RP 2A. Those sections of the current edition of RP 2A associated with the assessment of existing platforms i.e. Section 17 of API RP2A will form the basis of a new API publication RP2 SIM (Structural Integrity Management) (O'Connor et al, 2005).

In addition, API had removed some sections of RP 2A associated with specific design requirements, such as fire and blast, creating a third API standalone document. This reorganization will result in a risk management perspective in managing offshore platforms and also includes lesson learnt from Ivan.

MMS hosted a workshop in September 2003 on the "assessment of existing offshore structures". The discussion centered on the MMS Notice to Lessees NTL No: 2003-GIS (O'Connor et al 2005; MMS, 2003). NTL set out a time table for operators to conduct platform assessment in accordance with the provisions of API RP2A 21st edition. The workshop acknowledged that Section 17 provides important and robust process to determine the fitness-of-purpose of existing platforms. But it identified several areas where greater clarity was required. A long term need for separate API code for structural integrity was identified namely API RP2SIM (O'Connor et al, 2005).

Hurricane Katrina formed over the Bahamas on 23rd August 2005, and crossed southern Florida as a moderate Category 1 hurricane, causing some deaths and flooding there before strengthening rapidly in the Gulf of Mexico. It dissipated on 30th August 2005. The highest wind speed that was recorded during Hurricane Katrina was 280km/h. Hurricane Rita was formed on 17th September 2005 and dissipated on 24th September 2005. The highest wind speed that was recorded during Rita was 285km/h. It was also the fourth-most intense Atlantic hurricane ever recorded and the most intense tropical cyclone ever observed in the Gulf of Mexico (Robin-McCaskill, 2006).

The consequence of Hurricane Katrina on structural integrity failure was devastating. The normal production in the Gulf of Mexico was 547.5 million barrels of oil and 3.65 trillion cubic feet of gas per year. In preparation for Hurricane Katrina, 17.1 million barrels of oil and 84.2 billion cubic feet of gas were shut in. The production of oil in the

Gulf of Mexico fell by 1.4 million barrels a day. This accounted for 95% of the daily production of oil. The equivalent of 3.4 billion cubic feet of natural gas per day was shut in. This is over 34% of the daily production of natural gas in the Gulf of Mexico. Two weeks after Hurricane Katrina struck the Gulf of Mexico over 120 Oil and gas platforms were still shutdown.

Figure 2.11 shows both the paths of Hurricane Rita and Katrina. The orange dots are denoting mobile rig locations and the grey dots are denoting all fixed manned platforms. Due to the combination of the more westerly path of Hurricane Rita and the width of Hurricane Katrina most of the 2900 platforms in the Gulf of Mexico were affected. By September 11th, 60% of off-shore oil production was working. The reports officially were that approximately 150 rigs were severely damaged though at least 500 of them were not inspected. 36 rigs were sunk and several were floating free, having broken moorings (Robin-McCaskill, Natural Disasters and Oil: The Effect of Hurricane Katrina on Oil production in the Gulf of Mexico, ,2006).

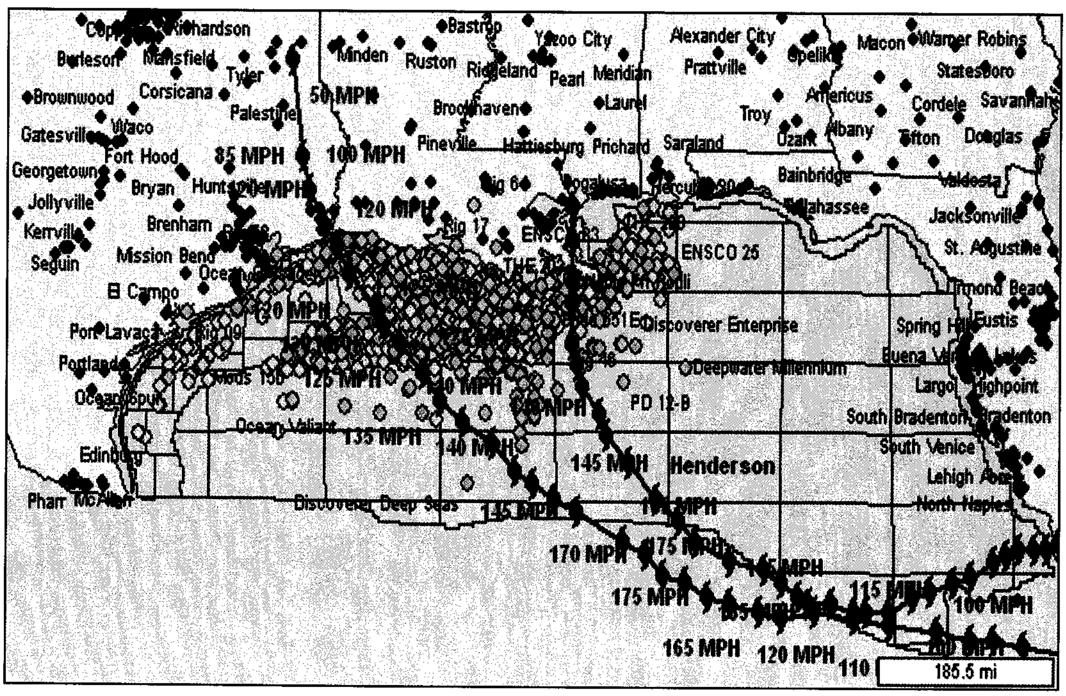

Figure 2.11: Path of Hurricane Rita and Katrina and location of fixed platform (Robin-McCaskill, 2006).

Figure 2.12 shows the summary of hurricane damages due to Ivan, Katrina and Rita. It can be observed that 118 offshore platforms were destroyed in the three (3) hurricanes that were discussed above. The most costly hurricane that has hit the GOM is Hurricane Rita. Hurricane Rita destroyed more platforms compared to Hurricane Ivan and Katrina.

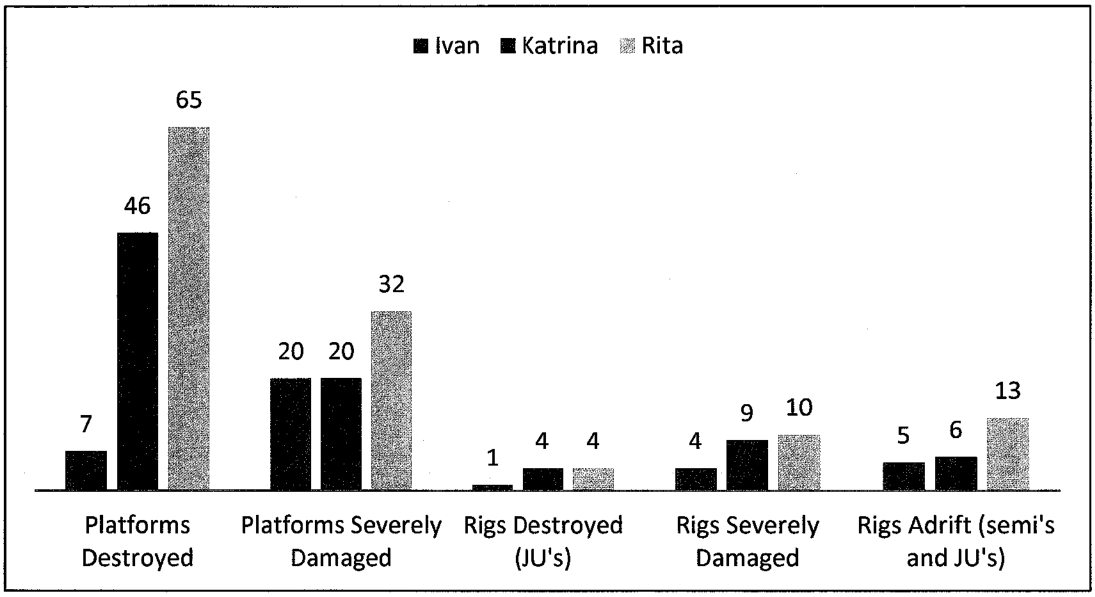

Figure 2.12: Summary of damages due to hurricanes Ivan, Katrina and Rita

Wisch (2006) observed that the impact on offshore oil facilities of the Hurricane Ivan, Katrina and Rita was to an extent never seen before. The shallow water facilities, dominated by fixed platform, exhibited much more damage than the deep-water facilities.

API Bulletin 2HINS (short form for Hurricane INSpection) (2009) was published to compliment the several API Recommended Practices that provide only general and limited guidance by providing additional guidance specific to structural inspection following hurricanes. Timely and cost effective inspection of offshore structures following a hurricane is critical in order to safely re-man the facilities and bring production back on line (Puskar and Spong, 2010).

API RP 2SIM (Ballot Draft) document is under consideration. It contains 12 sections consisting of scope, normative references, terms definitions and acronyms, SIM overview, SIM processes, surveys, damage evaluation, structural assessment process, assessment criteria and loads, mitigation and risk reduction and platform decommissioning. The key concept of the proposed RP will be Risk based inspection strategies; which will require the engineer to understand the platform's likelihood of failure and consequence of such a failure. Alternately RP2SIM will provide for the first time for the engineers the fitness-of-purpose acceptance criteria against platform's ultimate load capacity, measured as the Reserve Strength Ratio (RSR) (Westlake et al, 2006; De Franco et al, 2010).

2.7 Current SIM Practices Worldwide

Committee (1979) is the earliest discussion on the requirement of inspection after the platform installation on the OCS.

Bea et al (1988) presented the AIM (Assessment, Inspections and Maintenance) program developed for fixed and mobile platform in the GOM prior to the introduction of the section 17 of API. It outlines the general approach for re-qualifying platform. It is the product of a series of joint industry and government sponsored projects conducted since 1966. It aims at non-prescriptive integrated engineering approach to requalification of existing platform. A prescriptive approach was not preferred because there are different and workable engineering procedures to AIMS program. The AIMS approach is shown in Figure 2.14.

The three principal elements of the AIM approach are (A) Assessment, (I) Inspection and (M) Maintenance. The Assessment or Screening phase consists of the selection of a candidate platform based on its defect and consequence potentials, performing a condition survey to determine its present condition, then determining if the structure has significant defects that warrant mitigation. The second phase is a detailed evaluation phase that is entered if it is determined that there are potentially significant defects that need remedial measures. Various alternatives for making the platform meet serviceability requirements are identified and evaluated. The best remedial alternative is selected based on acceptability criteria. The third phase is an implementation phase that is initiated by designing or engineering the remedial alternative, implementing it, recording the results, and then defining the next AIM cycle (Bea et al, 1988).

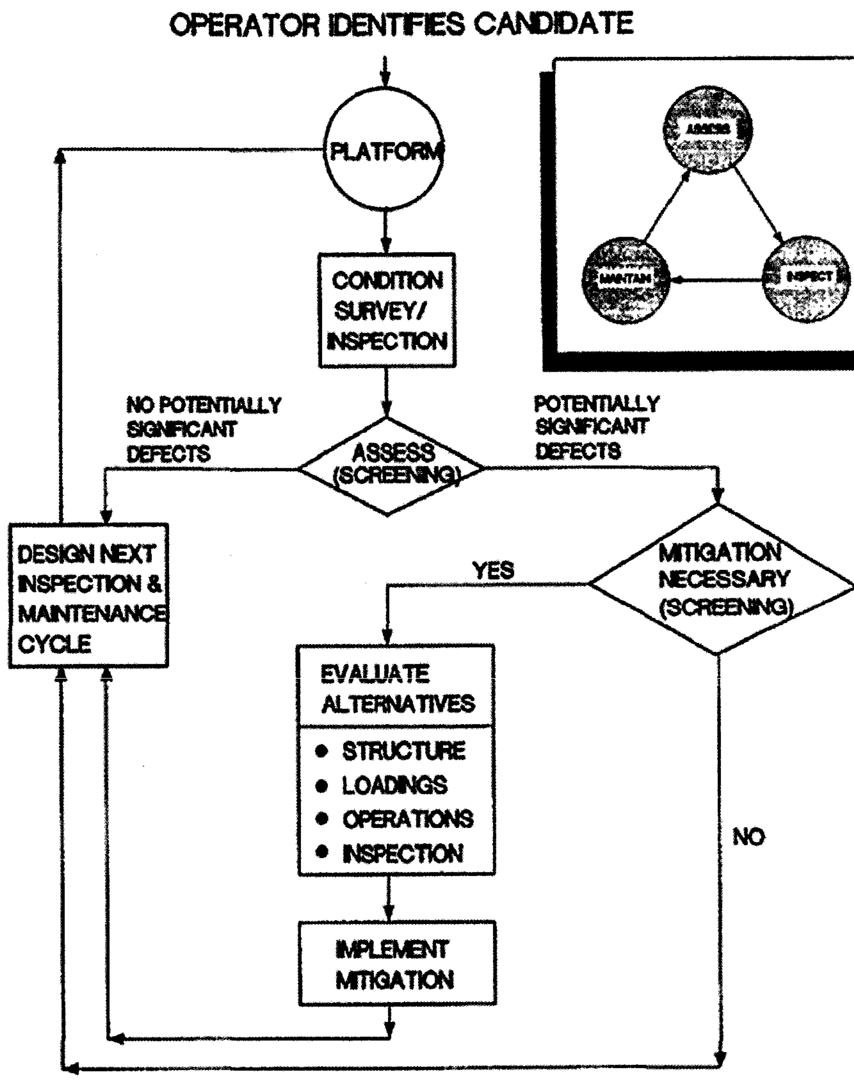

Figure 2.13: AIMS Process (Bea et al,1988)

Kallaby and Connor (1994) highlight the need for assessment of ageing platform in the Draft Section 17 of API RP2A – WSD. Although platforms maintenance has been ongoing for decades, it lacked uniformity, consistency and an integrated approach for

Planned Maintenance. Kallaby and Connor (1994) outline such an approach, discuss the essential elements of a planned maintenance program, provides guideline for survey planning and assessment of damage and presents the damage threshold guidelines. This was based on work carried out by Amoco in the North Sea. An example of 20 year plan for underwater survey is shown in Figure 2.15. The key elements of planned maintenance include 1. Assessment, 2. Survey and 3. Data Management.

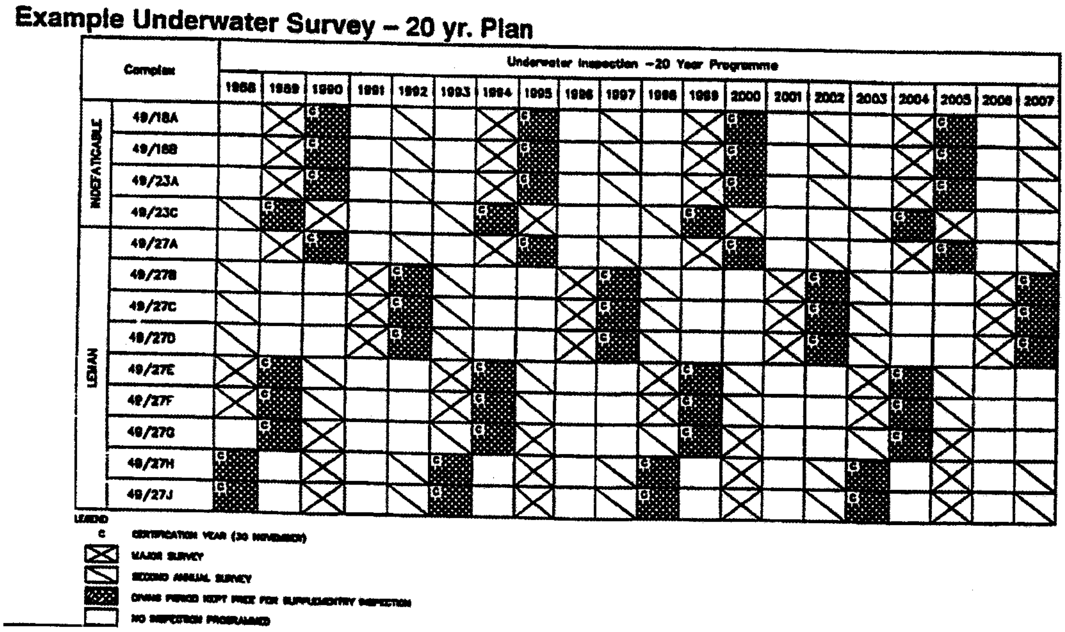

Figure 2.14 Example of Underwater Survey – 20 year plan (Kallaby and Connor, 1994)

Descamps et al (1995) stated that underwater inspection, repair and maintenance (IRM) of the platform jacket consumes a major proportion of the overall maintenance budget and consequently any reduction in this area is likely to have significant impact on the overall costs. All offshore platforms are inspected regularly to ensure structural integrity and satisfy strict statutory requirements. Expensive diver times have reduced with new technical advances like ROV capability. It is recognized that inspection costs could be further reduced by combining the advances with more rigorous planning philosophy, the SIM being to reduce the total amount of inspection activity while improving the effectiveness of the work. Methods are being developed to target inspection at areas of greatest criticality on a sound scientific basis by ranking components and defining the most appropriate inspection methods and optimum inspection intervals for a given structure. The paper reports the results of a survey carried out to explore the use of probabilistic technique for inspection planning within the offshore industry. Of 34 enquiries to oil and gas operators, 12 written answers were obtained and 16 people were successfully contacted over the phone. It was established that most of the operators in the UK North Sea do not use probabilistic techniques for inspection planning because of their complexity, lack of flexibility and cost. Traditional methods for inspection planning which are qualitative are used. They are based on engineering judgment, inspection history, fatigue life data, redundancy data and certification requirements.

The techniques used for inspection planning can be divided into a number of categories. Fig. 2.16 summarizes the options available, from relatively straightforward qualitative approaches, to more complicated quantitative ones. Qualitative approaches are based on engineering judgment and experience. Quantitative approaches are based on more scientific deterministic or probabilistic techniques, but maintain some qualitative input. The degree of complexity and reliability of the overall inspection planning approach depends on the balance between qualitative and quantitative input. New and improved strategies for optimizing the inspection planning of offshore structures are usually based on scientific quantitative analysis, as opposed to the traditional approach which relies heavily on qualitative judgment.

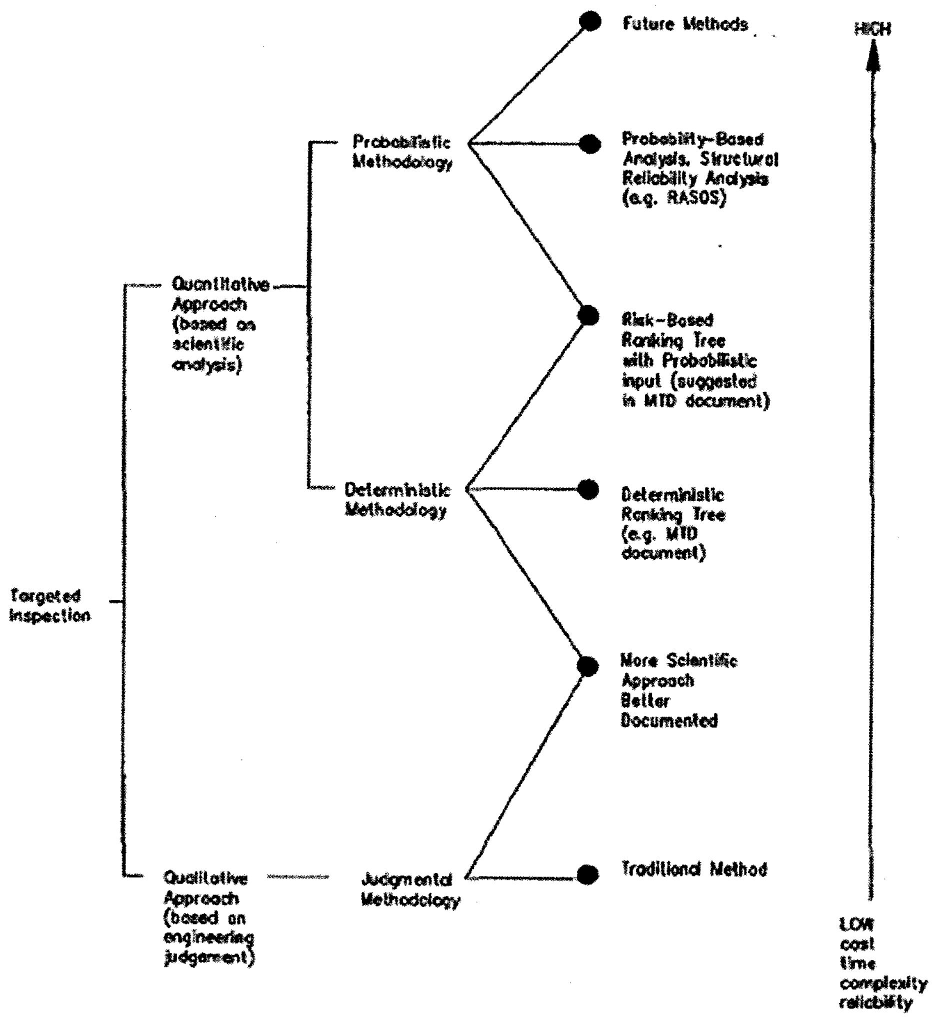

Figure 2.15: Different techniques used for inspection planning (Descamps et al., 1995)

A three-part inspection planning strategy is proposed to develop the inspection program (i.e. methods, frequency and selection of components for inspection). This approach includes: (1) Overview of the structure, (2) Quantitative risk-based ranking tree system, and (3) Development of the inspection program. The overview of the structure includes the assembly of available data and a qualitative evaluation of the jacket design, fabrication, installation, operations and IRM. This exercise will point out strengths and weaknesses of the structure and will highlight areas of concern for a more detailed quantitative analysis. The risk-based ranking tree system which identifies high risk structural components and ranks them in order of inspection importance is the second stage in the process.

The analysis starts with the compilation of an inventory of members and welded joints eligible for inspection, their potential failure effects and failure modes. Event trees represent graphically how the structure would respond to member failure and fault trees analyze the most likely mechanisms of member failure. An initial evaluation of the consequences of failure of each member is then carried out using redundancy data and engineering judgment. If no scientific evaluation of the importance of each component to structural integrity is available, a redundancy analysis should be performed. Only members defined as having significant consequences of failure are analyzed further. Their financial consequence of failure, probability of failure and overall risk is calculated using theory, existing data and engineering judgment. The third stage seeks to determine the optimum inspection program for members and welded joints and different options may be investigated (Different inspection sample sizes, methods and frequency). Using results of the risk-based ranking tree analysis and expert engineering judgment, candidate inspection strategies can be compiled. The most cost effective inspection strategy will then be selected in terms of expected financial risk and cost of inspection, including discounting if required.

One of the prime aims of inspection is to detect early signs of failure in order to take actions before serious consequences develop, therefore feedback from inspections and associated actions will affect component likelihood of failure and consequently risk of failure. In order to compare the candidate inspection strategies, the failure probabilities will need to be updated with the assumption that inspection will take place. Finally it will be possible to determine the best compromise between risk and inspection effort. In order to assist the development of the inspection planning methodology, the probabilities and costs of failure should be assembled on a computer spreadsheet, where they could be stored, modified and combined easily. Inspection results should continuously update the inspection planning process, using the spreadsheet.

The concept of expected cost, or risk, can be used to rank the components for inspection planning purposes. The expected cost of component failure is given by the probability of failure multiplied by the estimated cost of failure and can be regarded as the annual average cost incurred through failure of the component over a long period of time. Based on this concept, the proposed risk-based ranking tree system seeks to quantify the probabilities and financial consequences of failure of individual structural components and identifies the members and welded joints with the highest inspection priorities. The components eligible for inspection may include all underwater and splash zones jacket framing members and joints, plus the important conductor guide framing members and joints. However, the risk based ranking tree system primarily analyses the failure of structural members and not welded joints, for three reasons: (1) there are fewer members on a structure (2) it is easier to assess the consequences of member failure, and (3) using a reliability analysis software package (e.g.RASOS) since the increase in use of new inspection techniques, such as FMD and visual survey by ROV, subsea inspection has been moving towards assessment of members rather than joints.

An estimation of the overall risk of failure of the structure can be obtained by summing the risks of the critical members. This is only an estimate as components not critical to the integrity of the installation are not considered. The overall risk of failure will be used to compare candidate inspection programs.

It could be useful to compare different inspection strategies such as: (1) traditional re-certification program, (2) strategy where no subsea inspection at all is undertaken, and (3) strategy based on the results of the proposed risk-based ranking tree system. Figure 2.16 shows a possible graphical solution where these three inspection strategies are compared.

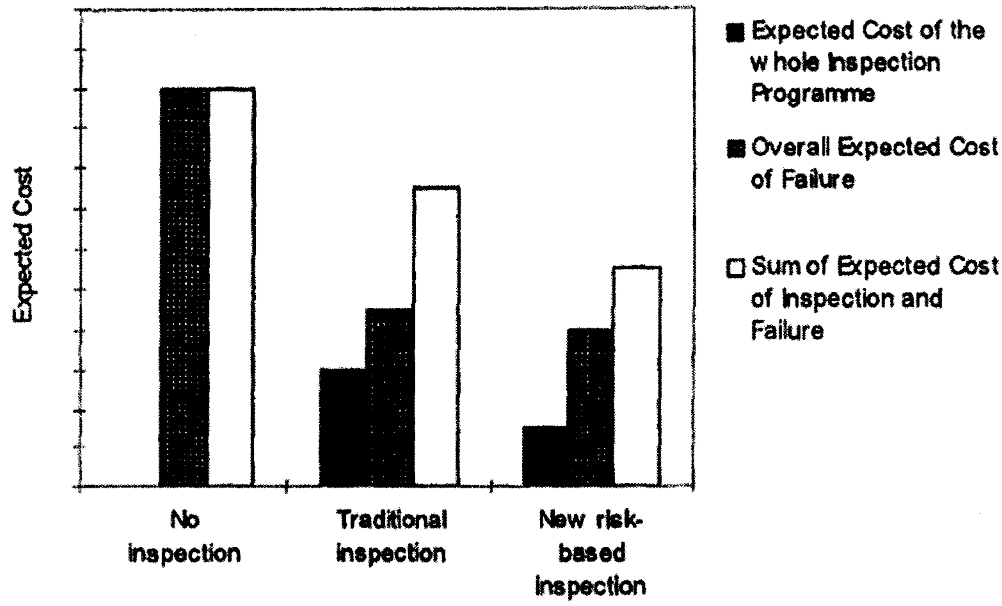

Figure 2.16: Comparison between inspection strategies (Descamps et al., 1995)

Barton and Descampes (2001) presents the methodology developed for RBI for 14 steel jacket structures located in the Bass Strait in Australia.

Landet et al (2000) presented the risk based inspection planning (RBI) analysis of the Jotun FPSO hull and topside structures which developed the basis for in-service inspection program for fatigue cracks. The work had the following steps: (1) initial risk screening to identify critical areas and summarize the fatigue lives for critical details in the structure (2) Establish the consequence of possible fatigue cracks and repair strategy in close co-operation with the operator (3) Establish the cost of inspection and repair of fatigue cracks, (4) Perform probabilistic crack growth analysis for number of representative welded connections, (5) Establish a cost optimal inspection strategy for different details, (6) Finally a cost optimized inspection schedule is established for the various areas and welded details of the structures.

ABS (2003) contains technical requirements and criteria employed by ABS to consider alternate survey arrangements using RBI approaches for offshore installations. The document is applicable to structures for offshore floating and fixed base platform.

ABS (2000) discusses the different risk assessment methods and the process of risk assessment. The different hazard identification methods, frequency assessment methods and consequence assessment methods are described. An overview of different risk analysis methods are given namely Preliminary Hazard Analysis (PrHA), Preliminary Risk Analysis (PRA), What-if checklist analysis, Failure modes and effects analysis (FMEA), Hazard and Operability Analysis (HAZOP), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Relative ranking / risk indexing, Coarse Risk Analysis (CRA), Pareto analysis, Root cause analysis, Change analysis, Common Cause Failure Analysis (CCFA) and Human error analysis.

Truchon et al (2007) stated that RBI methodologies had been developed for the Hull part and process part of the FPSO's. The approach developed for RBI of topsides is described. A qualitative approach was used due to the large variety of component types. An overall inspection plan is provided for all structural components of the topsides process modules: basic modules, pipe rack modules and manifolds. The approach developed considers fatigue cracking at welded connections in the structure as the main damage mechanism. Probability of detecting such cracks is assessed considering the use of adequate NDT techniques. Consequence is considered from the point of view of safety to personnel, environmental impact and production impact. The risk so determined is used to derive the inspection interval.

NORSOK (N006)(2008) developed by the Norwegian Petroleum industry gives the requirements for the assessment of the structural integrity of offshore structures in-service and for life extension. N001 Integrity of offshore structures (which refers to ISO 19900) is the principal standard dealing with integrity of offshore structures.

Sorenson and Ersdal (2008) discuss the application of Bayesian approach in risk and reliability based inspection. This implies that probabilities of failure can be updated in a consistent way when new inspection information becomes available.

API initiated the risk based inspection project in May 1993 with industry sponsorship (which included AMOCO) with specific aim to develop practical methods for RBI (API 581, 2000). The Base Resource Document (BRD) mainly deals with the qualitative analysis that allows operating units to be quickly prioritized using a 5x5 risk matrix which rates it from lower to higher risk. Guidelines are provided to develop and modify an inspection program to appropriately manage the risks that have been identified. A simple method is presented for categorizing inspection effectiveness and estimating the probability that the inspection plan will identify the true damage state in a piece of equipment. The effects of alternate inspection plans and an approach to develop an inspection program are presented.

The current SIMS approach to managing life extension of fixed offshore platforms is widely used in the GOM and North Sea. Various established operators such as Exxon Mobil and BP are currently implementing SIM strategy in ensuring the fitness for purpose of their fixed offshore platforms (Fraser, 2007). Exxon Mobil is facing the same problem as various operators worldwide which is ageing offshore fleets. Figure 2.17 shows the location of EM Operated Fixed Offshore Platforms as of end 2006.

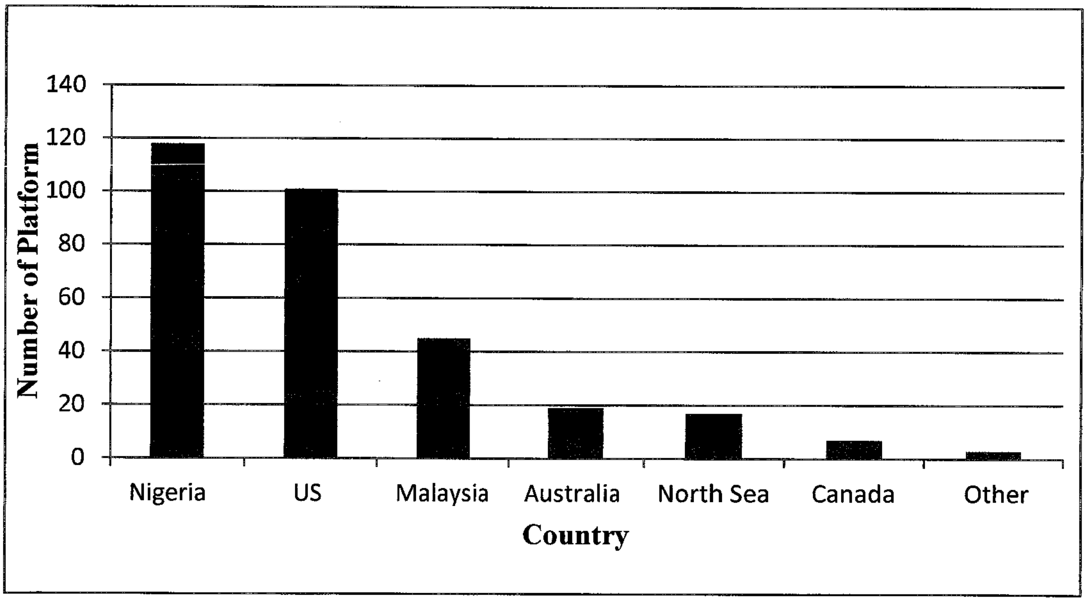

Figure 2.17: Location of EM Operated Fixed Offshore Platforms as of end 2006 (Fraser, 2007)

EM which is operating in 7 continents with approximately 400 fixed offshore platforms. The age distribution for these facilities is shown in Figure 2.18. It can be concluded that nearly 50% of ExxonMobil's fleet have exceeded 20 years of design life.

As for its North Sea facilities, eight (8) of its fixed offshore platforms is approaching the end of its design life.

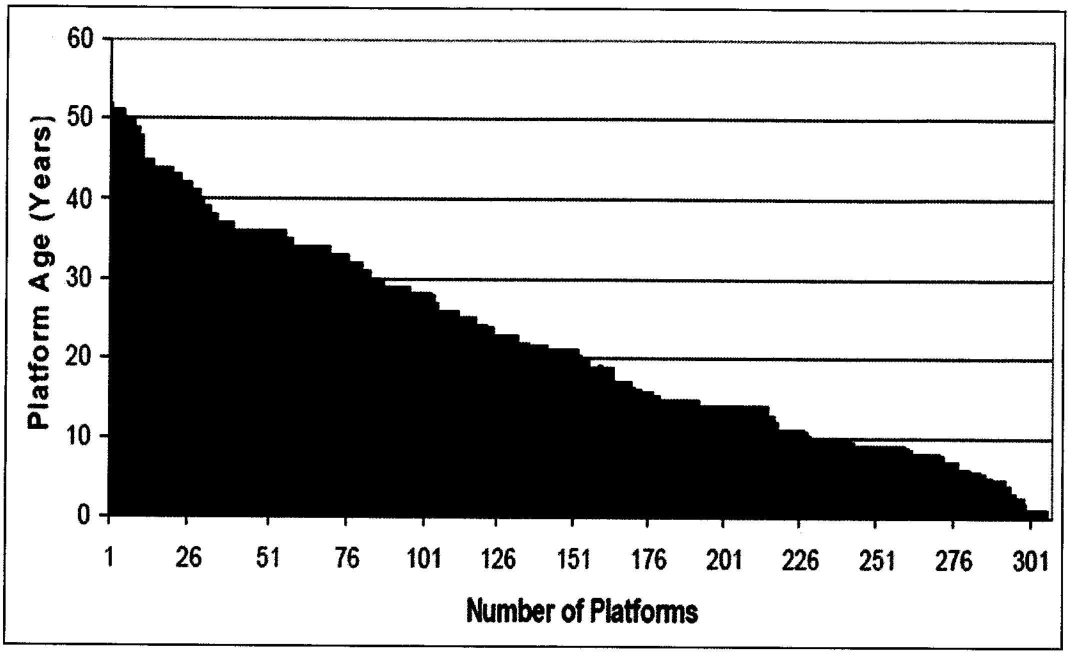

Figure 2.18: Age Distribution of ExxonMobil Operated Fixed Offshore Platforms (Fraser, 2007)

Table 2.5 shows the summary of EM North Sea assets. In order to continue maintaining these ageing facilities, ExxonMobil embarked on a platform life extension philosophy by implementing the SIM framework (Fraser, 2007). The first steps that ExxonMobil took were to conduct a gap analysis to determine the gaps against HSE expectations and internal Operations Integrity Management System (OIMS) requirements relating to life extension of offshore installations. Subsequently, it proceeded to do data gathering activities in order to know the current condition of its assets (Fraser, 2007).

Table 2.5: Summary of ExxonMobil North Sea Assets (Fraser, 2007)

Asset	Type	Installation Date	Design Life (Years)	Estimated Operational Life (Years)
Beryl Alpha	Condeep GBS	1975	25	42
	Flare Tower Flare Tower	1975	25	42
	Steel Piled Jacket	1990	25	27
Beryl Bravo	Steel Piled Jacket	1983	20	34
Thames AW	Steel Piled Jacket	1986	25	24
Thames AP	Steel Piled Jacket	1986	25	24

Upon completion of the data gathering activities, EM successfully compared the condition of platforms that they have with similar structures and recent assessments to understand the current condition and where to start in progressive analysis work. The outcome from the comparison and analysis work allowed ExxonMobil to decide whether each of their platforms can be accepted as-is or may require modification immediately or at some time in future. The data that was collected consist of:

- General Information
- Original Design Data
- Construction Records
- Platform History
- Present Condition
- Future Operating Strategy

Several analysis options were identified to be performed, starting with best understanding of structural and geotechnical condition, gravity and environmental loads. Criteria that were set for the ageing facilities are:

- Damages are tolerable under conventional design 100 year event but must survive 1000-10000 year event
- Include more aggressive/intervention program to address localized fatigue damage or overload of some structural bracing.

The analysis options that were identified to evaluate these existing facilities are Static In Place Analysis (SIA), Dynamic Spectral Fatigue Analysis, Ultimate Strength Analysis and Reliability Analysis.

