Purpose of Issue	Rev	Date of Issue	Author	Agreed	Approved
Issued to Participants	0	November 2000	JB/FP	JB/FP	JB

JOINT INDUSTRY PROJECT

RATIONALIZATION AND OPTIMIZATION OF UNDERWATER INSPECTION PLANNING CONSISTENT WITH API RP2A SECTION 14

FINAL REPORT

DOC REF CH104R006 Rev 0 **November 2000**

MSL Services Corporation
11111 Katy Freeway, Suite 620
Houston, Texas 77079

Tel: 713 463 6180
Fax: 713 463 6557
E-mail: JBucknell@mslengineering.com

NUMBER	DETAILS OF REVISION
A	Issued to JIP participants for review and comment ahead of the final meeting of the Project Steering Committee.
0	Reissued to reflect comments received at, and subsequent to, the final meeting of the Project Steering Committee.

FOREWORD AND ACKNOWLEDGEMENTS

This document has been prepared by MSL Services Corporation with contribution from EQE International for eight sponsoring organizations as follows:

- BP Amoco
- Chevron
- Devon Energy
- ExxonMobil Production
- Marathon
- Minerals Management Service
- Ocean Energy
- Texaco

A project steering committee including representatives of the sponsoring organizations oversaw the work and contributed to the development of this document. During the life of the project, the individuals listed below served on the committee and the benefit of their input and experience is gratefully acknowledged. MSL would like to offer special thanks to Dr. Sam De Franco for the guidance, advice and significant time he lent to the project in his role as Chair of the project steering committee.

R Beck
J Beene
K Bowman
J Bucknell
M Day
S De Franco (Chair)
AJ Delhomme
A Dier
J Gebara
A Ghosh
M Gordon
T Laurendine
J Maddox
B Manley
P O'Connor
F Puskar
J Theriot
P Versowsky

The Project Manager at MSL was Justin Bucknell who carried out the work with support and technical assistance from a number of MSL engineering personnel. MSL would like to acknowledge the valuable contributions to the project provided by EQE International, in particular Mr. Frank Puskar, and by other subcontractors who provided services throughout the course of the work including Mr. Lawrence Goldberg with Seatest Services and Mr. Bing Strasburg and his colleagues at Solus Schall.

JOINT INDUSTRY PROJECT

RATIONALIZATION AND OPTIMIZATION OF UNDERWATER INSPECTION PLANNING CONSISTENT WITH API RP2A SECTION 14

FINAL REPORT

CONTENTS

REFERENCES

An extensive list of data sources related to underwater inspections of offshore structures was developed during the course of the JIP. These are included in the Reference Section of this report including Title, Author and Publication. In particular, Reference 9 and 10 were procured through the JIP and copies can be made available to Participants upon request.

EXECUTIVE SUMMARY

This document has been prepared by MSL Services Corporation (MSL), with contribution from EQE International (EQE), and relates to the Joint Industry Project titled, 'Rationalization and Optimization of Underwater Inspection Planning Consistent with API RP2A Section 14'.

GOAL

The wider goal of the JIP was to provide industry with the data to implement the process of Structural Integrity Management (SIM) defined in existing ISO draft recommended practice [2], to allow optimized inspection-planning without compromise to safety.

OBJECTIVES AND DELIVERABLES

- A reliable, industry-wide database was compiled from the collective inspection data amassed by industry over the last ten years and beyond. The database contains platform, inspection and anomaly data for over 2,000 Gulf of Mexico platforms, drawn from the fleets of 12 major operators in water depths ranging from less than 20 ft. to over 2000 ft. Details of approximately 3,000 underwater inspections have been catalogued and almost 5,000 anomalies recorded. The screened and de-sensitized database was distributed to Participants on CD format.
- New Guidelines were developed for platform in-service inspection, reflective of the trends identified from inspection data, to permit rational inspection programs to be established consistent with API/ISO recommendations [1,2]. The Guidelines and commentary are contained in Section 6. The results of the platform defect trend analyses are fully reported in Section 5 and highlighted in summary form below.
- The Guidelines were benchmarked and calibrated against representative Gulf of Mexico platforms to demonstrate their validity and robustness. The benchmarked platforms are included within Section 7 as go-by examples in the use of the Guidelines.
- The reliability and applicability of flooded-member detection (FMD), and other inspection techniques, is reported in Section 8.

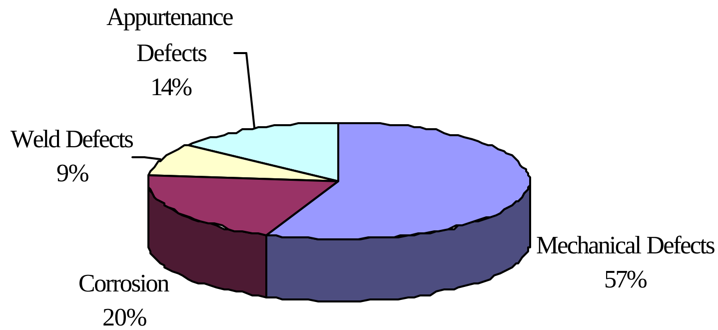
RESULTS OF DAMAGE TREND ANALYSES

The objective of the damage trend analyses was to find answers to a number of questions relevant to the structural integrity of offshore platforms; answers substantiated with data recorded by industry over the last 10-years and beyond.

- What defects are we finding on platforms in the Gulf of Mexico?
- Where are these defects occurring? What components are affected?
- What are the causes of the defects?
- Which platforms are susceptible to defects and why?

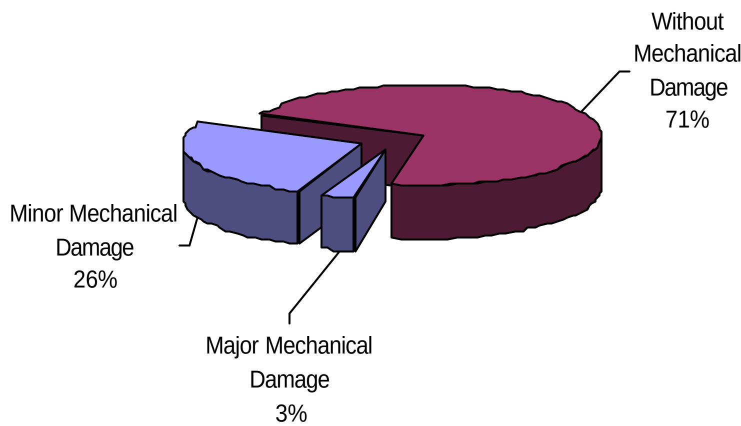
Platform Defects

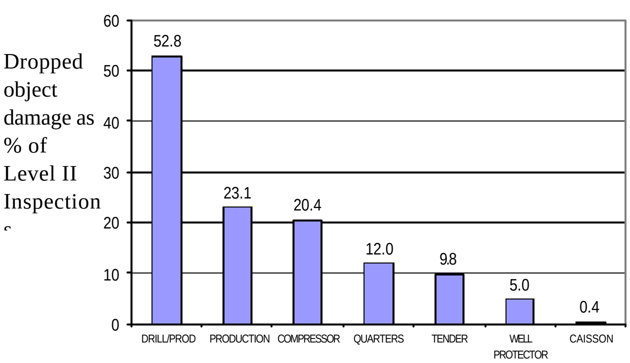
Damage found during underwater inspections of platforms in the Gulf of Mexico can be divided into four categories. The categories and their relative occurrence are shown in the figure. Neglecting non-structural defects, mechanical damage is responsible for two-thirds of the defects reported on platforms in the Gulf of Mexico.



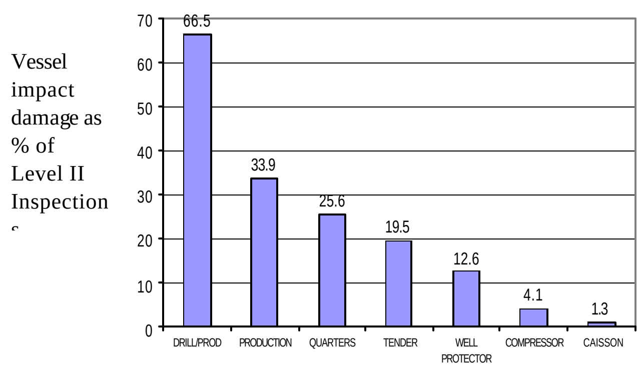
Mechanical Damage

Mechanical damage includes dents, bows, gouges and separated members. The figure summarizes the extent and severity of mechanical damage amongst the platform population in the Gulf of Mexico. The two primary causes of mechanical damage are vessel impact and dropped objects. The function/ type of a platform, as shown in the bar graphs below, influences its susceptibility to mechanical damage.





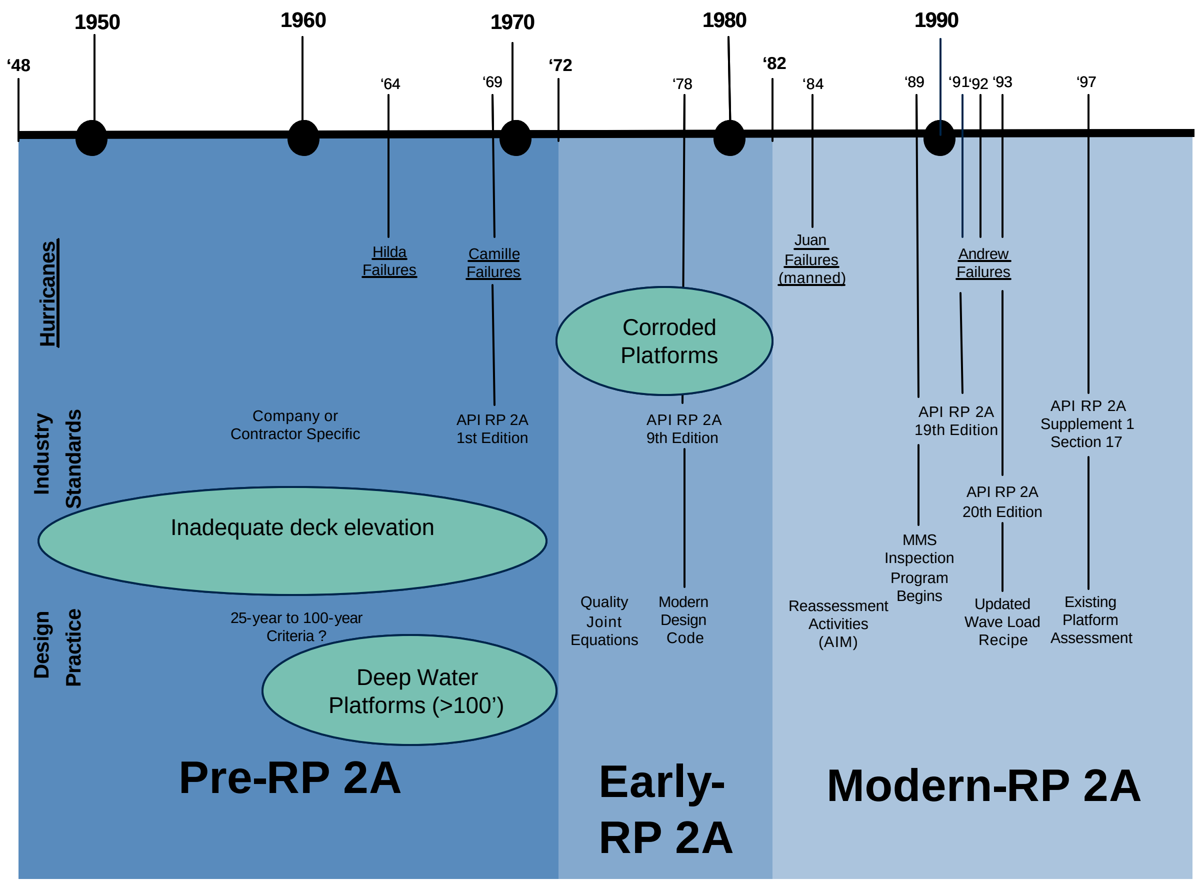
Dropped Object Damage by Platform Type



Vessel Impact Damage by Platform Type

Weld/Joint Defects

Weld/joint defects consist of cracks, fabrication defects and joint overload failures. Defects of this type correlate closely to platform vintage, and to identifiable subsets of platforms within vintages as defined in the figure below.



Gulf of Mexico Platform Vintage Categories

The following conclusions have been drawn in relation to the occurrence of weld/joint defects on platforms in the Gulf of Mexico.

i) Weld/joint defects occur on less than 1% of modern-RP2A vintage platforms and are associated with installation damage, fabrication defects and poor design/repair details.

ii) In both early-RP2A platforms and pre-RP2A platforms, approximately 80% of weld/joint defects result from a combination of fatigue damage and collateral damage from vessel impact.

iii) Fatigue damage in early-RP2A platforms is dominated by damage to the conductor guide frame at the first elevation below the water surface. This damage affects approximately 2% of the vintage population.

iv) General fatigue cracks have been found in around 1% of the early-RP2A platform fleet.

v) Early and Pre-RP2A vintage platforms where a failure of the CP system has been recorded at some time in the service life i.e. more heavily corroded platforms, are at increased risk of general fatigue damage.

vi) Conductor bay fatigue amongst the population of pre-RP2A platforms is consistent with early-RP2A vintage platforms. It occurs in a little over 3% of the vintage population; the relative increase being a function of the increased time of exposure.

vii) General fatigue damage is more widespread in pre-RP2A platforms than it is in early vintage platforms, affecting about 5% of the vintage population.

viii) Pre-RP2A platforms most susceptible to general fatigue damage are those installed in the latter part of the era in relatively (for the vintage) deep water, generally water depths of 100 feet or greater. The damage occurs mostly in primary joints close to the mud line.

ix) Joint overload failure defects occur at the mud line of pre-RP2A platforms that have inadequate deck heights (by modern criteria) and have been subject to extreme event loading.

Corrosion

Corrosion defects consist of pitting/holes, crevice corrosion, fretting and general/uniform corrosion. The majority of corrosion damage occurs in or above the splash zone.

i) Pitting corrosion and holes are the most common corrosion defects found on platforms in the Gulf of Mexico.

ii) Approximately 8% of the platform population has experienced interruption in the effective operation of the corrosion protection system although it was found that such interruption is not a good indicator of the level of corrosion on the platform.

iii) Inspection data indicates that close-visual joint inspection is a reliable indicator of the general corroded state of the platform. This finding is consistent with reports from underwater diving inspectors.

iv) More heavily corroded platforms, as defined by reported heavy visual corrosion of the steel surface, have an increased susceptibility to general fatigue damage.

Platform Anomalies

i) Marine growth measurements in excess of the API recommended design levels are widespread in the Gulf of Mexico.

ii) Marine growth anomalies beyond 40 feet water depth are rare in the coastal waters north of latitude 29° and west of New Orleans (longitude –90°).

iii) Marine growth thickness does not appear to increase indefinitely; a stable thickness is reached after a few years. Annual/seasonal variations in thickness do occur.

iv) Measured data indicates that a variable marine growth profile may be preferable in design to the constant 1.5 inches recommended in API RP2A and that marine growth should be considered, in design, beyond the 150 feet depth presently recommended in API RP2A. The impact of these findings is expected to be small.

v) Seafloor scour is not a concern for the large majority of Gulf of Mexico platforms due to the generally cohesive nature of the soils.

vi) Scour may occur because of temporary seabed movements during severe storms or hurricane events.

vii) Debris is not generally detrimental to structural integrity. Exceptions are; hanging objects that lead to fretting corrosion and metallic objects contacting the structure and reducing the efficiency of the CP system.

BENEFITS TO INDUSTRY

The JIP has achieved its goal of providing industry participants and regulatory authorities with the data and the means to collectively implement the SIM process, enshrined within API and ISO codes of practice, to allow a rational approach to optimized inspection-planning without compromise to safety. The results from the JIP are expected to have immediate and direct application for structures in the Gulf of Mexico and elsewhere, resulting in improved platform integrity assurance and substantial, safety, environmental and economic benefits. Specific benefits are highlighted in the conclusions summarized below.

CONCLUSIONS

Inspection Intervals: Through the analysis of existing data, the JIP has demonstrated that, provided an appropriate structural integrity management process is implemented and maintained, the present "default" level of 5 year inspections for certain categories of structures is unnecessary, and can be extended to 10 years, and longer, without compromising safety.

Inspection Targeting: Through the analysis of the in-service data, the JIP has identified where to target inspections on different categories of platforms, thereby optimizing inspection resources without compromising safety.

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

Flooded Member Detection: The JIP findings support the existing industry position, stated in API RP2A, Section 14, that the appropriate use of FMD, in some cases, provides an acceptable alternative to close-visual examination and may sometimes be preferable.

Guidelines: The JIP has developed guidelines for rational inspection planning consistent with the findings of the JIP. The Guidelines have been benchmarked to a variety of representative platforms in the Gulf of Mexico, and updated as appropriate.

Database: The JIP provides a screened and de-sensitized inspection database containing a large representative sample of Gulf of Mexico platforms supportive of the methodology presented in the developed Guidelines.

Regulations: It is anticipated that the findings of the JIP, which represent the collective input from a wide spectrum of Gulf of Mexico operators, will lead to future changes to both API and ISO codes of practice pertaining to platform integrity management.

FURTHER WORK

Damage Tolerance: Through the examination of in-service inspection data the JIP has been successful in defining categories of platforms with different susceptibilities to damage. The scope, however, did not explicitly address platform damage tolerance. The ability of a structure to tolerate damage will be influenced by its robustness and degree of redundancy. These properties are defined by many parameters of which existing damage is only one. Other important parameters, including number of legs, bracing configuration, grouted legs, vintage etc., are discussed in the Guidelines and their commentary. The benchmarking exercise was also designed to highlight the impact these parameters may have on the inspection strategy and program for a specific platform. Further work is required to investigate the damage tolerance of different platform types and, importantly, to define the level at which damage becomes significant to structural integrity for different platform categories.

Minimum Facilities: The inspection data considered in the JIP was drawn from the cross section of Gulf of Mexico platforms and, as such, was dominated by conventional platform configurations, which are most numerous within the total population. In recent years industry has moved towards less conventional structural forms often collectively referred to as minimum facilities. Further work targeted towards the in-service performance and robustness of these relatively newer facilities is warranted.

1. INTRODUCTION

This document has been prepared by MSL Services Corporation (MSL) and EQE International (EQE) for the Participants of the Joint Industry Project titled, 'Rationalization and Optimization of Underwater Inspection Planning Consistent with API RP2A Section 14'. The wider goal of the project was to provide industry and regulatory authorities with the data/information to collectively implement the Structural Integrity Management (SIM) approach enshrined within API and ISO codes of practice and develop a rational approach to optimized inspection-planning without compromise to safety. To achieve this goal, the project has employed the wealth of inspection data that has been collected by industry over the past decade and beyond and other data complimentary to the SIM process e.g. relating to inspection techniques, in particular FMD, to generate guidelines for the development of rational inspection plans.

The project scope of work was designed, at the outset, to achieve four primary objectives. These objectives are reproduced below from the original proposal.

- To develop a reliable, industry-wide inspection database compiled from the collective inspection data amassed by industry over the last ten years and beyond, particularly the large number of inspections that have been performed in the Gulf of Mexico. A screened and de-sensitized database, limited to damage and correlation of damage to specific platform parameters, will be compiled for distribution to Participants on CD format.

- To create detailed inspection planning guidelines, reflecting the trends observed from the database, and present practices, to permit rational inspection programs to be established consistent with API/ISO recommendations.

- To benchmark and calibrate the guidelines against a representative selection of individual structures and update the guidelines as required.

- To assess, using public domain data, other data made available to the JIP and interviews, the reliability of flooded member detection techniques.

Consistent with the stated objectives of the project, this report has been structured as follows:

Section 2 presents the background to the JIP and includes an overview of the structural integrity management process as defined in ISO draft practice [2].

Section 3 describes the structural integrity management approach, as it was adopted herein and applied to the Gulf of Mexico platform fleet.

Section 4 describes the managed system for the archive and retrieval of inspection data, and other relevant records, which was created under the JIP. The screened and de-sensitized database is a deliverable of the JIP and is provided herewith on compact disk. The system has been populated with a large proportion of the inspection data amassed by industry over the last ten-years and beyond for platforms in the Gulf of Mexico.

Section 5 describes the rigorous screening and interrogation of the inspection data, the trend analyses that were undertaken and the studies carried out to correlate reported damage to platform structural and operational parameters. It was, of course, necessary that the data evaluation extend across the entire fleet of Gulf of Mexico platforms. In order to manage the wide diversity of structures, criteria were established to categorize platforms into 'vintages' reflective of their susceptibility to damage and encompassing a combination of their age and original design criteria. Correlation studies were used to validate the vintage definitions and to identify platform sub-categories within vintages.

Section 6 describes the inspection strategy developed for underwater inspection of Gulf of Mexico platforms. The strategy was based on the results of the evaluation of the underwater inspection data and reflected in the 'In-Service Inspection Guidelines', also presented in Section 6. The Guidelines are consistent with the SIM philosophy outlined within ISO Clause 24. Knowledge from the underwater inspection data evaluation for the Gulf of Mexico fleet is the single most important contributor to the development of the inspection strategy proposed herein, although a number of other important considerations are essential to a successful structural integrity management process as discussed.

Section 7 describes the benchmarking procedures. Inspection programs were developed for six platforms in order to test the robustness of the Guidelines. The platforms were selected to represent a reasonable cross section of platforms in the Gulf of Mexico, both in terms of their structural configuration, their function and their likelihood and consequence of failure. The process of developing the inspection plans represented a benchmarking of not only the guidelines but also the overall SIM approach. An iterative process of benchmarking and updating led to improvements, which are reflected in the Guidelines contained herein. The logic process that went into the inspection programs for each of the structures is discussed and the inspection programs themselves presented to act as go-by examples in the application of the inspection strategy that has been proposed.

Section 8 summarizes common NDE techniques and the applicability to underwater inspection planning. The section focuses specifically on FMD techniques and the reliability of this method and how it can be used as part of the SIM process and inspection planning in general.

2. BACKGROUND

The Survey Section of API RP2A from the fifth through the seventeenth edition remained virtually unchanged. It recommended surveying "… on all major platforms following exposure to severe loading conditions, but at least every five years, unless experience indicates that a longer interval is sufficient." In 1989, API expanded the 'Surveys' section in a major revision to the API RP2A document. The section (now Section 14) included a description of four escalating levels of survey and defined guideline survey intervals.

In Supplement 1 of Section 14 in the 20th Edition of RP2A, API recognizes the safety and cost benefits of rationalizing inspection planning, and says that service history, experience and engineering analyses may be used to assign increased or decreased survey levels. API catalogues eight factors that require consideration in any such evaluation, namely:

(1) original design/assessment criteria

(2) present structural condition

(3) service history

(4) structural redundancy

(5) criticality of platform to other operations

(6) platform location

(7) damage

(8) fatigue sensitivity.

Further, API recommends that the inspection program should be compiled and approved by a qualified engineer familiar with the structural integrity aspects of the platform.

The offshore industry is in the process of creating an ISO Standard for fixed offshore structures. Work Group 3 of ISO Committee TC67/SC7 is charged with creating this standard, using API RP2A as the basis. Clause 24 of the ISO Standard [2] is entitled 'In-service inspection and structural integrity management', and is based on Supplement 1, Section 14 of API RP2A 20th Edition. ISO Clause 24 represents a more descriptive version of API guidance. Both deal with in-service inspection as an integral part of overall structural integrity management (SIM). SIM is an ongoing process to ensure structural integrity and fitness-for-purpose of an offshore platform or group of platforms.

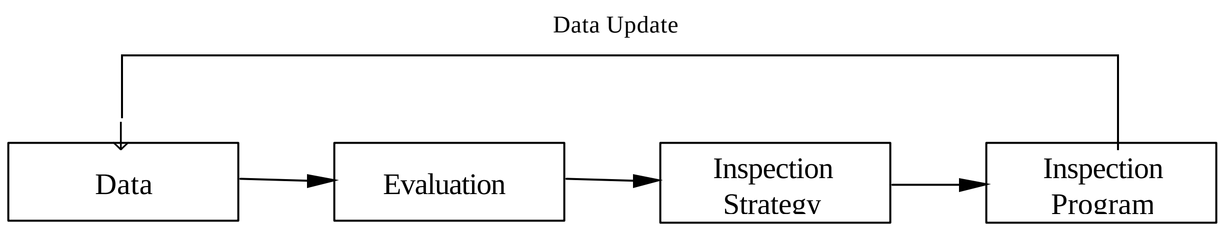
In 1988, the MMS published rules in the Congressional Federal Register, requiring offshore operators to inspect offshore oil and gas platforms, document the findings and report the results on an annual basis. Specified in the regulation (30CFR250.142) is a 5-year time interval between inspections. The industry is now into its 11th year of inspection reporting and has completed two full inspection cycles. The regulation permits the use of an inspection interval that exceeds five years subject to the approval by the regional supervisor. Such extensions are occasionally granted on a case-by-case basis, subject to specific criteria defined in NTL No. 99-G12 effective June 7, 1999.

Observations from platform operating companies and from underwater inspection contractors support the view that routine periodic surveys are not finding damage significant to the structural integrity of platforms. In particular, widespread fatigue damage has not been found and, what damage is identified, is generally isolated to known susceptible details on specific categories of structure. Further, CP systems, generally, have been shown to remain effective through the life of the structure if appropriate operational and maintenance procedures are employed.

These observations are supportive of a new approach to the inspection requirements of existing and future installations and may justify relaxation of inspection intervals for certain categories of structure. In addition, it is feasible that they could lend weight to a move away from the current focus on time dependant phenomena (fatigue and corrosion), which dictate periodic inspection intervals, towards event driven criteria such as hurricanes and incidents of accidental damage.

The structural integrity management (SIM) process provides a means by which these objectives can be achieved. SIM is described as an on-going process for ensuring the fitness-for-purpose of an offshore platform or group of platforms. By establishing, operating and maintaining an appropriate SIM system, platform owners/operators can rationalize and optimize underwater inspections to better focus valuable resources. The process can justify inspection requirements less than the default requirements of Section 14 of API RP2A and inspection intervals greater than currently permitted by regulations in the Gulf of Mexico and elsewhere in the world. In a few instances, for certain types and ages of structures, more severe inspection requirements and shorter intervals may be determined by application of the SIM process

The four phases of the SIM process, as illustrated in ISO Clause 24, are defined in the chart below.



Data	Evaluation	Inspection Strategy	Inspection Program
Managed system for archival and retrieval of inspection data and other pertinent records.	Evaluation of structural integrity and fitness for purpose; development of remedial actions.	Overall inspection philosophy and strategy and criteria for in service inspection.	Detailed work scope for inspection activities and offshore execution to obtain quality data.

- SIM represents a rational approach for ensuring fitness-for-purpose, and links the four primary processes of Data, Evaluation, Inspection Strategy and Inspection Program in a logical and sequential manner.

- The importance of maintaining platform and inspection data is fundamental to the SIM process and highlighted in both API and ISO.

- The Evaluation process may comprise analytical techniques, engineering judgments, simplified analysis, experience or use of experimental data, and encompasses a range of considerations including the eight noted earlier from API plus other factors such as risk assessment (likelihood/consequence of failure), reuse/abandonment planning and service life extension.

- The choice of inspection techniques, frequency and exploitation of similarities among platforms lies within the Inspection Strategy process of SIM. This process deals with inspection and requires appropriate knowledge platform robustness, damage tolerance and application, operation and reliability of suitable inspection techniques.

As illustrated in the figure above, the SIM procedure is an on going process. The system relies on periodic "data update" to ensure the results of new data and engineering assessments find their way into the SIM strategy and are implemented in the inspection program. These tasks rely on the input of suitable qualified engineers familiar with the structural aspects of the platform(s) in question. The importance of this role is highlighted in both API and ISO guidance.