During the gap assessments that were carried out, many issues were identified. They are:

- Assets were in good condition with no significant defects identified.
- A number of the guy wires on Beryl Alpha Flare had never been replaced, and it was operating beyond the original design life.
- Low fatigue lives on Beryl Bravo jacket, no defects were reported however in the last diver inspection in the late 90's.
- There were areas of overutilization on Beryl Bravo topsides, however no reported defects.
- No seismic analysis was carried out with reliance on engineering judgment.
- Thames platform structural models were on software which were no longer supported.
- Underwater inspection and maintenance (UIMC) program was based on remote operating vehicle (ROV) for general visual inspection (GVI) or Flooded Member Detection (FMD), no redundancy in analysis in place and so it was difficult to assess impact should defect be found.
- Inconsistent strategies were in place as a result of inheriting previous operator programs due to the expiry of profit sharing contract (PSC).
- Performance standards did not address life extension issues.

Each of the gaps that were found above was then risk ranked based on its severity. Furthermore, each gap was then prioritized. Each gap items were then allocated a special budget in order for it to be closed. From the gap that was identified, ExxonMobil carried out mitigation activities such as:

- Beryl Alpha Flare guy wires were changed in 2005, strategy now in place for future inspection and re-tensioning to be carried out.
- Bravo Jacket was inspected by divers in 2005, no defects found at low fatigue life locations
- Bravo Topside was reassessed and previously stated overutilization resolved. However, analysis identified further work in areas where cantilevers were added in late 80's.
- Ship impact data was updated.
- Seismic Analysis was carried out for Beryl fleet.
- Bravo Crane Pedestal and Flare Boom Fatigue assessment.
- Redundancy analysis completed to support UIMC program based on ROV for GVI/FMD. Natural frequency to be monitored.
- Consistent inspection strategies were put in place.
- Performance standards were updated to incorporate life extension requirements.

After the completion of all gap closure activities, the next strategy adopted by ExxonMobil was to develop a Risk Based Inspection (RBI) Program. Due to the nature of ageing facilities, the Probability of Failure (Pof) of the structure increases over time as component deteriorates. To reduce the Pof, ExxonMobil implemented an effective inspection method. The process is based on sound evaluation process depending on accuracy of models, data, competent inspection engineers and sufficient engineering resources.

After completing three (3) out of the four (4) main SIM frameworks which is Data, Evaluation, Strategy and Program, the final step is to implement the Program. ExxonMobil developed an inspection scope and planning program in accordance with the requirements of the Risk Based Inspection Strategies which contains a 5 year look ahead.

The annual work plan was developed based on current year and issued for implementation.

The inspection and maintenance program is developed to ensure the Pof of platform failure is reduced. To do this, the inspection and maintenance program needs to be developed by implementing a risk based underwater inspection (RBUI) strategy. The underwater inspection and maintenance scope of work (SOW) should include inspection of all relevant structural components or factors that affects the POF. With this, the POF of structures can be reduced. This will reduce the risk of platform.

Following the implementation of the SIM framework to all its facilities, Exxon Mobil gave the following conclusions.

- API provides a robust system for assessing and ensuring ageing platforms are fit for service.
- Life extension begins during design/fabrication and is enabled by appropriate facility integrity management systems.
- Risk based approach combined with prescriptive requirements of corporate integrity guides ensures adequate checks and balances are in place to ensure asset integrity.
- Re-analysis is not always the answer. Experienced, competent engineers should be utilized to ensure program are robust, focused, implemented, reviewed and updated going forward.
- Age is just one consideration during implementation and ongoing application of a robust structural integrity management system (SIMS).

The HSE (2009) published “SIM framework for fixed jacket structures” which evaluated the different approaches to structural integrity management by different operators to ascertain their adequacy in managing ageing structures. It serves as guidance for good practice for SIM. It develops a comprehensive framework for SIM for fixed jacket structures. The document is based on ISO 19902, API RP2SIM and PAS 55-1. Section 6 outlines the inspection strategy. It identifies default periodic inspection programs but states that these are generic and need to be carefully reviewed and customized before they are suitable for UKCS. It states that API RP2SIM provides guidance on the use of alternative risk based inspection strategies. However it provides only minimum details. On the basis of findings, structural risk assessment is reviewed considering the probability of an event and consequences. Interaction with other risks as well as cumulative risk associated with number of risks should be considered.

Bucknell et al (2010) discusses the rationalization and optimization of underwater inspection planning consistent with API RP2A Section 14.

Marshal and Goldberg (2010) reviews the decades of practical experience and recent developments in RBI for various types of structures for both topsides/interior and underwater. It stresses that the key concept is the detection and elimination of flaws that could progress to structural failure before the next inspection cycle.

2.8 Risk based underwater inspection (RBUI)

2.8.1 Concept

For offshore structures, risk and reliability based underwater inspection planning procedures have been developed and implemented since the 1980s, mostly for fatigue deterioration of fixed jacket steel structures. While the significant computational efforts required by RBUI hindered the applications in the past, this restriction has been resolved with the development of the generic approach to RBUI, which facilitates the highly efficient application of RBUI for portfolios of offshore structure.

A variety of qualitative and quantitative risk-based inspection strategies have been proposed and used widely in a number of industries. In many areas, including the process industry, they are generally referred to as risk-based inspection (RBI) schemes, or occasionally risk-informed inspection schemes. In the offshore industry they are referred to as inspection maintenance and repair (IMR) schemes.

In recent years, risk based approaches to optimizing inspection requirements for offshore platforms has become more widespread, with companies such as Exxon-Mobil, BP and Shell pioneering the approaches that are now beginning to be documented and made available to the public. Using risk-based principles offshore oil and gas operators are able to optimize their inspection resources to be more cost effective and to reduce the operating cost. To-date, implementation of a risk-based inspection program has been at the discretion of the oil and gas operator, with little industry guidance in the form of recommended practice or regulations available to the engineers.

The principal purpose for carrying out RBUI planning on a platform structure is to control the risk level over the intended service life of the structure, and to initiate cost effective remedial actions if found necessary. The RBUI approach prioritizes and optimizes inspection efforts by balancing risk costs (safety, environmental or business related) with inspection costs. In summary the reasons for selecting a risk-based approach to underwater inspection planning are:

- To focus inspection effort on structures where the economic or safety risks are identified as being high, and similarly to reduce the effort applied for low risk structures.
- To identify and apply the optimal inspection or monitoring methods according to the identified degradation mechanisms.
- To move away from time based inspection governed by minimum compliance with rules, regulations and standards for inspection.
- To apply a strategy of doing what is needed for safeguarding integrity and improving reliability and availability of the structure by planning and executing those inspections that are needed.

In order to achieve the above, it is necessary to determine both the Likelihood of Failure and Consequence of Failure associated with different hazards during the structures operational life. Risk is defined as a product of Likelihood of Failure and Consequence of Failure.

RBUI identifies which platforms carry the greatest risk and which of these are most likely to benefit from more inspection. A risk-based approach recognizes that platforms with low likelihood of failure may warrant less frequent, and less intense, inspection than platforms with high likelihood of failure. To realize the true benefits of RBUI, the process of inspection planning, execution and evaluation should not be a one-time activity, but a continuous process where information and data from the process and the inspection/maintenance/operation activities are fed back to the planning.

2.8.2 Risk evaluation

Risk is commonly defined as the product of the likelihood of an event occurring and the consequence of its occurrence. In order to reduce risk, therefore, it is necessary either to reduce the likelihood of an event or reduce its consequence, or both.

For example, the likelihood that a platform will fail (suffer unacceptable damage) during a hurricane or other design loading event is the likelihood that a hurricane will occur of sufficient magnitude to fail the structure. The consequence of the failure is the potential loss of life, pollution of the environment and/or economic costs of lost-production and replacement of the facility or non-recovery of hydrocarbon reserves. The overall risk is the product of the likelihood and the consequence.

In reality, for offshore platform failure, neither the likelihood nor consequences are known in absolute terms. Sophisticated analytical techniques exist to represent the variables in a probabilistic sense however it is generally recognized that the failure data necessary to provide confidence in the probabilistic distributions is inadequate. The alternative described below uses a deterministic approximation of the variables based upon specialist knowledge of the influential parameters calibrated to service experience and the platform survival and failure data that exists.

The RBUI likelihood of failure corresponds to the probability that the platform will fail at some point in time through environmental overload. Fire, blast, and other accidental conditions are not considered in RBUI. The RBUI consequence of failure corresponds to the safety, environmental and financial issues that would arise should the platform fail at a future date. These are the standard consequence issues typically addressed in risk assessments for any type of facility, either onshore or offshore.

A qualitative risk approach is applied. Qualitative risk indexing approaches are based on assigning subjective scores to the different factors that are thought to influence the probabilities and consequences of failure. The scores are then combined using simple formulae to give an index representing the level of risk. The sum of the representative risks for each of the probabilities of failure represent the total risk to the platform (S total = Total score for likelihood of failure). The resulting indices for different components can then be ranked to determine components with the highest risk.

Clearly the main advantage of this approach is that it is very simple to apply. Only a simple spreadsheet is required to undertake the indexing analysis.

2.8.3 Inspection Strategy

The RBUI strategy allows better focus of inspection resources on platforms that will benefit from more frequent inspections and has been developed to satisfy regulatory requirements.

Other essential considerations in the development of the strategy include the risk-ranking of the platform, its present condition, frequency of previous inspections, trend analysis and the knowledge gained from performing ultimate strength assessments. Evaluation of results may suggest a strategy of monitoring, or intervention for strengthening/repair. Depending on the circumstances these changes in strategy may or may not affect future inspection frequency.

The RBUI method provides an indication of the risk of an individual platform within a fleet of platforms. The frequency as well as the scope of inspection is increased for the higher-risk platforms. Such platforms warrant the application of more quantitative methods, such as nonlinear pushover analysis, to provide guidance in developing detailed inspection plans. A non – linear push over analysis will indicate the member / joints which have to be given particular attention during inspection. For lower risk platforms, generic inspection plans based on experience, engineering judgment and platform history are adequate.

In addition to a direct reduction of the total expected cost, RBUI enhances the understanding of the structural integrity. Because RBUI requires a detailed analysis of the structure, the deterioration processes as well as the inspection performances, it helps to identify the "weak points" of the structure. For some structures, the RBUI study may thus result in a recommendation for additional mitigation measures, which are more efficient than an increased inspection effort.

In the oil and gas industry, there are two extremes type of inspections; unfortunately both are undesirable to the operators. One is that very little inspection is done. This is undesirable because less inspection would result in less platform information acquired. The second type of inspection is inspection is done very often. This is also undesirable because it involves cost. More inspection means higher cost. American Petroleum Institute (API) has published a recommend practice for inspection intervals in API RP2A 21st Edition, Section 14. The guideline survey intervals are given in Table 2.6. The scope of survey (level as well as frequency) depends on the exposure category of the platform. An exposure (L-1) platform can have level 1 survey (at frequency yearly), level 2 survey (3 to 5 year frequency), level 3 survey (6 – 10 year frequency) and level 4 survey (based on outcome of the level 3 or previous level 4 survey). It is evident that the type of survey or frequency is time based. There is no priority assigned to different platforms.

Table 2.6 Guideline Survey Intervals (API 21st Edition, 2005)

Exposure Category	Survey Level			
Level	1	2	3	4
L-1	1 year	3 through 5 years	6 through 10 years	*
L-2	1 year	5 through 10 years	11 through 15 years	*
L-3	1 year	5 through 10 years	*	*

* Based on outcome of Level 3and Level 4 survey

RBI uses risk as a basis to give priority to types of inspection and inspection intervals. The methodology of RBI allows it to set inspection and maintenance to a platform in such a way that it gives priority to higher risk platforms before paying attention to lower risk platforms. The RBI system determines the likelihood of failure and consequence of failure. Risk is defined as:

Risk = Likelihood of failure X consequence of failure.

The likelihood of failure (structural) is a function of two primary factors, the platform strength and the extreme load. The consequence of failure corresponds to the safety, environmental and financial issues that would arise should the platform fail at a future date. It groups a structure into High, Medium and Low inspection risk. Because of these groups, it can be easily decided which platform should be inspected first and which platform should be inspected last.

The purpose of having this RBI is to identify which platforms have high risk, to design an inspection program and to manage the risk so that it doesn't fail. The RBI process consists of performing risk assessment of structure; determine inspection frequency and scope of work. The risk assessment is done to determine the baseline risk and current anticipated condition of the platform. It can be done by determining the following, but not limited to:

- Rate of marine growth.
- Rate of corrosion.
- Scouring condition.

The guidance for setting an Inspection Strategy can be achieved through platform ranking where the platforms in a fleet are defined in a measurement system and then "ranked" through a systematic process. The ranking process should be based upon the likelihood (structural characteristics, condition, etc.) and the consequence (safety, environment, business interruption) of platform failure. Since many important characteristics such as age, framing patterns, deck elevation, etc., are not influenced through inspection, all platforms in a ranking system will have an intrinsic "risk" value. In other words, a platforms risk ranking will always stay the same or be higher than its intrinsic value as determined through a systematic measurement system.

A ranking process must be updateable to account for inspection results. For example, platforms that are found through inspection to be in good condition, with no signs of damage or other degradation, would receive either a lower risk ranking or maintain its intrinsic value. Between inspections, a platform would move towards the top of the list again, where its relative risk level would trigger an underwater inspection. Depending on inspection findings, a platform's ranking would stay the same or increase should significant deterioration have occurred.

The concept of ranking the platforms for underwater inspection using a risk-based process used by Amoco is based on a similar approach being developed by API for refineries and chemical plants (Amoco, 2005). The RBUI likelihood of failure corresponds to the probability that the platform will fail at some point in time through environmental overload. Failure, in RBUI, is defined as collapse of the platform as a result of deterioration, extreme loading (storm or earthquake), or a combination of both. Fire, blast, and other accidental conditions are not considered in RBUI.

The determination of the likelihood of failure requires information on a platform's structural configuration in order to determine its "baseline" susceptibility to failure (e.g., tripod, 4 leg, 6 leg or 8 leg), as well as its current state, based upon inspection, that may influence the baseline likelihood (e.g., damaged members). As an example, a 1960's vintage 6 leg, K-braced platform has a higher likelihood of failure than a 1980's vintage 8 leg, X braced platform (O'Connor & DeFranco, 1999).

Newer platforms are designed to better standards, such as joint cans, and has more redundant structural configuration since it has 8 legs and is X braced. However, should the SIM cycle reveal that the newer platform has a track record of damage such as corrosion or fatigue cracking, then this may move the platform up the priority list, to a point where it is higher risk ranked than the older platform.

The contribution of appurtenances such as risers and conductors to likelihood of failure was also considered. Appurtenance failures may not necessarily lead to collapse of the platform (except in the case of a severe explosion) but may cause an environmental and/or financial loss (O'Connor & DeFranco, 1999).

The consequence of failure corresponds to the safety, environmental and financial issues that would arise should the platform fail at a future date. These are the standard consequence issues typically addressed in risk assessments for any type of facility, either onshore or offshore. As an example, a manned drilling and production platform would have a higher consequence of failure than an unmanned wellhead platform. Each of these consequences are converted to an abstract dollar value and then summed to result in the overall consequence.

While the resulting value is not expected to be a quantitative estimate of the real dollar value due to a failure, monetary value was adopted so that the effects of safety, environmental and business losses can be combined. Whenever two consequences have equal abstract monetary value, they should represent two events that have an equivalent detrimental effect on the operator, even though they may not be equivalent as measured by actual monetary costs (O'Connor & DeFranco, 1999)

The likelihood is determined using a rule-based system that determines the likelihood score based upon key platform information. The likelihood of failure (structural) is a function of two primary factors, the platform strength and the extreme load. The likelihood categorization system identifies the platform characteristics that affect the platform strength and loads, such as the year designed the number of legs, the bracing scheme, etc. Factors which indicate that the strength of the platform has deteriorated or is not up to current standards increase the likelihood. Factors which indicate that extreme platform loads may increase in frequency or severity also increase the likelihood.

Table 2.7 shows the method of determining score pertaining to the number of legs and bracing scheme. This score also shows how there may be interactions between the various parameters that must be accounted for in developing each rule (in this case the number of legs and the bracing scheme). As another example, the impact of finding flooded members is dependent upon the bracing scheme for the platform - an X braced platform may be more tolerant to having flooded members than a K-braced platform due to the additional load paths in an X-braced structure. Finally, each rule is modified to account for the overall effect on the platform likelihood of failure with due consideration to engineering evaluation on structural integrity.

Table 2.7: Bracing and Leg (BL) Score (De Franco et al,1999)

Bracing System	**Number of Legs**			
	3	4	6	8
K	10	8	6	5
Diagonal	7	6	4	3
X	5	4	2	1

The methodology in developing the rules for platform risk ranking is shown in Table 2.8. It can be seen that 12 elements were considered by Amoco in developing their internal risk based underwater inspection. Each of these elements was given a specific score. The summation of the score will then be used to risk rank the structure for future inspection programs.

The evaluation of each is done on a scale of 0-10 except for damaged members (0 or 10.5 x BL /100), remaining wall thickness (0 or 7.5 x BL/100) and flooded members (0 or 6.0x BL/100).

Table 2.8: General Rules for determining LOF (De Franco et al, 1999)

No.	Rule name	Input / Purpose	Weight
1	Year Load Location	Design year, location	5
		Accounts for how metocean design loads have varied over the years in different regions of the world	
2	Design Practice	Design year	5
		Accounts for how detailing practice has varied over the years	
3	Bracing Legs (BL)	Number of legs, bracing system	10
		Accounts for the how redundancy varies for basic structural bracing systems	
4	Earthquake	Earthquake zone, whether design considered earthquake loads	8
		Penalizes platforms that have not been designed for earthquakes in areas where earthquakes are likely	
5	Grouted Piles	Location, whether piles are grouted	3
		Accounts for the strengthening of joints due to grouting the annulus between the pile and the leg	

Table 2. 8- Continued

No.	Rule name	Input / Purpose	Weight
6	Damaged Members	Number of damaged members, Bracing legs score (BL)	$\frac{10.5xBL}{100}$
		Penalizes platforms that have observed damaged members. The weight is multiplied by the bracing leg score to account for the damage tolerance of different structural systems.	
7	Remaining Wall thickness	Remaining wall as % of nominal, Number of members marked as corroded	$\frac{7.5xBL}{100}$
		Penalizes platforms where inspections have detected actual member wall corrosion.	
8	Marine Growth	Measure marine growth, design marine growth	6
		Penalizes platforms where the observed marine growth has exceeded that used for design	
9	Flooded Members	Number of flooded members, legs bracing system score	$\frac{6.0xBL}{100}$
		Penalizes platforms where inspections have detected flooded members	
10	Last Inspection	The years of the last Level II, III, and IV inspections	8
		Penalizes platforms that have not been inspected recently. This penalty is more severe for less detailed inspections.	
		Accounts for the increased failure likelihood associated with the rupture or leak of a hydrocarbon carrying riser or conductor escalating to a platform failure.	

From the risk ranking of structure, each of the said platforms will then be inspected based on its risk. The higher the risk of the platform, the sooner it will be inspected and vice versa. Furthermore, the risk ranking would be able to provide a brief detail of the required scope of work which is to be executed during underwater inspection programs. This is so because, the qualitative risk ranking methodology that is used provides scoring for each of the rules. If a rule obtains the maximum score, the particular rule has to be inspected to ensure that the score is brought down to a tolerable level, thus ensuring the reduction in risk of the platform.

2.9 Current SIM practices in Malaysia

There is minimal published information on SIM practices in Malaysia compared to the GOM. Nichols et al (2006) shows the approach taken by PETRONAS Carigali Sdn. Bhd (PCSB) in managing aging platforms. Over 60% of PCSB asset have been in operation for over 20 years. Potty and Akram (2009) has reviewed the SIM practices in Malaysia based on discussions the latter had with PCSB Carigalli for his undergraduate project (Akram, 2009).

The basis of the study conducted by PCSB was to describe the challenges and solutions faced in managing the ongoing long term structural integrity of PCSB ageing platforms. In particular, the study touched on the assessment procedures, tools and technology programs implemented to ensure the long term fitness for purpose of PCSB's asset (Nichols et.al. 2006).

PETRONAS TECHNICAL STANDARD (2001) PTS 37.19.60.10 Structural Inspection of offshore Installations specifies the requirements and recommendations for structural inspection. It describes the structural integrity inspection philosophy. It is an adaptation of Shell UK's Expro's Engineering Reference Document No. EA/093, under the same title.

From the literature review and also incidences from the GOM, it has been acknowledged that platform robustness plays a vital role in ensuring the long term structural integrity of offshore platform. Nichols (2006) touches on assessment procedure, highlighting the need to perform advanced structural assessment by method of Structural Reliability Analysis (SRA) or optimum Risk Based Inspection (RBI) using quantitative method. The use of qualitative method has not been discussed in Nichols et al. (2006).

Therefore, this research has taken the lead to develop a statement of requirement for fixed offshore platform, which highlights the importance of designing robust structures, and development of a semi - qualitative RBUI methodology. Furthermore, a data handover guideline from Greenfield and Brownfield projects will also be developed. A Greenfield is a project which lacks any constraints imposed by prior work. Brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contaminations (Wikipedia, 2012).

Combination of these three (3) objectives will constitute the development of an integrated Structural Integrity Management (SIM) for fixed offshore structure in Malaysia.

Luin (2007) reports on the talk delivered by Goh Tok Kwang on the risk based inspection program in Malaysia. Kwang gives a general view of the scope of work involved. There are close to 200 platforms in Malaysia's offshore and it would take a year or two to assess about 10 such structures. Thus it would take a total of 20 years to assess all the offshore structures. This emphasizes the need for quantitative and simpler qualitative or semi-quantitative method of structural integrity assessment. The technical aspects of the assessment work include environmental factors, probabilistic fracture mechanics, fatigue assessment, non-linear plastic collapse analysis, structural reliability analysis etc.

2.10 Review of data handover practices in the O&G industry

Data requirement during design, fabrication and erection is covered in the design codes and standards. The design codes and standards considered in this research are:

1. API Recommended Practice 2A-WSD (RP 2A-WSD) Twenty-First Edition, December 2000.
2. ISO 19902 – 2007 Petroleum and natural gas industries —Fixed steel offshore structures
3. PTS 37.19.60.10 Structural Inspection of offshore Installations
4. HSE Structural Integrity Management Framework

The data requirement mentioned in each code is discussed below.

2.10. 1. API RP 2A-WSD) Twenty-First Edition, December 2000.

The API RP2A WSD, as the governing design standard that is currently being used in Malaysia (Nichols, Goh, & Bahar, 2006), provides basic guidance on the data requirement for design of fixed offshore structure. Two sections in API provide these requirements, which are:

- Section 9 : Drawings and Specifications
- Section 17 : Assessment of existing platform

In Section 9, the drawings and specifications required are specified which is listed below.

- Conceptual drawings
- Bid drawings and specifications
- Design drawings and specifications
- Fabrication drawings and specifications
- Shop drawings
- Installation drawings and specifications
- As built drawings and specifications

The API RP2A has made it very clear that these drawings are required during the design stages of an O & G project. API RP2A also describes in detail, the purpose of each of the drawings and its specification. However, in this section, the need to transfer all these data to the operator or operation team is not specified or emphasized. Further to that, a major gap in the API RP2A is that it focuses only on the design stage of a project. It excludes the operation requirement and what data that is required throughout the life of the platform to ensure the platform is continued to be fit for purpose.

In Section 17, the assessment of existing platform concerns the following:

- Platform Assessment Initiators
- Platform Assessment Information
- Assessment Process
- Metocean, Seismic and Ice Criteria/Loads
- Structural Analysis for Assessment
- Mitigation alternatives

The Platform Information sections explain that sufficient information should be collected to allow an engineering assessment of a platform's overall structural integrity. It also states that it is essential to have a current inventory of the platform's structural condition and facilities. The information that is required to perform an assessment is based on the following.

- Topside Survey
- Underwater Survey
- Soil data

API RP2A however does not specify what "inventory" is to be used to have the current platform structural information and condition. In addition, API RP2A does not have a dedicated section in Data Management, although the number of drawings and reports produced or required to ensure the continued fitness for purpose of a fixed offshore structure is a lot.

2.10.2. ISO 19902 – 2007 Petroleum and natural gas industries

Although it is not a governing design code and standard of offshore platform for Malaysia, it provides two chapters that relates to data requirement, which are:

- Section 23 : In service inspection and structural integrity management
- Section 24 : Assessment of existing structures

Section 23 discusses about the in-service inspection which is an integral part of structural integrity management. It is an ongoing process for ensuring the fitness-for-purpose of an offshore structure or group of structures. ISO 19902 – 2007 acknowledge that data is an integral aspect of integrity management; however, it only provides a very brief commentary on data collection and update.

Section 24 has a similar commentary like in API RP2A WSD. However, Section 24.3 provides a description of what data is required for assessment. The structure data required for assessment are similar to those required for a formal SIM system, as per Section 23. The following data shall, where possible, be reviewed as part of the assessment:

- General information on structure/configuration;
- Original design information;
- Construction information;
- Information on structure history;
- Information on present condition.

This data shall include results of numerical analyses, engineering evaluations and/or previous assessments. Finally, ISO 19902 -2007 states that: "Accordingly, records of all original design analyses, fabrication, transportation, installation (including piling) and in-service inspections, engineering evaluations, repairs, and incidents shall be retained by the owner for the life of the structure and transferred to new owners as necessary."

The statement 'transferred to new owners" shows that a consolidated data handover guideline is necessary in ensuring the integrity management and fitness for purpose of a fixed offshore structure.

2.10.3 PTS 37.19.60.10 Manual for Structural Inspection of offshore Installations

The manual specifies the requirements and recommendations for structural inspection. It describes a structural integrity inspection philosophy. It is not intended for equipment or the initial inspection of offshore structure (i.e. during the construction phase or prior to the installation in the field). The concept of risk based inspection is explained. It is based on the likelihood of structural failure and the consequences of its occurrence. The likelihood is either Time dependent or event related. Time dependent items refer to inspection areas where there is deterioration with time. Typical examples of these are cracks located in the chord of welded tubular joints due to high local stress concentration and fatigue growth, general corrosion etc. Event related items refer to inspection areas subject to extreme environmental or accidental loads.

Section 2.4.2.2 requires that records be maintained of damage incidents to help future inspection efforts. Future inspection is based on suspect areas where defects or damage have been found by previous inspections or where repairs have been carried out during the original construction or in service. Section 2.7 states that "all structural inspection data should be accurately recorded and organized in a standard format within a suitable database in order to aid the traceability and auditability of the inspection activities, results, trends, and remedial action". No specific guideline on data handover is provided.

2.10.4 HSE Structural Integrity Management Framework May (2009)

Gives details of information management process and documentation requirements based existing standards and industry, published documents including ISO 19902, API RP2SIM and PAS 55-1 (Institute of Asset Management, 2003). Section 7 explains the information management, which is the process by which all relevant historical and operational documents, data and information are collected, communicated, stored and made available to those who need it. Details of information to be stored for the duration of life of platform are given. They are to be transferred to the new owners as necessary. It is also mentioned that the documentation should be made available to the relevant parties.

2.11 Review of current SOR practices in the O & G industry

Figure 2.19 shows the comparison between conventional design process and new process of performance based structural design (Okada, 2000). Performance-based frameworks, which state the performance requirements of structures, are now needed to flexibly use new materials and structural design methods. The conventional method widely used in structural design is based on specification criteria rather than performance criteria. These criteria do not state the required structural performance such as earthquake resistance. Although it is difficult to predict external forces (such as earthquake) that may act on structures, structural technology without a clear statement of required performance is not a modern technology. Without statements of performance, occupants cannot select structures on that basis, and cannot use market principles to choose those offering lower cost and better performance. Performance statements allow various structural systems and materials to be used, and should promote the development and introduction of new technologies and the concept of cost performance (Okada, 2000).

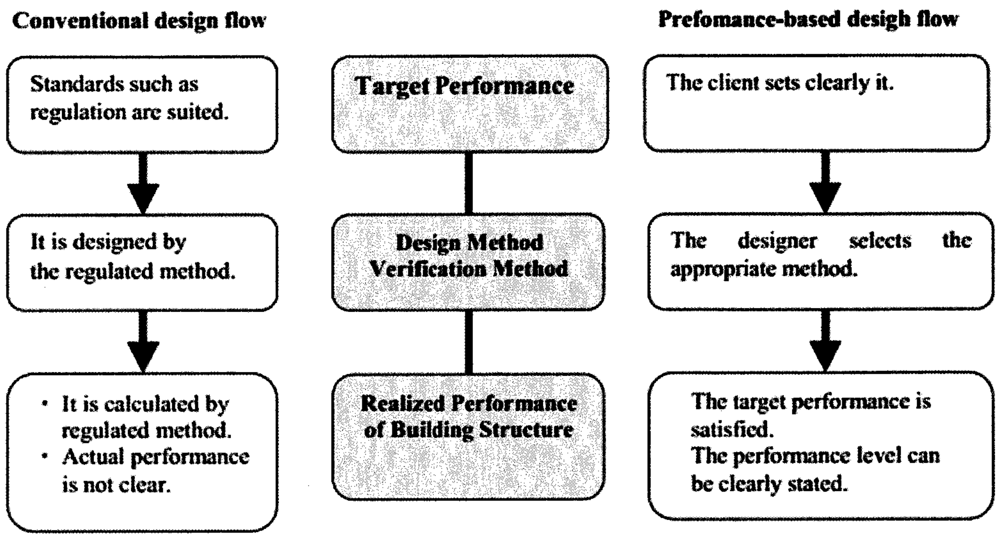

Figure 2.19: The comparison between conventional design process and new process of performance based structural design (Okada, 2000)

FEMA – 349 (2000) has stated that to prevent or mitigate losses from natural hazards we need to know what level of performance is expected from the buildings during an event such as an earthquake. The development of "performance-based seismic design" criteria would enable engineers and designers to improve the performance of critical classes of buildings that are currently only designed to a "life safety" level to avoid collapse, but would in fact probably still suffer significant damage in a design event.

Historically, building codes have required that buildings be built to a minimum level of Earthquakes safety. Specifically, structures designed for earthquake are expected to "resist a minor level of earthquake without damage, a moderate level earthquake with some nonstructural damage, [and] a major level of earthquake without collapse". Deaths in recent California earthquakes have been few, showing that the intent of the code has been met. However, there is a major misperception on the part of many owners, insurers, lending institutions and government agencies about the expected performance of a code conforming building. This has led to losses that were unexpected and in many cases financially ruinous. Building stakeholders, those with a financial or social interest in the built environment, who expect that their buildings are "earthquake proof" because they meet the code, have often been very disappointed. It must be said, too, that none of these recent events has been of an intensity that would typically be considered catastrophic. Catastrophic temblors with a magnitude similar to the 1812 New Madrid or 1906 San Francisco earthquakes will now likely result in losses several times larger than anything previously experienced if they occur in a densely populated area (FEMA 349, 2000).

Performance Based Seismic Design (PBSD) is a methodology that provides a means to more reliably predict seismic risk in all buildings in terms more useful to building users. It permits owners to make an efficient use of their design and construction budgets, resulting in more reliable performance for the money spent. Consider spending more money to achieve quantifiably higher performance than provided for in the code, thereby reducing risk and potential losses (FEMA 349, 2000).

PBSD will benefit nearly all building users. The PBSD methodology will be used by code writers to develop building codes that more accurately and consistently reflect the minimum standards desired by the community. A performance based design option in the code will facilitate design of buildings to higher standards and will allow rapid implementation of innovative technology. When performance levels are tied to probable losses in a reliability framework, the building design process can be tied into owner's long-term capital planning strategies, as well as numerical life cycle cost models (FEMA 349, 2000).

PBSD is not limited to the design of new buildings. With it, existing facilities can be evaluated and/or retrofitted to reliable performance objectives. Sharing the common framework of PBSD, existing buildings and new buildings can be compared equitably. It is expected that a rating system will develop to replace the currently used Probable Maximum Loss (PML) system. Such a system is highly desirable to owners, tenants, insurers, lenders, and others involved with building financial transactions. Despite its inconsistency and lack of transparency, the PML system is widely used and a poor rating often creates the financial incentive needed for retrofit decisions (FEMA 349, 2000).

The basic concept of performance based seismic design is to provide engineers with the capability to design buildings that have a predictable and reliable performance in earthquake. Further, it permits owners and other stakeholders to quantify financially or otherwise the expected risks to their buildings and to select a level of performance that meets their needs while maintaining a basic level of safety (FEMA 349, 2000)

PBSD employs the concept of performance objectives. A performance objective is the specification of an acceptable level of damage to a building if it experiences an earthquake of a given severity. This creates a "sliding scale" whereby a building can be designed to perform in a manner that meets the owner's economic and safety goals. A single performance objective that requires buildings remain operational even in the largest events will result in extraordinarily high costs. Conversely, a design where life safety is the only consideration may not adequately protect the economic interests of building stakeholders (FEMA 349, 2000).

A key to knowing how a building will perform in a given earthquake is having the ability to estimate the damage it will sustain and the consequences of that damage. Current codes do not evaluate a building's performance after the onset of damage. Instead, they obtain compliance with a minimum safety standard by specifying a design which historically has protected life safety in earthquakes. In some cases, the code may actually be non-conservative if a building's irregularities are very substantial, or if a higher performance level such as damage control is the desired (FEMA 349, 2000).

SEAOC Vision 2000 and FEMA 273 explain the concept of performance objectives. In Figure 2.20, the performance is shown in the horizontal axis (with increasing damage to the right) and the severity of earthquake (in terms of frequency) on the vertical axis. Each square represents a performance objective, a performance state at a given earthquake intensity. The diagonal line represents design criteria that an owner might impose on the building. For example a retail store may require "basic criteria" for cost effective design; the owner of a high tech structure may want a reduced risk obtained with "essential / hazardous criteria".

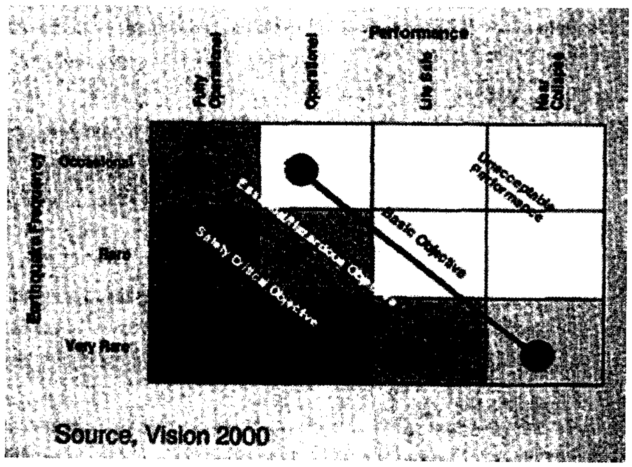

Figure 2.20: Concept of PBD and performance objectives

PBSD differs from current codes in that it focuses on a building's individual performance. It provides a road map that permits design professionals, owners and other stakeholders to learn more about a building's performance in different earthquakes, and implement a design that optimizes design and construction costs with respect to life-cycle performance. In its broadest sense, PBSD creates global planning opportunities for reducing economic and social losses to whole communities, regions and states (FEMA 349, 2000).

Six "products" are needed to create a PBSD that is comprehensive and acceptable to stakeholders (FEMA 349, 2000). They are:

1) A Planning and Management Program. Currently there is a demand within the stakeholder community for more reliable ways to predict and control building performance. These demands, however, are not clearly articulated and are often conflicting. Clearly, though, there is increasing recognition that problems exist with current design practice. The greatest challenge to creating a successful PBSD program is distilling the most important needs within these demands and synthesizing from them a cohesive guideline for performance based design. A significant effort will be required to ensure that the PBSD guidelines respond to these needs fairly, are accepted by stakeholders and are implemented effectively. The Action Plan must be a

vehicle to communicate these needs to the entire community, so that the solutions are appropriate and widely acceptable. A formal program will be necessary to educate people about how PBSD can respond to many of their current demands for more reliable and cost effective performance.

2) Structural Performance Products (SPP) The SPP will form the core reference material for the guidelines. They will consist of technical documents that quantify performance levels, define how to evaluate a building's performance, and develop methods for designing a structure to meet a performance level with defined reliability. They will present the necessary analytical information needed by engineers. A goal is to address new and existing buildings so that the guidelines will be appropriate for new design as well as retrofit. The creation of these products will require major technical research in order to produce a comprehensive framework for structural design.

3) Nonstructural Performance Products (NPP) The NPP function similarly to the SPP but focus on the nonstructural components of a building: partitions, piping, equipment, contents, etc. To truly achieve a desired performance, design of nonstructural components is as critical as the design of the structure itself. Engineers from many disciplines, architects and manufacturers who design and supply a building's nonstructural components will develop these products. Like the SPP, the NPP will require significant research, especially in the areas of equipment testing and certification. Also like the SPP, the NPP must include research focused on existing building stock.

4) Risk Management Products (RMVP) The RMVP is the key to bringing owners, financial institutions and governing agencies into the PBSD process. These documents will be financially oriented and will develop methodologies for calculating the benefits of designing to various performance objectives and for selecting appropriate design bases for individual and classes of buildings. The goal will be to provide a basis for

stakeholders to make rational economic choices about the level of performance and the comparative costs to reach those levels.