In the absence of an effective structural integrity management system, the default inspection requirements of Section 14, Supplement 1 API RP2A should be followed. Clause 24 of the draft ISO Guidance for Fixed Offshore Platforms also provides a default inspection program (including inspection frequencies) for use in lieu of a managed structural integrity management process. The ISO default inspection program is based closely on that given in the above referenced API guidance, however, more detail is provided for the scope of work for each level of inspection.

3. STRUCTURAL INTEGRITY MANAGEMENT

3.1 An Overview

An overview the structural integrity management process was provided in Section 2, which discusses the background to this Joint Industry Project. By establishing, operating and maintaining an appropriate structural integrity management system, platform owners/operators can rationalize and optimize underwater inspection to better focus valuable resources. The process of structural integrity management was defined in Section 2, in four phases, as illustrated in Figure 3.1.

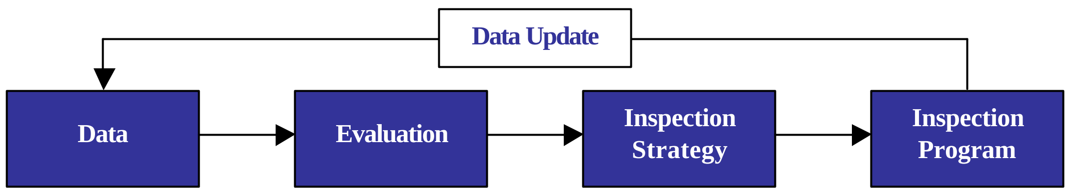


Figure 3.1: The Structural Integrity Management Process

The goal of the present JIP was to provide industry participants and regulatory authorities with the data/information to collectively implement a SIM process for the Gulf of Mexico. This section identifies each stage of the process and describes how it was interpreted and applied herein to develop the methodology, reflected within the inspection Guidelines, which allow the goal to be achieved.

3.2 Data

The existence of an up-to-date database of platform information is a pre-requisite to the SIM process. Information on the original design/assessment or fabrication/installation, including results of numerical analyses and in-service inspections, all constitute part of the data management system. The importance of maintaining and updating a data management system cannot be over-stated. The engineering evaluation is only as accurate as the data used. Missing or incomplete data will force the use of conservative or inaccurate assumptions. The commentary to ISO Clause 24 cites the following example of when a dent location is not correctly measured, it states…

'In this case, the engineer is forced to assume the dent is located where it will cause the highest strength reduction. In some instances, this error could… erroneously trigger a more detailed assessment…'

Section 4 of this report describes the managed system for the archive and retrieval of inspection data, and other relevant records, which was created for the JIP. The screened and de-sensitized database is a deliverable of the JIP and is provided herewith on compact disk.

3.3 Evaluation

Data evaluation is an ongoing function within the SIM process. Evaluation requires consideration of factors, which might affect the platform's integrity, safety or corrosion protection, and can include:

a) Robustness and Damage tolerance e.g.
   - Vintage (encompasses age and original design criteria)
   - Configuration of primary brace framing
   - Number of legs
   - Joint details
   - Skirt piles versus leg piles versus grouted leg piles

b) Present condition

c) Deck elevation

d) Water depth

e) Damage susceptibility

f) Similarities among platforms

Section 5 describes the rigorous data evaluation including screening and interrogation of platform and inspection data and subsequent trend analyses to correlate reported damage to platform structural and operational parameters.

3.4 Inspection Strategy

An inspection strategy provides the basis for defining the detailed inspection scope of work and frequency of inspection. The development of the inspection strategy is primarily influenced by the data evaluation within the SIM cycle, although it is also necessary to give consideration to:

- Motivation for inspection: Regulatory requirements, operator requirements, platform reuse, decommissioning, platform failure consequence and incident planning.
- Availability of inspection techniques: Application and reliability.
- Scheduling flexibility.

Section 6 describes the inspection strategy developed for the in-service inspection of Gulf of Mexico platforms including the determination of appropriate inspection intervals. The strategy is built around the evaluation of underwater inspection data for the Gulf of Mexico fleet with due consideration of likelihood and consequence of platform failure and present condition.

3.5 Inspection Program

The inspection program is the detailed scope of work that defines the full extent of the inspection activities to be carried out. Operator or regulatory requirements may enforce supplementary documents such as survey specifications and/or personnel qualification requirements and certification. The inspection program is developed from the inspection Guidelines, which in turn reflect the overall inspection strategy. Application of the guidelines results in an inspection program specific to each platform but with general consistency among families of platforms. In all cases, a suitably qualified engineer should develop the inspection program. The engineer should be familiar with the overall SIM process in operation and with the structural integrity issues pertaining to the platform(s) in question.

4. DATABASE

4.1 Introduction

The database that was developed contains platform, inspection and anomaly data for over 2,000 Gulf of Mexico platforms, drawn from the fleets of 12 major operators in water depths ranging from less than 20ft to over 2000ft. Details of approximately 3,000 underwater inspections are catalogued and almost 5,000 detected anomalies are recorded. Information has been drawn from the databases of the MMS, from the internal records of JIP Participants and non-participant operators, and from a number of third party inspection contractors.

This report describes the content and the structure of the database. It is intended to assist users in its application to the analysis of platform inspection and damage trends in the Gulf of Mexico. In particular, the document covers the source of the data, the structure of the database and the features available for data analysis.

4.2 Source Data

Platform and inspection data contained in the database has been drawn from a number of sources as defined hereunder.

United States Minerals Management Service

The JIP database contains information from five separate MMS databases. These databases cover all platforms ever installed in the Gulf of Mexico Offshore Continental Shelf (OCS). The MMS data is divided into five specific tables as follows:

1. Offshore Complex Data
2. Platform Structural Data
3. Platform Location Data
4. Platform Removal Data
5. Platform Reported Damage Data

Participants to the JIP

Participants to the joint industry project have each provided their own platform and inspection data. In some instances the data has been made available in electronic format, in particular, where the operator has used the CAIRS database. In all such instances, additional data have been manually collated to supplement the electronic data with information important to the process of structural integrity management of offshore facilities. In other cases, Participant data has been collected manually from hard-copy reports and in-house systems. Industry Participants were as follows:

- BP Amoco

- Chevron
- Devon Energy
- ExxonMobil
- Marathon
- Ocean Energy
- Texaco

Other Gulf of Mexico Platform Operators

A number of operators, not presently participating in the JIP, have kindly donated their inspection data for inclusion in the database. These operators include Conoco, Seneca, Spirit Energy and Vastar Resources.

4.3 Software

Microsoft (MS) Access was selected as the software platform for the development of the JIP Database. Access was chosen for a number of reasons, as follows:

i) MS Access resides within the MS Office Professional Edition program suite, which is widely used within the industry and ensures effective integration with other Windows based applications, in particular Microsoft applications.

ii) MS Access has efficient import and export facilities for data transfer to and from many other database formats as well as standard spreadsheet and ASCII files. This facility greatly assists the population of the database from the diverse formats of the source-data.

iii) The database consists of a series of related data tables. MS Access has in-built facilities to permit rapid comparison of data in different tables to help data screening and to avoid duplication.

iv) MS Access has powerful integrated data query functions to assist with user-friendly population categorization and trend analysis.

v) MS Access allows the final database to be delivered as a stand-alone Windows application, which ensures a user-friendly product.

4.4 Database Structure

Platform and inspection information is stored in the database in more than twenty separate data-tables. The data-tables are relationally linked to one another in a hierarchical structure. The contents of each of the data-tables are described below. The relationships, which have been created to link the tables, are illustrated in Figure 4.1.

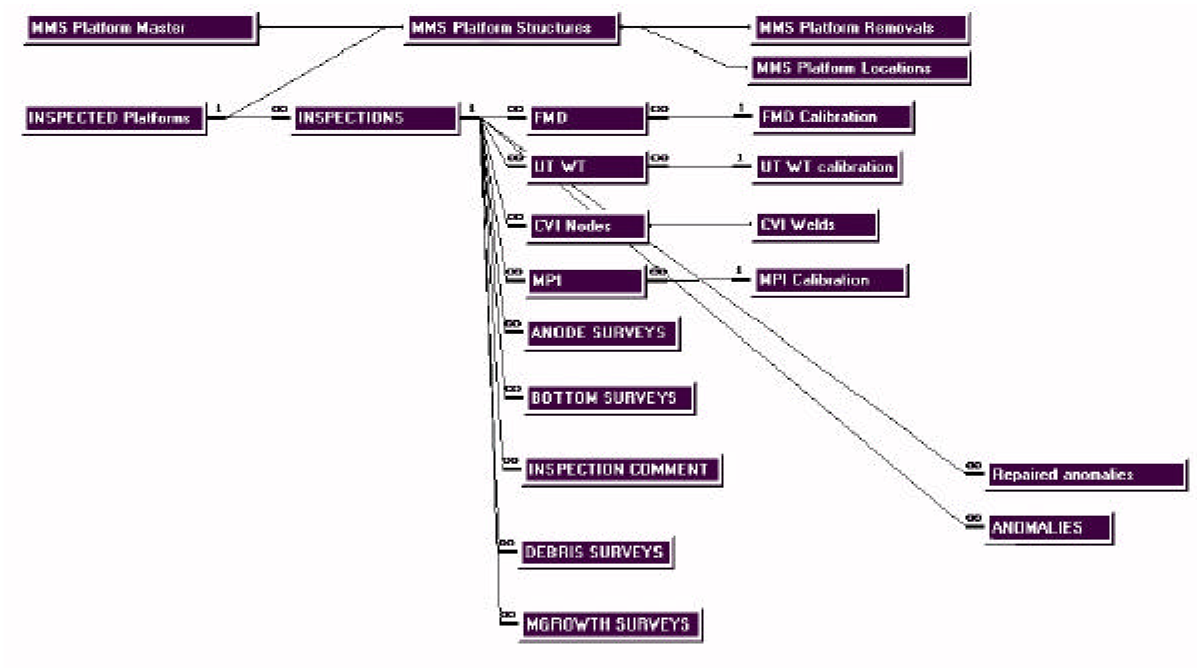


Figure 4.1: Relational Dependence of Data-Tables

In addition to the data-tables, the database includes a number of other objects. These include queries and HTML Pages. Queries are used to cross-reference and interrogate data from any combination of data-tables. The results are presented in a new query-table. This offers the advantage that if the source data in a specific data-table is modified then the query automatically updates. HTML Pages are used to analyze data either in data-tables or in queries or any combination thereof. Pivot tables are typically to facilitate the analysis. The data from the pivot table/s can be presented graphically and the Pages permit user interaction for investigation of what-if scenarios without affecting the source data, as illustrated in Figure 4.2.

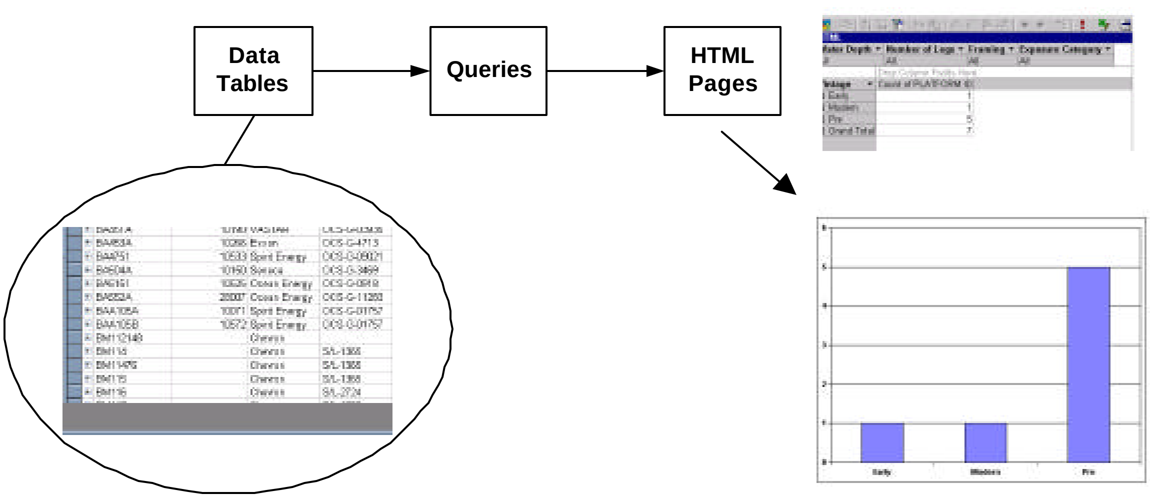


Figure 4.2: Database Configuration

4.4.1 Platform Data

The platform data-table contains fields for the inclusion platform data relevant to its structural integrity management. The data-table includes platform identification details, structural details and selected operational data. The platform data-table includes referential links to five MMS databases, which contain information relating to the complex, the structure, the location, the removal status and reported damage of all Gulf of Mexico OCS installations. In the development of the database and the establishment of the links, each platform was given a unique identifier, consistent with that used in the MMS databases, essentially a concatenation of the complex ID number and the structure number. Also provided was a name formed from the Area, Block and Platform number; the identification commonly used by operators. The platform identification details and all other details that identify specific platforms have been removed in the delivered database, to fully de-sensitize the data.

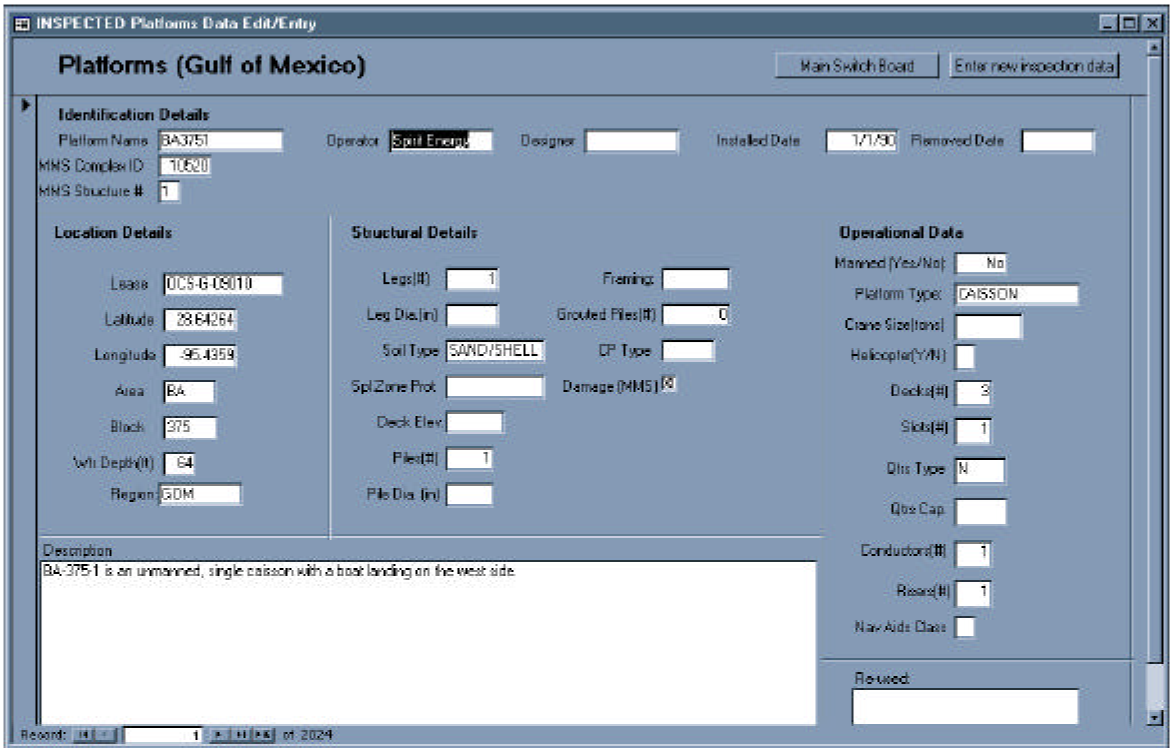


Figure 4.3: Platform Data

4.4.2 Inspection Data

For the purposes of this document and the subject database the term 'inspection' is used to describe the visit to the platform for purposes of collecting data important to the structural integrity and continued operation of the platform. The term 'survey' is used to describe the numerous specific activities and/or non-destructive tests, which collectively make up the complete inspection. Which surveys are carried out during a particular inspection depends on the purpose of the inspection, the level to which it is conducted and the judgment of a qualified engineer familiar with the structural integrity aspects of the platform.

The inspection data-table contains fields for the inclusion of information necessary to describe each platform inspection. General information includes the contractor, vessel and inspector details, the type, API level and the duration of the inspection, the surveys carried out and a summary of the results of each survey. Once again, fields containing platform identification information or other sensitive data have been removed from the delivered database.

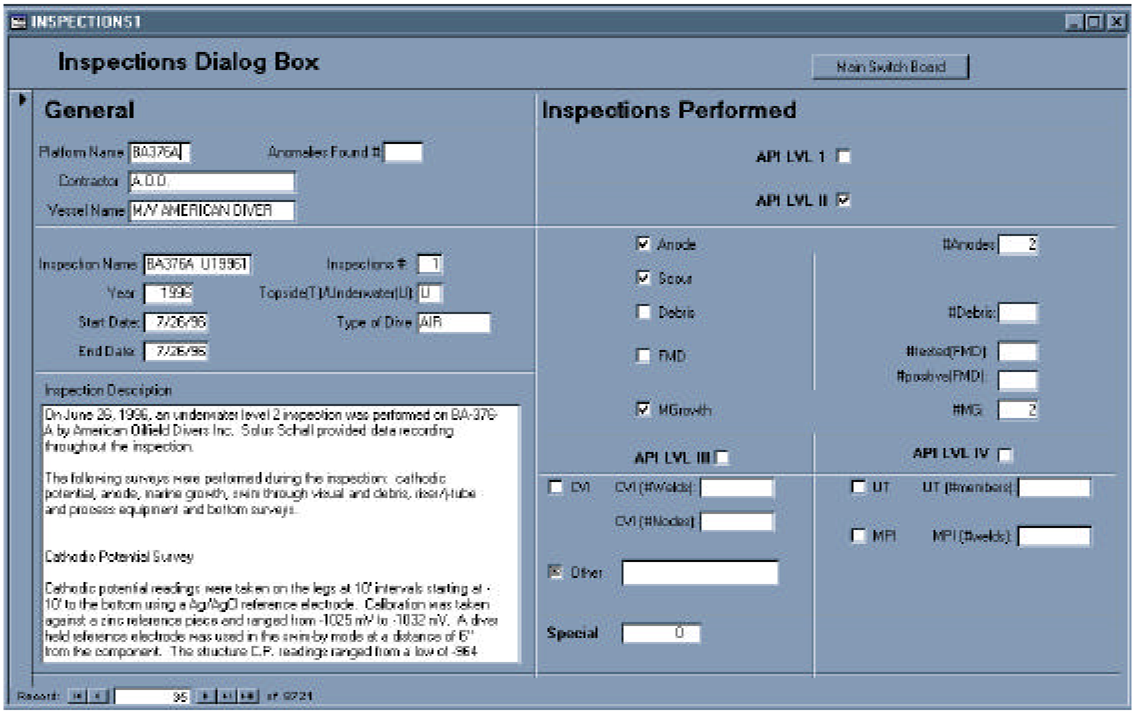


Figure 4.4: Inspection Data

4.4.3 Survey and Anomaly Data

In the Gulf of Mexico, a number of underwater surveys are carried out during routine platform inspections. The API Level for a typical inspection of a Gulf of Mexico platform is often unclear as most inspections are labeled as combinations of Levels. This issue is addressed in the following Sections of the report, where alternative inspection Guidelines are presented. The JIP database contains separate data-tables for each of the underwater surveys in addition to anomaly tables, which identify defects and anomalies detected during each survey. The surveys included are as follows:

- Anode survey
- Scour survey
- Close visual (CV) survey

- Debris survey
- Flooded member detection survey (FMD)
- Marine growth survey
- Weld survey using magnetic testing (MT)
- Ultrasonic wall thickness survey (WT-UT)

5. DAMAGE TREND ANALYSIS

5.1 Introduction

This section presents the findings of an investigation of platform defects and anomalies recorded during 3,021 underwater inspections of 2,024 platforms in the Gulf of Mexico.

The objectives of the investigation were to seek answers to a number of fundamental questions relevant to the structural integrity management of offshore platforms; answers substantiated with data recorded by industry over the last 10-years and beyond.

1. What defects are we finding on platforms in the Gulf of Mexico?
2. Where are these defects occurring? What components are affected?
3. What are the causes of the defects?
4. Which platforms are susceptible to defects and why?

Section 5.2 of this report defines various defect types and survey anomalies reported in the JIP database. Four types of defect are identified including mechanical damage defects, weld/joint defects, corrosion defects and appurtenance defects. The latter are not relevant to the structural integrity of platforms and, therefore, are not considered herein. The other three, however, are each considered in detail in Section 5.3, Section 5.4 and Section 5.5, respectively. Survey anomalies, in particular, marine growth, scour and debris anomalies, are the subject of Section 5.6. The findings of the various investigations are brought together in Section 5.7, which presents the conclusions of the damage trend analyses.

5.2 Platform Defects and Anomalies

5.2.1 Definitions

A distinction is made herein between a defect and a recorded anomaly. For the purposes of this report, a defect is defined as an imperfection, fault, flaw or blemish in a component of the platform, which falls into one of the categories defined herein.

A number of surveys carried out during platform underwater inspections, however, may result in anomalous readings but not defects. These include marine growth-surveys, scour-surveys and debris-surveys. Consistent with the wording of API RP2A, these surveys are routinely carried out during Level II inspections and large amounts of data have been collected. The definition of anomalous readings, however, is subjective, depending, at best, on the guidelines defined by the inspection-planning engineer familiar with the structural integrity aspects of the platform, and, in lieu of such guidance, on the interpretation of the diver or data-recording technician. In practice, despite the large amount of readings anomalies often go unreported. Anomaly trends (marine-growth, scour and debris) are considered in Section 5.6.

5.2.2 Defect Categories

To facilitate the investigation of trends in the data, platform defects have been grouped into categories, including mechanical damage, corrosion and weld defects. A fourth category, appurtenance defects, is included for defects associated with non-structural elements. This type of categorization is consistent with that commonly used for offshore pipeline (and riser) defect categorization and assessment. A number of specific defect types can be identified within each main category as listed in Table 5.1. Definitions of the sub-categories within each of the main categories are given in the following sections, which consider each defect type in more detail.

Mechanical Damage	**Corrosion**	**Weld/Joint Defects**	**Appurtenance Defects**
Dents	Uniform (general)	Crack indications	Anodes
Bows	Pitting	Fabrication defects	Risers/Conductors
Gouge (incl. thru wall holes)	Holes	Overload	Boat landing
Separated Members	Crevice		Intake caissons
	Fretting		Other

Table 5.1: Platform Defect Categories

Figure 5.1 shows the distribution of reported defects by category. The figure shows that the majority of defects relate to mechanical damage. Excluding defects associated with non-structural components, mechanical damage (dents, bows and gouges) accounts for approximately two-thirds of reported platform defects in the Gulf of Mexico.

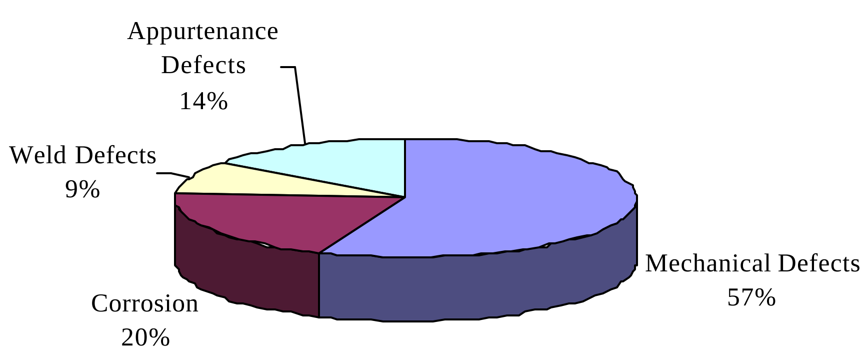


Figure 5.1: Reported Defects by Category

5.3 Mechanical Damage

5.3.1 Defect Types

As indicated in Figure 5.1, 57% of reported defects in the JIP database relate to mechanical damage. Mechanical damage includes a number of defect types, as follows:

***Dent*:** A dent is defined as a visible disturbance in the curvature of the wall of a tubular member without reducing the wall thickness.

***Bow*:** A bow is defined as a visible permanent deviation of the original (unbowed) longitudinal axis of a structural element.

***Gouge*:** A gouge is defined as a visible surface imperfection caused by mechanical removal or displacement of metal that reduces the wall thickness. Included in gouge defects are incidences where elements (e.g. anodes or stand-offs) have been torn off a member resulting in a through thickness gouge, or tear.

***Separated Members*:** A separated member is defined as a member that has been fully severed from the structure at one or both ends.

5.3.2 Collateral Damage

A single incidence of mechanical damage may result in a combination of defect types. Typically, the source data used in the compilation of the JIP database reports multiple defects individually, even if they result from a single incident. Alternatively, the source data may mention associated damage only within comment fields, without quantification, making assessment difficult without further inspection. These types of data recording distort the perception of the amount of damage occurring. This has been overcome, where possible, by careful screening of reported instances of mechanical damage. The method used was to identify a 'primary' defect for each event and to define associated defects as collateral damage. For consistency, a defect hierarchy (dent - bow - gouge - other) has been used. For example, if a dent is present, any associated damage is defined as collateral damage, if a bow is present without a dent, then the bow becomes the primary defect and associated damage is defined as collateral damage, and so on.

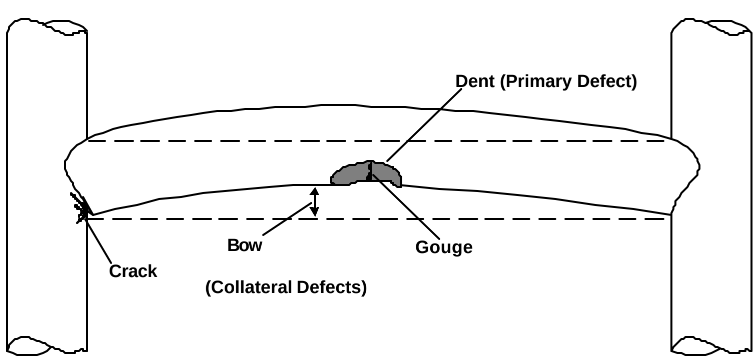


Figure 5.2: Primary and Collateral Damage

5.3.3 Extent and Severity

The JIP database contains information on 2,308 primary mechanical damage defects. Screening of the data has been carried to: -

i) Remove instances of the same defect being reported in multiple inspections.

ii) Identify collateral damage distinct from primary damage.

A summary of mechanical damage defects is presented in Table 5.2.

Defect Type	Occurrence as primary defect	Occurrence as collateral damage
Dents	2017	-
Bows	165	86
Gouges	80	0
Separated Members	46	8

Table 5.2: Summary of Mechanical Damage Defects

Mechanical damage defects are most commonly found during general visual (GV) surveys carried out as part of Level II inspections. To put the absolute defect numbers presented in Table 5.2 into a clearer context, it is helpful to identify the number of platforms found to contain mechanical damage (one or more dents, bows or gouges) as a ratio of the number of GV surveys carried out. Figure 5.3 shows that of 1,436 platforms, for which one or more GV surveys were performed, 29% were found to contain mechanical damage defects.