5) The PBSD Guidelines. The PBSD Guidelines will be the actual document used by design professionals, building officials, material suppliers and equipment manufacturers to implement performance based design. It will distill and synthesize information from the SPP, NPP and RMP into one document that is usable by each of the groups. It is intended that this document will be published as a FEMA guideline and will serve as a basis for codes and practice thereafter. The guidelines will contain a technical commentary for reference It will address new design as well as retrofit and it will serve as a basis for development of building rating" systems, to provide financial guidance to stakeholders.

6) A Stakeholders' Guide. This document will function as a non-technical commentary to the Guidelines, explaining PBSD and providing instruction to the nontechnical audience. PBSD will require a shift in the role owners, lending institutions and others play within the design process. These stakeholders will now be a fundamental part of developing the design strategy. The Stakeholders' Guide will help these groups choose objectives that best meet their cost and performance goals.

The movement towards performance based codes and standards have become a world wide effort, especially in the standards developed for reference in building codes (ASME, 2004). The use of such standards offers significant advantages. A performance based standard states goals and objectives to be achieved and describes methods that can be used to demonstrate whether or not products and services meet the specified goals and objectives. In contrast a prescriptive standard typically prescribes materials, design and construction methods frequently without stating goals and objectives. A performance based standard focuses on desired characteristics of the final product, service or activity rather than requirements for the processes to produce it. Performance based standards are also known as objective based standards. Many ASME standards include both prescriptive and performance elements, but most lean heavily towards being prescriptive standards. Performance based standards allow users flexibility in choosing materials, design and construction to meet the standards' goals and objectives. The advantages include:

• New Technology – Performance based standards allow earlier use of new technology. The users of these standards are free to implement new technology as soon as it is demonstrated, without waiting for standards development committees to modify standards to explicitly permit use of new technology.

• Innovation – Performance based standards encourages people to find optimum ways to meet performance criteria, which results in building the knowledge base and developing the entrepreneurial spirit, which in turn leads to economic development

• Barriers to Trade – Performance based standards permit the use of new or non-traditional parts and methods when their use meets the performance criteria. This widens the marketplace, no longer limiting the acceptable suppliers to those manufacturers or countries with specific resources.

- Transparency – Performance based standards that have clearly stated goals and objectives answer the question of what is to be achieved. For most prescriptive standards, the goals and objectives are implied at best and unknown at worst. For many rules in prescriptive standards, we cannot answer with certainty the question of what end function is to be achieved.

• Efficiency – The development and maintenance of performance based standards ultimately requires less effort. While initially more difficult to establish goals and objectives, the decision for inclusion or not of various requirements is much simpler. Maintenance can be simpler as well. For example, a standard that describes the properties of acceptable materials of construction is much easier to maintain than one that lists acceptable materials by reference to various material standards.

Currently design of offshore structures satisfies the limit state conditions specified in the API and ISO codes. Platforms designed in Malaysia too follow this concept. Other than that there is no requirement to be satisfied in terms of performance. Many countries are moving towards designing structures to satisfy certain performance requirements especially when designing structures to earthquake loads. Such design is done by providing a "Statement of Requirement". The statement of requirement is 'a performance based design (PBD) approach to offshore engineering design'. PBD is defined as a 'performance driven approach to offshore engineering design'. Its objective is to facilitate the design of structures that have predictable performance in compliance with performance goals selected for the intended life. The PBD methodology provides guidance in three key areas:

- Managing risk
- Operational Experience
- Structural System Robustness

PBD is distinct from risk-based or consequence-based design, introduced in the 21st Edition of API RP2A, in that it does not try to optimize the likelihood of failure on the basis of an understanding of the consequence of failure. Instead, the objective of PBD is to facilitate the design of structures that have predictable performance in compliance with performance goals selected for the intended life (PETRONAS, 2003, Performance Based Design, WW ALL E 009 2003)

Emphasis is provided on the consideration of entire platform life cycle; from appraisal and selection to disposal, potentially after one or more change-of-use or reuse. The PBD process aims to combine technology and experience to deliver structures with predictable performance in compliance with selected performance goals.

If applied competently, with the appropriate technical assurance, a performance-based approach to design provides the opportunity to optimize facilities to better deliver the life-cycle performance goals most closely aligned with operator financial targets and HSE expectations.

Existing industry design standards for offshore facilities (with some exceptions relating to design for accidental loading) are component-based; therefore, the strength of the structure is defined by the strength of the weakest component. No benefit is taken from load redistribution, a feature that is largely responsible for the inherent robustness and damage tolerance of offshore platforms.

A PBD approach allows the implementation proven technologies to take advantage of the additional capacity that exists where doing so the platform can be demonstrated to achieve performance consistent with selected performance objectives. Many lessons arising from previous design and operational experience have application to future PBD. By making the design process open to the adoption of past service experience, and new analytical tools and technologies, competent engineers will be able to optimize facilities to better deliver the life-cycle performance goals most closely aligned with operator financial targets and HSE expectations.

The PBD approach is applicable to other engineering disciplines where conventional approaches to design can be extended to better deliver the performance objectives defined by the Project. Whatever the discipline (materials and corrosion, process and facilities, pipelines, drilling etc.), it is important that the potential for innovation is considered during the Design Process and the appropriate level of technical assurance is maintained to ensure performance goals are achieved over the life-cycle of the development. (Performance Based Design, WW ALL E 009 2003)

O' Connor et al (2005) has pointed out that BP Trinidad and Tobago has adopted SIM Strategy developed by BP in the GOM and has also extended its application to incident driven inspection planning and performance based design (PBD).

Performance based seismic design has been adopted in the seismic design of an offshore platform in the Caspian Sea (Wilcock et al, 2010). PBD for seismic design was adopted for the self-installing gravity based structure (GBS) designed by Arup in Caspian

Sea. The suitability of design was demonstrated using advanced non-linear analysis. The design satisfied the performance requirements of ISO 19901. In addition, the performance based design provided the client with an improved understanding of the likely response of the structure to a real earthquake and greater ability to manage the risks associated with the facility (Gibson et al., 2012).

Ali (2012) proposed a PBD methodology for Topsides that emphasizes the structure predictable behavior and protection of personnel and assets. The end result will be an optimum design which satisfies the function of a topsides structure system without compromising safety. At present topsides structures are designed based on WSD / LRFD design which is quite safe but not economical due to uncertain extent of the levels of the protection. Xue et al (2007) describes the PBD codes being developed for seismic design of buildings in Taiwan.

2.11.1 Managing risk

As emphasized, the design of structures with predictable life-cycle performance that meets project performance goals (e.g. a reusable structure or a structure installable with a jack-up) usually requires the implementation of technologies. Many times, although these technologies are relatively mature with proven track records, they will be outside of existing codified guidance and unfamiliar to project personnel and/or design contractors.

The technologies, therefore, bring with them a level of additional risk over and above the risk associated with a conventional design for the same application. It is important that these risks are understood to allow project managers to make informed decisions in the consideration of a PBD alternative. Experience indicates that an increased level of technology assurance is usually necessary to manage the additional risks. If the appropriate level of technology assurance is not available then it is unlikely that the project will be successful in meeting the desired performance goals.

The level and the nature of the technology assurance necessary to ensure that performance goals are met depend on the risks associated with the technologies used. Figure 2.22 can be useful in understanding the need for, and the appropriate level of, technology assurance (UKOOA, 2005).

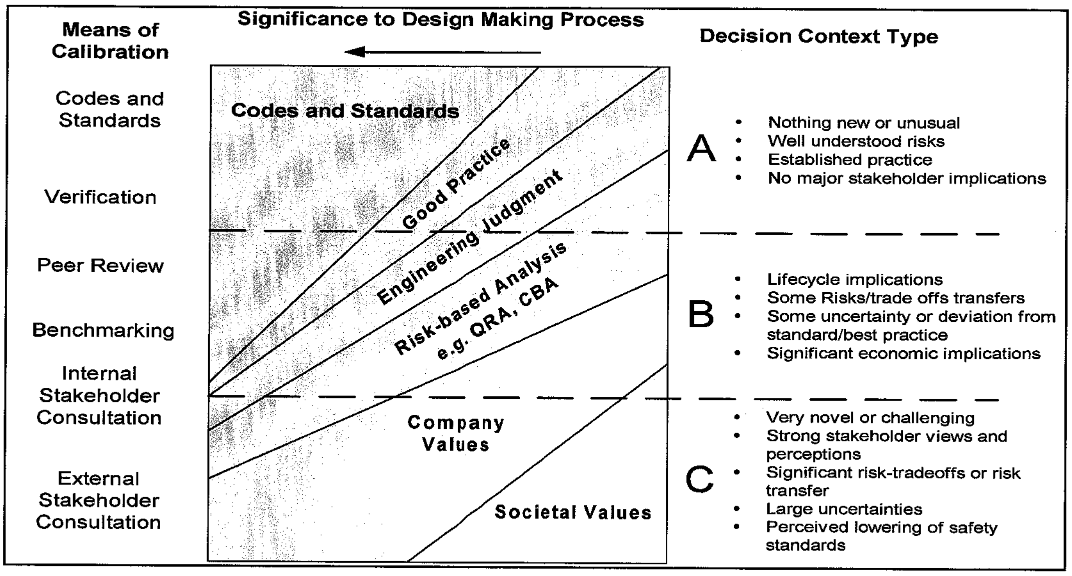

Figure 2.21: Level of technology assurance (UKOOA, 2005; O'Connor et al, 2005)

In Figure 2.21, three 'decision context' types are identified, A, B and C. Conventional designs of fixed offshore platforms typically reside in the A-category; the designs are 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 assurance 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. (UKOOA, 2005)

A PBD solution, 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 assurance required increases and may include peer review, benchmarking and perhaps internal stakeholder consultation. (UKOOA, 2005)

The assurance process should assist in preventing, controlling or mitigating risk and ensure that, in addition to code and regulatory compliance, best practice is followed to produce inherently safer designs. Inherently safe structures will be robust in their ability to withstand extreme loading but also in their tolerance of accidental loading, damage and human error. The level of assurance required will depend on the complexity and the maturity of the technology being implemented. (UKOOA, 2005)

2.11.2 Operating Experience

Operating experience gained in widely separated parts of the world consistently shows that the largest proportion of damage to offshore structures is due to mechanical damage (boat impacts or dropped objects) or corrosion. Weld/joint defects are nothing like as widespread as is suggested by the results of fatigue analyses. Service experience shows that designing a degree of robustness, or redundancy, into a structure makes it remarkably tolerant to damage. (Nichols, Goh, & Bahar, 2006)

Robust structures suffering apparently major damage retain a large proportion of their original ultimate strength, to the extent that the damaged capacity in all likelihood still exceeds the design loading. In addition a robust structure is more inherently tolerant of human error as may result in fabrication defects or acceptance of defective materials e.g. out of tolerance components.

Parallel to the many technology development studies to support assessment, other joint-industry initiatives have been undertaken to examine in-service performance of structures. In particular, valuable lessons have been learned from the behavior of platforms subjected to extreme loading, most significantly from hurricanes, but also from accidental events including blast and vessel impact (Nichols, Goh, & Bahar, 2006).

More recently major joint industry efforts were made to collate analyzes and interpret underwater inspection data collected by industry over the last twenty years. This has application to future inspection planning but also provides a performance benchmark for the variety of traditional designs that exist. This in-service performance data can be effectively used to validate the use of new technologies in future design and to quantify associated risks so that they may be suitably managed in future.

2.11.3 Structural system robustness

PBD should take into account the structures system configuration. At present the system strength is not addressed in detail in the codes and guidance documents. However, it has been demonstrated analytically, 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.

In traditional component-based design, the practicalities are no different whether the structure has X-brace, K-brace 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. (Westlake H.S, 2005)

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.

Framing arrangements therefore impact directly on the safety and economic considerations through the life cycle of jacket structures. To date there has been no structured approach to take rational account of these framing issues at the design stage. It shows that higher capital expenditure may not be necessary to derive the operational benefits of robust framing. A range of performance measures is proposed to compare framing configurations. Alternative design approaches, with different levels of complexity and completeness are also set down, either to check framing adequacy or to optimize configurations. (Performance Based Design, WW ALL E 009 2003)

The full capacity of jacket components has not been accounted for in traditional design using codified component-based methods. The reason is that in the underlying isolated tests of strength, components generally failed prematurely in the absence of the constraints and continuity within a 3-dimensional structure.

The new insight to the true performance of structures means that design safety levels can be rationalized to an appropriate level and applied consistently to different component types. Non-linear analysis software, applied by users with an understanding of the physical processes involved, provides the basis for explicit assessment of risk levels with respect to structural failure.

Through the life of the installation the occurrence of greater load levels than those calculated is conceivable due, for example, to an extreme Metocean event, a required change in topsides load, a new interpretation of Metocean data, structural damage etc. In such circumstances research has demonstrated that the effects on different structures would be influenced by:

- The actual response of the component in the frame compared with the characteristics deduced from simple tests embodied in the design code; and
- The surrounding framing pattern and alternative load paths through the structure.

Together these factors mean that in reality a structural system can offer significantly better performance than indicated by component based design codes. The issue is how this can be exploited to minimize lifecycle risks by harnessing the benefits at the design stage.

The contribution of structural framing to performance has long been recognized in principle. In the context of seismic design API RP2A includes guidance on appropriate framing to provide the (quantified) potential for alternative load paths to impart ductile energy absorbing system characteristics. ISO 19902 recognizes the lesser safety margins acceptable for ductile systems than those with brittle response characteristics.

However, load redistribution comes about as components fail, plasticity occurs and forces redistribute. The physical processes are complex and it is only over the last decade that analysis methods have become practicable, with validation from large-scale test investigations.

The selection of framing patterns can influence lifetime performance and economics of offshore installations. Appropriately configured structures can offer greater tolerance to conditions beyond the notional design envelope.

Robustness is a useful measure for determining damage tolerance for a platform. For a robust structure, damage may result in little immediate risk to the facility. For other less robust structures, even a small damage event may significantly degrade the platform's global capacity resulting in a high-risk situation, justifying immediate response such as platform de-manning, platform shutdown, or emergency repair.

Robustness is also useful for inspection planning. Robust structures may not need as much inspection as other structures since they are more damage tolerant. Information on platform robustness can also be used to identify key local regions of a platform system that are crucial in terms of critical and secondary load paths that should be the focus of inspections.

The ability of offshore platforms to withstand global damage caused by ship impact, fatigue cracking, extreme storms, dropped objects and other events without collapsing is a function of robustness. A robust structure has inherent redundancies in terms of alternative load paths around damaged areas and adequately proportioned alternative member strength that allow it to survive these types of incidents.

The degree of provision for lifecycle robustness over and above component capacity in offshore jacket design has been, to a degree, a matter of chance. The consequence is that structures designed to the same code can be substantially different with regard to:

- The level of reliability / safety to withstand extreme hazards and accommodate change
- The number and criticality of components / load paths for which inspection activity is required.

2.12 Chapter summary

The critical points of current knowledge including substantive findings as well as theoretical and methodological contributions to structural integrity management (SIM) and Risk Based Underwater Inspection (RBUI) were extensively reviewed. In summary, the following topics were looked into in detail:

- General overview of the Oil and Gas (O&G) industry
- Analysis of United Kingdom Continental Shelf (UKCS) and North Sea Oil Production
- Analysis of Malaysia oil production
- Evolution of American Petroleum Institute (API) design codes in the Gulf of Mexico (GOM)
- Impact of hurricane to existing fixed offshore platforms in the GOM
- Current SIM practices in the GOM, North Sea and Malaysia
- Risk based inspection (RBI)
- Review of data hand over practices in the O&G industry
- Review of current SOR practices in the O&G industry

The critical review of the literature has enabled the comprehension and identification of the various methodologies used, either in the GOM or North Sea, in design and operation activities of fixed offshore structure. The analysis of UKCS and North Sea oil production shows a similar trend of ageing of offshore platforms in European countries, especially UK and Norway. However, for the local O & G industry, it is to be validated whether similar problems like what is being experienced by UK and Norway exist.

The API design code has evolved through the years due to various hurricane events. These events caused the API committee to review their design code. Most notable changes that were made from these reviews are the design return period to be used, robustness of structure and the required air gap calculation. Section 17 was introduced as part of the structural integrity management (SIM) of offshore structures. Nevertheless, API have now decided to remove the Section 17 and developed a standalone API RP

2SIM code. This shows how sincere and earnest the API committee is in managing the fitness for purpose of the O & G industry ageing structures.

The various hurricanes that has hit the GOM, presented a unique opportunities for the design fraternity to "test" the API RP 2A design process by comparing platforms that survived, were damaged, or failed in hurricane against what API RP2A would have predicted. A Joint Industry Project (JIP) was initiated. The result indicated that the API RP 2A design approach results in a conservative platform design with about 10 to 20 percent margin (Puskar, Ku, & Sheppard, 2004) prior to the application of factors of safety.

With the normal factors of safety included, the conservatism would be much higher. This finding is very significant as it will have a bearing on any future strengthening, modification or repair works that needs to be done on an ageing structure because although the factor of safety has been exceeded, structures still have a 10-20 percent margin from its design conservatism. The findings from API are also true for Malaysia's offshore platform, where previous and current design philosophy is based on the same API design codes and standards (Nichols, Goh, & Bahar, 2006).

Review of the SIM practices in Malaysia has identified the gaps in current practices. Further there exists no framework for an integrated SIM practice.

Review of the Data management practices indicate that though API RP 2A discusses the data requirement at each stage (design, fabrication and erection) of the project there is no formal guideline on the data handover requirements.

Review of the design practices and new trends towards performance oriented designs indicate the need to introduce PBD in the design of offshore structures since it has much importance in the SIM of platforms.

Based on these the objectives of the current research have been set as given in section 1.4. The methodology for achieving the objectives is discussed in Chapter 3 Methodology.

CHAPTER 3:

METHODOLOGY

3.1 Introduction

Many of the 200 platforms in Malaysia have exceeded their design life. Such platforms require a fitness for purpose assessment before they can continue to be used. The aim of this study is to develop an Integrated SIM Framework for fixed offshore structures in Malaysia. The methodology adopted for the work is given below:

1. Selection of methodology for evaluation of baseline risk and RBUI
2. Site investigation
    - 2.1.1. Data gathering
    - 2.1.2. Data verification
    - 2.1.3. Gap identification during design of offshore platform.
3. Platform selection criteria for RBUI
    - 3.1.1. Platform evaluation for baseline LOF score
    - 3.1.2. Platform evaluation for present condition LOF score (This is discussed only under item 6)
    - 3.1.3. Platform evaluation for COF score
4. Development of Statement of Requirement for Design of offshore structures
5. Development of Data Handover Guideline for Greenfield and Brownfield projects
6. Development of an integrated SIM framework for fixed offshore structures in Malaysia

7. Chapter summary

The author has approximately 4 years' experience in Structural Integrity and Design Engineering, specializing in Structural Integrity Management (SIM) of Offshore Structures, Strengthening, Modification and Repair (SMR) of Offshore Structures, and Underwater Inspection and Maintenance Campaigns. He has been involved in a number of industry projects and has developed particular skills in the areas of structural Integrity Management and SMR Packages. These skills have been developed through deep involvement on projects, as well as research work during the study for his engineering degree. He has also experience in development of Risk Based Underwater Inspection (RBUI) and SMR Guidelines for his current employer.

3.2 Selection of methodology for evaluation of baseline risk and RBUI

Once a platform has exceeded its design life, the requirement for life extension will be initiated. The methodology developed by Exxon Mobil in undertaking the life extension of its existing fleet will be used as a benchmark in this research. The methodology developed by Exxon Mobil as well as others available in literature will be evaluated and the best possible methodology will be implemented to suit Malaysia's fixed offshore platform and a suitable integrated SIM framework for Malaysia fixed offshore structures will be recommended.

The concept of life extension is that there is a time when an offshore platform be considered for retirement, but where, with certain processes and mitigation, life can be extended for a further period without a reduction in margins below safe operating conditions. The concept of RBUI is to develop a risk ranking of a fleet of platforms. The risk ranking is then used to obtain the inspection internals and scope of work. This is a move from current time based inspection intervals as per API RP2A 21^{st} edition to a risk based inspection program.

The RBUI methodology developed by (De Franco et al,1999) will be used as a benchmark in this study. The methodology will also include the scoring range that was used by AMOCO in developing their RBUI process. However, this study will not include the seismic likelihood of failure rule as the author believes that more understanding and in depth study of Malaysia's seismic locations is required before being able to produce an acceptable scoring level. This study will also make some changes to the consequence of failure modeling developed by AMOCO.

A weighing system is used to capture the relative importance of each rule. The summation of the product of the weight and the score, as given in the following expression, will give the overall likelihood of structural failure score for each platform.

$$S_{total} = \sum_{i}^{o} WiSi \tag{3.1}$$

S_{total}	=	Total score for likelihood of failure
W_i	=	Weightage attributed to i-th rule
S_i	=	Score attributed to the i-th rule

The RBUI system is based on the assumption that Jacket type platforms designed according to modern structural design practice to resist present day design metocean loads have the lowest likelihood of failure. The factors that affect the original strength, the maximum design loads, and the degradation of strength are used to measure any individual platform's failure likelihood against the ideal platform.

The first approach in establishing a RBUI risk ranking for Malaysia's offshore platform is to identify the baseline likelihood of failure (Lof) of each platform. At the time of installation, the likelihood that the platform will fail during the Design Event is a function of the design strength and the robustness and ductility of the structure. These properties collectively define the 'baseline likelihood of failure' of the platform. During the life of a platform the robustness of the structure may change due to deterioration or degradation in the platform's condition, thus the platform's likelihood of failure will change.

A platform may also see an increased vulnerability to the extreme Design Event (e.g. due to subsidence or addition of facilities) or accidental loading (e.g. drilling operations, changes in operational practice), which may change the likelihood of failure. The rule for the definition of the baseline likelihood of structural failure of the platform considers the influence of API's Recommended Practice used for the design, fabrication and installation of the platform and the redundancy and robustness of the structure.

The "platform present condition" rules are used to adjust the baseline likelihood of failure score to represent the present condition of the platform (i.e. any degradation of the structure during fabrication, installation or operation). The rules account for the severity of the detected damage and the possibility of the structure having undetected damage.

The "platform loading susceptibility" rules are associated with the platform's ability to resist extreme loads. The score is combined with the adjusted baseline likelihood of structural failure score to give the overall platform score.

Rules have been developed (De Franco et al,1999), which combine various characteristics of the platform to produce a score that defines the relative likelihood of structural failure of the platform with due regard for the baseline likelihood of structural failure, the present condition of the structure and its loading susceptibility. The system qualitatively assesses the failure likelihood using a scoring system that categorizes the effect of each factor.

For a given factor or group of factors, its value is related to its effect on the failure likelihood. Each factor or group of factors is scored independently, and for most items, this score, S_i ranges between 0 and 10. High scores are assigned when the value of the factor increases the likelihood of failure, while low scores are assigned when the factor value decreases the failure likelihood. The total score for the platform is a weighted sum of the individual scores. High weights are used to emphasize the factors that strongly affect the likelihood and low weights are used for factors that moderately affect the likelihood, as shown in Table 3.1, 3.2, 3.3 and 3.4. The methodology described above and adopted for the research is shown in flowchart in Figure 3.1.

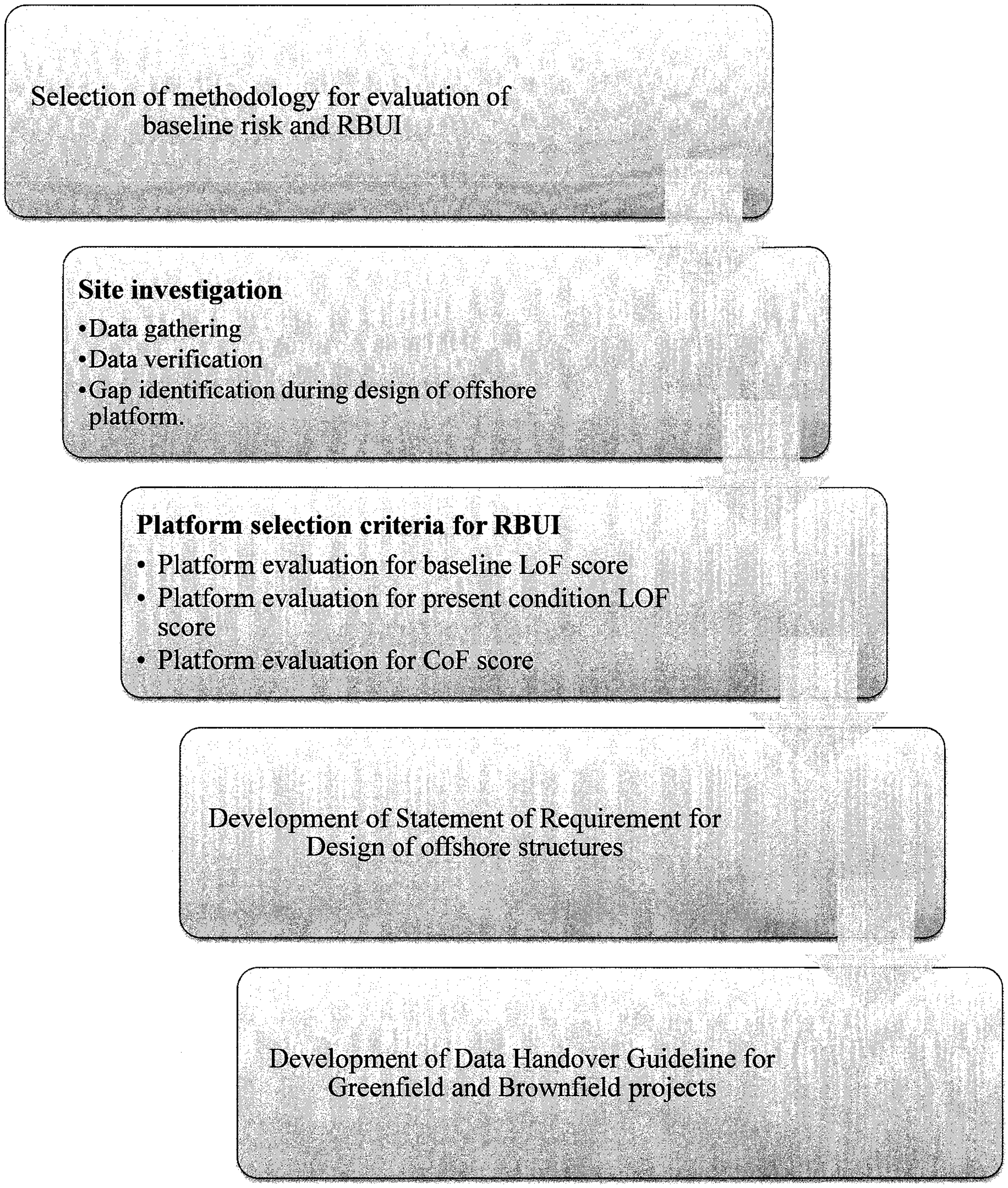

Figure 3.1: Methodology of the research

The basic platform data on platforms required for evaluation of the baseline risk is to be systematically collected, verified for authenticity and gaps if any has to be resolved. Further, any feature which may affect the baseline risk of the structure is to be identified. The methodology adopted for this is described in section 3.3.

3.3 Site investigation

As part of this research, two (2) site visits were conducted. The site visits were at Offshore Sarawak. The purpose of the site visits were to:

- Get acquainted with the facilities and operations at offshore
- Data gathering regarding current operating conditions, and constraints
- Conduct a preliminary assessment of the structural conditions of the platform.

The site visit was conducted at the following dates:

- 31st May to 2nd June 2011 at Sarawak
- 11th to 14th October 2011 at Sarawak

3.3.1 Data Gathering

The data gathering activity was conducted during the early part of this study. As per the research schedule, the preliminary data gathering activities were conducted from July 2009 to January 2010. The types of data or reports that are crucial for this study are:

- Platform Characteristic Data
- As-Built drawing
- Design Report
- Assessment Report
- Inspection Report

The five (5) reports mentioned above can be divided into two main categories, which are pre-service condition and in-service condition. The pre-service condition defines the condition of platform before it is installed. The in-service condition defines the condition of platform after installation. The above mentioned report was obtained from various parties that are involved in the local oil and gas industry. However, due to the sensitivity of the information, this study will not specifically mention any platform name in this thesis.

3.3.2 Data Verification

After gathering the data as per Section 3.3.1, the data verification is done as shown in Figure 3.2.

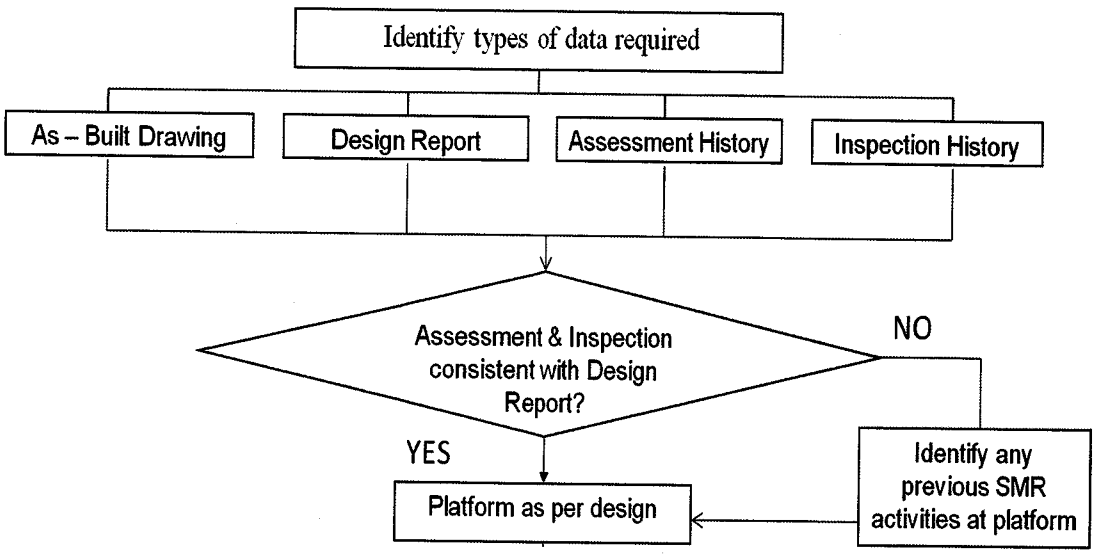

Figure 3.2: Data Gathering and Verification Methodology

It can be observed that upon the compilation of data required, a verification process is carried out where the consistency of report obtained is verified by comparing the pre-service reports against the in-service report. This is done by identifying major changes to the structure i.e. additional riser, conductor or loading to the structure. This is crucial because additional loading will increase the Likelihood of Failure (Lof) of the structure whereas a change of function from unmanned to manned will increase the Consequence of Failure (Cof) of the platform.

These differences are then recorded and the revised platform characteristic is then used in this research. The significance of identifying these anomalies up front is to ensure that the risk ranking of platform obtained in Chapter 4 (Results and Discussion) represents the actual condition of the platform with no significant errors.

3.3.3 Gap identification during design of offshore platform.

During the site visit, it was observed that most of the platforms do not have a riser guard protection system. Figure 3.3 confirms this. The importance of having a riser guard is to protect the risers from possible boat impact or collision due to any accidental events.

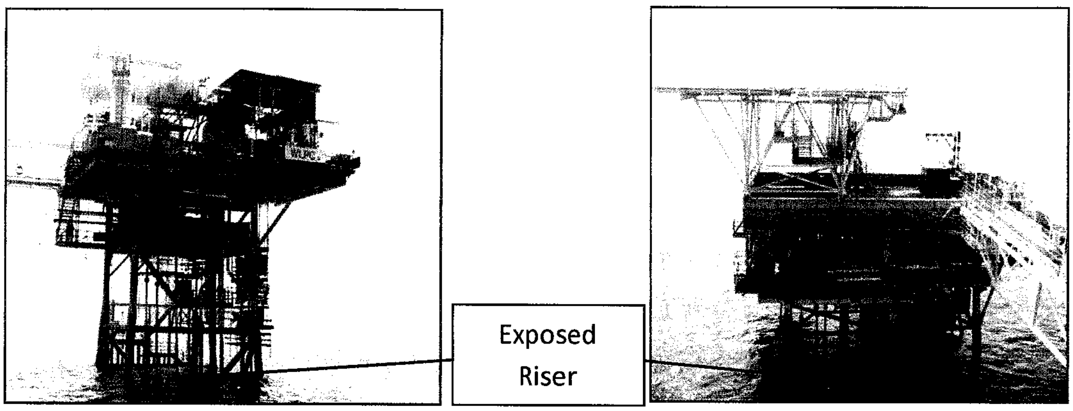

Figure 3.3: Fixed offshore structure without riser guard

The findings of the site visit would then be compared with the initial as built drawings of the platform. This is to ensure and identify whether there has been any changes to the platform throughout its operating life. If this is so, the changes would be recorded like what is mentioned above in Figure 3.3.

3.4 Platform selection criteria using RBUI

3.4.1 Platform Evaluation for Baseline LOF Score

In order to select the appropriate platform for inspection under RBUI, an objective method that removes all subjectivity and ambiguity is employed where a baseline risk of a platform is identified. Baseline LOF represents the platform robustness, where the year of design, number of legs and bracing types plays a vital role. In order to quantify a platform baseline LOF, this research employs a numerical scoring system; where the higher the score, the higher the platform baseline LOF will be. The scoring range and weighting was adopted using the AMOCO methodology that was developed by (O'Connor & Andy Tallin, 1999). However, for this research, a new flowchart was developed to ensure consistency with Figure 3.2. The flowchart for platform selection criteria is shown in Figure 3.4.

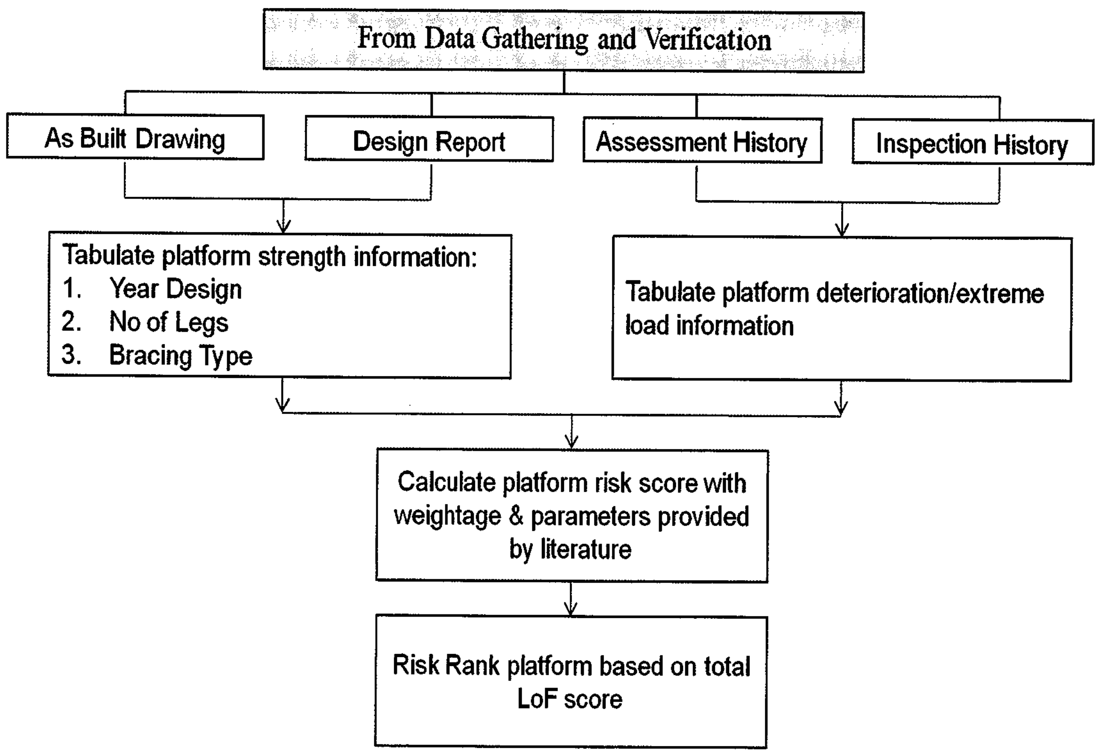

Figure 3.4: Platform Selection Criteria for Baseline LOF Risk

To arrive at a score, each rule is given a score range of between 0 to 10. In the case of platform characteristic, each platform structural feature will be evaluated. A high score will be given to a feature that conforms to, while a lower score will be given to a feature that deviates from the selection requirement. The original design configuration, such as the year designed the number of legs and the bracing scheme is used to determine the baseline LOF, where it establishes the highest possible likelihood of failure score for the platform.

The reason why only design configuration and bracing leg rule is used for baseline LOF is because, these two (2) criteria describes the as installed condition of the structure without any deterioration taken into consideration. Furthermore, these two (2) rules shows the weakness and disadvantage of designing a fixed offshore structure which is less robust and tolerant to additional loadings, be it environmental loadings or due to additional loads increment during operation activities.