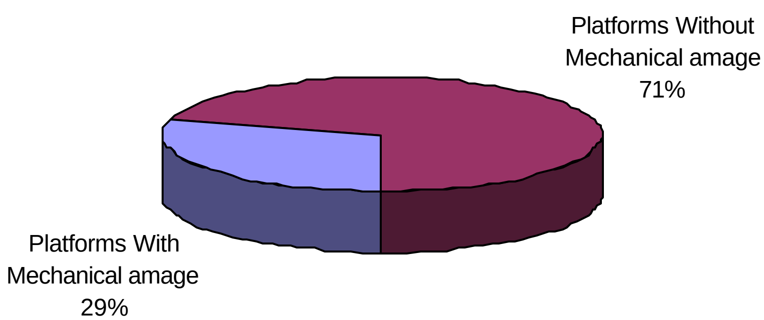


Figure 5.3: Extent of Mechanical Damage

The dominant type of mechanical damage defect is member denting, as shown in Table 5.2. The significance of dents to the structural integrity of the member may be estimated from whether the member was subsequently repaired, unfortunately very little of the source data includes repair information. As an alternative, we have adopted approximate criteria to classify a dent as either major or minor. The method, which gives a relative indication of dent severity is not intended to replace rational assessment.

Major Dent: Dent depth greater than 30% of the nominal member diameter and/or 10 times the nominal wall thickness.

Minor Dent: Dent depth less than 30% of the nominal member diameter and/or 10 times the nominal wall thickness.

For 785 (39%) of the 2,017 dents in the database there is insufficient information to determine whether the dent is major or minor, even using the simple criteria shown above. Of the remaining 1,232 dents, 10% are classed as major dents and 90% as minor dents. Figure 5.4 illustrates the dent severity classification on the population of inspected platforms.

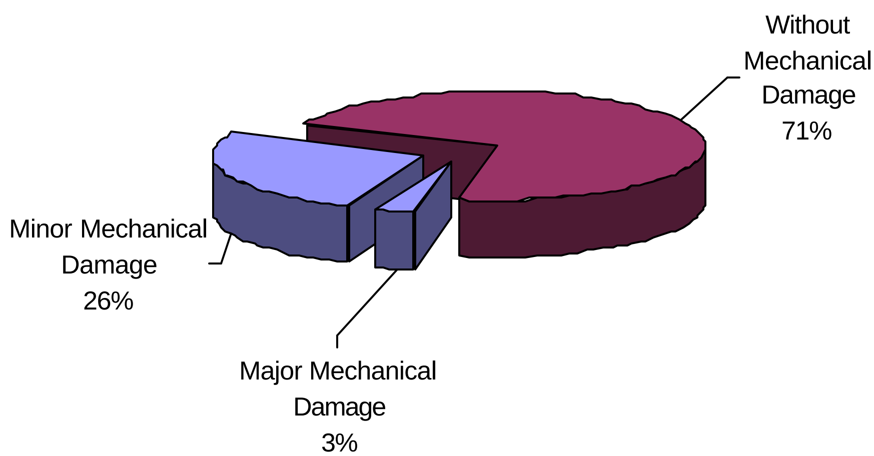


Figure 5.4: Extent and Severity of Mechanical Damage

5.3.4 Causes

Identifying causes of mechanical damage is important to the process of trend analysis, in particular, in the identification of platform parameters that increase the susceptibility to mechanical damage. For example, the presence of skirt piles may increase the likelihood of installation damage, or a drilling facility may be more susceptible to impact damage than a wellhead facility. Information relating to cause is typically absent from the source data and, in lieu of explicit information, we have relied on a variety of clues to establish the cause of mechanical damage, as follows:

***Installation Damage*:**

- Mechanical damage consistent with installation events recorded in the comment field in the database.
- Mechanical damage consistent with piling or other installation operations.

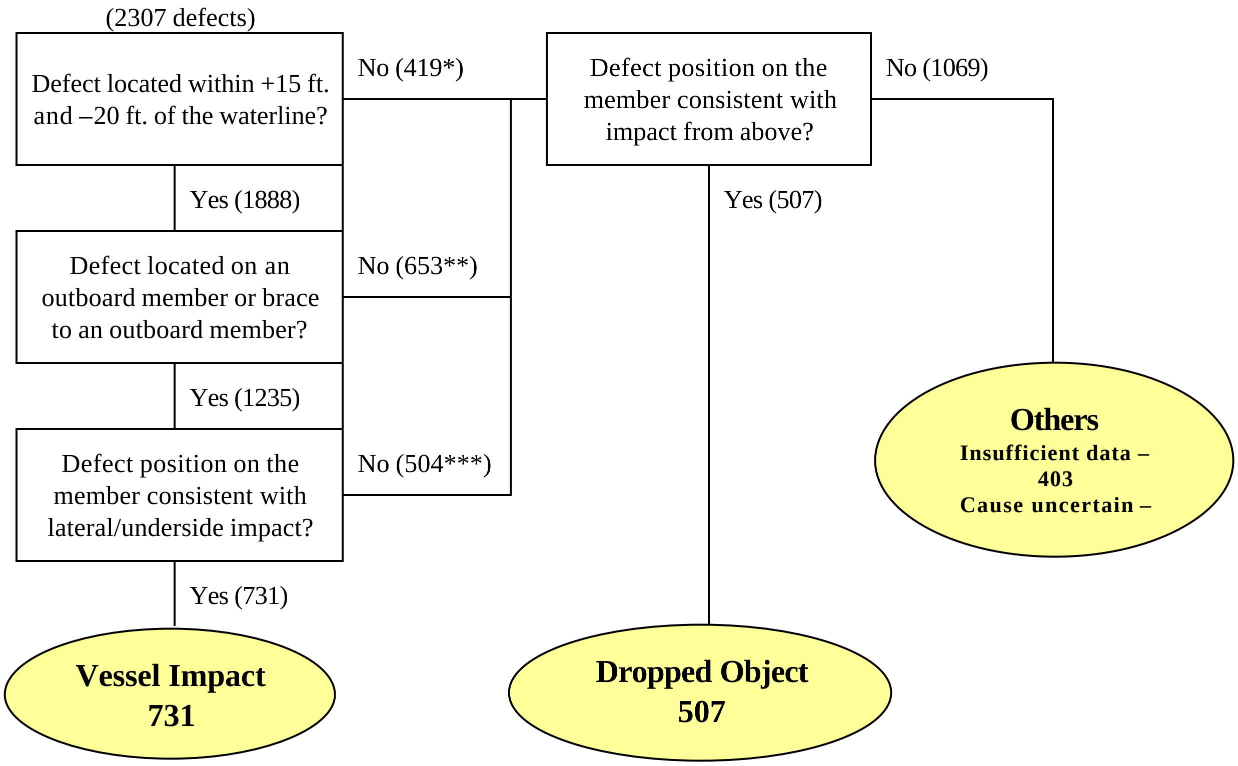
***Dropped Object*:**

- Mechanical damage where dropped object impact is cited as the cause in the comment field.
- Mechanical damage on the upper facing surface of the member (or consistent with impact from above).

***Vessel Impact*:**

- Mechanical damage where vessel impact is cited as the cause in the comment field.
- Mechanical damage to splash zone members and located on the outboard face of the member (or consistent with lateral/underside impact).

The criteria given above are not intended to be absolute; rather, they are intended to isolate the cause of a sufficient number of defects to provide information on the relative importance of each of the possible causes of mechanical damage. The process of applying the criteria to the mechanical damage defects in the database is illustrated in the flow chart, Figure 5.5. The defects falling into the "other" category were either assigned as installation defects if identified as such in the comment fields in the database or else they were categorized as "cause unknown".



*No depth information for 5 of these 419 defects
**No defect location information for 95 of these 653 defects
***Dent defect position unknown for 303 of these 504 defects

Figure 5.5: Flow Chart to Determine Cause of Mechanical Damage Defects

It was not possible to reliably isolate the cause for approximately 50% of the total mechanical damage data. This was due to incomplete defect recording in the source data. The guidelines being generated will endeavor to address the issues of data recording and reporting on a survey-by-survey basis to ensure the suitability and completeness of data for engineering assessment and trend analysis. Nevertheless, due to the quantity of the source data we were able to identify significant populations of data associated with both vessel impact and with dropped object damage as shown in Figure 5.5.

The results of the investigation into the most probable cause of mechanical damage defects are shown in Figure 5.6. The figure indicates that, of the defects for which cause could be reliably estimated, approximately 53% were by vessel impact and 47% by impact from dropped objects. None of the defects could be reliably attributed to installation damage. Of the 666 defects for which cause could not be reliably determined, a large number were suspected to be vessel impact damage due to their location in the splash zone, however, because other data was incomplete the defects did not meet the filter requirements, illustrated in Figure 5.5, and were screened out of the trend analyses.

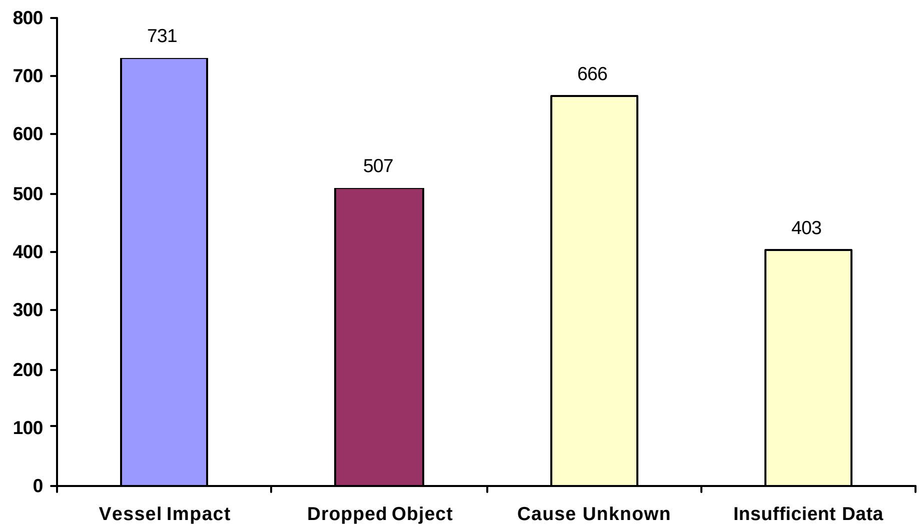


Figure 5.6: Causes of Mechanical Damage Defects

Figure 5.7 provides an indication of the severity of the mechanical damage defects resulting from vessel impact and from dropped object impact. Member denting is the dominant form of damage in both cases. The figure shows that only 3%-5% of dents are classified as being of major structural significance. The method of classification applied is that discussed above.

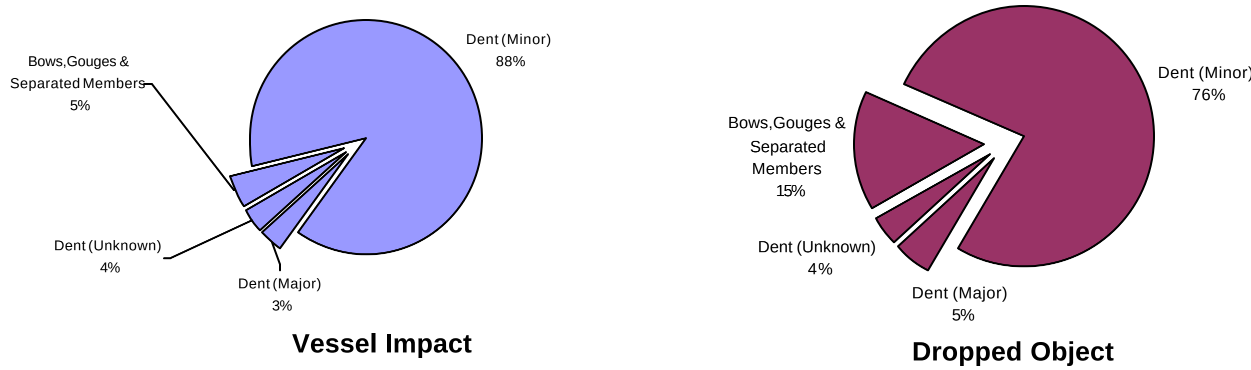


Figure 5.7: Severity of Mechanical Damage Defects

5.3.5 Platform Susceptibility

Based on analyses of the data, presented above, subsets of the inspected platform population were identified; one for platforms that suffered vessel impact and another for platforms that suffered dropped object damage. These two events are jointly responsible for the majority of reported mechanical damage defects in the Gulf of Mexico. The numbers of defects and damaged platforms within the two screened subsets of the full data population are shown in Table 5.3.

Cause of Damage	Number of Defects	Number of Platforms
Vessel Impact	731	248
Dropped Object	507	210

Table 5.3: Platform Subsets for Mechanical Damage

Figure 5.8 shows the intersection of the platform subsets. It can be seen that a significant proportion of the platforms with damage of one cause also have damage from the other. This fact is related to the fact that the type/function of the platform influences its susceptibility to mechanical damage from both vessel impact and dropped objects. This is explored more fully in the following section.

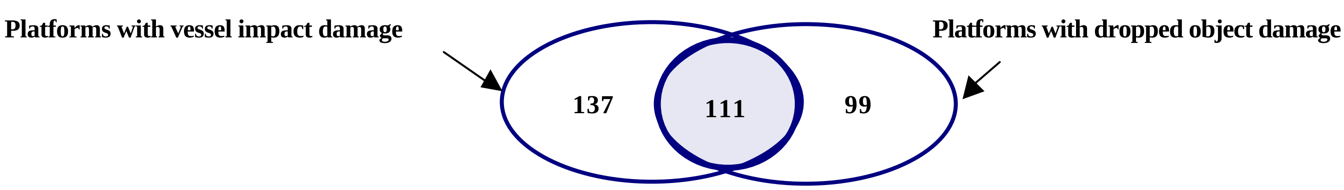


Figure 5.8: Platform Subsets with Mechanical Damage

Platform Type

The platforms in the database are divided by their operational function into a number of types. The occurrence of dropped object damage among platforms of different types is illustrated in Figure 5.9. The vertical scale is a ratio of platforms found with dropped object damage to the number of API Level II inspections carried out on platforms of that type (expressed as a percentage). Figure 5.10 shows the same distribution but for vessel impact damage. Figure 5.9 shows that mechanical damage from dropped objects was found in more than half of all inspections of drilling/production platforms. In contrast, the occurrence of dropped object damage to caisson type platforms is extremely rare.

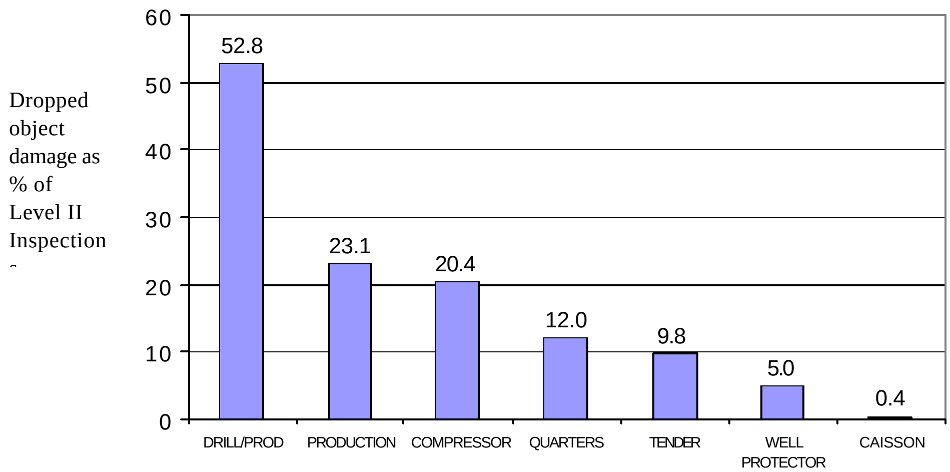


Figure 5.9: Dropped Object Damage by Platform Type

Figure 5.10 shows the correlation between platform type and occurrence of mechanical damage from vessel impact. A similar pattern is evident to that for dropped object damage. Vessel impact damage is found in two-thirds of all inspections of drilling/production platforms whilst its occurrence on caisson type platforms is rare.

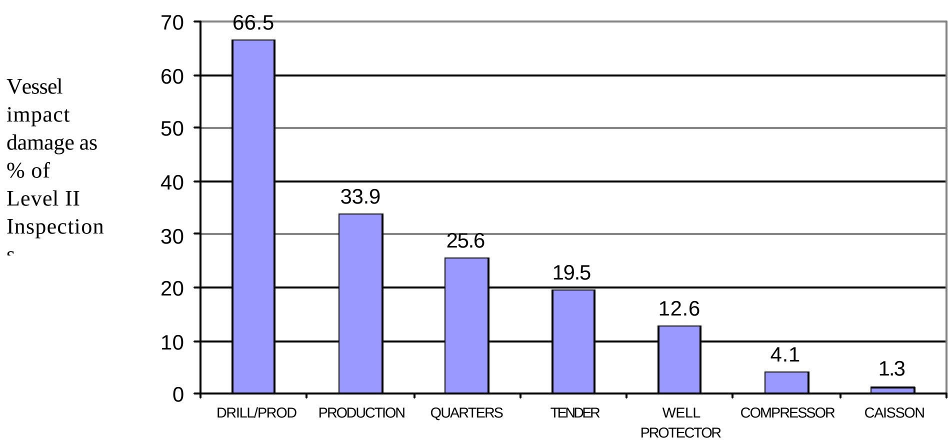


Figure 5.10: Vessel Impact Damage by Platform Type

Location

The influence of the platform location on the likelihood of vessel impact damage was explored. The black circles in Figure 5.11 show the location of platforms in the database that have received at least one API Level II underwater inspection. The red triangles show platforms that have suffered mechanical damage from vessel impact. The figure shows no clear pattern indicating correlation with shipping routes, indicating that platform supply and service vessels are likely responsible for the majority of impacts. This is supported by the fact that most damage is of minor structural significance, consistent with low vessel mass and/or velocity during impact.

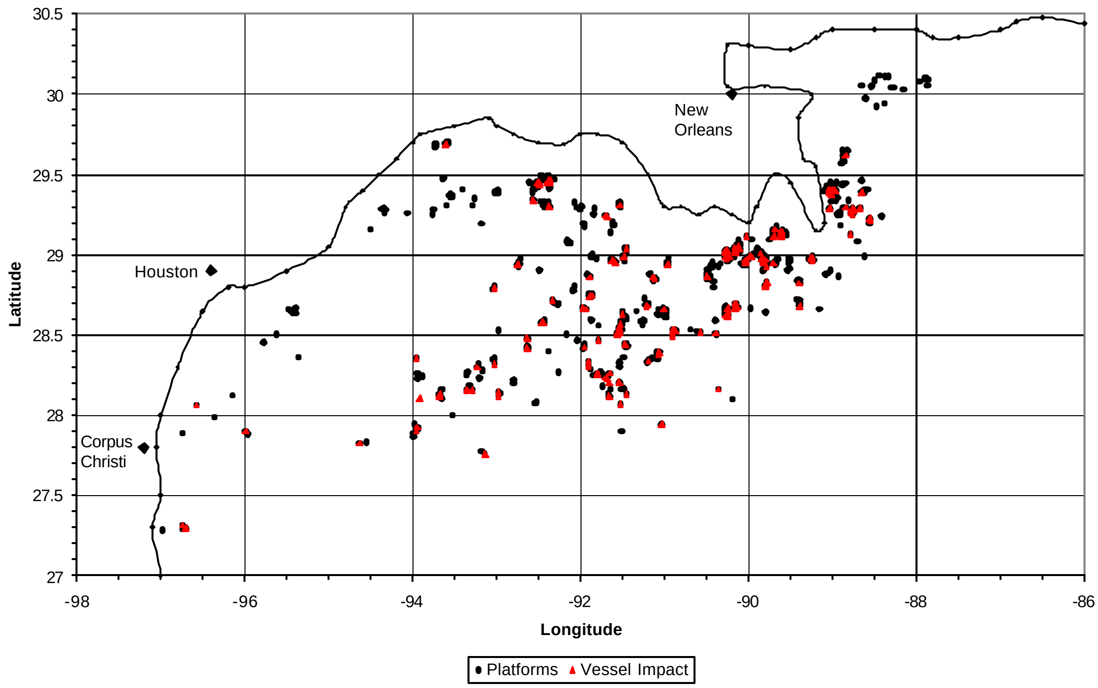


Figure 5.11: Platform Location and Vessel Impact Damage

5.4 <u>Weld/Joint Defects</u>

5.4.1 <u>Defect Types</u>

Weld/joint defects are responsible for 9% of reported defects in the JIP database as illustrated in Figure 5.1. Weld/joint defects may be broadly categorized into a number of specific defect types, as follows: -

***Crack Indications*:** A crack indication is a linear discontinuity in a weld or in the parent material of the member/s framing into the joint.

***Fabrication Defects*:** A fabrication defect is a flaw or imperfection in the weld originating from the fabrication process. For the purposes of this report, fabrication defects include omitted or incomplete welds.

***Overload*:** An overload defect in a joint is a permanent distortion of the cross-section of the chord wall and/or of one or more of the braces framing into the joint.

It should be noted that joint overload sometimes results in the development of crack indications. Consistent with the approach adopted for mechanical damage, such crack indications, where they are identifiable, have been classified as collateral defects to the primary overload defect.

5.4.2 Platform Vintage Definitions

At the outset of the JIP an attempt was made to define platform categories, within the Gulf of Mexico, to assist with the identification of different platform susceptibilities to various types of damage. This initial categorization of the platform fleet into 'vintages' was based largely upon the prevalent design practice at the time of installation. The validity of the initial vintage categories was tested by close examination of reported damage within and across platform vintages and the vintage classification adjusted to accord with the recorded platform damage. Three vintages were identified, as illustrated in Figure 5.13. The basis for their selection is discussed below

Figure 5.12 shows the population of platforms with weld/joint defects categorized by installed decade. The figure shows a marked drop in the occurrence of weld/joint defects in the last two decades.

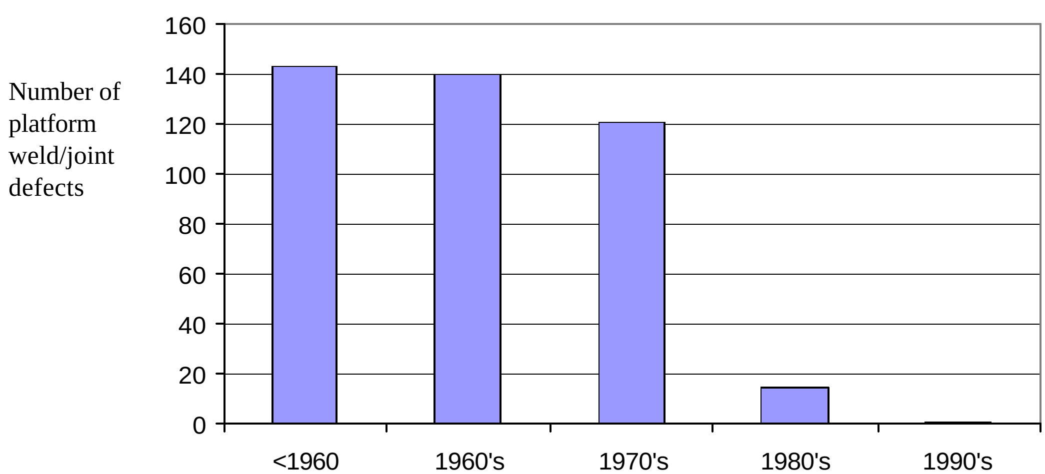


Figure 5.12: Weld/Joint Defects by Decade

Table 5.4 summarizes all weld/joint crack-indication defects reported on platforms installed in the 1980s and 1990s. It is noteworthy that the database contains only a single weld/joint defect on a platform installed in the 1990s; unfortunately, the details of the defect are wholly incomplete in the source data.

Platform ID	# Defects	# Legs	Water Depth	Year Installed	Inspection Date		Description & Cause
					Latest	Previous	
1	1	6	750 ft	1986	1998	1993	Inter-bead crack in weld @ -600 ft, installation damage
2	3	8	50 ft	1984	1993	1992	External stiffener rings @ +6 ft (design?)
3	2	4	219 ft	1985	1997	1995	HD to CG & CG @ +10 ft (installation damage?)
4*	1*	8	165 ft	1981	1999	1993	Separated gusset plate @ -73 ft (design?)
5*	7*	4	143 ft	1981	1994 (?)	1992 (?)	Pile-leg weld failure (3) CGF @ -37 ft (4)
6	1	1	61 ft	1989	1995	1990	Tower leg to base (caisson) weld @ +15 ft
7	1	4	43 ft	1990	1991	-	Details of crack unknown

*These platforms fall outside the eventual JIP definition of modern-RP2A vintage platforms

Table 5.4: Details of Joint/Weld Defects on Platforms Installed in the 80s and 90s

Modern-RP2A Vintage Platforms

The data presented in Figure 5.12 and Table 5.4 is supportive of the industry perception that a division exists within the platform population between modern-RP2A vintage platforms and earlier platforms. The modern era is commonly associated with the ninth edition of API RP2A, which was released in 1978. Platforms designed to the ninth, or more recent, editions of RP2A would be expected to be less susceptible to joint/weld crack-indication defects, in particular, crack indications around the conductor-guides at the first horizontal bay below the waterline. Table 5.4 shows, however, that one of the platforms installed in the 1980s contains defects more commonly associated with earlier vintage platforms. That platform was installed in 1981. Since there is a time lag between the release of a new edition of the code and its adoption for new designs, modern-RP2A vintage platforms have been defined herein as platforms installed after December 31, 1981, i.e. from 1982 onwards.

Early-RP2A Vintage Platforms

The first edition of API RP2A was released in 1969. Prior to that time, platforms were designed with Company or Contractor specific design criteria with little recognized guidance for the design of joints. Assuming (consistent with modern vintage platform) a time lag of three years for the adoption of the code for new designs, we have defined herein a vintage of platforms installed between 1972 and 1981, inclusive. The term 'early-RP2A vintage' has been used for this group of platforms.

Pre-RP2A Vintage Platforms

The first platform was installed in the Gulf of Mexico in 1948 in shallow water offshore Louisiana. The original design practice used multiple steel or wooden piles to support the topsides facilities. These designs were gradually replaced over the next few years with more conventional steel template jackets. In the absence of a recognized code of practice, Company or Contractor specific design criteria were used. One important area of inconsistency was in the selection of the design wave height. Return periods for the extreme wave varied from 25-years to 100-years. It is possible therefore, that the population of pre-RP2A vintage platforms are further divided by those with adequate deck elevation (by modern design criteria) and those without. Pre-RP2A platforms are defined herein as platforms installed between 1948 and 1971 i.e. prior to 1972. The influence of deck height and other potential subdivisions of the platforms, including water depth and extent of corrosion, within pre-RP2A and early-RP2A vintages is further explored and discussed in subsequent sections, below.

Figure 5.13 illustrates the vintage definition in the context of the occurrence of major Gulf of Mexico hurricanes and significant changes in design practice and industry standards.