A weighting system is used to capture the relative importance of each rule. The summation of the product of the weight and the score will give the overall of the likelihood of structural failure score for each platform, as explained in Section 3.2 and shown by Equation 3.1.

Table 3.1: Baseline LOF selection rule

Rule Name	**Input**	**Weight**
Design Practice	Accounts for the historical development of the API's fixed offshore structure design code and the significant changes to the level of Metocean loading and joint resistance formulations used in platform design.	5
Bracing Leg	Accounts for how the redundancy varies for basic structural bracing systems.	10
Grouted Piles	Accounts for the strengthening of joints due to grouting the annulus between the pile and the leg	3

The total score for the platform is a weighted sum of the individual scores. High weights are used to emphasize the factors that strongly affect the likelihood while low weights are used for factors that moderately affect the likelihood. As for the bracing legs (BL), Amoco methodology is also adopted where the scores are distributed as shown in Table 3.2. However, the Amoco scoring system (Table 2.7) was modified to better suit the current O & G industry, such as the introduction of monopods and platforms with more than 8 legs (say 10 leg platform).

Table 3.2: Bracing leg (BL) Score

Bracing Configuration	**Number of Legs**				
	≤3	**4**	**6**	**8**	**>8**
K	10	10	8	6	4
VD	10	7	5	4	3
X	6	5	4	3	2
Weightage (O'Connor, Puskar 1999)	10				
Total Score	100 - 60	100 – 50	80 - 40	60 - 30	40 - 20

There was another gap in Amoco's methodology, where a distinct definition on Design Year was not given. The literature clearly states that the evolution of API design codes can be contributed to three distinct groups which are Pre-RP2A, Early-RP2A and Modern-RP2A (De Franco et al 1999). In order to obtain the baseline risk of platform, the scoring shown in Table 3.3 is proposed, combining Amoco's weighted score and the three distinct API design codes.

Table 3.3: Weighted score for design year

Design Year	Score for Year	Weight	Score Range
Pre-RP2A	4	5	20
Early-RP2A	8	5	40
Modern-RP2A	10	5	50
	Total		20 – 50

In addition, the grouted piles scoring used in the baseline risk ranking for offshore platform is adopting the scoring developed by AMOCO and no changes has been made. The grouted piles score is shown in Table 3.4.

Table 3.4: Weighted Score for Grouted piles (De Franco et al,1999)

Grouted	No	Yes
Score	10	0
Weightage	3	
Total Score	30	0

The overall weighted score that would be used to select the RBUI case study is shown in Table 3.5.

Table 3.5: Overall weighted score RBUI case study

Criterion	Min and Max Score	Weight	Score Range
Design Year	4 – 10	5	20 – 50
Bracing Type	1 – 10	10	10 – 100
	Total	10	30 – 150

3.4.2 Platform evaluation for present condition LOF

The rules for assessing present condition LOF were developed by modifying the rules developed by modifying the rules developed by Amoco. Amoco had 7 rules namely damaged members, remaining wall, marine growth, flooded members, last inspection, scour and appurtenances. From these, the year of inspection, EQ and flooded members were replaced. Year was replaced by deck load (changes over years), deck elevation (changes over years due to subsidence and other factors) and fatigue loading (cumulative fatigue damage over years); whereas EQ was considered unimportant; flooded members was included as "mechanical damage". The rules and the changes made are presented in Section 4.5.

3.4.3 Platform evaluation for COF score

The consequence of failure corresponds to the safety, environmental and financial issues that would arise should the platform fail at a future date. These are the standard consequence issues typically addressed in risk assessments for any type of facility, either onshore or offshore. As an example, a manned drilling and production platform would have a higher consequence of failure than an unmanned wellhead platform. Each of these consequences are converted to an explicit scoring system and then summed to result in the overall consequences.

The platform COF takes into consideration the following aspect:

- Life Safety
- Business Loss
- Environmental loss

Figure 3.5 shows the scoring calculation for COF risk of platform. The COF scores in the figure below are exemplary scores. Actual COF scores are shown in Chapter 4.

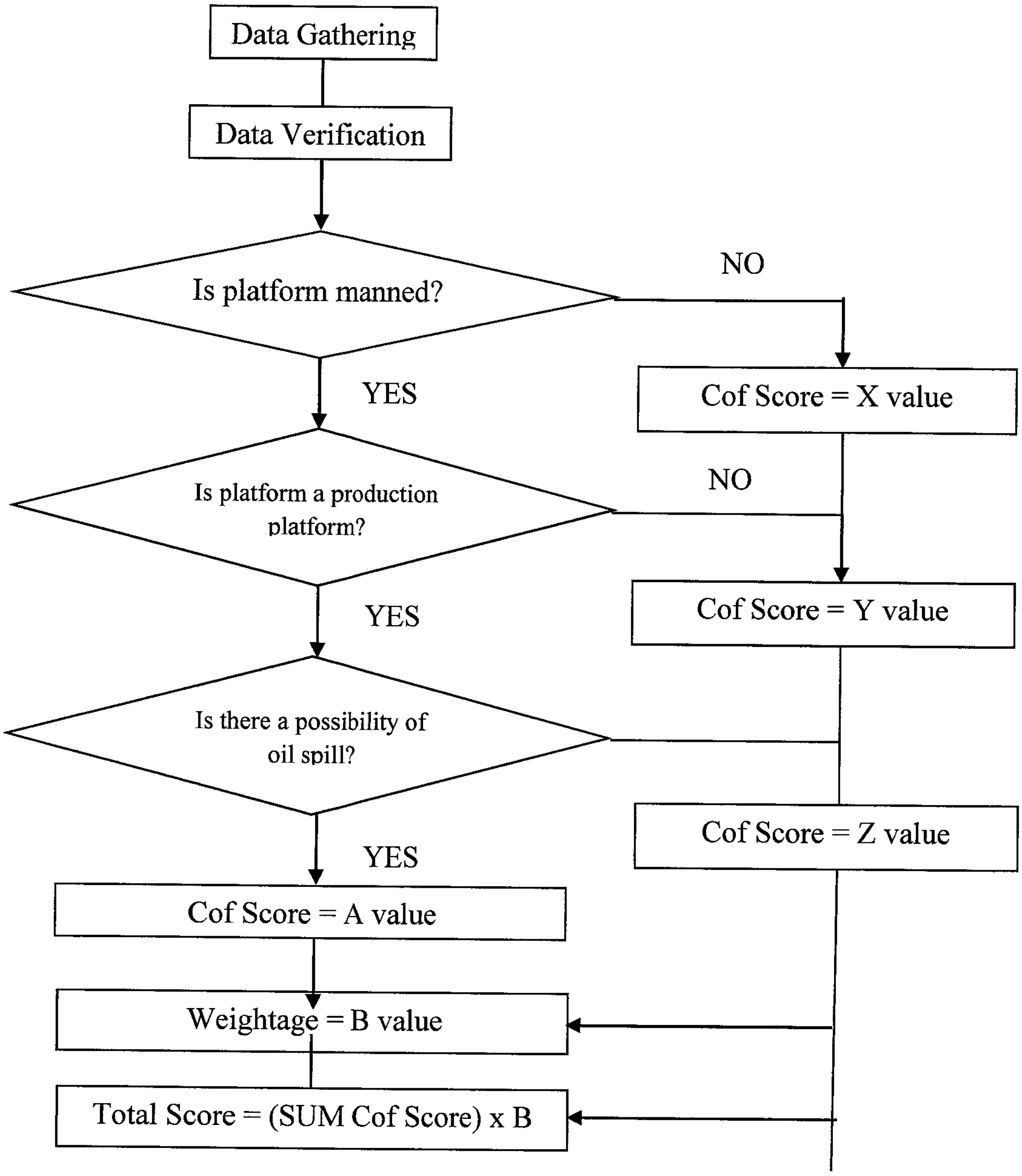

Figure 3.5: Platform selection criteria for Cof risk

RBUI framework for offshore structures can be developed by combining the Figure 3.4 and Figure 3.5.This framework will take into consideration both the Lof and Cof factors and subsequently determine the risk of the structure. The RBUI methodology is shown in Figure 3.6. It also shows how the inspection strategy and program are decided based on the rules that have obtained high score.

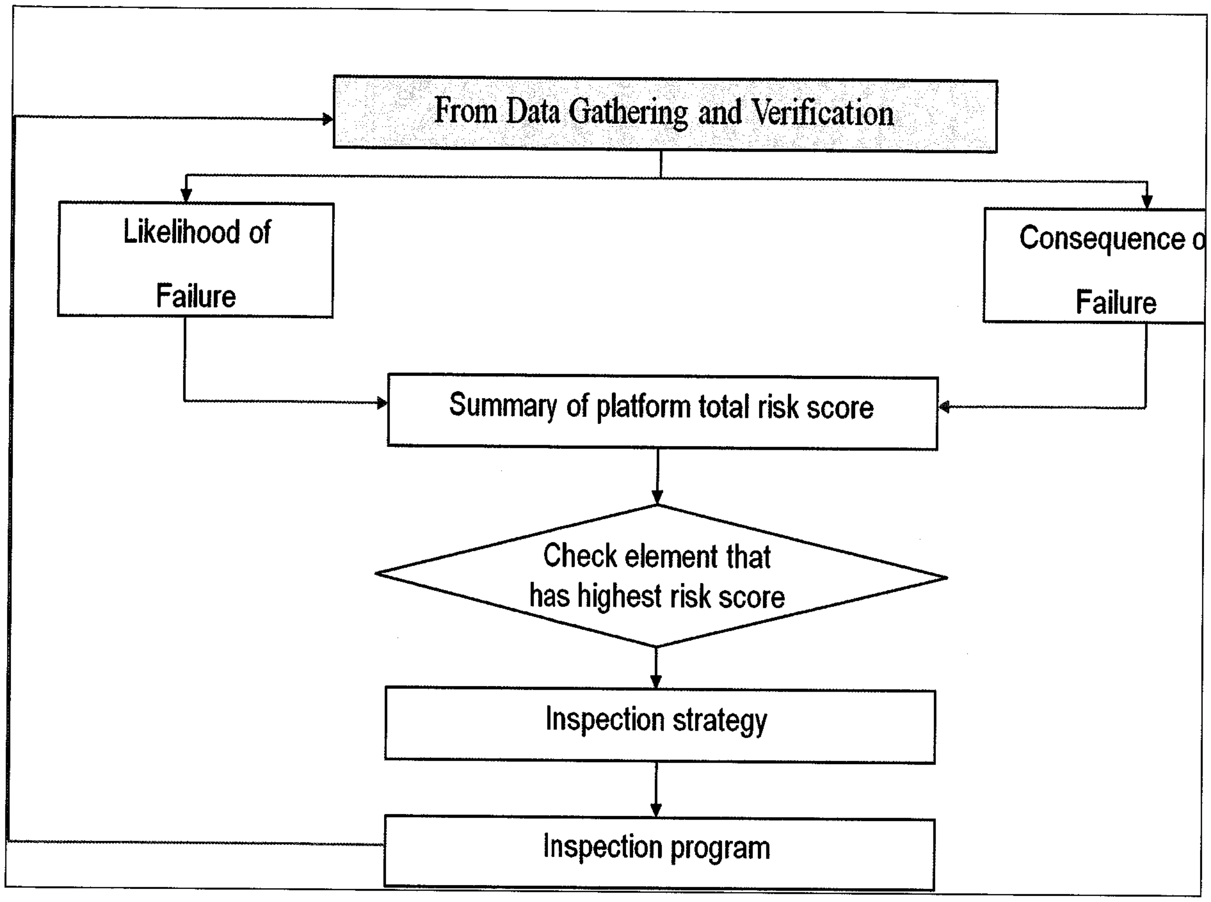

Figure 3.6: Platform selection criteria for RBUI

3.5 Development of Statement of Requirement for Design of offshore structures

Existing industry design standards for offshore facilities (with some exceptions relating to design for accidental loading) are component-based; therefore, the strength of the structure is defined by the strength of the weakest component. No benefit is taken from load redistribution, a feature that is largely responsible for the inherent robustness and damage tolerance of offshore platforms.

The statement of requirement is 'a performance based design (PBD) approach to offshore engineering design'. It is distinct from risk-based or consequence-based design, introduced in the 21st Edition of API RP2A, in that it does not try to optimize the likelihood of failure on the basis of an understanding of the consequence of failure.

The development of PBD takes into consideration two aspects to create value. These aspects are:

- Technology
- Experience

Advancement in technology is taken into consideration during design. Example of advancement in technology during design is the construction of tarpon structures for marginal fields. Marginal fields are fields that have low reserve of oil or gas, with expected life of less than 25 years. Designing an offshore structure, as per API RP2A or PTS, allows for a structure to operate for 30 years is a waste of money when the field life is less than that. In this case, a performance based design should be implemented, where a platform is designed based on its performance and requirement.

In addition, the experience of the author in the O & G industry, and his interaction with various industry players allows for the development of a SOR. This is because, experience and lesson learned in offshore projects across Malaysia has never been exhaustively documented.

In addition, PBD is to facilitate the design of structures that have predictable performance in compliance with performance goals selected for the intended life. Furthermore, it is intended to reduce the Likelihood of Failure (Lof) risk of an offshore structure, by ways of designing more robust structure.

In this thesis, emphasis is provided on the consideration of entire platform life cycle; from appraisal and selection to disposal, potentially after one or more change-of-use or reuse. As illustrated in Figure 3.7, the PBD process aims to combine technology and experience to deliver structures with predictable performance in compliance with selected performance goals.

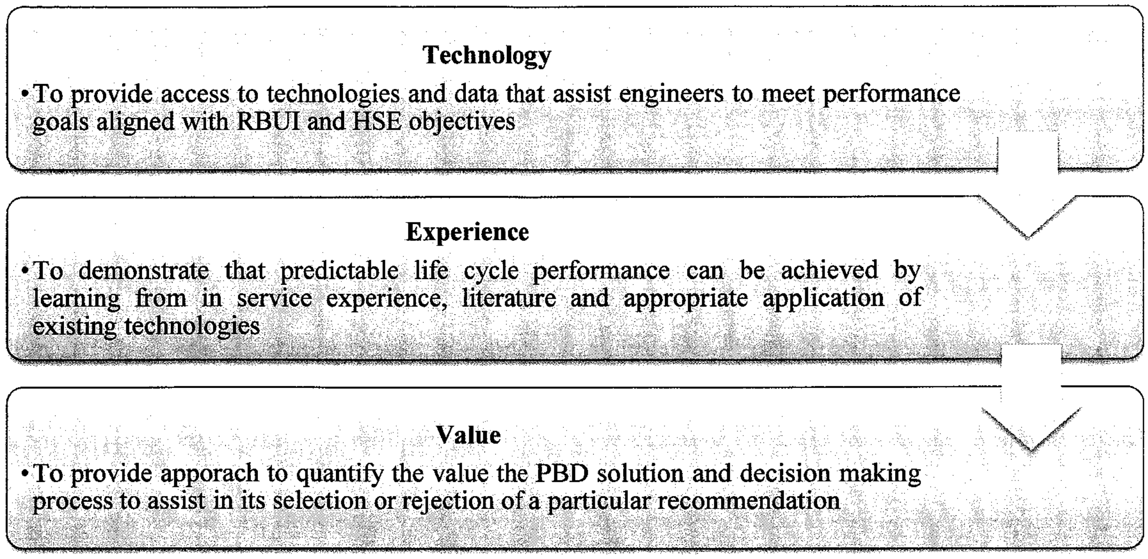

Figure 3.7: Performance based design

A PBD approach allows the implementation of proven technologies to take advantage of the additional capacity that exists where doing so can be demonstrated to achieve platform performance consistent with selected performance objectives.

PBD is integrated with Structural Integrity Management (SIM), where SIM is a process for ensuring the fitness for purpose of an offshore structure from installation through to decommissioning. The process is a rational means for understanding the effects of degradation, damage, changes in loading, accidental overloading, changes in use, life extension, and the evolution of the offshore design practice.

3.6 Development of Data Handover Guideline for Greenfield and Brownfield projects

The management of relevant SIM data plays a big part in the future RBUI strategy of a fixed offshore structure. This is demonstrated later in the thesis where the RBUI methodology developed will penalize structures that have insufficient data, thus increasing the risk of the structure. This is so because without sufficient data, there would be more uncertainty regarding the behaviour and response of the fixed offshore structure due to various conditions, i.e. surge in environmental conditions, infill drilling activities and etc. Figure 3.8 below provides the SIM data requirement:

Figure 3.8: SIM Data requirement

To further expand the SIM data requirement, this research has further studied and explored various improvements that can be undertaken. The information shown in Figure 3.8 only concerns the data during design. In order to develop an integrated SIM framework, data during operation would also need to be considered. Data requirement in Figure 3.8 is further expanded as shown in Figure 3.9:

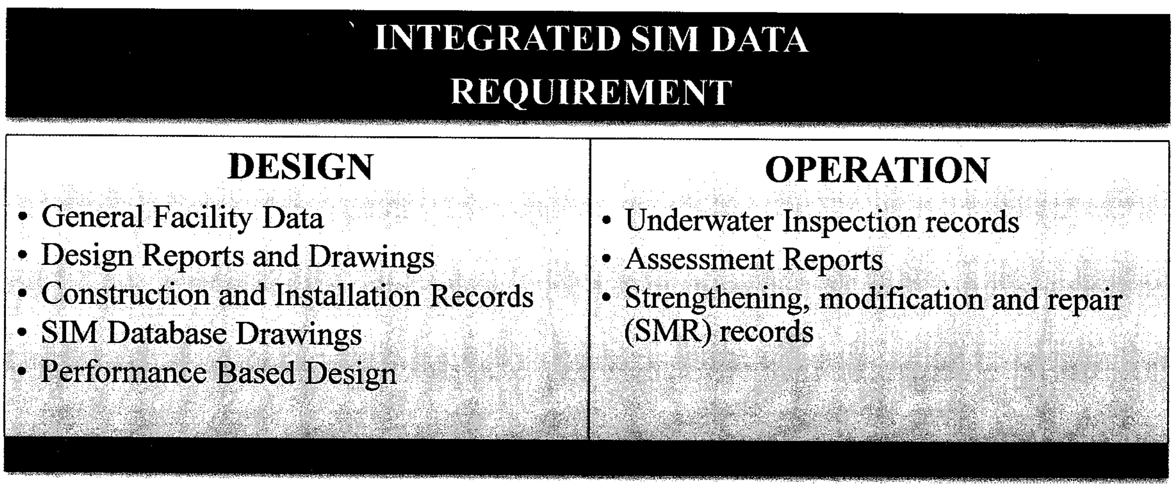

Figure 3.9: Integrated SIM Data Requirement

API RP2A WSD 21st Edition and ISO 19902 – 2007 Fixed Steel offshore structure, has given basic data requirement and specification that needs to be adhered to during design and assessment of offshore platform. ISO 19902 – 2007 Fixed steel offshore structure also states that all data and reports incidents shall be retained by the owner for the life of the structure and transferred to new owners as necessary.

However, no proper guideline is in place to determine what and when the data required is to be handed over. This research combines both the requirement in API RP 2A WSD 21st Edition and ISO 19902 – 2007 requirements and develops a data handover guideline for Greenfield and Brownfield projects.

3.7 Development of an integrated SIM framework for fixed offshore structures in Malaysia

The development of an integrated SIM framework for fixed offshore structures involves two (2) major stages, which is design and operation. These two (2) stages have different sets of requirement, where each has its own benefits. The integrated SIM framework can be best explained using the Figure 3.10:

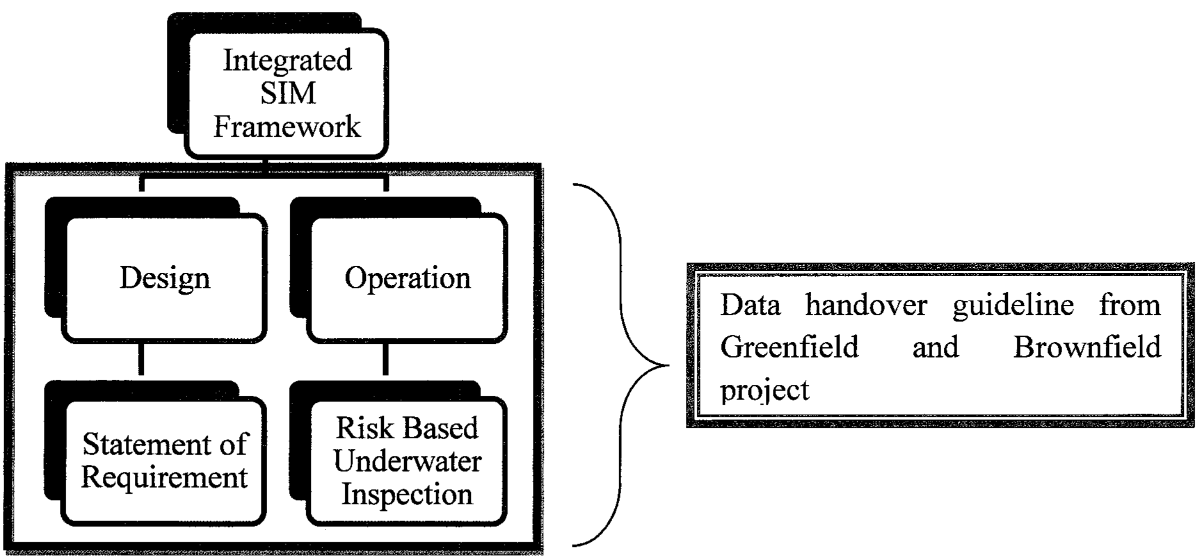

Figure 3.10: Integrated SIM Framework flow chart

Data is the first process for a SIM framework. Data can be obtained either during design or operation. To ensure that the appropriate data is available to develop an integrated SIM framework, the SOR will provide guidance above and beyond the conventional design codes and standards, which are API RP 2A WSD 21st Edition and ISO 19902 – 2007 Fixed Steel Offshore Structure.

During operation, it was clearly stated in ISO 19902 – 2007 that certain types of data is required for the re-assessment of existing platform. The data that is required will be covered under the RBUI guideline that is developed in this research.

The combination of both design and operation data, will provide for the development of "Data handover guideline from Greenfield and Brownfield project".

3.8 Chapter summary

This chapter has discussed the methodology used in this study. The methodology developed constitutes a generic framework for SIM for fixed platforms in Malaysia. The sub-processes provide for the sub objectives in Section 1.4. The component of framework is presented in the following Chapter 4 Development of an integrated SIM framework for Malaysia's offshore platform. The case study to illustrate each component of the integrated SIM is presented in Chapter 5.

CHAPTER 4

DEVELOPMENT OF AN INTEGRATED SIM FRAMEWORK FOR MALAYSIA'S OFFSHORE PLATFORMS

4.1 Introduction

The main objective of this research is to develop an integrated SIM framework for Malaysia's fixed offshore platforms. This requires a structured and comprehensive study of Malaysia fixed offshore structure where gaps in design, assessment and inspection programs will be identified (or gaps in current SIM processes), and proper mitigation is proposed. Results in this research are divided based on the four (4) sub objectives stated in section 1.4 which are:

- The classification of Malaysia fixed offshore structure
- Development of a Risk Based Underwater Inspection (RBUI) methodology.
- Development of a statement of requirement for structural design
- Development of a data handover guideline for Greenfield and Brownfield projects

It should be noted that the above four components form an essential part of an effective integrated SIM framework. The results presented in this section will provide an insight on what data was obtained, evaluated and how the result is used in the Structural Integrity Management (SIM) for Malaysia fixed offshore structure. Each of the four sub objectives are described briefly below.

4.1.1. The classification of Malaysia's fixed offshore structure

The classification of Malaysia's fixed offshore structures is based on the structure characteristics and will provide results on the distribution of platforms based on design codes used, age of structure, bracing types and inspection history. This data is crucial to identify the baseline risk of the structure when it was installed (Pat O'Conner, 2005) and subsequently will provide a basis for the development of a Risk Based Underwater Inspection (RBUI) program.

4.1.2. Development RBUI Methodology

The RBUI methodology describes the methodology by which a Risk-Based Underwater Inspection (RBUI) program can be established for fixed offshore structures. The guideline outlines the methods for evaluating the likelihood of catastrophic failure and the resulting consequences, making an assessment of the risk level, and concluding on the appropriate inspection mitigation that should be implemented to manage the risk.

4.1.3 Statement of Requirement for design of fixed offshore structure

The statement of requirement for design of new offshore fixed structure provides a framework within which a performance based design (PBD) approach to offshore engineering design can be applied. It is distinct from risk-based or consequence-based design, introduced in current design codes and standards, in that it does not try to optimize the likelihood of failure on the basis of an understanding of the consequence of failure. Instead, the objective of PBD 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 entire life cycle of the structure; from appraisal and selection to disposal, potentially after one or more change-of-use or reuse. The PBD process aims to combine technology and experience to deliver structures with predictable performance in compliance with selected performance goals. This guideline is intended for welded steel structures used offshore, such as oil and gas platforms. The guideline is intended to identify, address, and prioritize issues related to design motivations and methodologies. It is not intended to be a comprehensive specification that eliminates the flexibility necessary for specific situations and conditions that might be encountered.

4.1.4. Data handover guideline for Greenfield and Brownfield project

The data handover guideline for Greenfield and Brownfield projects specifies the minimum Structural Integrity Management (SIM) data that is required to be transmitted from new projects and the acquisition of a new offshore facility to the engineering personnel responsible for the long-term structural integrity of operator offshore structures. This guideline is intended to assist project personnel responsible for the design, construction and installation of the new facility, modification to an existing facility, and is applicable to a newly acquired asset to deliver the necessary data required for continued operations. It includes details of the format in which the data should be provided, consistent with the SIM process proposed in this research. It is expected that usage of this guideline will lead to a world class SIM of the physical asset in any operator, to meet the challenges in the O & G operations as well as accomplishing operator's overall business objectives.

As a part of the development of the SIM framework for Malaysia, each of the objectives is discussed below. The discussion includes what data is obtained, evaluation of the data and the output. Definitions and procedures are also described in detail as they form a part of the framework developed. Each objective is also illustrated using case study in Chapter 5.

4.2 The classification of Malaysia fixed offshore structure

The discussions reported in this section address the first objective stated in section 1.4. Malaysia currently has in operation over 200 fixed offshore structures divided into three (3) operating regions, namely Peninsular Malaysia (PMO), Sarawak Operation (SKO) and Sabah Operation (SBO). Many of these structures have exceeded the design life of 30 years. In order to ensure the continued fitness for purpose of these structures, this research first determined the characteristic of Malaysia fixed offshore structures. The characteristic data includes the (1) Design code, (2) Bracing configuration and (3) Number of legs.

These three (3) data are required to identify the preliminary baseline risk of the structure, implementing the methodology developed (De Franco et al, 1999). The dataset, consisting of 186 fixed offshore structure data were obtained from local O & G operator. The importance of knowing the baseline risk of the structures is to identify which platform is exposed to the highest risk prior to operation, and which platforms are most likely to benefit the most from a more focused inspection effort.

Table 4.1 and 4.2 shows the combined methodology developed after incorporating comments by De Franco et al (1999) and by the author in developing a baseline risk table for Malaysia fixed offshore structure. In the Table 4.1, the changes adopted were the inclusion of the period of the codes and change of weighing factor from 8 to 6. In Table 4.2, additional columns were added to include platforms with legs more than 8 and columns with legs "less than or equal to three" to include monopods also. The weighting factors were also modified. The criteria as mentioned above consists of identifying the design code, bracing configuration and number of legs. A score is allotted based on the year of the code used for design (Figure 4.1). Based on the bracing configuration and number of legs, a score will be allotted using Table 4.2, which is known as "the robustness rule".

Table 4. 1: Design code rule

Design Code	**Pre – RP2A** **Pre - 1971**	**Post – RP2A** **1971 - 1979**	**Modern – RP2A** **After - 1979**
Score	10	6	4
Weightage	5		
Total Score	50	30	20

Table 4. 2: Robustness rule

Bracing Configuration	**Number of Legs**				
	≤ 3	**4**	**6**	**8**	**>8**
K	10	10	8	6	4
VD	10	7	5	4	3
X	6	5	4	3	2
Weightage	10				
Total Score	100 - 60	100 – 50	80 - 40	60 - 30	40 - 20

Baseline risk categories were defined based on specialist knowledge of parameters influential to platform robustness and exhaustive studies of in-service performance data of existing platforms and lessons from occurrence of extreme load events especially hurricanes which have been responsible for the majority of platform failures worldwide. The basic categories are modified to reflect the present condition of the platform as determined by inspection data or assumed from known platform damage susceptibility.

The baseline risk of structural failure is determined using a rule-based system that determines a likelihood score based upon key platform information. The likelihood categorization system identifies the platform characteristics that affect the platform strength, such as the year designed, the number of legs and the bracing configuration.

At the time of installation, the likelihood that the platform will fail during the Design Event is a function of the design strength and the robustness and ductility of the structure. These properties collectively define the 'baseline likelihood of failure' of the platform. A weighing system is used to capture the relative importance of each rule. The summation of the product of the weight and the score will give the overall likelihood of structural failure score for each platform. The platform baseline risk ranking can now be determined based on the different categories given in Table 4.3. The categories have been obtained by dividing the range of scores into bands, either equally or by fixing probability range (μ-2σ, μ-σ, μ, μ+σ, μ+2σ).

The assumption in this rule is that the rule more heavily penalizes platforms that were designed before the introduction of the API design code, and less heavily those platforms that were designed using API codes that pre-date the introduction of the 100-year recurrence criteria. The date bands include a contingency for the year that the code was introduced compared to the date that the first designs to the new code would likely have been installed based on the figure obtained from (Westlake, 2003).

Table 4. 3: Baseline risk ranking categories

Baseline Risk Ranking	**Qualitative**
Very High Risk	≥120
High Risk	≥ 90- < 120
Medium Risk	≥ 70 - < 90
Low Risk	≥ 50 - < 70
Very Low Risk	< 50

The bracing configuration and number of legs is significant because most offshore structures possess an inherent reserve strength that is greater than the strength of its critical components. This is derived from a variety of sources, such as over-design, design for pre-service condition and design code safety factors, etc., which in redundant systems allows mobilization of alternative load paths. Some structures display considerable levels of reserve strength whereas others suffer from a sudden drop in capacity as soon as one critical member fails. The level of reserve strength that a platform possesses is regarded as a measure of its robustness.

The number of legs and bracing system on a platform together with its redundancy and susceptibility to failure is related to its robustness. Table 4.2 summarises the levels of robustness identified for each platform configuration. The number of legs together with the bracing system is a strong indicator of the overall redundancy and damage tolerance of a platform.

The rule also accounts for how redundancy varies for different basic structural bracing systems. The rule heavily penalizes K-braced structures and moderately penalizes structures with vertical diagonal bracing configurations. The rule also recognizes the lower redundancy attributable to a lesser number of legs.

The baseline risk ranking requires that structures be grouped into "bins" that represent categories of platforms with different risk level. The total score is taken by summarizing the two (2) baseline risk ranking rules i.e. design code and robustness.

Referring to Table 4.1, the maximum score for design code rule is 50 and minimum score is 20. Referring to Table 4.2, the maximum score for BL rule is 100 and minimum score is 20. The overall maximum combining both is 150 and overall minimum score is 40. The overall maximum value will fall under "very high risk" and the overall minimum value will fall under "very low risk" based on the baseline risk ranking categories given in Table 4.3.

Using the rules developed above and the year of commissioning of fixed offshore structure the following results were obtained. Figure 4.1, 4.2 and 4.3 shows the distribution of design code of the offshore structures for PMO, SKO and SBO.

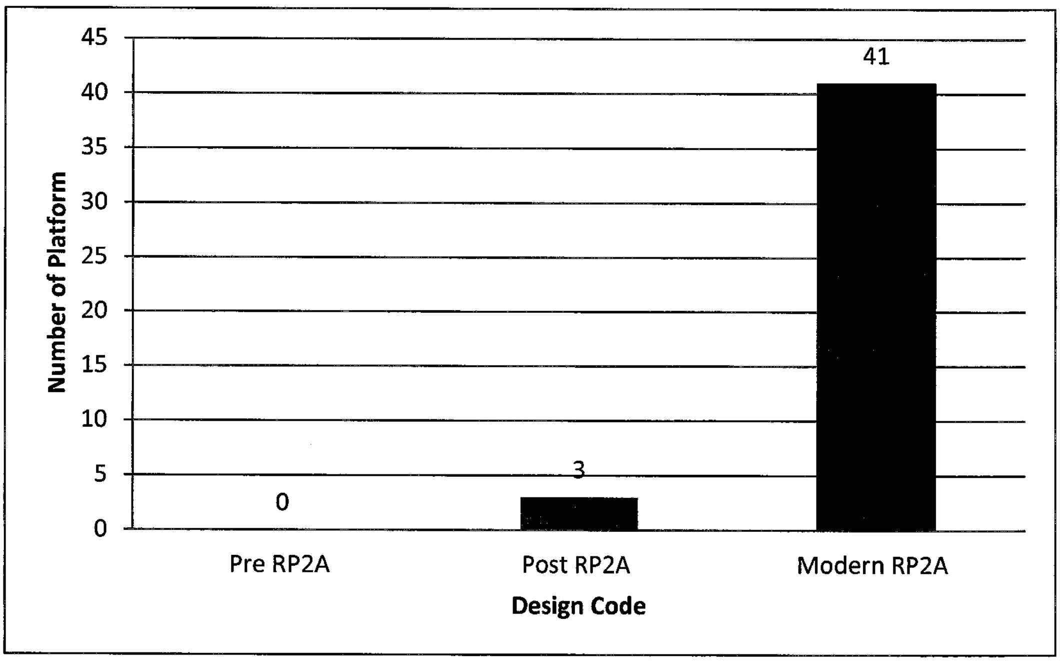

Figure 4.1: Distribution of platform based on Design Code for PMO

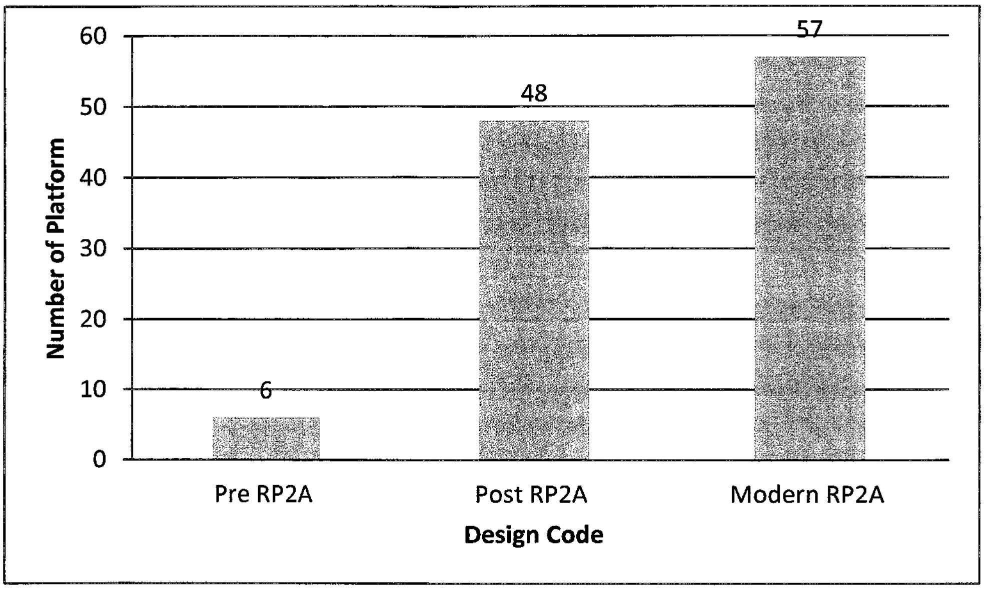

Figure 4.2: Distribution of platform based on Design Code for SKO

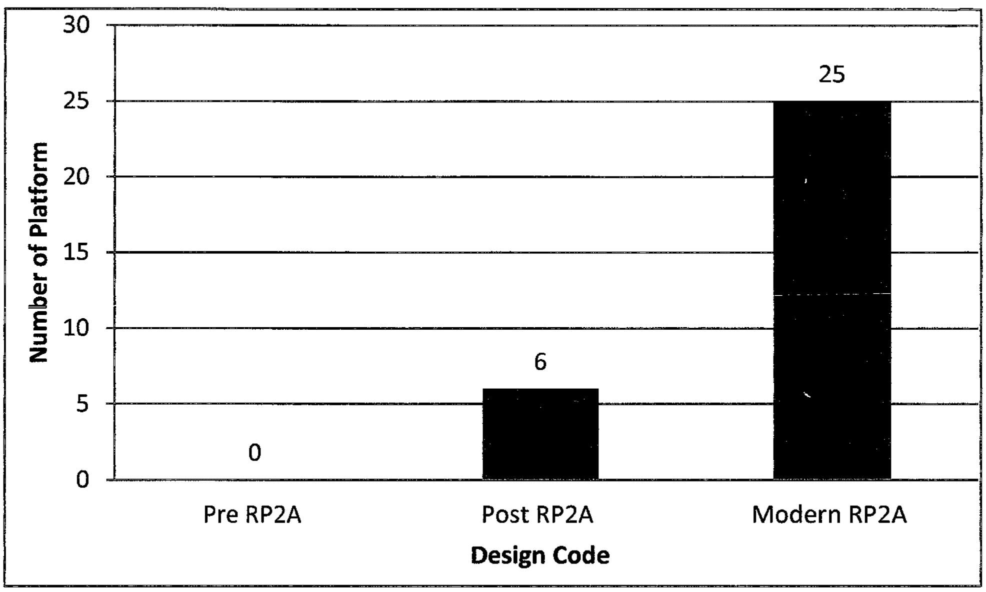

Figure 4.3: Distribution of platform based on Design Code for SBO

Figures 4.1 to 4.3 shows that the majority of structures in Malaysia was designed using the modern RP2A code. The critical differences between the three (3) different periods in the code development were discussed and described in detailed in Chapter 2, Section 2.5. However, the main objective in identifying the design code for these structures is to identify the baseline risk of these structures during their initial operation life i.e. when it was installed.