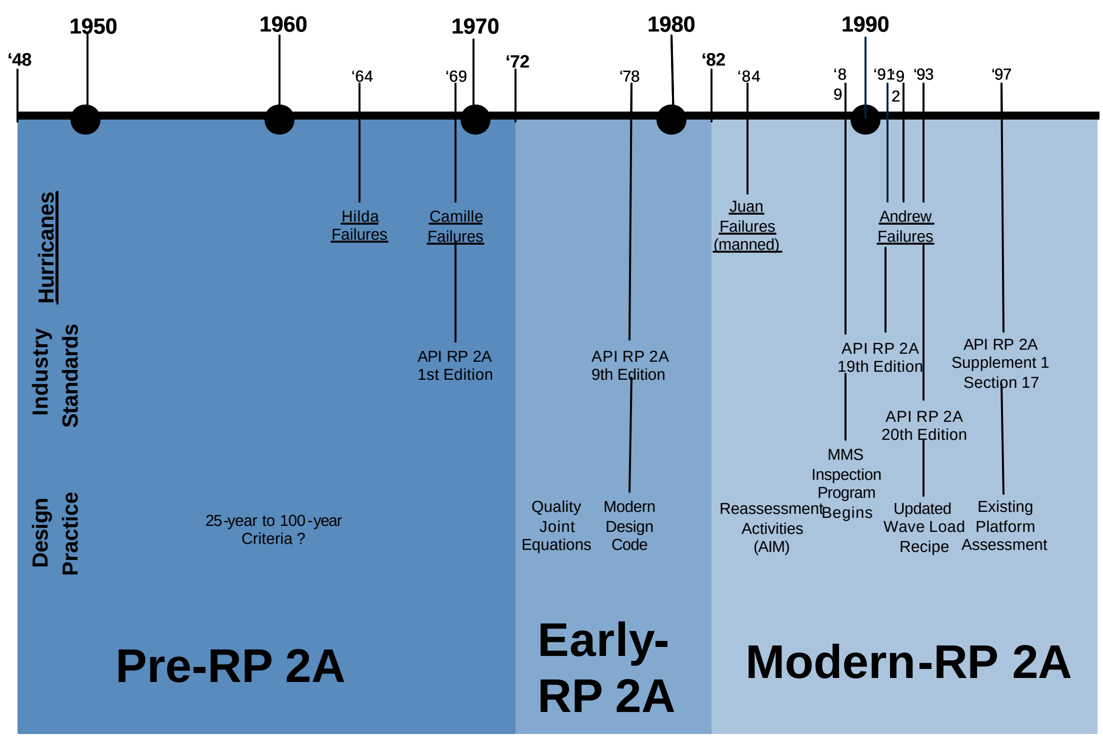


Figure 5.13: Gulf of Mexico Platform Vintage Definitions

Figure 5.14 shows the proportional distribution of the database platform population by vintage. The figure shows the JIP database contains a sizable population of platforms for each of the three vintages. The numbers and levels of underwater inspections contained in the database for each vintage of platform are shown in Table 5.5.

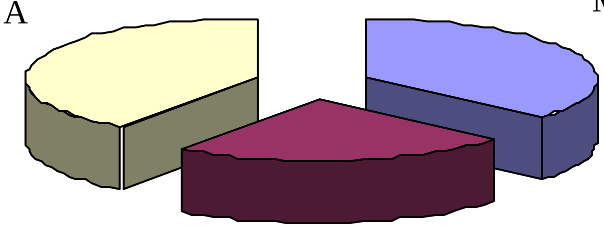


Figure 5.14: Database Platform Population by Vintage

Platform Vintage	Number of Underwater Inspections Carried Out			Platform Population*
	Level II	Level III	Level IV	
Modern-RP2A	753	288	27	657 (36%)
Early-RP2A	621	240	23	429 (24%)
Pre-RP2A	1409	584	107	720 (40%)

*Population of inspected platforms with known installation dates (1,806)

Table 5.5: Underwater Inspections by Platform Vintage

5.4.3 Defect Causes

From Table 5.6 we can see that less than 1% of modern platforms contain joint/weld defects. This increases to 6% for early-RP2A vintage platforms and to 11% for pre-RP2A platforms.

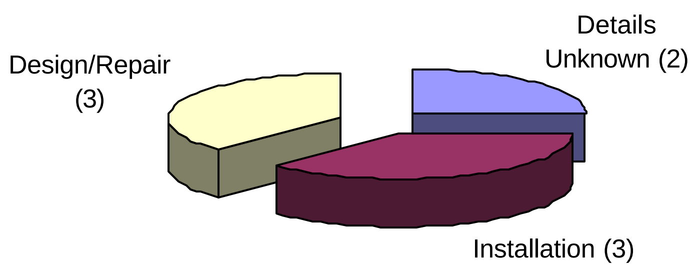
Platform Vintage	# Weld/Joint Defects	# Damaged Platforms	% Damaged Platforms	Platform Population*
Modern-RP2A	8	5	< 1%	657 (36%)
Early-RP2A	86	26	6%	429 (24%)
Pre-RP2A	327	81	11%	720 (40%)

*Population of inspected platforms with known installation dates (1,806)

Table 5.6: Weld/Joint Defects by Platform Vintage

Modern-RP2A Vintage Platforms

The weld/joint defect population for modern-vintage platforms, presented in Table 5.4, is illustrated by type in Figure 5.15. Conductor bay fatigue defects have not been widely found (none are reported in the JIP database) on modern-vintage platforms. In fact, the presence of any weld/joint defects is scarce, occurring on less than 1% of these platforms. The defects that are found are associated with fabrication, installation damage, or undesirable design details e.g.



external stiffeners /gusset plates.

Figure 5.15: Weld/Joint Defect Causes on Modern Platforms

Early-RP2A Vintage Platforms

In order to identify the cause of as many of the weld/joint defects reported in the JIP database as possible, defect data has been screened through a series of criteria designed to categorize by cause. The procedure is illustrated in the flow chart, Figure 5.16, for early-RP2A vintage platforms. The causes of defects for this vintage are summarized in Figure 5.17. The figure shows that conductor-guide frame fatigue cracking at the first elevation below the waterline is the dominant cause of weld/joint defects for early-RP2A vintage platforms in the Gulf of Mexico. Other causes of weld/joint defects are cracks associated with appurtenance fixings to the structure (doubler plates), collateral damage from vessel impact around the splash zone, cracks adjacent to undesirable design details (external stiffeners/gusset plates) and to welded repairs and fabrication defects. The cracks not allocated to the causes defined above may be the result of fatigue at joint intersection welds. Ten defects occurring on six different platforms fall into this category.

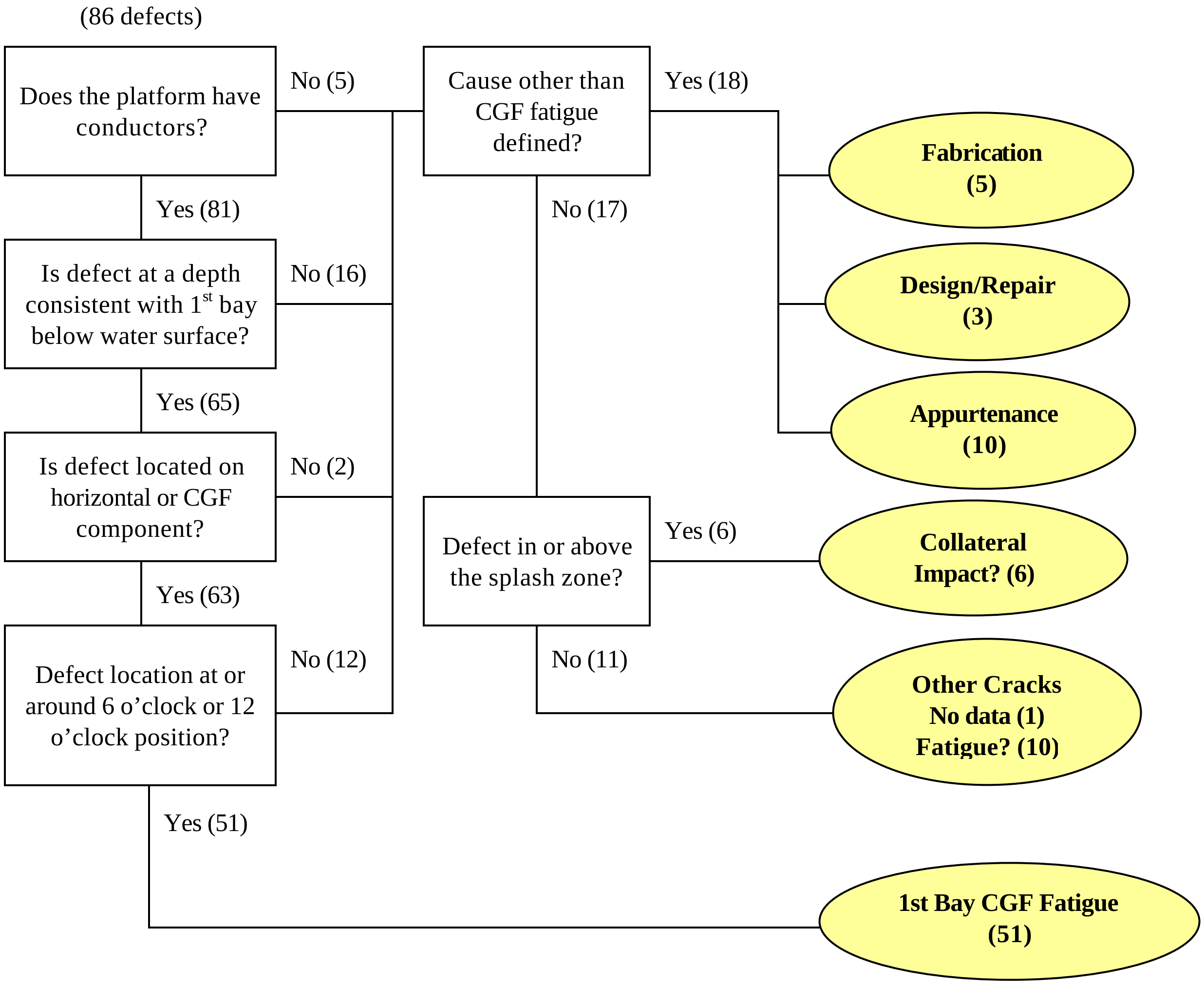


Figure 5.16: Flow Chart - Cause of Weld/Joint Defects in Early Vintage Platforms

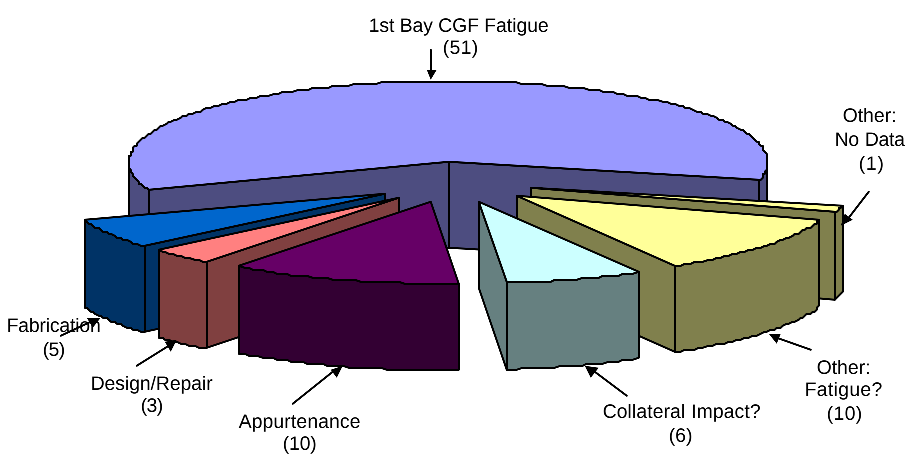


Figure 5.17: Cause of Weld/Joint Defects – Early Vintage Platforms

Pre-RP2A Vintage Platforms

The flow chart, Figure 5.18, illustrates the categorization by cause for pre-RP2A vintage platforms. The causes of defects are summarized in Figure 5.19, which shows a somewhat different distribution to that for early-RP2A vintage platforms. The relative importance of conductor-guide frame fatigue cracking reduces from 59% to 23%. There is also a significant relative increase in cracks associated with undesirable design and welded-repair details. The most significant difference, however, is in the number of fatigue cracks (not associated with the first conductor frame), which increase eight-fold compared with the three-fold increase in the total number of weld/joint defects. The defects assumed collateral damage, associated with vessel impact around the splash zone, also increase significantly for the pre-RP2A vintage platforms. Figure 5.19 shows ten defects caused by joint overload i.e. permanent distortion of the cross-section of the chord wall and/or of one or more of the braces framing into the joint. These ten overload defects occur on a group of five platforms.

Based on the cause of damage defined above, and presented in Figures 5.16 to 5.19, subsets of platforms have been identified to better define common parameters for the purposes of determining what makes certain platforms more susceptible to specific types of damage. Platform susceptibility to weld/joint defects is discussed in the next section for the following platform subsets.

- Early-RP2A and pre-RP2A vintage platforms with 1st bay CGF fatigue cracks
- Early-RP2A and pre-RP2A vintage platforms with general fatigue cracks
- Pre-RP2A vintage platforms with overload joint failure defects

Susceptibility to collateral vessel impact damage is covered under mechanical damage.