In order to do this, to some extend the methodology adopted by (O'Connor, Puskar 1999) was used, where it states that the newer structures is designed to better standards, such as joint cans, and has an inherently more redundant structural configuration. Therefore, the baseline risk of platform for older structures, which were designed using earlier codes and standards, would be higher compared to the newer codes.

The second type of data that is required is the bracing and number of leg configuration which constitute the platform robustness. According to (O'Connor, Puskar 1999), the more redundant and robust the structure is, the less likelihood the platform will fail. As an example, a 1960's vintage 6 leg, K-braced platform has a higher likelihood of failure than a 1980's vintage 8 leg, X braced platform. This is because the 1980's platform has an inherently more redundant structural configuration since it has 8 legs and is X braced.

In order to implement the methodology by (O'Connor, Puskar 1999), the required information related to the bracing configuration and number of legs of the fixed offshore structure in Malaysia was obtained. The data are tabulated in Figures 4.4, 4.5 and 4.6.

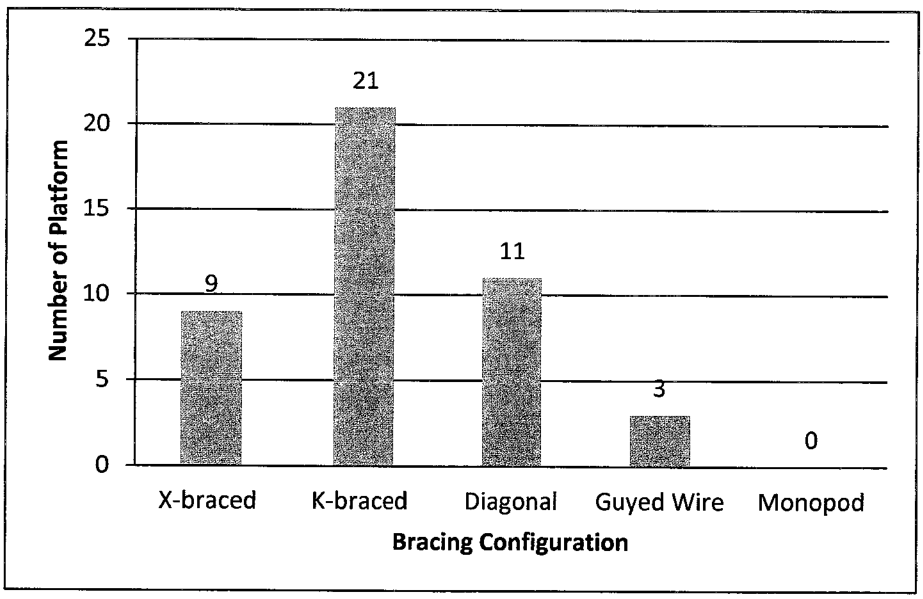

Figure 4.4: Distribution of platforms based on Bracing Configuration for PMO

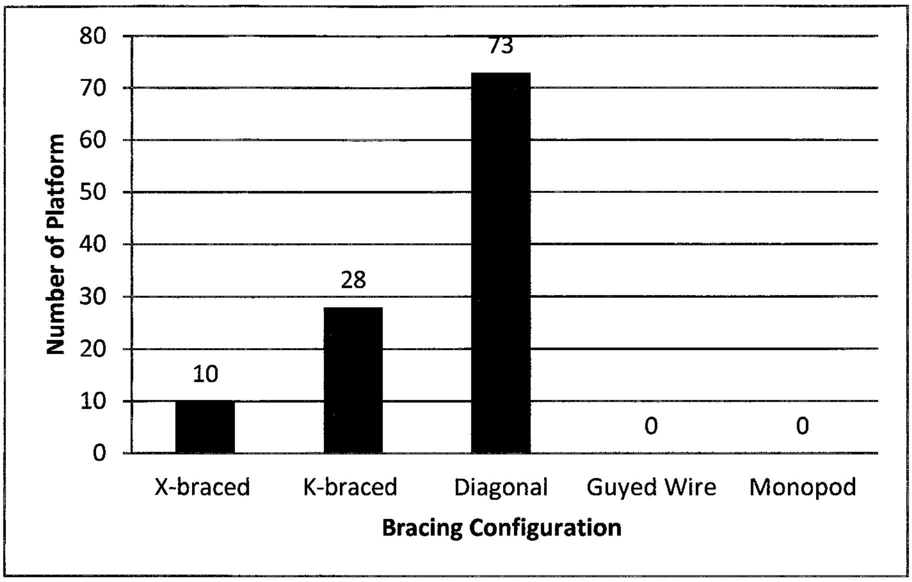

Figure 4.5: Distribution of platforms based on Bracing Configuration for SKO

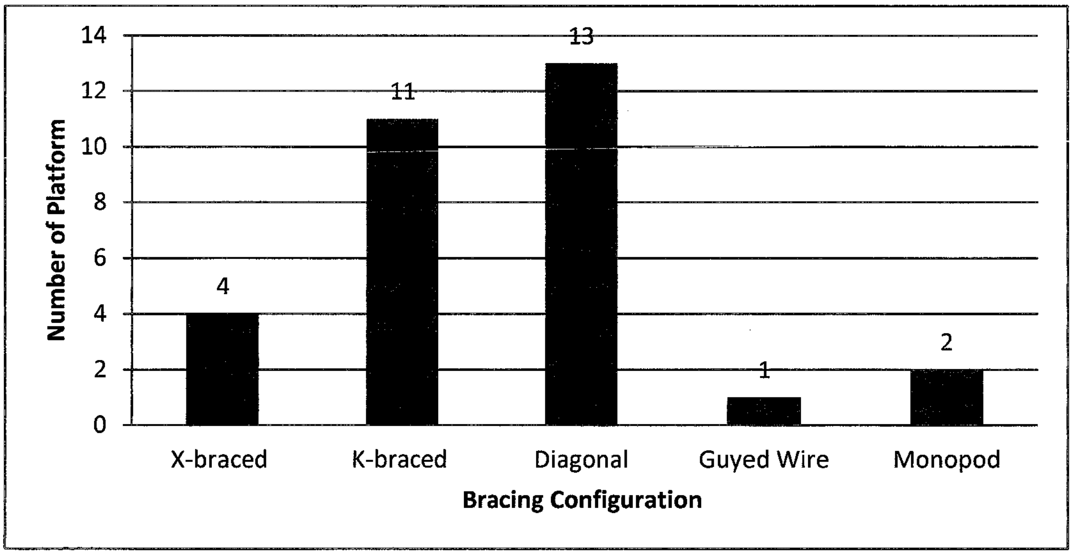

Figure 4.6: Distribution of platforms based on Bracing Configuration for SBO

The results of the bracing configuration study indicate that the main bracing configuration for Malaysia fixed offshore structures is diagonal bracing. However, having only two (2) data, i.e. design code and bracing configuration is still not sufficient in identifying the baseline risk based on (O'Connor, Puskar 1999) methodology. The third set of data i.e. number of legs for each structure is shown the Figures 4.7, 4.8 and 4.9.

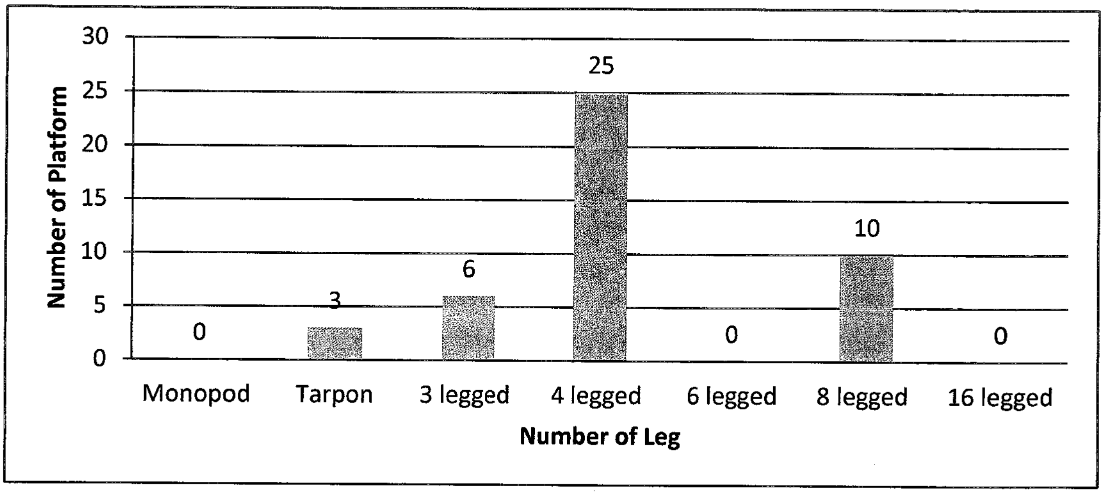

Figure 4.7: Distribution for PMO platform based on number of legs

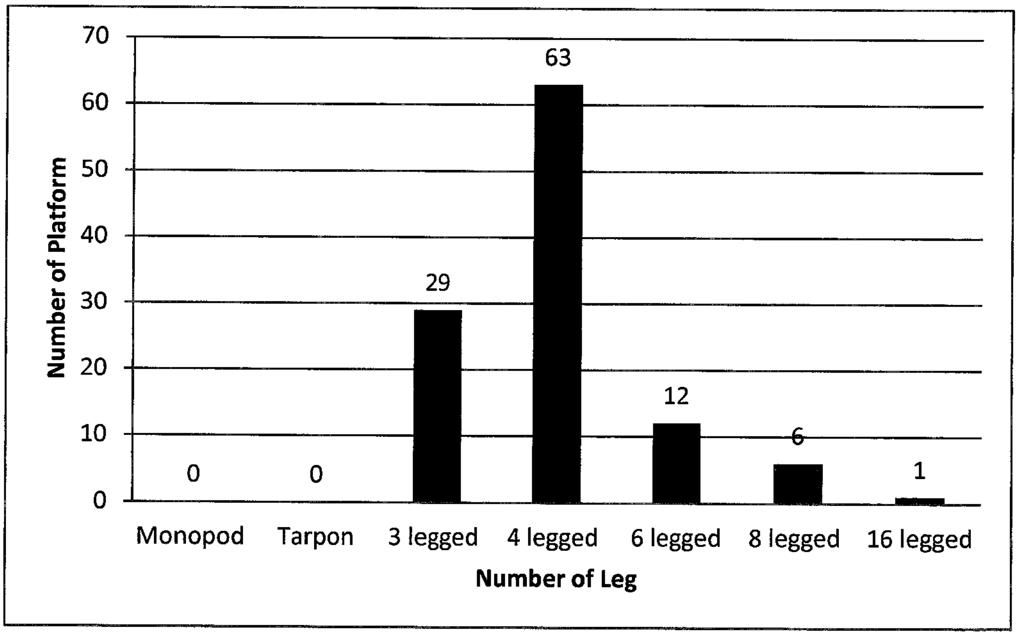

Figure 4.8: Distribution for SKO platform based on number of legs

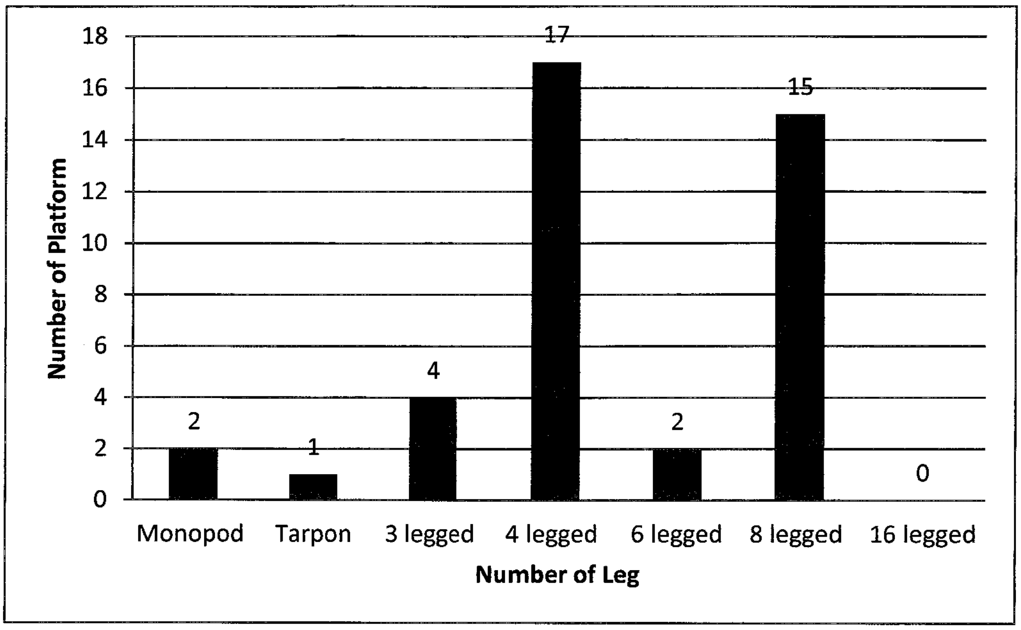

Figure 4.9: Distribution for SBO platform based on number of legs

In order to obtain the baseline risk, data from Figures 4.4 to 4.9 is combined as per the format in Table 4.2, which gives the baseline risk for Malaysia's fixed offshore structure for Bracing configuration and Number of Leg rule. After that, each platform will be divided into each separate design code as per the year installed to obtain the scoring for design code rule in Table 4.1. The summation of the total score will provide the baseline likelihood of failure score. The summary of results for "Design Code" and "Bracing Configuration and Number of Leg" rule for Malaysia fixed offshore structure (combining the three regions) is given in Figure 4.10 and Figure 4.11.

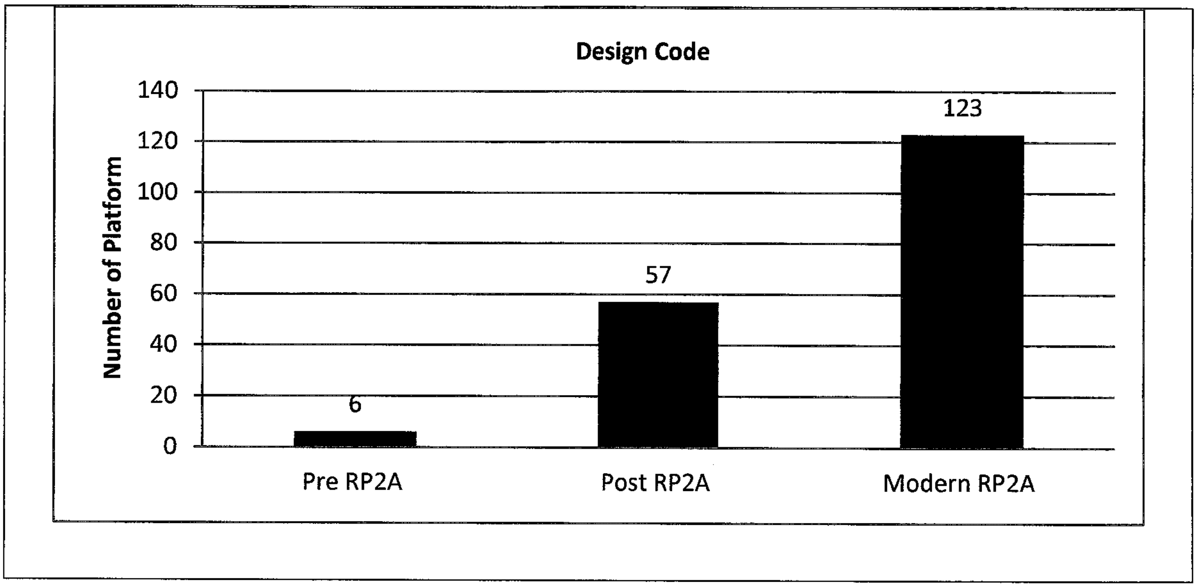

Figure 4.10: Distribution of platform based on Design Code for Malaysia

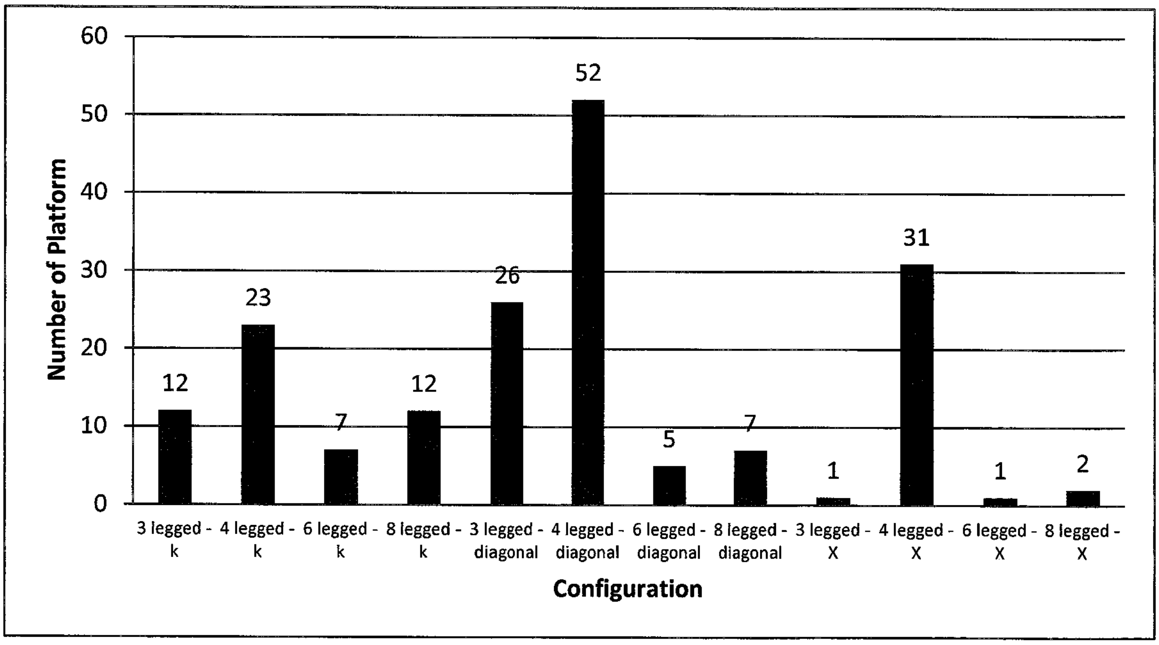

Figure 4.11: Distribution of Malaysia's platforms based on bracing configuration & number of leg

Figure 4.12 shows the risk ranking framework that has been developed. The risk ranking is first divided into two categories, which are Likelihood of Failure (LOF) and

Consequence of Failure (COF). The LOF is further divided into three sub-categories which are (1) Baseline risk, (2) Presnt condition, and (3) Loading susceptibility. The COF is also divided into three sub-categories which are (1) life safety, (2) Environmental loss and (3) Business Loss.

The summation of the scores from all these sub-categories will provide the risk category of the said platform. The risk ranking will provide the inspection strategy, where different levels of risk will provide different levels of inspection intervals and inspection scope of work.

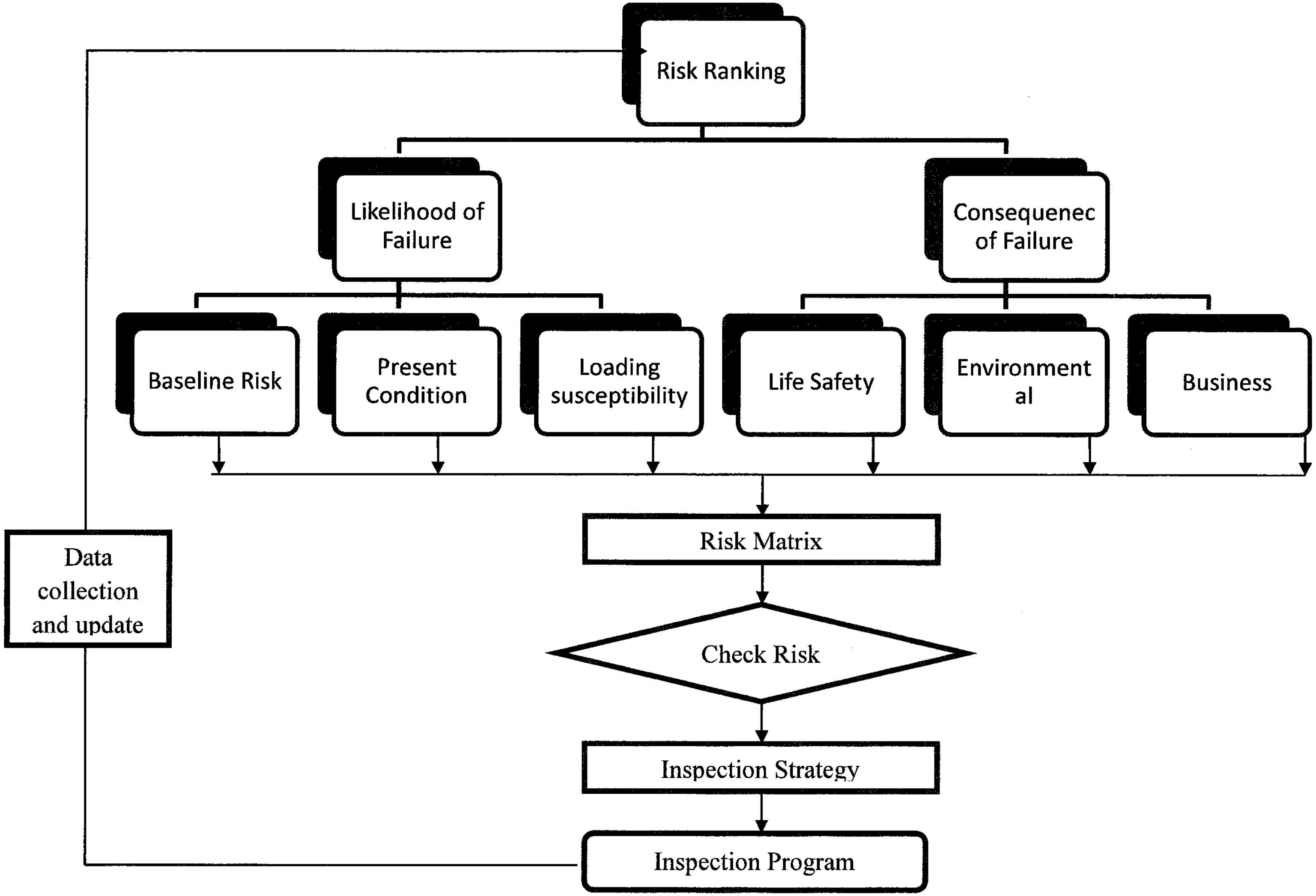

Figure 4.12: Risk ranking framework

4.3 Statement of requirement for design of offshore structure

The second objective of this research is to develop a "Statement of Requirement for Design of Offshore Structure". The document provides a framework within which successful statement of requirement for design of steel offshore platforms can be executed.

However, the redundancy, ductility and systems capacity can now be controlled by the design team as validated and efficient non-linear analysis software is available to model system performance. This is backed by an understanding of the physical processes involved and of the associated uncertainties for meaningful reliability evaluations. Figure 4.13 shows the statement of requirement framework for this research.

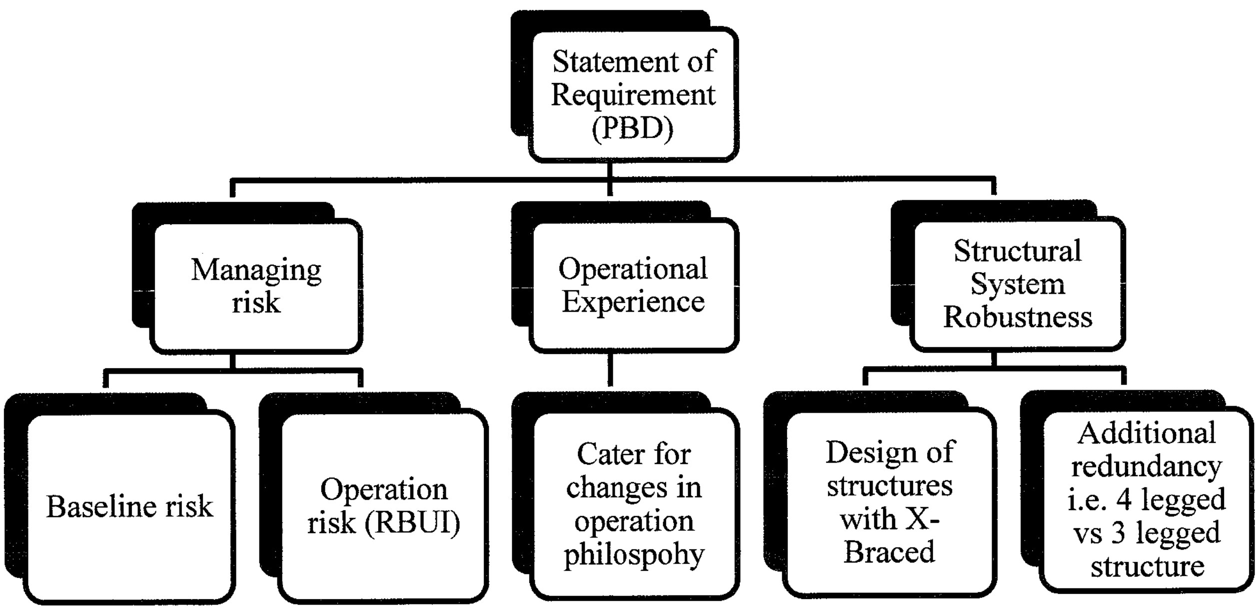

Figure 4.13: Statement of Requirement framework

4.4 Data handover guideline for Greenfield and Brownfield project

This Data Handover Guideline for Greenfield and Brownfield Projects specifies the minimum Structural Integrity Management (SIM) data that is required to be transmitted from new projects and the acquisition of a new offshore facility to the engineering personnel responsible for the long-term structural integrity of offshore structures.

This guideline is intended to assist projects, responsible for the design, construction and installation of the new facility, modification to an existing facility, and is applicable to a newly acquired asset to deliver the necessary data required for continued operations.

It includes details of the format in which the data should be provided, consistent with the SIM process proposed in this research. It is expected that usage of this guideline will lead to a world class SIM of the physical asset in any operator, to meet the challenges in the O & G operations as well as accomplishing operator's overall business objectives.

4.4.1 Data requirement

Design information on the facility generated during a Project is a pre-requisite for defining the long-term SIM strategy. Before the start of operations of a new or newly acquired facility, certain data should be made available to the operations team that will be responsible for the long-term structural integrity of the facility. The data includes design data, fabrication data and installation data that are important to the future SIM of the platform and related infrastructure.

The project data will be evaluated by qualified engineering personnel, to determine the appropriate strategy for the management of the facility and a suitable program for the inspection and/or monitoring of the facility throughout its service life. Vital data and records from the design, fabrication and installation phases of an offshore structure, which are required by the engineering personnel responsible for SIM include:

- General Facility Data
- Design Reports and Drawings
- Construction and Installation Records
- SIM Database Drawings

- Performance Based Design

The data and records from the Project shall be sufficient to enable the engineering personnel responsible for SIM to develop a risk ranking of the structure. Once all necessary SIM data are obtained, this data can then be evaluated by qualified engineering personnel to determine the appropriate strategy for the management of the facility and a suitable program for the inspection and/or monitoring of the facility throughout its service life.

4.4.2 General facility data

The following data shall be summarized from the design project:

- Geographical region, Field name and Platform name
- Platform co-ordinates and platform orientation
- Design year
- Design code and edition
- Design life
- Design water depth
- Design air gap
- Design cellar deck bottom of steel elevation
- Design jacket, deck and pile weights
- Platform configuration, i.e. number of legs, number of leg piles, number of skirt piles, longitudinal/transverse framing, leg/skirt annulus grouting, etc.
- Primary function of the facility
- Design drilling rig (TADR and/or Jack-up) and the weight
- Design number of bridges and bridge weight
- Design number and size of caissons
- Design number and size of conductors
- Design number and size of risers
- Design number and size of J-tubes and/or I-tubes

- Design production rate
- Design number and location of boat landings
- Design number of riser guard and/or conductor guards
- Accommodation type and capacity
- Type of cathodic protection
- Helideck material and rating
- Crane type and capacity
- Jacket, deck and foundation design contractor(s)
- Certifying authority
- Metocean and soil consultants
- Jacket, deck and foundation construction contractor(s)
- Installation contractor(s)

4.4.3 Design reports and drawings

The project shall provide an electronic archive of the following design documents:

- Basis of design report, including all criteria used in the design
- Topsides structural life-cycle design reports, including where appropriate; transportation, lift, installation, load-out, in-place, fire and blast, fatigue and/or seismic.
- Substructure structural life-cycle design reports, including where appropriate; transportation, lift, installation, load-out, launch, flotation & upending, in-place, boat impact, dropped object, fatigue, seismic, fire and blast, on-bottom stability, ultimate strength, reliability, decommissioning and/or redundancy.
- Foundation life-cycle design reports, including where appropriate; pile make-up, in-place, fatigue, and/or pile drivability.
- Soil boring reports
- Cathodic protection design reports
- Appurtenance life-cycle design reports
- AFC/IFC substructure drawings, including appurtenances and attachments
- AFC/IFC deck and topside drawings

- Design model computer input files for corresponding design reports
- Weight control report and data file
- Monitoring systems design reports

4.4.4 Construction and installation records

The project should provide an electronic archive of the following construction and installation records:

- As-built drawings
- Fabrication non-conformance reports
- Material tracing and quality control records-material tests, heat treatments, welding inspection records, dimensional checks, weighed weight, etc.
- Pile and conductor installation driving records
- Pile grouting records & grout strength test records
- Appurtenance installation records
- Platform position and orientation
- Platform leveling records
- Load-out, Transportation and Installation Manuals
- Name of derrick barge, marine surveyor, hook-up weight of packages
- As measured water depth
- As installed/measured air gap
- Number of installed wells and well internal string make-up
- Number of well slots in use, their location and the nature of application
- Post installation baseline underwater inspection
- Construction phase weight control report
- Topsides weighing report
- Substructure weighing report
- Lessons learnt

4.4.5 *Baseline structural component risk registers*

At the time of commissioning of a new facility, the risk of the degradation of structural component shall be determined. This baseline component risk register is the sum of all the structural critical elements and shall document the structural baseline component risk for each Facility. For new structures, not yet installed, the baseline risk register and the air gap should be identified in the project Statement of Requirements (SOR) as a deliverable to the operator. The baseline component risk scores for each structural critical element (SCEs) shall be determined upon completion of each development project. Structural SCEs may include:

- Primary structural framing
- Secondary structures (including ladders, plating, grating, walkways, handrails, wind walls, stairways, access platforms, catch nets and vessel, piping and equipment support structures)
- Equipment tie-downs i.e. drill rig skid connections
- Appurtenances and their structural connections (conductors, service caissons, risers)
- Bridges and bridge bearings
- Lifting equipment
- Helideck
- Fire and blast walls
- Vent and flare booms
- Communication towers

The development of the structural component risk register at the design stage has the added benefit of getting the design team to consider risk as an inherent element of the design which often stimulates opportunity for baseline risk reduction by defect elimination. An example is the use of FRP instead of steel for structural walkways which eliminates the potential for corrosion defects.

Over time as deterioration and degradation mechanisms develop across the structure, the residual risk will tend to increase. The component risk management strategy defines the required program of risk-prioritized inspection and testing activities required to maintain residual risk at acceptable levels and where appropriate to support continuous risk reduction.

4.4.6 Baseline system risk registers

In addition to the component risk register the Projects shall provide a baseline risk register for system risks of the newly commissioned facility. System risks are generally associated with hazards that threaten the integrity of the structural facility as a whole. Certain component risks may have the potential to become system risks e.g. through escalation, either alone or through aggregation across an asset or site. Specific hazards that present structural facility risks i.e. that threaten failure of a structure or group of structures by overload are listed below.

- Extreme storm
- Earthquake
- Mudslide
- Geo-hazard
- Passing vessel impact
- Individual and aggregated component risk above the system thresholds.
- Change in regulatory requirements e.g. revised assessment criteria or decommissioning requirements.
- Simultaneous Operations, i.e. jack-up adjacent to platform.

Baseline system risks shall be determined from analytical results during the design of the facility. Likelihood or probability of failure can be determined quantitatively through Structural Reliability Analysis (SRA) or more commonly through an ultimate strength or collapse analysis that defines the capacity of the structure usually expressed in terms of the Reserve Strength Ratio (RSR). RSR is a measure of the capacity relative to the design point loading event, usually 100-year return period for extreme storm or hurricane events. The relationship between RSR and probability of failure varies from region to region and should be established for the region in question to allow RSR to be used to define failure probability.

Figure 4.14 shows the flowchart of the data handover guideline. The data is then fed into the RBUI methodology, where a risk ranking of a platform would be developed. The risk ranking would then provide the relevant scope of work, and when the structure should undergo an underwater inspection program.

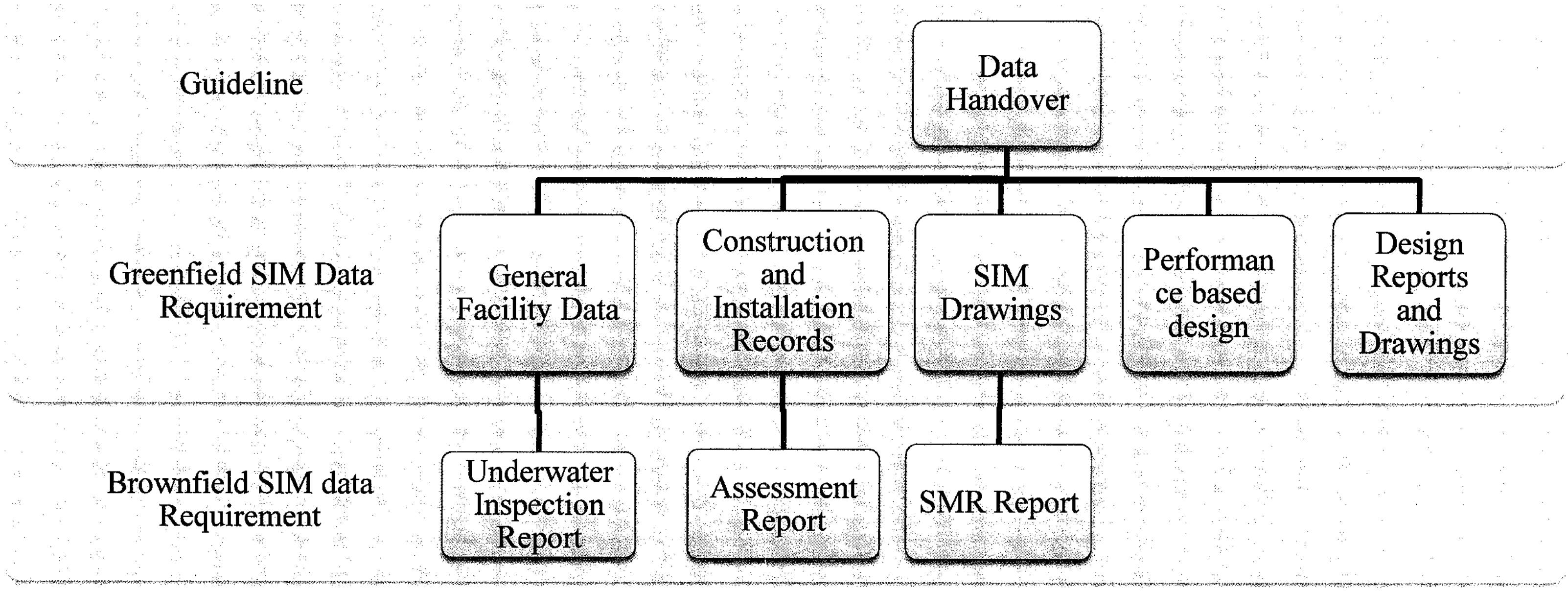

Figure 4.14: SIM Data Handover guideline flow chart

The development of data handover guideline from Green field and Brownfield projects was explained in Figure 4.14. The Greenfield SIM data requirement is divided into five major categories namely:

- General Facility Data
- Construction and Installation records
- SIM drawings
- Performance based design
- Design reports and drawings

The Brownfield SIM data requirements are divided into three categories namely:

- Underwater Inspection reports
- Assessment report
- SMR Report

The combination of all the data constitutes the data handover guidelines for Greenfield and Brownfield projects.

4.5 Risk Based Underwater Inspection (RBUI) Guideline

4.5.1 Introduction

The objective of this Guideline is to establish a procedure on how to conduct Risk Based Underwater Inspection (RBUI) planning for in-service inspection of jacket structures. This Guideline is to be used for the planning of in-service inspection for offshore platform structures, considering possible total platform failure through structural collapse. This Guideline addresses the most commonly experienced degradation mechanism found on platform structures, but the inspection personnel should make themselves aware of any special hazards that are relevant to the platform structural integrity which are not included in this document. Examples of such hazards, which shall be treated separately, are:

a. Foundation founded on shallow gas pockets
b. Conductor subsidence
c. Deck loading increases
d. Boat impact
e. Seismic

The RBUI plan is an integral part of a wider Structural Integrity Management (SIM) process. The SIM process allows for the adoption of risk principles to develop SIM strategies. The four phases of the SIM process are illustrated in Figure 4.15

The underwater inspection plan defines the annual Program that will be executed each year. The Program represents the periodic routine inspections with the purpose of gathering performance data for the facility. An engineering evaluation of the in-service performance data allows the integrity strategy and subsequent inspection programs to be further optimized. Examples of optimization may include modified inspection intervals or use of alternative survey techniques. The SIM Program is developed from a sound strategy based upon qualified engineering evaluation of appropriate data.

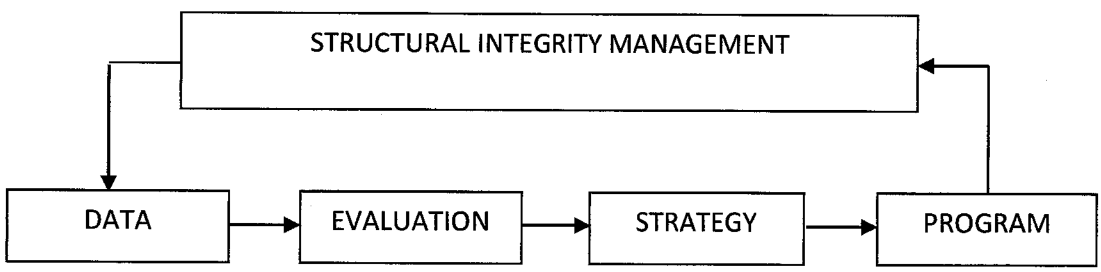

Figure 4.15: Structural Integrity Management (SIM) Process

It is important to recognize that the RBUI Strategy is an integral part of a wider structural integrity management (SIM) process to minimize "ad hoc" expenditures. The SIM process requires that quality data on the condition of offshore platforms be collected and suitably evaluated by qualified engineering personnel to determine their value to the long-term management of the fleet. The RBUI strategy can then be updated as required to ensure the inspection plan continues to meet performance requirements. The RBUI approach used in this document with the specific definitions are explained below.

4.5.2 RBUI Approach

There are six (6) basic steps in the determination of risk-based underwater inspection strategies. The six (6) basic steps are as below:

- Data requirement
- Likelihood of Failure Score
- Consequence of Failure Score
- Risk Categorization
- Inspection planning
- Inspection strategy

For the RBUI planning it is essential that the analyses utilize the most recent information regarding the design, construction and installation of a structure. Also the condition of the jacket in the operational phase is important in order to optimize future inspections: any findings of reassessment/fitness assessment, inspections and maintenance on the structure are therefore to be considered. All relevant data available should be collected into a dedicated database which is properly, documented and reviewed. Data to be collected and assessed are:

- General structural data
- Environmental criteria
- Anode conditions, potential measurement, aspects related to corrosion
- Geotechnical data & foundation data
- Type and quality of analysis performed
- Type and quality of inspections performed and inspection findings
- Repair/upgrade records

The availability and accuracy of information should be evaluated for each of the platforms considered. The information should constitute design basis and specifications, structural drawings, design/ (re-)analysis reports, inspection reports, maintenance and repair records. All ambiguous data shall be treated as "not available" and default values shall be assigned.

4.5.3 Data requirement

The platform information is divided into different data types. These data types are used to organize and collect the data in worksheets. Each data type is entered on a separate worksheet. These data categories are:

- Characteristic data
- Present condition data
- Loading data

The characteristic data has been explained in Section 4.4 in this chapter namely **"Data handover guideline for Greenfield and Brownfield project". Section 4.4.2 and section 4.4.3** describe and shows the kind of information required for the characteristic data. The present condition data requires the following information:

- Design Change Data, which includes: the current use of the platform such as drilling, production, well-head, flare, quarters, or other, the current number of conductors, risers and caissons, the current deck load and the current environmental loading conditions maximum wave height and surface current speed.
- Inspection Data, which includes: the year and type of last inspection related to API inspection Level I, II, III and IV.
- Marine Growth, which includes: the current level of marine growth and whether a fitness for service has been incorporated to account for possible marine growth exceeding the design condition?
- Scouring, which includes: the measured scouring depth and whether a fitness for service assessment has been conducted to account for corresponding change in structural integrity?
- Corrosion, which includes: the corrosion design life, corrosion allowance, anode condition and depletion, measured wall loss and whether a fitness for service

assessment has been conducted to account for corresponding change in structural integrity?

- Crack History, which includes: whether the platform considered has a history of crack observation?
- Missing or Damaged Members, which includes: whether the platform has damaged and missing members and whether a fitness for service assessment has been conducted to account for corresponding change in structural integrity performance.

The loading data are all loads that act upon the structure, which caused deterioration and affects the structural integrity and response of the platform. Information that is required is:

- Deck Load Changes, which includes: the year of deck load change, if any, and whether any measures were introduced in order to assess the change in deck load and whether fitness for service has been incorporated.
- Reserve Strength Ratio, which includes: the platforms Reserve Strength Ratio and whether remedial and monitoring program has been incorporated.
- Wave in Deck, which includes: the measured foundation subsidence, latest estimate for maximum wave height and storm tide and whether fitness for service has been conducted to account for possible wave in deck loading.
- Conductors, which includes: changes in the number of conductors and whether a fitness for service assessment has conducted to account for corresponding increase in environmental loading.
- Risers, which includes: changes in the number of risers and whether a fitness for service assessment has conducted to account for corresponding increase in environmental loading.
- Caissons, which includes: changes in the number of caissons and whether a fitness for service assessment has conducted to account for corresponding increase in environmental loading.
- Fatigue, which includes: the derived fatigue assessment life, detected fatigue cracks and whether a fitness for service assessment has been conducted to account for corresponding change in structural integrity performance.

The likelihood of failure is analogous to the probability that the platform will experience catastrophic failure. Failure is defined as collapse of the platform caused by deterioration, extreme loading, or a combination of both. Key platform attributes contribute to overall likelihood of failure and can be used to establish a rule-based qualitative scoring mechanism or alternatively used to quantify an explicit probability of failure.

The likelihood that a platform will fail as a result of severe loading, whether that is extreme storm loads, earthquake or some other foreseeable design event, is a function of the robustness of the structure. Robustness is a complex property but may be thought of as the combination of the strength of the structural components (members and joints) and the ductility and redundancy of the structural system. Essentially, the robustness of the platform is the inverse of the likelihood of failure i.e. the more robust the structure the less likely it is to fail (Nichols et al, 2006).

In very simplified terms, the likelihood of structural collapse is a function of two primary factors, the platform strength – or capacity, and the extreme load. The likelihood categorization system identifies the platform characteristics that affect the platform strength and loads. Factors that indicate the strength of the platform has deteriorated or is not up to current standards increase the likelihood. Factors that indicate that extreme platform loads may increase in frequency or severity also increase the likelihood.

4.5.4 Factor affecting likelihood of failure

In the RBUI system the likelihood categorization depends on the following factors that are associated with the degradation of strength:

- Baseline Likelihood Failure
    - Platform Vintage
    - Number of legs and bracing system
    - Grouted pile/leg annulus
- Platform Present Condition
    - Last inspection

    - Mechanical damage
    - Corrosion
    - Marine growth
    - Scour
- Platform Loading Susceptibility
    - Deck load
    - Deck elevation
    - Appurtenance load
    - Fatigue load

4.5.5 Qualitative likelihood of failure

Likelihood categories are defined herein based on specialist knowledge of parameters influential to platform robustness and exhaustive studies of in-service performance data of existing platforms and lessons from occurrence of extreme load events especially hurricanes which have been responsible for the majority of platform failures worldwide. The basic categories are modified to reflect the present condition of the platform as determined by inspection data or assumed from known platform damage susceptibility.

Likelihood of structural failure is determined using a rule-based system that determines a likelihood score based upon key platform information. The likelihood categorization system identifies the platform characteristics that affect the platform strength, such as the year designed, the number of legs, the bracing scheme, etc. Factors that indicate the strength of the platform has deteriorated or is not up to present standards increase the likelihood. Factors that indicate that extreme platform loads may increase in frequency or severity also increase the likelihood of structural failure.

At the time of installation, the likelihood that the platform will fail during the Design Event is a function of the design strength and the robustness and ductility of the structure. These properties collectively define the 'baseline likelihood of failure' of the platform. During the life of a platform the robustness of the structure may change due to deterioration or degradation in the platform's condition, thus the platform's likelihood of failure will change. A platform may also see an increased vulnerability to the extreme

Design Event (e.g. due to subsidence or addition of facilities) or accidental loading (e.g. drilling operations, changes in operational practice), which may change the likelihood of failure.

A weighing system is used to capture the relative importance of each rule. The summation of the product of the weight and the score, as given in the following expression, will give the overall likelihood of structural failure score for each platform.

$$S_{Total} = \sum_i W_i S_i$$

S_{total} = Total score for likelihood of failure

W_i = Weightage attributed to i-th rule

S_i = Score attributed to the i-th rule

So, for example from Table 3.3 presented in the explanation of the methodology, for 'Platform Vintage' score, the weighing is 5 and the score is 4 for pre-1971 platforms and 10 for post-1979 platforms. Therefore, the maximum value will be 50 and the minimum will be 20, thus defining the band including all possible scores.

The RBUI system is based on the assumption that Jacket type platforms designed according to modern structural design practice to resist present day design metocean loads have the lowest likelihood of failure. The factors that affect the original strength, the maximum design loads, and the degradation of strength are used to measure any individual platform's failure likelihood against the ideal platform.

At the time of installation the likelihood that the platform will fail during the design event is a function of the design strength and the robustness and ductility of the structure. Platforms that are less robust and have small air gaps will inherently have higher risk to due to the impact of the extreme storm compared to platforms that are more robust and have large air gaps.

The rule for the definition of the baseline likelihood of structural failure of the platform considers the influence of API's Recommended Practice used for the design, fabrication and installation of the platform and the redundancy and robustness of the structure. Table 4.4 shows the platform baseline LOF rule.

Table 4.4: Platform baseline Likelihood of Failure (Lof) Rule

Rule	Details
Platform Vintage	Accounts for the historical development of the API's fixed offshore structure design code and the significant changes to the level of metocean loading and joint resistance formulations used in platform design.
Number of Legs and Bracing System	Accounts for how the redundancy varies for basic structural bracing systems.
Grouted Piles	Accounts for the increase in system strength due to the grouting of the jacket leg-to-pile annulus.

The "platform present condition" rules are used to adjust the baseline likelihood of failure score to represent the present condition of the platform (i.e. any degradation of the structure during fabrication, installation or operation). The rules account for the severity of the detected damage and the possibility of the structure having undetected damage. Table 4.5 shows the platform LOF rules for present condition.

Table 4.5: Platform Present Condition LOF

Rule	Details
Last Inspection	Accounts for the possibility of sustained damage, defects or deterioration going undetected within the platform structure.
Mechanical Damage	Accounts for the reduction in the overall structural system capacity due to discovered mechanical damage.
Corrosion	Accounts for the reduction in the overall structural system capacity due to material loss of a primary structural component may cause..
Marine Growth	Accounts for the reduction in the overall structural system capacity due to increased marine growth above that considered in the design..
Scour	Accounts for the reduction in the overall structural system capacity due to increased scour above that considered in the design.

The "platform loading susceptibility" rules are associated with the platform's ability to resist extreme loads. The score is combined with the adjusted baseline likelihood of structural failure score to give the overall platform score. Table 4.6 shows the platform loading susceptibility LOF rules.

Table 4.6: Platform Loading Susceptibility LOF rule

Rule	Details
Deck Load	Accounts for the increase in deck loads during the operational life of a platform and the possible impact to the overall system capacity.
Deck Elevation	Accounts for the increase in overall loading on the platform due to wave in deck.
Appurtenance Load	Accounts for the increase in appurtenance loads during the operational life of a platform and the possible impact to the overall system capacity.
Fatigue Load	Accounts for the increase in fatigue loads during the operational life of a platform and the possible impact to the overall system capacity.

4.5.6 Score categories

Rules have been developed, which combine various characteristics of the platform to produce a score that defines the relative likelihood of structural failure of the platform with due regard for the baseline likelihood of structural failure, the present condition of the structure and its loading susceptibility. The system qualitatively assesses the failure likelihood using a scoring system that categorizes the effect of each factor.

For a given factor or group of factors, its value is related to its effect on the failure likelihood. Each factor or group of factors is scored independently, and for most items, this score, S_i ranges between 0 and 10. High scores are assigned when the value of the factor increases the likelihood of failure, while low scores are assigned when the factor value decreases the failure likelihood. The total score for the platform is a weighted sum of the individual scores. High weights are used to emphasize the factors that strongly affect the likelihood and low weights are used for factors that moderately affect the likelihood, as shown in Table 4.7.

Table 4.7: Summary of Qualitative LOF Scores

Rule	Score Range, S_i	Weightage, W_i	Total S_{total}
Installed Likelihood Failure			
Platform Vintage	4 – 10	5	20 – 50
Robustness	2 – 10	10	20 – 100
Grouted Piles	0 – 10	3	0 – 30
Platform Present Condition			
Last Inspection	0 – 10	8	0 – 80
Mechanical Damage	0 – 10	10	0 – 100
Corrosion	0 – 10	5	0 – 50
Marine Growth	0 – 10	6	0 –60
Scour	0 – 10	2	0 – 20
Platform Loading Susceptibility			
Deck Load	0 – 10	5	0 – 50
Wave in Deck	0 – 10	10	0 – 100
Appurtenance Load	0 – 10	5	0 – 50
Fatigue Load	0 – 10	5	0 – 50
Minimum to Maximum Score Range			40 - 740

4.5.7 Likelihood of failure categories

The RBUI methodology requires that platforms in the fleet be grouped into "bins" that represent categories of platforms with different likelihood of failure during the occurrence of the Design Event. Representative score bands for the bins A to E (or 5 to 1) are shown in Table 4.8. The bands represent distinctly different categories of platforms and have been calibrated from a tool developed for the purpose.

Table 4.8: LOF Categories

Lof Ranking		**Qualitative**
A	5	≥650
B	4	≥ 500- < 650
C	3	≥ 350 - < 500
D	2	≥ 200- < 350
E	1	< 200

4.5.8 Consequence of failure

The consequences of failure categorization accounts for the following consequences that might result in the event of platform catastrophic failure:

- Life-safety related losses.
- Environmental losses
- Business losses

The American Petroleum Institute (API) provides industry standard guidelines for the determination of what are defined as Exposure Categories of offshore structures in its Recommended Practice API RP2A 21st Edition. Platforms are categorized as L-1, L-2 or L-3 in descending order of failure consequence. The Exposure Categories provide useful guidelines for the consideration of life-safety and environmental consequences of platform failure although economic consequences are not considered. Consideration of economic consequences will serve to raise the overall consequence of failure for certain platforms; essentially refining the simpler evaluation based on API guidelines alone.

To ensure consistency with API recommendations, the definitions for Exposure Categories from API RP2A, are used and supplemented with consideration of business consequences. The consequence category to be used in the subsequent risk-assessment is always the more onerous categorization from assessment of any consequence type i.e. life-safety, environmental or economic.

4.5.8.1 Life safety consequence

The evaluation of safety consequences comprises an estimation of the extent of failure on the safety of personnel on the platform structure. The life-safety consequence of failure categories are provided in Table 4.9. Table 4.9 was developed by reviewing two codes which are:

- API RP2A WSd 21st Edition Design of Fixed offshore Structures
- API RP 2SIM Draft 1st balloting

In API RP2SIM, a 3x3 matrix is used in developing the risk ranking of structures. However, this study has further expanded the risk matrix to include certain elements that is not in API RP2SIM. The API RP2SIM proposed only three categories for life safety which are:

- **High** : Manned – Non evacuated
- **Medium** : Manned – Evacuated
- **Low** : Unmanned

However, Malaysia's fixed offshore platform layout and logistic arrangement is different compared to the GOM. Some of Malaysian platforms are bridge linked to other platforms and some are accessible by boat. Taking all these facts into consideration, the research has developed the following Life Safety consequence categories as shown in Table 4.9.

Table 4.9: Life-Safety COF Category

Cof Ranking	Manned Category	Description
E	Manned Non-Evacuated	The manned, non-evacuated category refers to a platform that is continuously occupied by persons accommodated and living thereon, and personnel evacuation prior to the design metocean event is either not intended, or it is impractical.
D	Not-Normally Manned with Temporary Accommodation	The not-normally manned category refers to a platform that is not normally manned, which is occasionally manned.
C	Not-Normally Manned with a Boat-Landing	
B	Not-Normally Manned Bridged Link to a Quarters Platform	
A	Unmanned or Manned-Evacuated	The unmanned category refers to a platform that is not normally manned or a platform that is not classified as either, manned non-evacuated or manned-evacuated. An occasionally manned platform could be categorized as unmanned in certain conditions.

4.5.8.2 Environmental consequence

The environmental consequence accounts for the pollution that may result in the event of a platform structural failure. This is a function of the volume of oil or other hydrocarbons released during collapse and the proximity of the platform to the shoreline and/or environmentally sensitive areas.. The environmental consequence of failure categories are provided in Table 4.10.

Table 4.10: Environmental COF Category

COF Ranking	**Quantitative BOE**	**Description**
E	$\geq$ 50,000	Event where structural failure is expected to cause more than 50,000 equivalent bbl oil leaks.
D	$\geq$ 5,000 – < 50,000	Event where structural failure is expected to cause between 5,000 to 50,000 equivalent bbl oil leaks.
C	$\geq$ 500 – < 5,000	Event where structural failure is expected to cause between 500 to 5,000 equivalent bbl oil leaks.
B	$\geq$ 50 - < 500	Event where failure is expected to cause between 50 to 500 equivalent bbl oil leaks.
A	< 50	Event where failure is expected to cause between 1 to 50 equiv. bbl oil leaks.

4.5.8.3 Economic consequence

The determination of economic consequence of platform failure is strongly influenced by specific corporate and regional business drivers which will depend on many factors including the political environment, specifics of production sharing agreements, sales contracts, performance incentives, regional and global oil and gas prices etc. As general guidance economic costs of platform failure should be evaluated, including lost production, replacement of facilities, lost reserves (if facility not replaced) etc. . The economic consequence of failure categories are provided in Table 4.11.

Table 4.11: Economic Impact COF Category

COF Ranking	Quantitative US$ Million	Description
E	$\geq$ 100	The consequence of failure represents very high cost.
D	$\geq$ 75 – < 100	The consequence of failure represents high cost.
C	$\geq$ 45 – < 75	The consequence of failure represents medium cost.
B	$\geq$ 6 - < 45	The consequence of failure represents low cost.
A	< 6	The consequence of failure represents very low cost.

The overall consequence of failure is modeled as the most restrictive of the three consequences of failure components:

- Safety consequences
- Environmental consequences
- Economic consequences

4.5.9 Risk Matrix

For the purposes of categorizing the fleet of platforms, a 5x5 matrix, as shown in Figure 4.16, has been developed, which offers enough range to distinguish the difference between platforms. The matrix provides five categories of consequence (1 to 5) and five categories of likelihood (A to E) of failure.

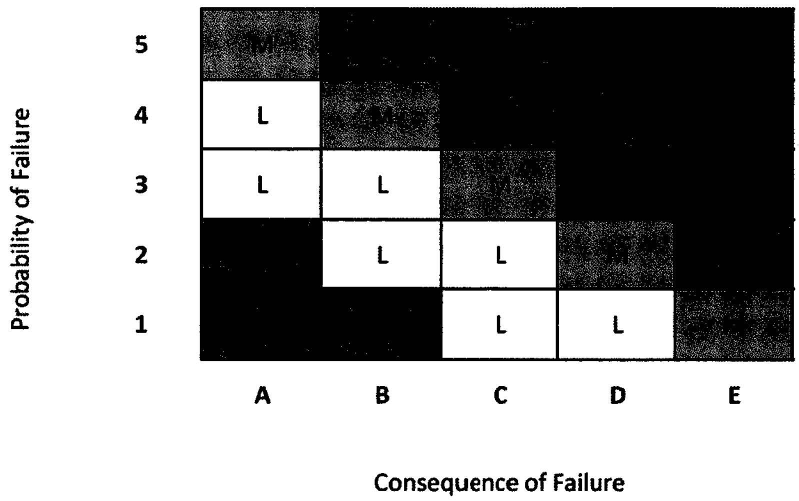

Figure 4.16: Risk Matrix

Five risk levels are distinguished, represented by the following five zones:

- Zone Very High (Red) represents Very High Risk Exposure
- Zone High (Orange) represents High Risk Exposure
- Zone Medium (Brown) represents Medium Risk Exposure
- Zone Low (Yellow) represents Low Risk Exposure
- Zone Very Low (Green) represents Very Low Risk Exposure

The matrix is used by utilising the LOF score and COF score. The ranking corresponding to the LOF and COF scores will then be matched into the existing risk matrix. Table 4.8, in section 4.5.7 explains how the representatives score bands for column A to E (or 5 to 1) is developed. The bands represent distinctly different categories of platforms based on the scores that it received. The COF rank (A to E) is based on the most restrictive failure consequence. The case study in Section 5.5 provides a better explanation on how to use the risk matrix.

4.5.10 Inspection plan

Guidance for setting inspection intervals as part of an overall inspection plan may be achieved through an understanding of the risk posed to the offshore structure. For offshore structures the risk-based strategy optimizes future inspection requirements and will focus valuable resources on the platforms "most at risk". These, most-at-risk platforms will be inspected more frequently and using more detailed inspection surveys, whereas those platforms with a low risk ranking will have less frequent and less stringent inspections.

The inspection plan will define the frequency and scope of the inspection, the tools/techniques to be used and the deployment methods. The inspection plan should be developed for the operated platforms and would be expected to cover a number of years. The plan should be periodically updated throughout the platforms service life following receipt and evaluation of relevant SIM data, e.g. inspection data, results of platform assessments etc.

The risk-based inspection plan is designed to ensure agreement with the inspection intervals provided in Section 14 of the 21st Edition of API RP2A. API RP 2A stipulates that the time interval between surveys for fixed platforms should not exceed the guideline intervals shown in Table 4.12;

Table 4.12: Guideline Survey Intervals

Exposure Category level	Survey Level			
	I	II	III	IV
L-1	1 year	3 through 5 years	6 through 10 years	*
L-2	1 year	5 through 10 years	11 through 15 years	*
L-3	1 year	5 through 10 years	*	*

*Survey should be performed as indicated in Section 14.3.3 and 14.3.4 in API RP 2A.

Table 4.12 shows that the maximum inspection interval for an offshore structure is 15 years. The minimum interval is 1 year. Taking into consideration the operation limitation and the cost incurred in conducting a yearly level 1 survey, this research has proposed that a minimum of 3 – 12 years range is used for underwater inspection programs based on the risk ranking of the platform. The basis for proposing a range of 3 – 12 years is because this study omits the 1 year level 1 survey, and reduces the interval duration from 15 to 12 years. Risk-based inspection intervals are assigned to each platform based on the matrix of intervals shown in Figure 4.17.

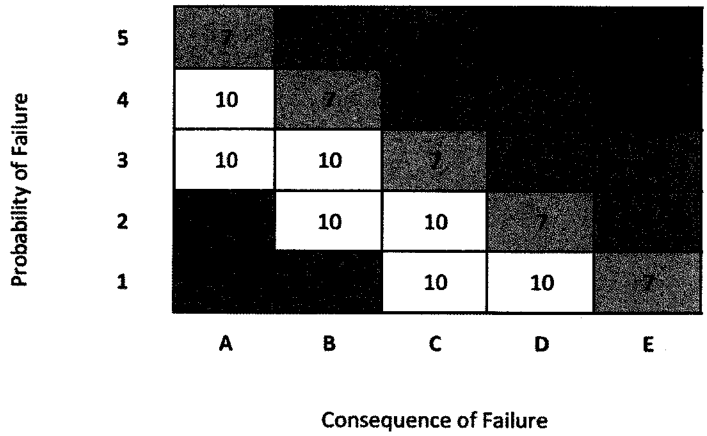

Figure 4.17: Inspection Intervals

Whereas the guideline survey intervals proposed by API gives maximum inspection intervals, the proposed Inspections interval Matrix recommends the intervals based on the risk varying between 3 – 12 years. Figure 4.17 shows that platforms having very high risk has to be inspected every 3 years, whereas a very low risk platform can be inspected at 12 year interval. To come to this decision, the risk ranking of the platform has to be identified. This will be explained in Section 5.5.

Once the risk-based inspection interval has been defined for each of the platforms in the fleet, the default long-term plan can be readily created based on the last inspection date of each platform and the inspection interval. For example, a platform last inspected in 2000 with a 12-year interval will be scheduled for its next routine periodic inspection in 2012.

The intervals determined from the fleet risk ranking provide a basis for setting inspection intervals. To account for items that might warrant more frequent inspection or allow better use of resources, consideration is given to adjusting the intervals for the following:

- High Consequence Appurtenances, for High consequence platforms, where the consequence category is driven by the presence of pipeline risers at the platform, the inspection intervals should not exceed 5-years. This adjustment ensures that the riser and its connections to the platform are inspected at least every 5-years. In instances where the risk-based interval for the platform itself is 10-years the intermittent 5-year inspection may, subject to other considerations, consist of solely a riser survey.
- Anode Wastage Rates, where the risk-based inspection interval exceeds 5-years and anode depletion is known or suspected to be in excess of 50% of original material, and/or cathodic protection (CP) proximity readings indicate that the CP system is not within specification then, the next underwater inspection shall be scheduled within 5-years of the prior underwater inspection. This adjustment is intended to ensure sufficient time for planning and implementation of anode retrofit requirements and thus avoid periods without adequate corrosion protection.
- Special Inspection Requirements, The program is adjusted to recognize Special Inspection requirements, to facilitate, for example, evaluating the structural damages from a boat impact, structural assessment, re-use, decommissioning, etc. In some instances post-event inspection may be scheduled to coincide with planned routine periodic inspections and vice-versa.

4.5.10 Inspection Program

The Inspection Program represents the execution of the detailed scope of work and should be conducted to complete the activities defined in the RBUI plan. The work scopes and specific surveys and techniques executed during the inspection are developed based on the RBUI factors that were developed

Any factor that provides a high score, and has a direct influence on the risk ranking of the platform, will be part of the inspection scope of work. This can remove the number of work that needs to be done offshore, and optimize the operator maintenance cost.

For example, if underwater inspection shows that marine growth is at its maximum score, the current underwater inspection should include marine growth as its scope of work. New data that will be obtained from the new inspection, will allow for the reduction in marine growth score, and thus reduce the risk of the platform.

It is thus of utmost importance that besides the detailed inspections planned according to RBI, general (visual) inspections are performed to ensure the validity of the assumptions made in the RBI analysis. The inspection planning procedures must then ensure that fatigue calculations and consequently the RBI analyses are revised when such general inspections reveal defects which were not anticipated.

Deterioration processes such as fatigue crack growth and corrosion will always be present to some degree and depending on the adapted design philosophy in terms of degradation allowance and protective measures, the deterioration processes may reduce the performance of the system beyond what is acceptable. To ensure that the given acceptance criteria are fulfilled throughout the service life of the engineering systems it may thus be necessary to control the development of deterioration and, if required, to install corrective maintenance measures. In most practical applications, inspection is the most relevant and effective means of deterioration control.

4.5.11 Platform baseline LOF rule

4.5.11.1 Platform vintage

Structural design practice over the years has improved. Modern codes may require joint cans or other reinforcement in order to meet stricter modern design checks.

The platform “vintage” rule recognizes the historical development of the API’s fixed offshore structure design code and the significant changes made to the level of environmental loading and joint resistance formulations used in platform design.

Table 4.13: Rule to determine LOF score for Platform vintage

Design Code	**Pre – RP2A** **Pre - 1971**	**Post – RP2A** **1971 - 1979**	**Modern – RP2A** **After - 1979**
Score	10	6	4
Weightage (O'Connor, Puskar 1999)		5	
Total Score	50	30	20

The rule more heavily penalizes platforms that were designed before the introduction of the API design code, and less heavily those platforms that were designed using API codes that pre-date the introduction of the 100-year recurrence criteria. The date bands include a contingency for the year that the code was introduced compared to the date that the first designs to the new code would likely have been installed.

4.5.11.2 Robustness

Most offshore structures possess an inherent reserve strength that is greater than the strength of the critical components. This is derived from a variety of sources, such as over-design, design for pre-service condition and design code safety factors, etc., which in redundant systems allows mobilization of alternative load paths. Some structures display considerable levels of reserve strength whereas others suffer from a sudden drop in capacity as soon as one critical member fails. The level of reserve strength that a platform possesses is regarded as a measure of its robustness.

The number of legs and bracing system on a platform together with its redundancy and susceptibility to failure is related to its robustness. Table 4.14 below summarises the levels of robustness identified for each platform configuration. The number of legs together with the bracing system is a strong indicator of the overall redundancy and damage tolerance of a platform.

Table 4.14: Rule to determine LOF score for Platform robustness rule

Bracing Configuration	**Number of Legs**				
	≤ 3	**4**	**6**	**8**	**>8**
K	10	10	8	6	4
VD	10	7	5	4	3
X	6	5	4	3	2
Weightage (O'Connor, Puskar 1999)	10				
Total Score	100 - 60	100 – 50	80 - 40	60 - 30	40 - 20

The "number of legs and bracing system" rule recognizes the influence of platform structural configuration on redundancy and susceptibility to structural failure. The rule accounts for how redundancy varies for different basic structural bracing systems.

The rule accounts for how redundancy varies for different basic structural bracing systems. The rule heavily penalizes K-braced structures and moderately penalizes structures with vertical diagonal bracing configurations. The rule also recognizes the lower redundancy attributable to a lesser number of legs. Table 4.14 associates robustness with an equivalent score reflecting risk of failure.

4.5.11.3 Grouted piles

This rule accounts for the strengthening of joints due to grouting the annulus between the pile and the leg (Table 4.15). The "grouted piles" rule recognizes the influence that grouting the annulus between the pile and the jacket leg has on the strength of the platform. A notable strength increase is attributed to the grouted leg-joints.

Table 4.15: Rule to determine LOF score for Grouted pile rule

Grouted	No	Yes
Score	10	0
Weightage	3	
Total Score	30	0

4.5.12 Platform Present Condition LOF Rule

4.5.12.1 Last inspection

The last inspection rule reflects the fact that offshore structures are susceptible to damage and degradation mechanisms with time and penalizes platforms that have not been inspected for extended periods on the basis that they may have suffered undetected damage or degradation (Table 4.16). This is true of all platforms; however, the more robust the structure, the more tolerant it will be to damage and/or degradation.

The last inspection rule recognizes the possibility of sustained damage, defects or deterioration going undetected within the platform structure. The rule penalizes platforms that have not been inspected. The following assumptions are applied:

- Inspection frequency: a platform's failure likelihood increases as time between inspections lengthens. The longer the interval between inspections, the greater the likelihood that an undetected problem can initiate failure.

Table 4.16: Rule to determine LOF score for Last inspection

Inspection Gap (years)	**≤ 5**	**6 - 10**	**11 - 15**	**> 15**
Score	0	6	8	10
Weighting	8			
Total Score	0	48	64	80

4.5.12.2 Mechanical damage

The 'mechanical damage rule considers the significance the identified mechanical damage has on the platforms susceptibility to failure. The rule considers the level of damage within the platform structure and penalizes platforms that have observed mechanical damage. No distinction is made between types of mechanical damage (bow, gouge, hole, crack or dents). To account for the damage tolerance of different structural systems the 'mechanical damage' rule is weighted to recognize the damage tolerance of different platform configurations to possible damage. Table 4.17 indicates that the rule is based on the number of damaged members detected.

For platforms where detailed inspection records of the condition of the platform are not available, representative mechanical damage is imposed on the platform that reflects the anticipated damage that the platform is likely to have sustained throughout its design life.

The purpose of this loop is to account for any reduced structural integrity due to damaged or missing members. Damaged members are defined as members that have dents, holes, cracks, out-of-straightness or other defects that will reduce the member's strength. The rule requires the followings information:

- Number of damaged / missing members
- Possible re-assessment incorporating damaged / missing members

Table 4.17: Rule to determine LOF score for Mechanical damage

Damaged braces/flooded member	**> 10**	**4 - 9**	**1 - 3**	**None**
Score	10	8	4	0
Weighting	10			
Total Score	100	80	40	0

4.5.12.3 Corrosion

Significant material loss to a primary structural component may cause a reduction in the overall structural system capacity. This may be as a result of an ineffective CP system and can be measured from proximity CP readings or indirectly detected through ultrasonic wall thickness measurements. The "corrosion" rule considers the influence of the extent of corrosion presently identified within the platform structure (Table 4.18). The rule penalizes platforms, which have had a period of non-protection, or surveys have revealed heavy corrosion or UT readings indicating heavy wall thickness loss. The following assumptions form the basis of the corrosion logic rule:

- All CP of the jacket constitutes of sacrificial anodes.
- Anodes depletion of less than 50% is classified as not critical. This is based on inspection reports from SKO platforms that show that anodes depletion up to 70% still did not generate considerable wall loss.
- No penalty is applied if the corroded wall thickness is less than the designed corrosion allowance. For conservatism, corrosion of more than the designed corrosion allowance is not allowed.

The reason anode depletion is used as a criterion for corrosion is based on ISO 19902 – 2007, which specifies that anode depletion information can be used to evaluate the corrosion protection systems in an offshore structure.

Table 4.18: Rule to determine LOF score for Corrosion

Anode depletion (%)	**> 75**	**50 – 75**	**10 – 50**	**No depletion**
Score	10	7	3	0
Weighting	5			
Total Score	50	35	15	0

4.5.13 Platform loading LOF rule

4.5.13.1 Marine growth

Platform design typically includes a representative marine growth thickness, which may be exceeded during the platform's operational life span. Increased hard marine growth above that considered in the design will increase the environmental loads on the structure in an extreme event due to hydrodynamic drag and effectively larger brace diameters. Soft marine growth accumulations are not counted because they tend to be washed off during a Design Event storm.

The marine growth logic accounts for additional loading caused by marine growth (Table 4.19). The logic considers that as the structure ages the marine growth will continue to grow thus incurring additional hydrodynamic loading and overstressing structural components. In instances of missing or unknown present marine growth levels, default values based on historical evidence are included in the logic. The purpose of this loop is to account for the additional loading caused by marine growth. The marine growth score incorporates the following aspects:

- Design marine growth thickness
- Measured marine growth thickness
- Acceptable marine growth level re-assessment.

Table 4.19: Rule to determine LOF score for Marine growth

Marine Growth thickness (mm)	**> 100**	**75 – 100**	**50 – 74**	**< 50**
Score	10	7	3	0
Weighting	6			
Total Score	60	42	18	0

4.5.13.2 Scour

Platform design typically includes a representative scour value, which may be exceeded during the platform's operational life span. Increased scour above that considered in the design may lead to unwanted settlements and/or overstressing of the foundation.

The scouring logic accounts for possible additional loading caused by mudline scouring (Table 4.20). The logic considers that as the structure ages the scouring will continue to increase thus incurring additional hydrodynamic loading and overstressing structural components. In instances of missing or unknown present scouring levels, default values based on historical evidence are included in the logic. The purpose of this loop is account for the effect of scouring. The marine growth score incorporates the following aspects:

- Design scour depth
- Measured scouring
- Acceptable scouring

The scouring has a direct impact on the hydrodynamic loading of the platforms. With deeper scour depth, more piles will be exposed and this will introduce more hydrodynamic loading, causing overstressed structural components.

Table 4.20: Rule to determine LOF score for Scour

Scour (m)	**> 2.5**	**2.1 – 2.5**	**1.5 – 2.0**	**< 1.5**
Score	10	7	3	0
Weighting	2			
Total Score	20	14	6	0

4.5.13.3 Deck load

The deck load has a direct impact on the topside loading of the platforms. Non-compliance with the design deck load will lead to overstressed structural components, in particular the "weak link" members. Thus, for platforms not complying with the design deck load, the inspection program should focus on "weak link" structural components (note: these are weak links / potential damaged structural components that can be deduced from static in-place / nonlinear push over analysis).

The Deck Loading logic accounts for the addition of deck loads beyond those considered during the design of the structure (Table 4.21). The logic considers that as the structure ages additional loading is likely to be added to the deck to improve the platforms production performance. In instances of missing or unknown present deck load, default values based on platform type are included in the logic. The deck load rule takes into consideration the number of members with maximum member unity check (UC) greater than unity. As per the API 21st Edition, the acceptable UC value should be 1.0.

Table 4.21: Rule to determine LOF score for Deck load

Number of member with Max UC > 1.0	**> 10**	**4 - 9**	**1 - 3**	**Unknown**
Score	10	7	3	0
Weighting	5			
Total Score	50	35	15	0

4.5.13.4 Deck elevation

The Wave-in-Deck logic accounts for the additional load effect caused by possible wave-in-deck loading that may result from platform subsidence, a low cellar deck or high wave heights. In instances of missing or unknown parameters such as wave height the logic assumes conservative values.

The "deck elevation" rule recognizes the susceptibility of the platform to structural failure should water ingress the deck during an extreme metocean event (Table 4.22). The rule penalizes platforms for which the calculated wave crest is higher than the lowest deck elevation, which may be the case during the assessment of older platforms.

Nevertheless, for this research, the main criteria that are taken to consider the wave in deck phenomena will be the air gap value. The air gap is calculated based on the equation below:

- New crest height = 0.6 * (Wave height) + (Storm tide) + (Storm surge)
- Air Gap = Deck Elevation – New crest height

The minimum air gap allowed is 1.5 m, as per the minimum requirement of API 21st Edition.

Table 4.22: Rule to determine LOF score for Deck elevation

Air Gap (m)	**< 0**	**0.1 – 1.0**	**1.1 – 1.5**	**≥ 1.6**
Score	10	7	3	0
Weighting	10			
Total Score	100	70	30	0

4.5.13.5 Appurtenance

The Appurtenance Loading logic accounts for actual number of caissons/risers/conductors and the influence they have on the platform's hydrodynamic loading. The logic considers that the longer a platform is in service the more likely additional appurtenance will be added. In instances of missing or unknown present appurtenance numbers, default values based on platform age are included in the logic.

The purpose of the loop is to account for the actual numbers of caissons / risers / conductors and their impact on the metocean load response in the structure.

- Design number of caissons / risers / conductors
- Current number of caissons / risers / conductors

Similar to deck load, caissons/risers/conductors loads have a direct influence on the environmental loading of the platforms.

Non-compliance with caissons/risers/conductors loads will lead to overstressed structural components, in particular the "weak link" components. Thus, for platforms not complying with caissons/risers/conductors loads, the inspection program should focus on "weak link" structural components. This research takes into consideration has there been any increase to the number of riser, conductor and caisson (Table 4.23). If there is an increase, the likelihood of failure score will increase as the platform is more susceptible to hydrodynamic loads.

Table 4.23: Rule to determine LOF score for Appurtenance

Increase in appurtenance	**Yes**	**No**
Score	10	0
Weightage	5	
Total Score	50	0

4.5.13.6 Fatigue load

Fatigue damage is often limited to older platforms in deeper water and to conductor-guide frame cracking at the first elevation below the waterline. Both pre-RP2A vintage and early-RP2A vintage platforms can be susceptible to conductor-guide frame 'panting' fatigue. However, conductor-guide frame 'panting' fatigue is unlikely to influence the Likelihood of Failure of the platform because it is a local phenomenon, but it may however influence the Consequence of Failure criteria.

The "fatigue loading" rule recognizes the increased likelihood of fatigue-induced structural failure in platforms that have conductor guide framing (Table 4.24). This research takes into consideration the fatigue life of each joint on the structure compared with the design life. As we are aware, according to PETRONAS Technical Specification (PTS), the design life for offshore structures is 25 years. Therefore, any joint that has a fatigue life of less than 25 years will be penalized with a high score. Table 4.24 indicates that the scoring is based on number of members with fatigue life less than 25 years.

Table 4.24: Rule to determine LOF score for Fatigue Loading

Number of member with Fatigue life < 25 years	**≥100**	**76 - 99**	**51 – 75**	**26 – 50**	**1 – 25**	**0**
Score	10	8	6	4	2	0
Weighting	5					
Total Score	50	40	30	20	10	0

4.5.14 COF Rule

4.5.14.1 Life Safety

The evaluation of safety consequences comprises an estimation of the extent of failure on the safety of personnel on the platform structure. The life-safety consequence of failure categories are provided in Table 4.9.

4.5.14.2 Environmental Consequence of Failure

The high consequence of failure category refers to major platforms and/or those platforms that have the potential for well flow of either oil or sour gas in the event of platform failure. In addition, it includes platforms where the shut-in of the oil and gas production is not planned or not practical prior to the occurrence of the design event (such as areas with high seismic activity). Platforms that support major oil transport lines and/or storage facilities for intermittent oil shipment are also considered to be high consequence category.

The low, medium or high consequence of failure category refers to platforms where production would be shut-in during the design event. All wells that could flow on their own in the event of the platform failure must contain functional, subsurface safety valves manufactured and tested in accordance with the applicable API specifications. Oil storage is limited to process inventory and "surge" tanks for pipeline transfer.

This research takes into consideration the number of barrels of oil equivalent (BOE) that would be spilled if the structure were to collapse and the amount of BOE it can store in its facility (Table 4.26). The higher the number of BOE spilled/stored, the greater the consequence would be.

Table 4.25: Rule to assess LOF score for Environmental COF

(Structural P-RBI manual, 2008)

COF Ranking	**BOE spilled / Storage capacity**
E	$\geq$ 50,000
D	$\geq$ 5,000 – < 50,000
C	$\geq$ 500 – < 5,000
B	$\geq$ 50 - < 500
A	< 50

4.5.14.3 Economic Consequence of Failure

The economic consequences of failure are calculated as the sum of the production deferment, the cost of platform replacement and the loss of future earning from reserve hydrocarbon product.

When considering the production loss, the individual conditions for the platform should be considered. Some platforms have little or no effect on production. Some platforms are not required to produce continuously or have spare capacity that can be substituted. Oil field economics using discounted cash flows often mean that production deferred usually means production loss. Any unrecoverable loss of products is also included in the production loss.

This research takes into consideration the equivalent economic loss in a monetary form. The higher the loss, the higher is the COF of the structure. The details are given in Table 4.27.

Table 4.26: Rule to assess LOF score for Economic COF

(Structural P-RBI manual, 2008)

COF Ranking	**Quantitative US$ Million**	**Description**
E	≥ 100	The consequence of failure represents very high cost.
D	≥ 75 – < 100	The consequence of failure represents high cost.
C	≥ 45 – < 75	The consequence of failure represents medium cost.
B	≥ 6 - < 45	The consequence of failure represents low cost.
A	< 6	The consequence of failure represents very low cost.

Figure 4.18 below shows the complete RBUI framework that is developed in this research. The framework shows the two (2) main aspect of RBUI, which are Likelihood of Failure (LOF) and Consequence of Failure (COF). The LOF can further be divided into three (3) categories which are Baseline Risk, Platform Present Condition and Platform Loading Susceptibility. The COF can also be divided into three (3) more detailed elements which are Life safety, Environmental and Business loss consequences.

Figure 4.19 provides the integrated SIM framework that is being developed in this research project. The integrated SIM framework constitutes two (2) major engineering stages which are design and operation. In each of the engineering stages, elements of SIM are incorporated to meet the objectives of this research. Each of the elements in Figure 4.19 is inter-related. The SOR would ensure that for any new design of fixed offshore structure, the operation requirement would be taken into consideration.

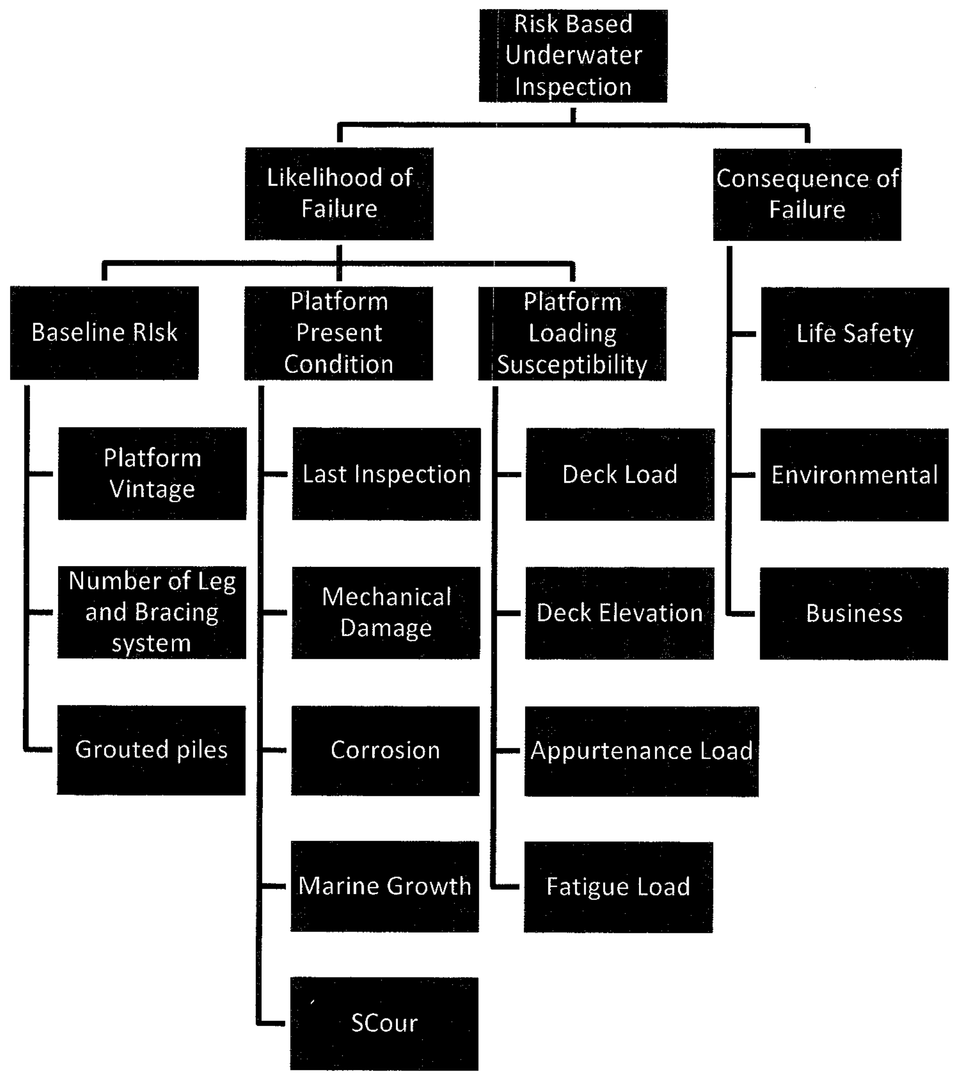

Figure 4.18: RBUI framework flowchart

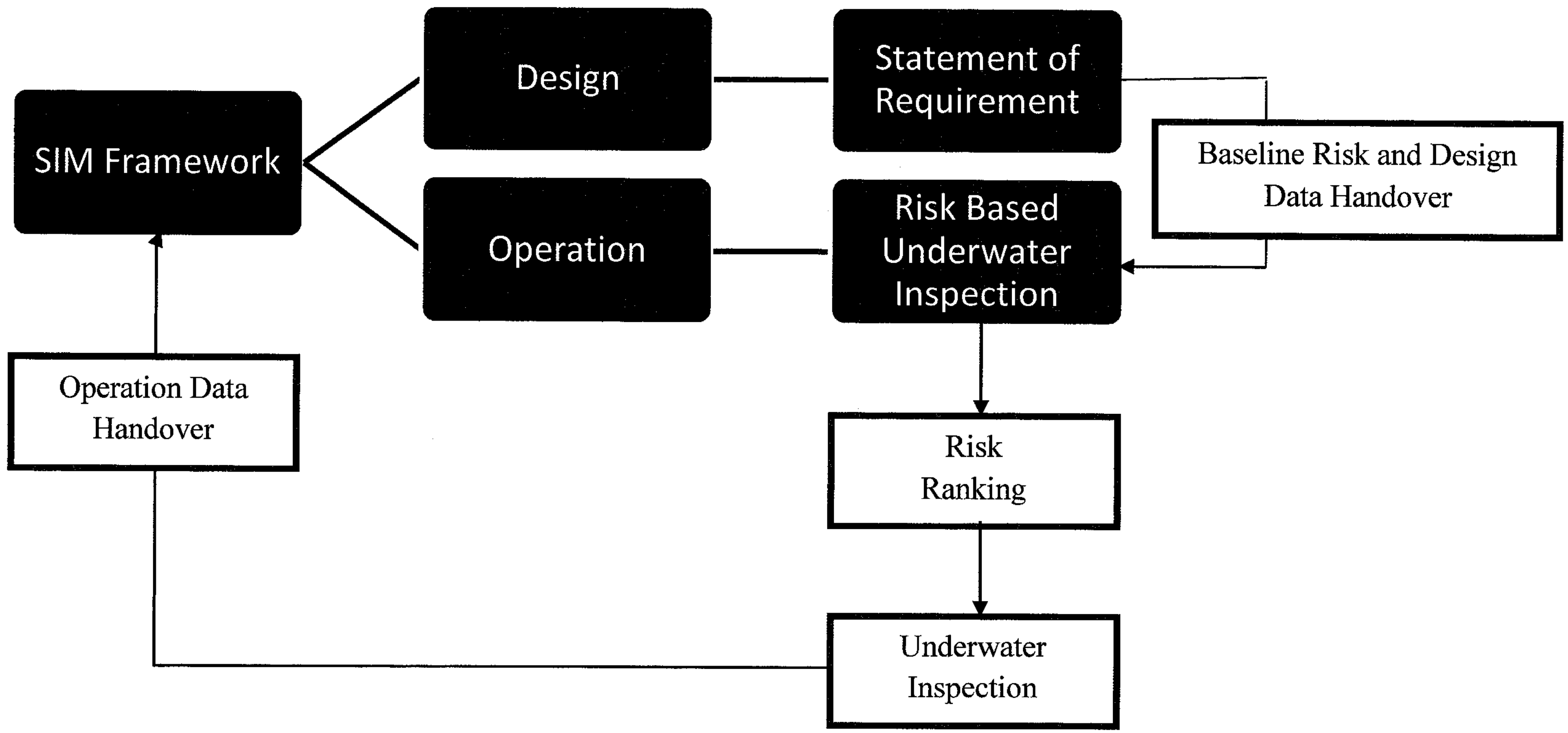

Figure 4.19: Integrated SIM flowchart

CHAPTER 5

CASE STUDIES

5.1 Introduction

The aim of the research is to develop an integrated SIM framework for Malaysia's fixed offshore platform. Chapter 4 described the development of the integrated framework for SIM for platforms in Malaysia. This chapter describes the case studies that were carried out to understand more details of the elements of the integrated framework and developments. The case studies consist of:

1. Case Study on determining the Base line Risk of platforms in Malaysia
2. Case study on "Statement of Requirement for Structural Design"
3. Case Study on Data Handover for projects
4. Case study on development the Risk Based Underwater Inspection (RBUI) Method

5.2 Case Study on determining the Base line Risk of platforms in Malaysia

5.2.1 Introduction

Figure 5.1 shows the methodology of the case study. The initial step is arrange the platforms based on a number i.e. P1 to P 'x'. Next, the total baseline likelihood score is calculated as explained in Section 4.2.

The result is then sorted based on largest to smallest total score, as shown in Table 5.1 to Table 5.3. This is to obtain the baseline risk of the platform.

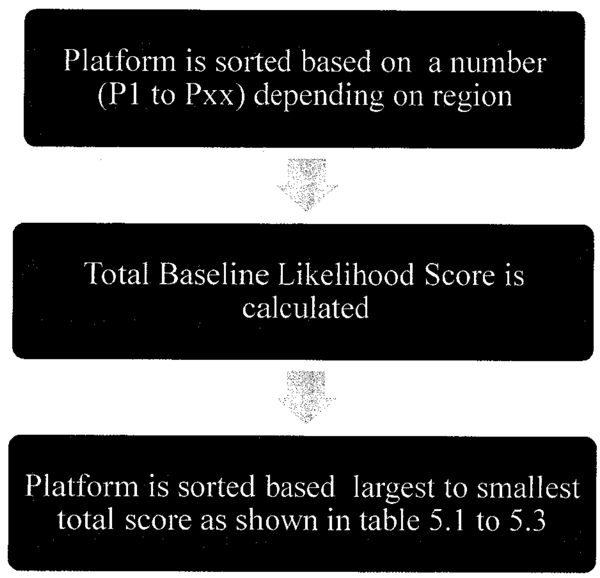

Figure 5.1: Case study approach

5.2.2 Case study

Tables 5.1 to 5.3 shows the case study of the baseline likelihood of failure risk of Malaysia's 186 fixed offshore structure, presented for PMO, SKO and SBO respectively. The table is divided into 8 columns; with the critical result of the Baseline Risk Level of the structure shown in the 'Risk Level' column. This is determined based on Table 4.3 which classifies the baseline risk into very high risk (≥120); high risk (≥90 to <120); Medium risk (≥70 to <90); Low risk (≥50 to <70) and very low risk (<50).

Table 5.1: PMO Baseline Risk Ranking

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 10	1979	30	K	4	100	130	Very High
Platform 4	2003	20	K	3	100	120	High
Platform 6	2003	20	K	3	100	120	High
Platform 12	1986	20	K	3	100	120	High
Platform 13	1990	20	K	4	100	120	High
Platform 16	1993	20	K	4	100	120	High
Platform 18	1983	20	VD	3	100	120	High
Platform 27	2006	20	None	1	100	120	High
Platform 30	2003	20	None	1	100	120	High
Platform 31	2003	20	None	1	100	120	High
Platform 33	1983	20	K	4	100	120	High
Platform 36	1999	20	VD	3	100	120	High
Platform 44	1983	20	K	4	100	120	High
Platform 9	1978	50	K	8	60	110	High
Platform 32	1976	50	K	8	60	110	High
Platform 15	1993	20	VD	4	70	90	High

Table 5.1 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 19	1995	20	VD	4	70	90	High
Platform 20	1983	20	VD	4	70	90	High
Platform 21	1983	20	VD	4	70	90	High
Platform 22	1983	20	VD	4	70	90	High
Platform 23	1983	20	VD	4	70	90	High
Platform 24	1983	20	VD	4	70	90	High
Platform 25	1982	20	K	4	70	90	High
Platform 2	1998	20	X	3	60	80	Medium
Platform 11	1981	20	K	8	60	80	Medium
Platform 14	1990	20	K	8	60	80	Medium
Platform 42	1982	20	K	8	60	80	Medium
Platform 43	1981	20	K	8	60	80	Medium
Platform 1	2006	20	X	4	50	70	Medium
Platform 3	2001	20	X	4	50	70	Medium
Platform 5	2005	20	X	4	50	70	Medium

Table 5.1 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 26	2005	20	X	4	50	70	Medium
Platform 28	2004	20	X	4	50	70	Medium
Platform 29	1998	20	X	4	50	70	Medium
Platform 34	2007	20	X	4	50	70	Medium
Platform 37	1999	20	X	4	50	70	Medium
Platform 38	1998	20	X	4	50	70	Medium
Platform 39	2004	20	X	4	50	70	Medium
Platform 40	2002	20	X	4	50	70	Medium
Platform 41	2005	20	X	4	50	70	Medium
Platform 7	2001	20	VD	8	40	60	Low
Platform 17	1983	20	VD	8	40	60	Low
Platform 8	2000	20	X	8	30	50	Low
Platform 35	1999	20	X	8	30	50	Low

Table 5.2: SKO Baseline risk ranking

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 13	1969	50	K	4	100	150	Very High
Platform 16	1969	50	VD	3	100	150	Very High
Platform 102	1968	50	VD	3	100	150	Very High
Platform 103	1968	50	VD	3	100	150	Very High
Platform 108	1968	50	K	4	100	150	Very High
Platform 110	1970	50	VD	3	100	150	Very High
Platform 1	1971	30	VD	3	100	130	Very High
Platform 2	1978	30	VD	3	100	130	Very High
Platform 15	1973	30	K	4	100	130	Very High
Platform 17	1973	30	K	3	100	130	Very High
Platform 20	1977	30	VD	3	100	130	Very High
Platform 21	1971	30	K	3	100	130	Very High
Platform 22	1974	30	K	4	100	130	Very High
Platform 24	1974	30	K	3	100	130	Very High
Platform 25	1975	30	VD	3	100	130	Very High

Table 5.2 – Continued

Platform Name	**Design Year**	**Total Design Score**	**Bracing Configuration**	**Number of Leg**	**Total Robustness Score**	**Total Baseline Likelihood of Failure Score**	**Risk Level**
Platform 31	1976	30	VD	3	100	130	Very High
Platform 32	1976	30	VD	3	100	130	Very High
Platform 33	1977	30	VD	3	100	130	Very High
Platform 34	1978	30	VD	3	100	130	Very High
Platform 35	1979	30	VD	3	100	130	Very High
Platform 39	1973	30	VD	3	100	130	Very High
Platform 40	1977	30	VD	3	100	130	Very High
Platform 67	1973	30	VD	3	100	130	Very High
Platform 68	1975	30	VD	3	100	130	Very High
Platform 83	1978	30	K	4	100	130	Very High
Platform 84	1978	30	K	4	100	130	Very High
Platform 85	1977	30	VD	3	100	130	Very High
Platform 87	1973	30	VD	3	100	130	Very High
Platform 98	1975	30	K	4	100	130	Very High
Platform 100	1975	30	VD	3	100	130	Very High

Table 5.2 – Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 101	1975	30	VD	3	100	130	Very High
Platform 111	1972	30	K	3	100	130	Very High
Platform 9	1994	20	K	4	100	120	Very High
Platform 28	1991	20	K	4	100	120	Very High
Platform 45	1982	20	K	4	100	120	Very High
Platform 53	1992	20	K	4	100	120	Very High
Platform 54	1983	20	VD	3	100	120	Very High
Platform 57	1986	20	K	4	100	120	Very High
Platform 58	1986	20	K	3	100	120	Very High
Platform 61	1999	20	K	3	100	120	Very High
Platform 64	1994	20	K	4	100	120	Very High
Platform 65	2003	20	K	4	100	120	Very High
Platform 69	2004	20	K	4	100	120	Very High
Platform 74	1984	20	VD	3	100	120	Very High
Platform 4	1973	30	K	6	80	110	High

Table 5.2 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 105	1971	30	K	6	80	110	High
Platform 106	1972	30	VD	6	80	110	High
Platform 12	2006	20	K	6	80	100	High
Platform 19	1978	30	VD	4	70	100	High
Platform 23	1974	30	VD	4	70	100	High
Platform 36	1971	30	VD	4	70	100	High
Platform 37	1977	30	VD	4	70	100	High
Platform 62	1993	20	K	6	80	100	High
Platform 76	1979	30	VD	4	70	100	High
Platform 77	1981	20	K	6	80	100	High
Platform 86	1979	30	VD	4	70	100	High
Platform 90	1979	30	VD	4	70	100	High
Platform 91	1977	30	VD	4	70	100	High
Platform 97	1975	30	VD	4	70	100	High
Platform 109	1972	30	VD	4	70	100	High

Table 5.2 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 8	1981	20	VD	4	70	90	Medium
Platform 10	2006	20	VD	4	70	90	Medium
Platform 29	1991	20	VD	4	70	90	Medium
Platform 38	1993	20	VD	4	70	90	Medium
Platform 43	1988	20	VD	4	70	90	Medium
Platform 44	1988	20	VD	4	70	90	Medium
Platform 46	1982	20	VD	4	70	90	Medium
Platform 51	1993	20	VD	4	70	90	Medium
Platform 52	1983	20	VD	4	70	90	Medium
Platform 55	1991	20	VD	4	70	90	Medium
Platform 56	1991	20	VD	4	70	90	Medium
Platform 63	1993	20	VD	4	70	90	Medium
Platform 73	1984	20	VD	4	70	90	Medium
Platform 78	1989	20	VD	4	70	90	Medium

Table 5.2 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 80	1988	20	VD	4	70	90	Medium
Platform 81	1990	20	VD	4	70	90	Medium
Platform 82	1988	20	VD	4	70	90	Medium
Platform 92	1980	20	VD	4	70	90	Medium
Platform 93	1981	20	VD	4	70	90	Medium
Platform 94	1982	20	VD	4	70	90	Medium
Platform 95	1986	20	VD	4	70	90	Medium
Platform 96	1981	20	VD	4	70	90	Medium
Platform 99	1982	20	VD	4	70	90	Medium
Platform 3	1969	50	VD	16	30	80	Medium
Platform 5	1972	30	VD	6	50	80	Medium
Platform 30	1992	20	K	8	60	80	Medium
Platform 42	1984	20	K	8	60	80	Medium

Table 5.2 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 88	1974	30	VD	6	50	80	Medium
Platform 89	1975	30	VD	6	50	80	Medium
Platform 6	1994	20	X	4	50	70	Medium
Platform 7	1994	20	X	4	50	70	Medium
Platform 11	1992	20	X	4	50	70	Medium
Platform 14	1993	20	VD	6	50	70	Medium
Platform 18	1978	30	VD	8	40	70	Medium
Platform 26	1974	30	VD	8	40	70	Medium
Platform 48	1987	20	X	4	50	70	Medium
Platform 49	1991	20	X	4	50	70	Medium
Platform 50	1991	20	X	4	50	70	Medium
Platform 59	1993	20	X	4	50	70	Medium
Platform 60	1993	20	X	4	50	70	Medium

Table 5.2 - Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 66	2004	20	X	4	50	70	Medium
Platform 70	2004	20	X	4	50	70	Medium
Platform 71	2005	20	X	4	50	70	Medium
Platform 72	2006	20	X	4	50	70	Medium
Platform 79	1990	20	X	4	50	70	Medium
Platform 107	1992	20	X	4	50	70	Medium
Platform 27	1997	20	VD	8	40	60	Low
Platform 41	1981	20	VD	8	40	60	Low

Table 5. 3: SBO baseline risk ranking

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 23	1975	30	None	1	100	130	Very High
Platform 25	1976	30	K	3	100	130	Very High
Platform 5	1984	20	K	4	100	120	Very High
Platform 6	1980	20	K	4	100	120	Very High
Platform 7	1983	20	K	3	100	120	Very High
Platform 17	2002	20	None	1	100	120	Very High
Platform 21	1984	20	K	4	100	120	Very High
Platform 24	1983	20	VD	3	100	120	Very High
Platform 26	1987	20	K	3	100	120	Very High
Platform 28	2007	20	None	1	100	120	Very High
Platform 4	1979	30	VD	4	70	100	High
Platform 11	1983	20	K	6	80	100	High
Platform 12	1976	30	VD	4	70	100	High
Platform 13	1976	30	VD	4	70	100	High
Platform 14	1976	30	VD	4	70	100	High

Table 5. 3 – Continued

Platform Name	Design Year	Total Design Score	Bracing Configuration	Number of Leg	Total Robustness Score	Total Baseline Likelihood of Failure Score	Risk Level
Platform 18	1975	30	VD	4	70	100	High
Platform 19	1976	30	VD	4	70	100	High
Platform 22	1975	30	VD	4	70	100	High
Platform 2	1989	20	VD	4	70	90	Medium
Platform 10	1976	30	K	8	60	90	Medium
Platform 15	1980	20	VD	4	70	90	Medium
Platform 30	1978	30	K	8	60	90	Medium
Platform 31	1993	20	VD	4	70	90	Medium
Platform 1	1980	20	K	8	60	80	Medium
Platform 3	1983	20	K	8	60	80	Medium
Platform 8	2003	20	X	4	50	70	Medium
Platform 9	1975	30	VD	8	40	70	Medium
Platform 20	1987	20	X	4	50	70	Medium
Platform 27	2007	20	X	4	50	70	Medium
Platform 29	2007	20	X	6	40	60	Low

5.2.3 Case study result

The result of the Baseline Likelihood of Failure risk ranking of Malaysia fixed offshore structure is given in Table 5.4.

Table 5.4: Summary of baseline LOF risk ranking for Platforms in Malaysia

Risk Level	**PMO**	**SKO**	**SBO**	**Total**
Very High	1	44	10	55
High	22	18	8	48
Medium	17	47	12	76
Low	4	2	1	7
Very Low	0	0	0	0
Total	44	111	31	186

5.2.4 Conclusion

Based on the Baseline Likelihood of Failure risks ranking of Malaysia's fixed offshore structure discussed in the section, the following conclusion are made.

- A qualitative risk based system for screening a fleet of platforms for underwater inspection was developed and tested.
- The system makes use of physical characteristics of the platforms to set baseline likelihood of failure scores.
- A platform is "ranked" according to a set of rules relative to other platforms in a fleet.

- Malaysia offshore fixed platform fleet consisting of 186 platforms were tested using the methodology developed by modifying the risk ranking system of (O'Connor, Puskar 1999)

- In PMO which has 44 platforms, the oldest platform and newest platform had design year of 1976 and 2006 respectively; the maximum score was 130 and minimum score was 50. In SKO which has 111 platforms, the oldest platform and newest platform had design year of 1968 and 2006 respectively; the maximum score was 150 and minimum score was 60. In SBO which has 31 platforms, the oldest platform and newest platform had design year of 1975 and 2007 respectively; the maximum score was 130 and minimum score was 60.

- There are a total of fifty-five (55) "Very High" risk baseline likelihood of failure structure, forty-eight (48) "High" risk baseline likelihood of failure structure, seventy-six (76) "Medium" risk baseline likelihood of failure structure, and seven (7) "Low" risk baseline likelihood of failure structure, based on the methodology that was developed in this research.

5.3 Case study on "Statement of Requirement for Structural Design"

5.3.1 Introduction

The main objective of PBD as mentioned in Section 2.9 is to produce platform designs with predictable life-cycle performance, compliant with selected performance objectives. The structural framing of a platform influences the load redistribution on the platform. Furthermore, the selection of framing patterns can influence lifetime performance and economics of offshore installations. Appropriately configured structures can offer greater tolerance to conditions beyond the notional design envelope. A case study was initiated to demonstrate the effect of robustness in design consideration. This case study describes the use of the Structural Analysis Computer System (Bentley Systems, 2011) software to study how the framing pattern influences the capacity of a platform to take additional loadings.

5.3.2 *Case study*

The case study utilizes a Tender Assisted Drilling Rig (TADR), with a maximum load of 1713.20 MT. This load is distributed on eight (8) points to the platform. The case study considers two (2) platforms in offshore Sarawak. These two structures are located at the same field with same number of conductors and same function. The only difference between these two (2) structures is the structural framing. Table 5.5 describes in detail the characteristic of these two (2) platforms.

Table 5.5: Comparison of Characteristics of Platform A and B

CHARACTERISTIC	**PLATFORM A**	**PLATFORM B**
Water Depth (m)	74.4	78.2
Number of Leg	4	4
Maximum Leg Diameter (mm)	1657	1657
Number of Conductor	15	15
Number of Bays	4	4
Structural Framing	X	Vertical Diagonal (VD)

Table 5.6 shows the values of the fixed variables used for this case study. These fixed variables are consistently used for both "Platform A" and "Platform B".

Table 5.6: The values of variables for Reassessment

VARIABLE	VALUE
Corrosion Allowance	3.0 mm
Wave Load (1-year operating)	6.0 m
Wave Load (100-year storm)	12.2 m
Wind Load (1-year operating)	8 m/s
Wind Load (1-year storm)	42 m/s
TADR Rig Load	1713.20 MT
Number of Rig Reaction	8 point

The conductor arrangement for both Platform A and B are shown in Figure 5.2 and Figure 5.3 respectively. It can be observed that both platforms have the same conductor arrangement. The conductor arrangement for both platforms is 3 x 5. The red markup is the conductors that were "drilled" for this case study.

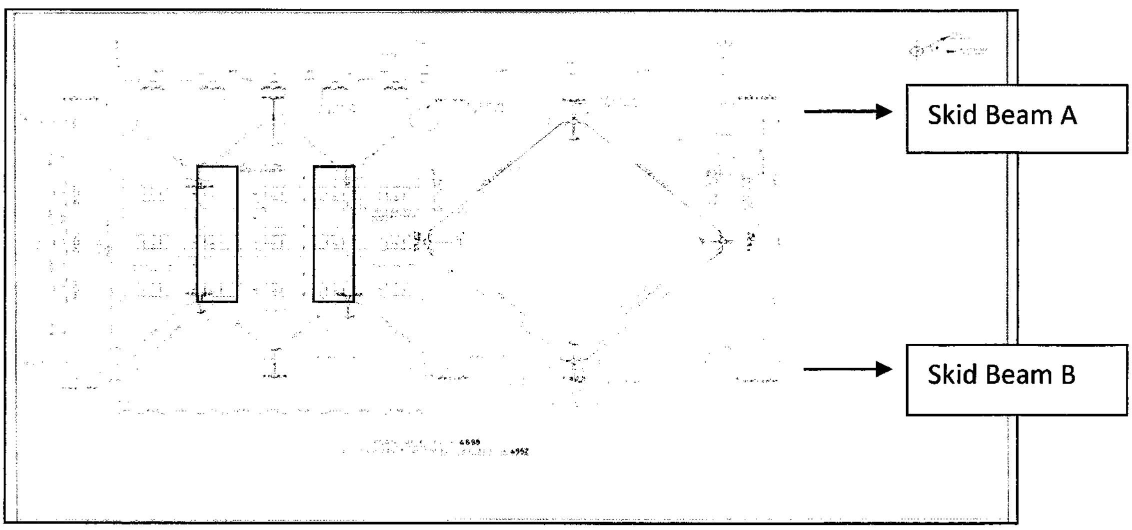

Figure 5.2: Platform - A conductor slot to be "drilled"

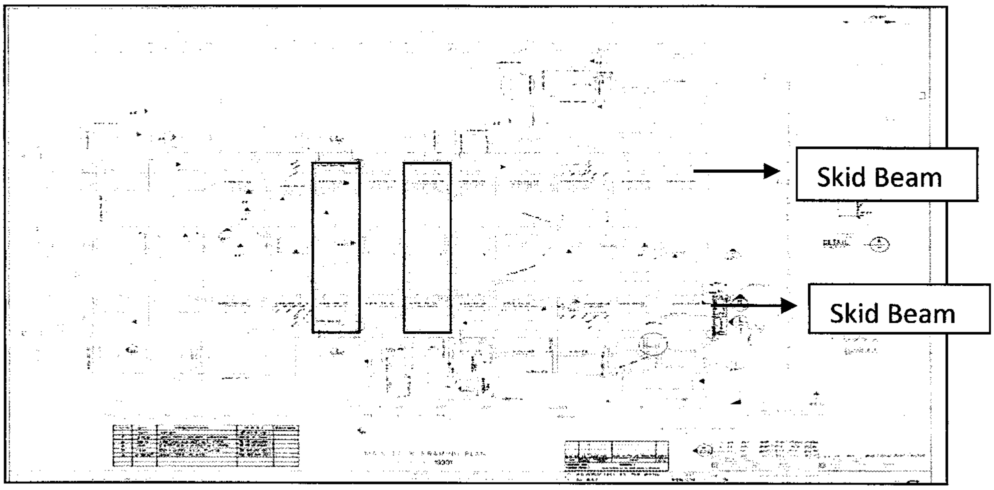

Figure 5.3: Platform B conductor slot to be "drilled"

ISO 19902 – 2007 Fixed Steel Offshore Structures, Section 24 provides guideline and provision for the assessment of existing structures. However, it does not provide the requirement and recommendation for:

1. Validation of SACS model.
2. Physical Strengthening of structure.

The SACS model is validated by reviewing the input data and 'As-Is' structural condition. This is to ensure that the latest structural model is used for the analysis. The input data consist of, but not limited to:

1. Metocean
2. Marine Growth
3. Flooded member
4. Structural Damage
5. Latest As-Built drawings

Platforms that do not meet the code requirements are deemed not fit for purpose. Physical strengthening of structure is then initiated. Strengthening can include grouting, installation of underwater clamps or addition of structural members. A structural reassessment procedure is developed by referring to ISO 19902 – 2007 and some modification was done as shown in Figure 5.4, to better suit this case study.

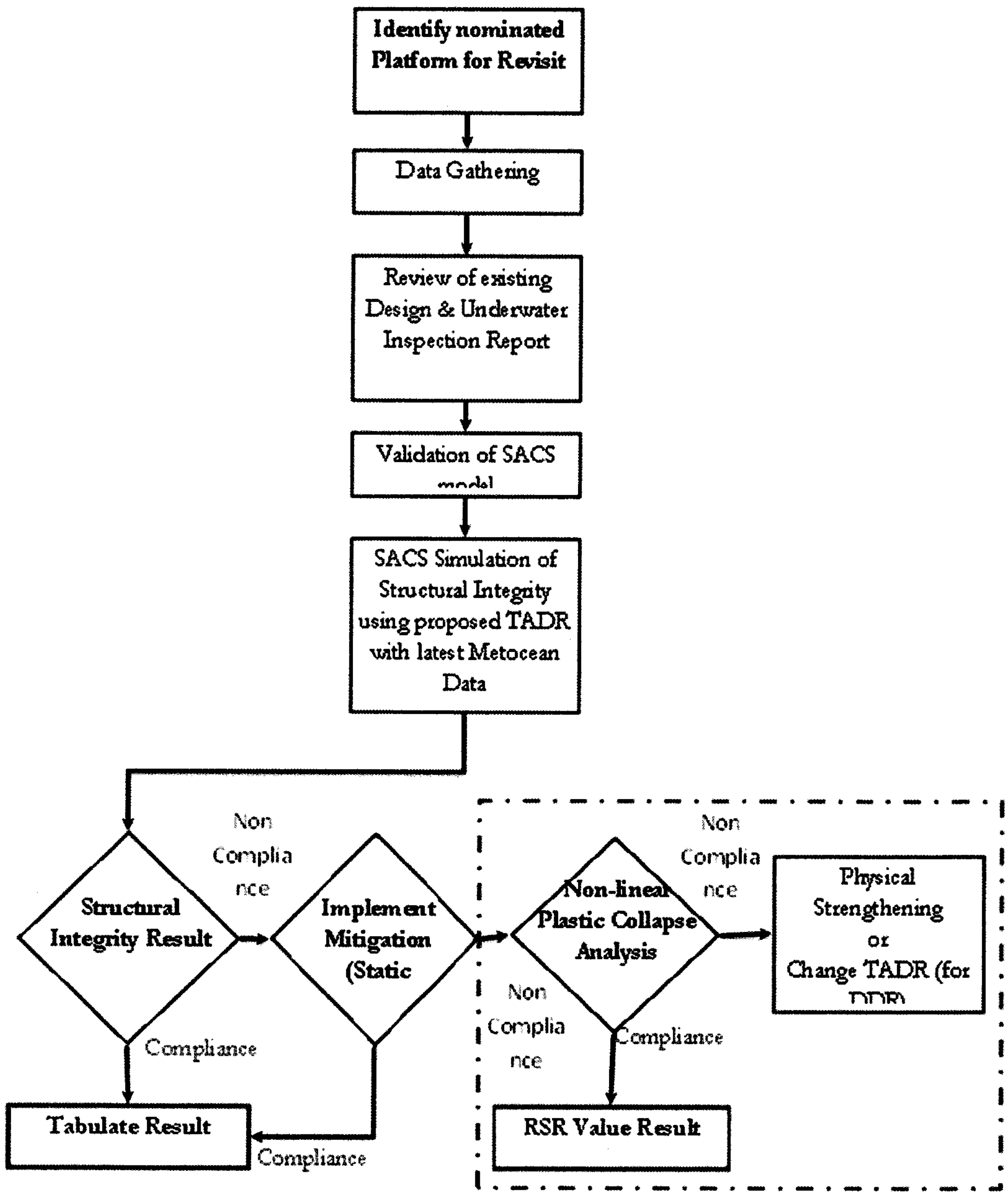

Figure 5.4: Structural Reassessment Procedure

The TADR used in this study is Global Sapphire which is owned by Global Tender Barges. Table 5.7 shows the TADR Rig Data, where each load and weight of the TADR is shown. Figure 5.5 shows the location and load reaction of Global Sapphire. Global sapphire has an eight (8) point reaction with each reaction point having different load values. The 8 points of reaction are R1, R2, R3, R4, M1, M2, M3, and M4 as shown in Figure 5.5, 5.6 and 5.7

Table 5.7: TADR Rig Data

NAME	SELF WEIGHT (MT)	Hook Load (MT)	Setback Load (MT)	Rotary Load (MT)	Total Load (MT)
GLOBAL SAPPHIRE	620.6	450.00	250.00	408.00	1728.60

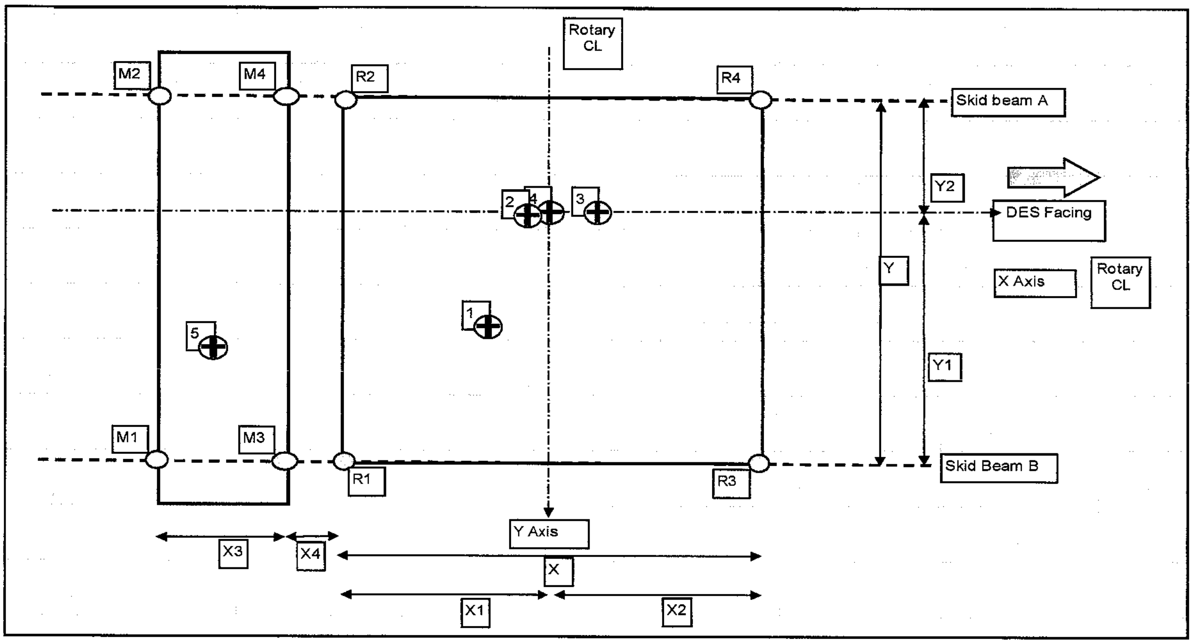

Figure 5.4: Skid Beam A Global Sapphire Reaction

Figure 5.6 and 5.7 shows the Skid Beam reaction for platform B. Figure 5.6 shows the reaction when the Rig is drilling at conductor at Skid Beam B. Figure 5.7. Show the reaction of platform B when the Rig load is exerted at conductor center to the platform.

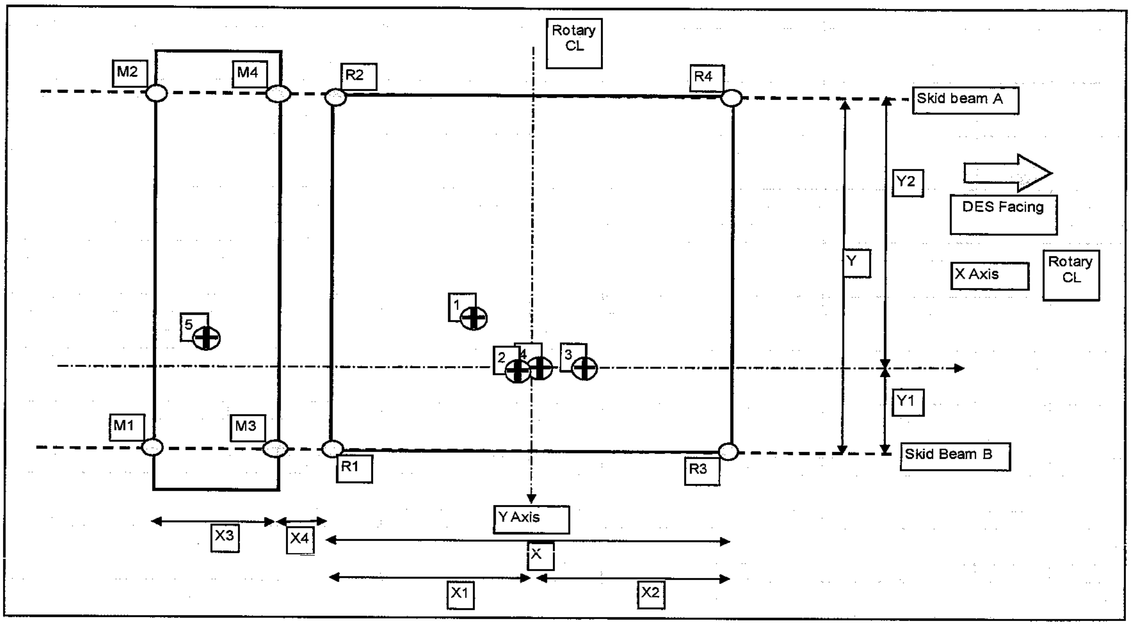

Figure 5.5: Skid Beam B Global Sapphire Reaction

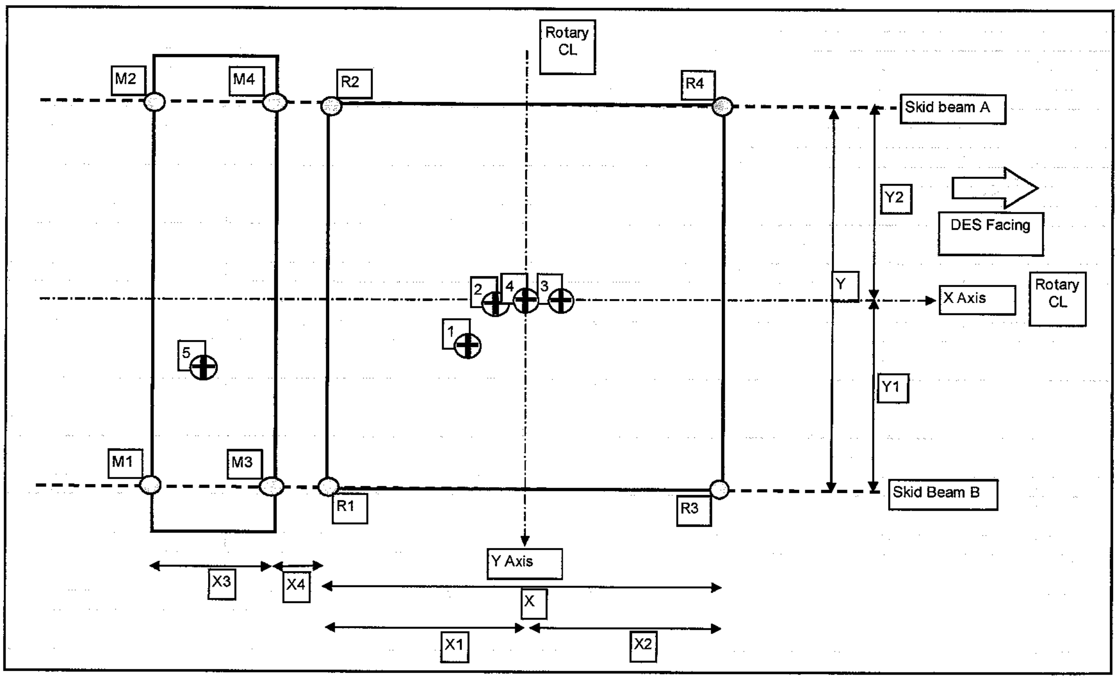

Figure 5.6: Centre Drilling Global Sapphire Reaction

5.3.3 *Case study result*

Table 5.8 and Figure 5.8 show the SACS model and the results of the SACS analysis that was carried out in the case study. The result is divided into three structural member locations, which is Jacket, Pile below seabed and pile above seabed. The result shows that all the structural members comply with API RP2A 21st Edition requirement.

Table 5.8: Reassessment result for Platform – A

Member Location	Max. Unity Check	Remarks
Jacket	0.82	Comply with API RP2A 21st Edition requirement
Pile Above Seabed	0.50	Comply with API RP2A 21st Edition requirement
Pile Below Seabed	0.46	Comply with API RP2A 21st Edition requirement

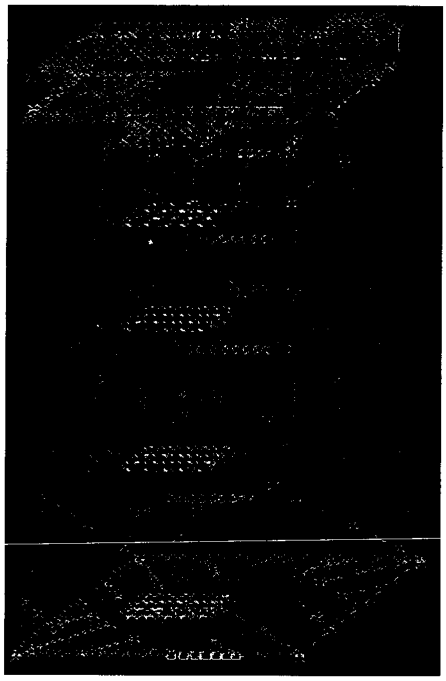

Figure 5.8: SACS Model of Platform – A

Table 5.9 and Figure 5.9 show the SACS model and the results of the SACS analysis that was carried out in the case study. The result is divided into three structural member locations, which is Jacket, Pile below seabed and pile above seabed, similar to the breakdown of result as per Platform – A. The result shows that not all the structural members for Platform – B comply with API RP2A 21st Edition requirement.

Table 5.9: Reassessment result for Platform – B

Member Location	Max. Unity Check	Remarks
Jacket	1.01	Not Comply with API RP2A 21st Edition requirement
Pile Above Seabed	0.50	Comply with API RP2A 21st Edition requirement
Pile Below Seabed	0.46	Comply with API RP2A 21st Edition requirement

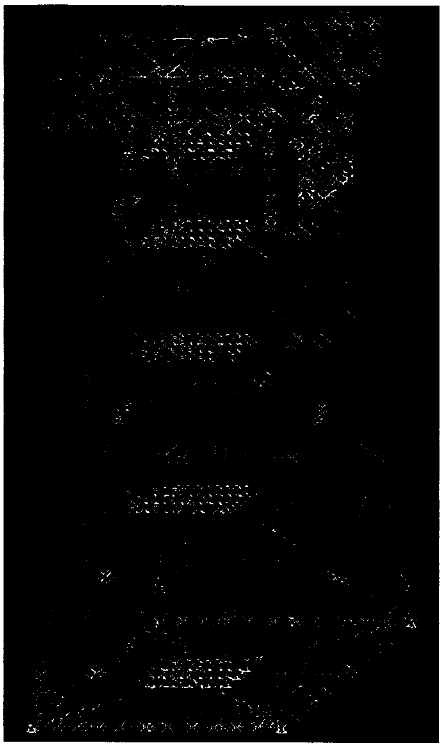

Figure 5.9: Platform - B Reassessment Result

The reassessment result of platform A and B shows that the jacket member unity check (UC) of Platform B is higher than of Platform A. The maximum jacket member UC for platform B is 1.01, which is considered as marginally overstressed. Platform A maximum jacket member UC is 0.82, which meets the API RP 2A 21st Edition requirement.

5.3.4 Conclusion

Platform – B has a higher jacket member unity check (UC) compared to Platform – A. All variables used in the analysis is consistent, except the bracing configuration of the structure. Platform – A is X-braced, and Platform – B is a K – Braced structure. It can be concluded that, a K - Braced structure is susceptible to overstress compared to an X – Braced structure, thus reducing its load bearing capacity.

The result from this case study justifies the recommendation of SOR where, a platform is required to be designed using as a X – Braced structure. The X – Braced structure has the ability to withstand higher load, without affecting the structural integrity of the platform.

Furthermore, it is also highly favorable to O&G operators, where increased robustness and redundancy will result in minimal cost required for strengthening, modification and repair (SMR) activities. SOR for PBD is also crucial, as shown by this case study where structural redundancy and robustness could support for infill drilling of additional wells, risers or caissons as may become necessary in the future.

5.4 Case Study of Data Handover Requirements

5.4.1 Introduction

The case study for data handover requirement is discussed in this section. A platform, called Platform – A was chosen as a candidate. The reason Platform – A was chosen is because it has the most complete data available for this case study.

5.4.2 Case study

The requirement of data handover was developed based on the document requirements stipulated in API WSD 21st Edition at each stage during the life cycle of the platform and the requirements of data for SIM. This was discussed in detail in Section 4.4. The vital data and records from the design, fabrication and installation phase of an offshore structure which are required for SIM are:

- General facility data.
- Design reports
- Fabrication reports and As – Built drawings.
- SIM database drawings
- Installation records

5.4.3 *Case Study Result*

For the chosen platform, the data required are collated and presented as a case study in Table 5.10 till Table 5.14.

Table 5.10: General facility data sheet

General facility data	
Platform Name	Platform A
Field	Field A
Platform Type	DP
Platform Function	Drilling & Production
Heritage	No previous owner
Operator	Confidential
Operational Status	Active
Partner	No Partner
Holding Percentage	100
Installation Method	Lifting
Year Installed	2007
No in complex	1
Linked Platform	No linked platform
Orientation *TN (degrees)	-45
Easting (deg)	533 809.7
Northing (deg)	676 423.2
Water Depth (m)	60.7
Jacket Height (m)	66.734
Air Gap (m)	3.5 m
Deck Elevation (m)	16.5

Table 5.10 - Continued

General facility data	
Long Framing	X
Transverse Framing	X
Number of Bays	3
Number of Legs	4
Number of Piles	4
# of Leg Piles	NA
# of Skirt Piles	NA
Maximum Leg Diameter (mm)	1720
Grouted Piles	No
Deck Weight (MT)	780.46
Jacket Weight (MT)	1293.89
Pile Weight (MT)	1393.39
Base Length (cm)	27256
Base Width (cm)	26750
Manned	Unmanned
Shore Distance (KM)	320
Quarters Capacity	0
Number of slots	12
Number of caissons	3
Number of conductors	9
Number of riser	2
Max Conductor diameter (mm)	610
Number of deck	3
Number of cranes	1
Max crane size (MT)	20
Number of Boat landing	1
Helipad	1
Helipad type	Steel

Table 5.11: Platform design data sheet

Platform design data	
Platform Name	Platform A
Field	Field A
Platform Function	Drilling & Production
Partner	No previous partner
Installation Method	Lifting
Year Installed	2007
Number in complex	1
Orientation to True North	-45
Easting (deg)	533 809.7
Northing (deg)	676 423.2
Water depth (m)	60.7
Design Service (years)	25
Design Air gap (m)	1.5
Design Deck Elevation (m)	16.5
Design Code	API RP 2A WSD 21st Edition
Design Life (years)	20
Design Return Period (years)	100
Design Wave Height (m)	10.8
Design Current Speed (m/s^2)	1.1
Design Tide (m)	1.33
Design Caisson (number)	4
Design Conductor (number)	12
Design Risers (number)	4
Design Marine Growth (mm)	153
Design Scour (m)	0.9
Design Deck Weight (MT)	780.46
Design Conductor Subsidence (m)	0

Table 5.12: Baseline static in place analysis information sheet

Baseline static in place analysis information	
Platform Name	Platform A
Analysis ID	Baseline
Analysis Year	2006
Analysis Type	Linear Elastic
Analysis Software	Structural Analysis Computer System (SACS)
Analysis Contractor	Confidential
Fitness for Purpose	Yes
More Analysis Required	No

Table 5.13: Baseline static in-place analysis design data

Baseline static in-place analysis design	
Analysis Code	API WSD 21st Edition
Wave load recipe	American Petroleum Institute (API)
Jacket Max member Unity Check (UC)	0.9
Jacket Max joint UC	0.698
Soil liquefaction potential	No
Dynamically sensitive	Yes

Table 5.14: Baseline Static In-Place Analysis Result

Baseline Static In-Place Analysis	
Caisson	4
Conductors	12
Risers	2
Tide (m)	1.33
Hmax (m)	10.8
Deck Elevation (m)	16.5
Total Load (MT)	3859
Marine Growth (mm)	100
Scour (m)	0.9
Corrosion (mm)	3

5.4.4 Conclusion

The case study result from the data handover requirement will provide the information required to:

1. Assess a platform Baseline Risk Ranking

2. Assess a platform Risk Based Underwater Inspection (RBUI) Ranking

The platform Baseline Risk Ranking can be obtained from the General facility and Design data sheet since the General facility and Design data sheet requires the same information such as:

1. Design code

2. Number of legs

3. Bracing types

4. Grouted piles

The platform RBUI ranking information and data can be obtained from:

1. General facility data sheet
2. Platform design data sheet
3. Baseline static in place analysis information sheet
4. Baseline static in-place analysis design data
5. Baseline Static In-Place Analysis Result

Thus, the data handover requirement from Greenfield and Brown field projects will be able to provide the O & G operator a sufficient amount of SIM data for the Baseline Risk and RBUI risk ranking of a fixed offshore platform. This in return, would provide the operation the proper inspection interval and scope of work for the Underwater Inspection and Maintenance program.

5.5 Case study on development of the Risk Based Underwater Inspection (RBUI) Method

5.5.1 Introduction

The development of this case study is to demonstrate how the Risk Based Underwater Inspection (RBUI) will affect the inspection planning of the offshore structure. This research uses one (1) fixed offshore structure as a sample, with data taken from a local O & G operator.

The data that would be looked into for this structure are data's that affect the Likelihood of Failure (LOF) and Consequence of Failure (COF) of the structure, which in turn will provide the appropriate risk level and inspection plan of the platform.

Calculations would be done to develop the risk ranking of the platform and the final score will be tabulated. The sample platform contains the following information:

- Baseline Likelihood Failure
    - Platform Vintage
    - Number of legs and bracing system
    - Grouted pile/leg annulus
- Platform Present Condition
    - Last inspection
    - Mechanical damage
    - Corrosion
    - Marine growth
    - Scour
- Platform Loading Susceptibility
    - Deck load
    - Deck elevation
    - Appurtenance load
    - Fatigue load
- Platform Consequence of Failure (COF)
    - Life Safety
    - Environmental
    - Economic

5.5.2 Case study

The risk ranking is evaluated as a case study for platform – X which information is given in Table 5.15.

Table 5.15: Information about platform for Case study

Likelihood of Failure (LOF) Rule	**Information**
Design Code	1971 - 1979
Robustness	8 Leg / VD Bracing
Grouted	No
Last Inspection	2003
Number damaged/flooded member	14
Lowest Anode depletion (%)	100%
Marine growth thickness (mm)	100
Scour (m)	1.5
Number of member Max UC > 1	9
Air Gap (m)	2
Number of increase in appurtenances	0
Number of member with Low Fatigue Life < 30 years	103

The data obtained above, will then be calculated as per Section 4.5.12 and section 4.5.13 to obtain the LOF score of Platform – X. The score would then be summed up to obtain the risk level and subsequently the inspection plan of the structure. Table 5.16 shows the LOF rule score for Platform – X.

Table 5.16: LOF rule weighted score

	Likelihood of Failure (LOF) Rule	Information	Score	Weightage	Total Score
BASELINE	Design Code	1971 - 1979	6	5	30
	Robustness	8 Leg / VD Bracing	4	10	40
	Grouted	No	10	3	30
PRESENT CONDITION	Last Inspection	2003	6	8	48
	Number damaged/flooded member	14	10	10	100
	Lowest Anode depletion (%)	100%	10	5	50
	Marine growth thickness (mm)	100	10	6	60
	Scour (m)	1.5	3	2	6
LOADING SUSCEPTIBILITY	Number of member Max UC > 1	9	7	5	35
	Air Gap (m)	2	0	10	0
	Number of increase in appurtenances	0	0	5	0
	Number of member with Low Fatigue Life < 30 years	103	10	5	50
	TOTAL LOF RISK SCORE				449

5.5.3 *Case study result*

The result of the case study shows that Platform – X has a total LOF risk score of 449. Comparing this score with LOF risk category in Table 4.24 shows that Platform – X is a category three (3) platform. It can be seen from Figure 5.10 which shows the risk matrix, that the Platform – X is located in the center of the matrix.

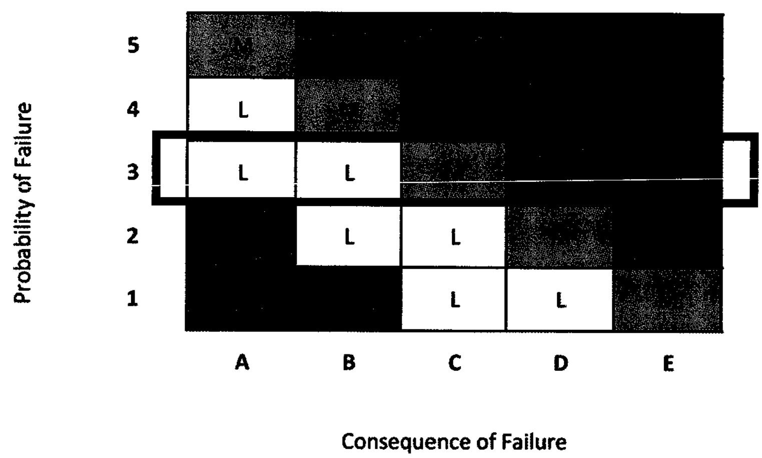

Figure 5.10: Platform - X case study LOF risk matrix

The result shows that there are only three (3) possibilities of risk for Platform – X which are "Low", "Medium" and "High" risk. The next step would be the calculation and subsequently determination of the COF risk ranking for the Platform – X. The COF rule was explained in detailed in Section 4.5.14 and comprises of three (3) major items namely (1) Life safety (2) Environmental and (3) Economics. The COF information of Platform – X is showed in Table 5.17. The information is then compared to the COF rule which was developed in this research to obtain the COF risk ranking.

Table 5.17 : Platform - C case study COF information

Consequence of Failure (COF) Rule	Information	COF
Life Safety	Unmanned	A
Environmental / BOE spilled / Storage capacity	20000	D
Economics	E	E

The economic consequence is taken as the most restrictive of the values based on the experience of BP Horizon oil spill in the Gulf of Mexico (GOM). The result of the three COF rule are "E", which implies that the overall risk ranking of Platform – X is 3E. The risk matrix in Figure 5.11 shows that Platform – X is located at row 3, column 5.

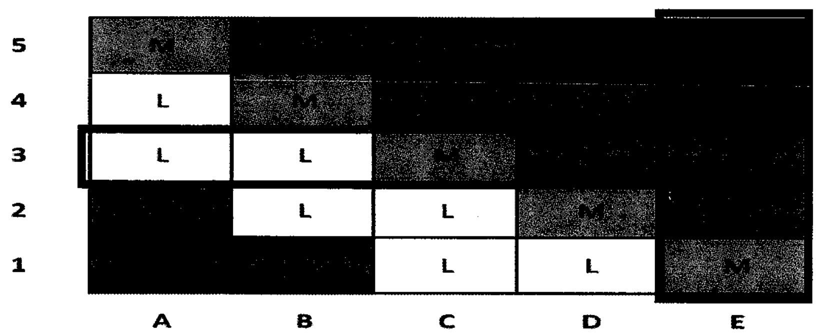

Figure 5.11: Platform - X case study risk matrix

5.5.4 *Conclusion*

The overall risk ranking for Platform –X is 3E (High Risk). Therefore, referring to Figure 4.18, platform – X should be inspected every five (5) years. However, Table 5.16 indicates that the last inspection of Platform – X was conducted in 2003, with a lapse of nine (9) years now. Therefore as a conclusion of this study, Platform – X needs to undergo its underwater inspection and maintenance as soon as possible to ensure the continued fitness for purpose of the structure.

CHAPTER 6

CONCLUSIONS AND SCOPE FOR FUTURE STUDIES

6.1 INTRODUCTION

In this thesis, issues related to Structural Integrity Management (SIM) are studied. These include a review of the world O & G industry, analysis of UKCS, North Sea and Malaysia oil's production, review of existing codes and standards, SIM and RBUI practices worldwide. The main objective of this research is to develop an integrated framework for SIM for Malaysian Platforms. The sub-objectives have been listed in section 1.4. The SIM framework recommended by O'Connor, and Westlake (2005) has been found to be the most relevant framework for the development of an integrated SIM framework for fixed offshore structure.

The elements of the framework have been further investigated in this thesis. This includes an evaluation of current design practices that has an impact on future structural integrity of a platform, underwater inspection philosophies and failure modes of ageing structures.

6.2 CONCLUSIONS

The main conclusion and contribution from the research study are presented below in the same order as the objectives listed in Section 1.4.

1. **Classification of Malaysia's fixed offshore structures based on as-built asset characteristics:** Prior to the commencement of this research, the Malaysia O & G industry was evaluated, to identify the current status of the assets. Section 4.2 presented and described in detail the region wise distributions of Malaysia's fixed offshore structure based on the year of design, code period and bracing-leg criteria. The result obtained shows and confirms that most of these structures have exceeded the design life of thirty (30) years.

2. Based on the data that was available, a case study was done with a sample case of one hundred and eighty- six (186) structures to identify the baseline risk of these structures. A total of fifty-five (55) platform were identified to be "Very High" risk.

3. **Statement of requirement for design of new offshore structures:** Section 4.3 talks about the development of a "Statement of Requirement for Design Offshore Structure". The document provides a framework within which is to ensure that the reduction of baseline risk can be achieved. A sample case study was conducted to demonstrate the effect of robustness in design. The study uses actual data from a tender assisted drilling rig (TAD) and two (2) Structural Analysis Computational System (SACS) model. The analysis that was executed confirms that the structural framing and robustness of a structure plays a vital part in the continued operation of an offshore facility. An X-Braced structure has an ability to withstand higher load without affecting the structural integrity of the platform. Furthermore, this provides an opportunity to reduce further spending in strengthening, modification and repair (SMR) of ageing facilities even if the operation philosophy has been changed.

4. **Develop a data handover guideline for Greenfield and Brownfield projects:** With respect to data management, Section 4.4 talks about the development of a "Data Handover Guideline for Brownfield and Greenfield Project". The guideline will

specify the minimum SIM data that is required to be transmitted from new projects and acquisition of a new offshore facility. It includes the details of the format in which the data should be provided, consistent with the SIM process proposed in this research. A case study was done to demonstrate the data format that is required for the overall continued SIM of fixed offshore structure.

5. **A risk based underwater inspection (RBUI) guideline was developed in Section 4.5**. The RBUI guideline is a procedure on how to conduct RBUI planning for in-service inspection of jacket structures. This Guideline is to be used for the planning of in-service inspection for offshore platform structures, considering possible total platform failure through structural collapse. This Guideline addresses the most commonly experienced degradation mechanism found on platform structures, but the inspection personnel should make themselves aware of any special hazards that are relevant to the platform structural integrity which are not included in this document.

6. **A case study is done, to demonstrate how the Risk Based Underwater Inspection (RBUI) will affect the inspection planning of the offshore structure.** This research uses one (1) fixed offshore structure as a sample, with data taken from a local O & G operator. The data that would be looked into for this structure are data's that affect the Likelihood of Failure (LOF) and Consequence of Failure (COF) of the structure, which in turn will provide the appropriate risk level and inspection plan of the platform. The overall risk ranking for Platform –X is 3E (High Risk), with an inspection interval of five (5) years. However, from table 4.44, it was shown that the last inspection of Platform – X was conducted in 2003, with a gap now of nine (9) years. Therefore as a finding, Platform – X needs to undergo its underwater inspection and maintenance campaign (UIMC) as soon as possible to ensure the continued fitness for purpose of the structure.

7. **Development of an integrated SIM framework for Malaysian platforms.**

   The integrated framework for SIM of offshore jacket structures was presented in Figure 4.19. The different components of the framework were explained in detail.

6.3 SCOPE FOR FUTURE STUDY

Development of an integrated SIM framework for Malaysian platforms should consist of:

1. Statement of Requirement (SOR) for design of offshore structures.
2. Data handover guideline for projects.
3. Determination of Baseline Risk of platform.
4. Development of RBUI guideline
5. Guideline for decommissioning.

The details of the work done on 1, 2, 3 and 4 were presented. Item 5 can taken up for future research.

An integrated SIM approach for design and operation is insufficient through the whole life cycle of an offshore fixed structure. More focus and attention is needed to cater for decommissioning requirement, and how design can influence future decommissioning methods and decision. In addition, the work on SIM and RBUI needs to be extended to include other major hazards such as boat impact, earthquake and fatigue.

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APPENDIX A

Table A1 RBUI term and definition

Term	Definition
Component Failure	The point at which a component ceases to fulfill its function and the limits placed on it. The failure condition must be clearly defined in its relationship to the component. Failure can be expressed, for example, in terms of non-compliance with design codes, or exceeding a set of risk limit, neither of which necessarily imply total loss of load bearing capacity and / or loss of functionality of the component.
Consequence of Failure	The outcomes of a failure. This may be expressed, for example, in terms of safety to personnel, economic loss and damage to the environment
Condition Monitoring	Monitoring of platform structure physical conditions which may indicate the presence of given damage mechanisms. Examples are marine growth monitoring, corrosion monitoring, and fatigue crack.

Damage Mechanism	Damage to offshore structure can result from a number of mechanisms, including: • Corrosion • Cyclic Loading • Dropped object • Fire/blast • Fish bombing • Helicopter crash • Ship collision • Subsidence • Topsides overloading • Vibration • Well blow out • Wave-in-deck
Damage Model	A mathematical representation of the results of degradation. This may express the accumulation of damage over time as functions of physical or chemical parameters, and normally includes the estimation of the conditions that give rise to failure.

Damage Type	The observed effect on a component of the action of a degradation mechanism. The damage type gives rise to the failure mechanism of a component. Examples of damage include fatigue cracking, wall thinning and corrosion pitting.
Damage Rate	The development of damage over time.
Degradation	The reduction of a component's ability to carry out its function.
Degradation Mechanism	The method by which a component degrades. Degradation mechanisms, for example fatigue, corrosion and stress corrosion cracking, may be chemical or physical in nature, and may grow / progressing over time (time driven) or instantaneous without noticeable progression / growth path (event driven).
Global Failure Mode	The method by which the structural collapse of a platform structure occurs. Examples are: piles buckling failure, piles punch-through failure, leg compression failure and lateral soil failure.
Inspection	An activity carried out to assess the progression of damage in a component. Inspection can be by means of non-destructive testing or as a visual examination.
Inspection Effectiveness	A description of the ability of the inspection method to detect the condition inspected for.
Inspection Methods	The means by which inspection can be carried out, covering the inspection technique and a description of the application of that technique.

Inspection Techniques	The type of inspection that is to be applied, such as eddy current, MPI, flooded member detection etc.
Likelihood	A qualitative expression of probability, given as a description or a ranking.
Limit State	A mathematical description involving the extent of load on a component in relation to the damage to that component at which failure is expected to occur.
Limit State Design	Limit state design identifies explicitly the different local failure mechanisms and provides a specific design check to ensure that component failure does not occur.
Local Failure Mechanism	The underlying phenomenon by which a component fails due to the progression of damage beyond the set limits imposed by the designer or by physical limits. Examples are through thickness crack of the brace wall or circumferential crack of the chord wall.
Monitoring	An activity carried out over time whereby the amount of damage is not directly measured but is inferred by measurement of factors that affect that damage. Monitoring may include direct measurements such as weld crack detection through CVI and/or MPI, or indirect measurements through changes in natural frequency monitored by accelerometers located on the platform topsides.
Probability	A quantitative description of the chance of an event occurring within a given period.

Probability of Detection	Probability that a given damage in a component will be detected using a given inspection method. PoD usually varies with the size or extent of damage and inspection method.
Probability of Failure	The probability that failure of a component will occur within a defined time period.
Reserve Strength Ratio	The Reserve Strength Ratio (RSR) measures the reserve strength of a platform structure beyond the 100-years characteristic (design) environmental load. The RSR is defined as the ratio between the base shear / overturning moment value at the collapse of platform structure to that of the 100-years characteristic (design) environmental load.
Risk	Risk is a measure of possible loss or injury, and is expressed as the product of the incident probability and its consequences. A component may have several risk levels associated with it depending on the different Cof and the different probabilities of those failures occurring.
Risk Based Inspection	A decision-making technique for inspection planning based on risk, combining Lof and Cof.
Risk Ranking	A qualitative category expressing the risk of a platform structure and its relative ranking within a fleet of platform structures.
Safety Loss	Safety loss is expressed as the product of potential fatalities and equivalent fatality cost.
Structural Collapse	The point at which the external loads have exceeded the

	ultimate load resistance capacity of a platform structure and caused the platform structure to deteriorate beyond its intended functionality and serviceability. The structural collapse must be clearly defined in its relationship to the local failure mechanism and global failure mode.