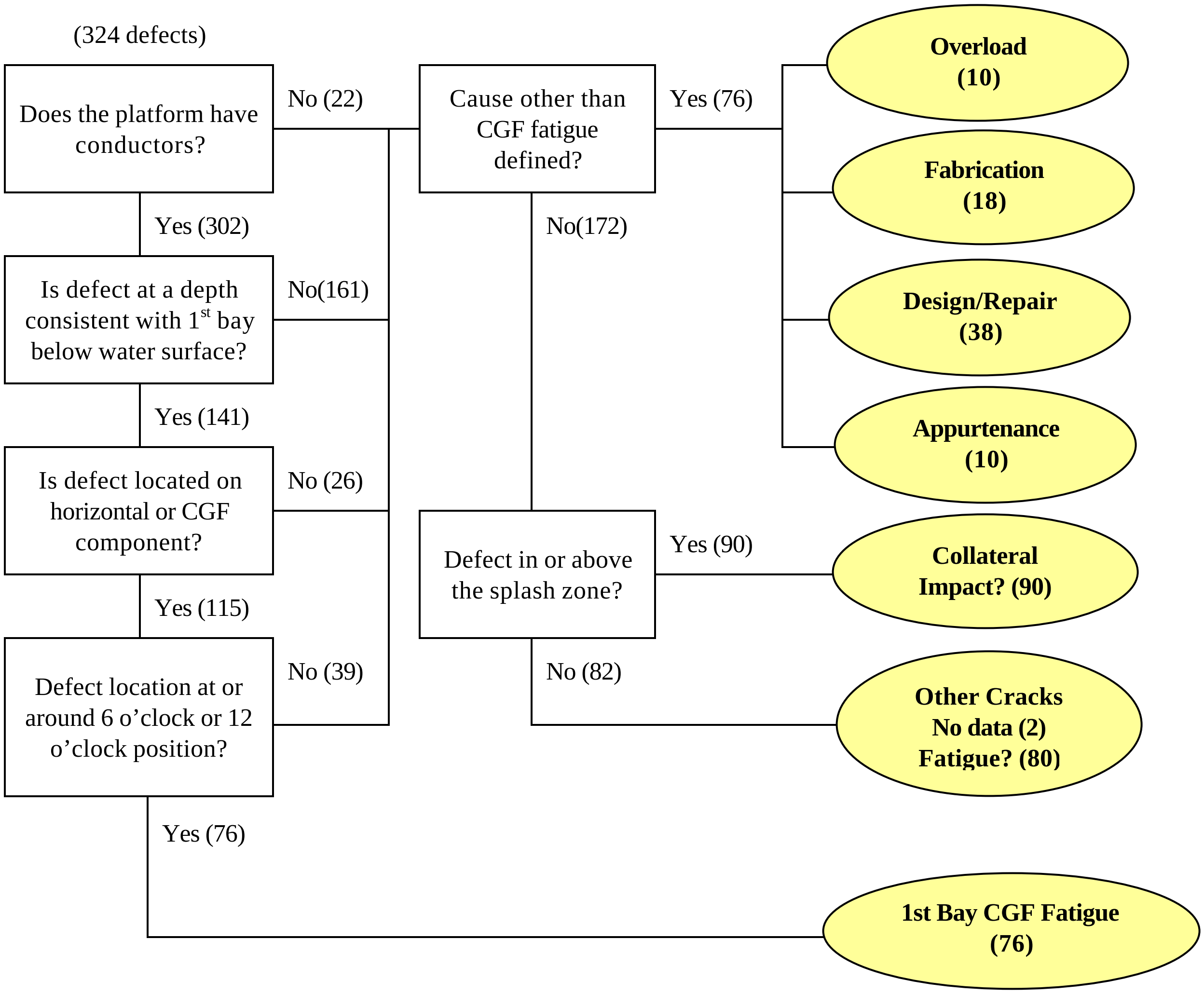


Figure 5.18: Flow Chart - Cause of Weld/Joint Defects in Pre-RP2A Platforms

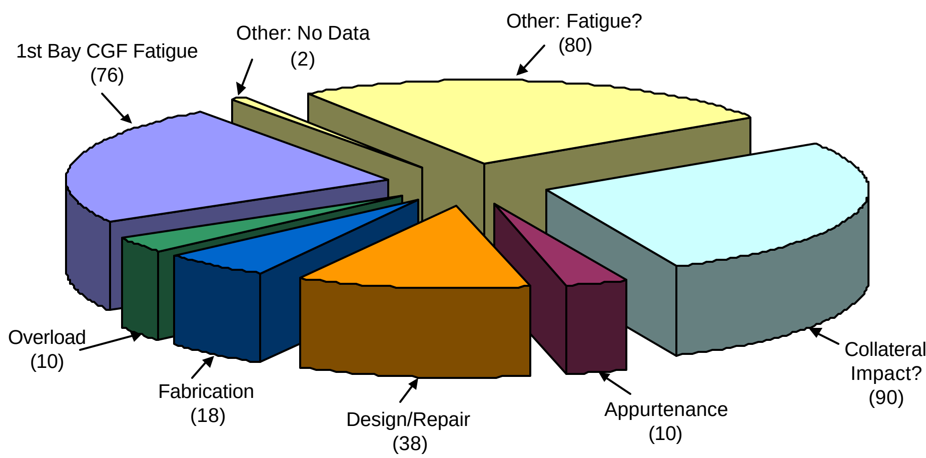


Figure 5.19: Cause of Joint/Weld Defects – Pre-RP2A Platforms

Platform Susceptibility

Based on the analyses of the data, presented above, subsets of the inspected platform population have been identified as follows: -

- Early and pre-RP2A vintage platforms with 1st bay CGF fatigue cracks
- Early and pre-RP2A vintage platforms with general fatigue cracks
- Pre-RP2A vintage platforms with joint overload failure defects

Together with collateral crack defects resulting from vessel impact, the above defect types are responsible for 80% of all weld/crack defects found in early-RP2A vintage platforms and 79% of those found on pre-RP2A vintage platforms. The number of defects and the number of affected platforms within the platform subsets are shown in Table 5.7.

Platform Vintage	Defect Cause	# Defects	# Platforms	% of the Platform Vintage Population
Early-RP2A	1st bay CGF fatigue	51	8	1.9%
Early-RP2A	General fatigue	10	6	1.4%
Pre-RP2A	1st bay CGF fatigue	76	23	3.2%
Pre-RP2A	General fatigue	80	31	4.3%
Pre-RP2A	Joint overload	10	5	0.7%

Table 5.7: Weld/Joint Platform Subsets by Cause

First bay CGF fatigue cracks

The flow charts, Figure 5.16 and Figure 5.18, are designed to identify crack indications associated with ‘panting’ action at the first conductor-guide frame below the waterline to a high confidence level. Table 5.7 shows that approximately 2% of early-RP2A vintage platforms and more than 3% of pre-RP2A vintage platforms exhibit damage of this type. The difference between the two groups is, most likely, simply a function of time i.e. cracks have had more time to grow in the older platforms.

Investigations show no clear correlation between precise installation dates or water depth and unfortunately, conductor-guide framing configuration data is not generally available in the database. However, we do know that the phenomenon is essentially a design oversight resulting from the inability of industry, at the time, to properly account for the harmful influence of vertical water particle kinematics within the active wave zone. From this understanding, we can draw a couple of logical conclusions as to parameters that may influence platform susceptibility (identified below, which appear to be borne out by the available data.

Both pre-RP2A vintage and early-RP2A vintage platforms can be susceptible to conductor-guide frame 'panting' fatigue. For both vintages, the susceptibility increases when: -

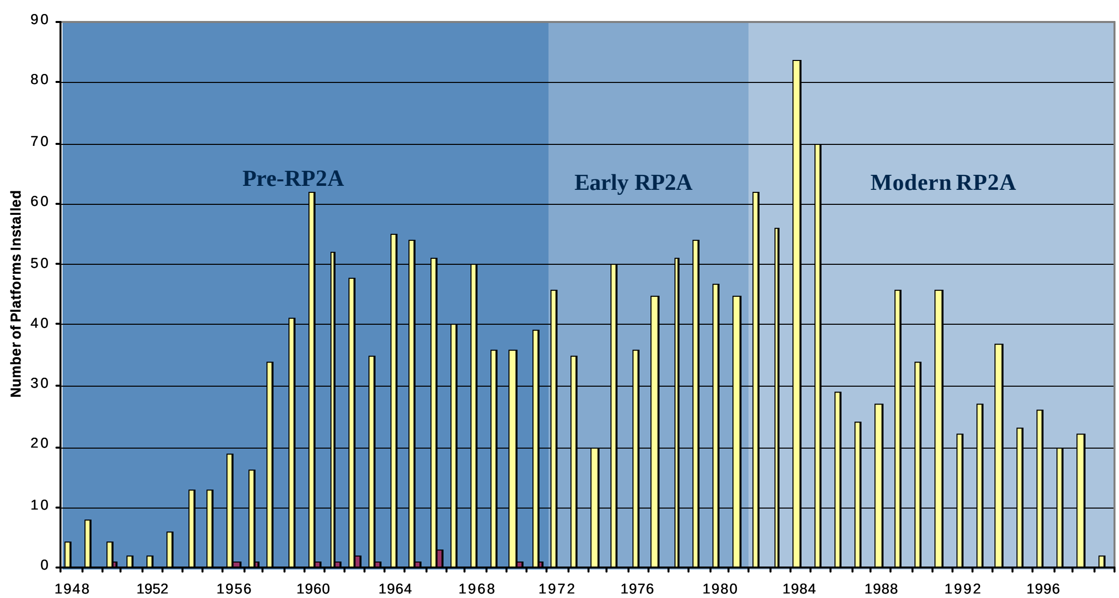
i) The platform contains exposed conductors and associated guide frames.

ii) The first conductor-guide frame below the waterline is positioned relatively close to the water surface, generally within 40 feet.

iii) The conductor guide-framing configuration has low out-of-plane stiffness. For example, vertical framing is absent or the in-plane diagonal bracing does not frame into hard points (for example jacket legs).

General fatigue cracks

Pre-RP2A platforms are defined as those platforms installed between 1948 and 1971, inclusive. Figure 5.20 shows the number of inspected platforms in the JIP database installed each year in the Gulf of Mexico. Also shown on the figure are those pre-RP2A platforms where suspected general fatigue damage has been found. Since fatigue is a time-dependant phenomenon, it would be expected, all else being equal, that fatigue cracks would be found on the oldest of the platforms in the vintage. The figure shows that, in fact, the platforms installed towards the latter part of the era have a higher susceptibility to general fatigue cracking. This apparent contradiction can be explained by looking at platform water depth.



Yellow (longer) bars show number of platforms installed
Red bars show number of platforms with multiple (>1) suspected general fatigue cracks

Figure 5.20: Pre-RP2A Vintage Platforms with Multiple Fatigue Cracks

The first platform in the Gulf of Mexico was installed in just 38 feet of water. Figure 5.21 shows the gradual increase in platform water depth with time. The figure shows that around 1961 maximum water depth was approaching 200 feet and that this had increased to 300 feet by the time the first Edition of RP2A was issued in 1969. These platforms were designed without the benefit of modern joint strength and/or fatigue capacity formulations. It is likely that the joint designs, although generally adequate for shallow water, became increasingly susceptible to fatigue damage as platforms moved to deeper water.

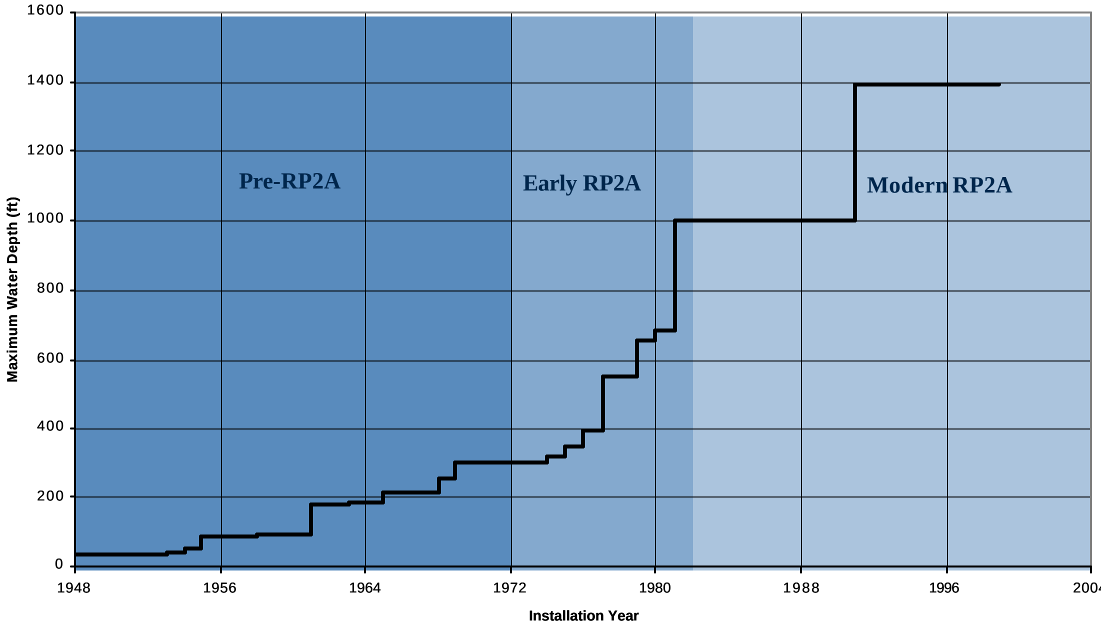


Figure 5.21: Inspected Platforms, Water Depth Increase with Time

The database provides a number of useful statistics in this regard: -

- 64% of the pre-RP2A platforms are in water depths of less than 50 feet.
- 75% of suspected general fatigue damage on pre-RP2A platforms occurs on platforms in water depths of greater than 50 feet.

Unfortunately, the JIP database contains a description of the primary framing configuration for only a small percentage of platforms. Data is especially scarce for older platforms with the most suspected fatigue damage. Experience in other areas of the world has suggested a correlation between framing (joint types) and fatigue cracks.

In summary, general fatigue cracking affects less than 5% of pre-RP2A vintage platforms and less than 2% of early-RP2A vintage platforms. For the pre-RP2A vintage, the damage is more commonly associated with relatively deeper water platforms (for the vintage), i.e. platforms in water depths of 100 feet or greater, and is likely the result of inadequate joint design for these water depths. The damage is generally manifested as brace/chord intersection cracks in main joints, usually close to the mud line.

For the early-RP2A platforms with suspected fatigue-damage the cause is not entirely clear through the investigations presented in this section. However, Section 5.5, below, reveals that at least some of the early platforms with fatigue damage have experienced a loss of corrosion protection at some stage of their service life. It is possible that a more advanced state of corrosion, particularly localized crevice or pitting corrosion could accelerate or even precipitate fatigue crack growth in joints. This may explain the fatigue cracks in early-RP2A vintage platforms and indeed in some of the shallower water pre-RP2A platforms.

Joint overload failure defects

The database contains records of seven weld/joint overload defects i.e. joints that have suffered permanent distortion from overload. The joints occur on three platforms in water depths ranging from 50 feet to 140 feet. All the platforms are pre-RP2A vintage. Deck elevations for the structures are not included in the database; however, it is likely that they would be considered, as having 'inadequate deck height' under Section 17 of API RP2A and would have experienced wave inundation of the deck during extreme event loading. In all cases, the overloaded (failed) joints are located at the lowest jacket elevation adjacent to the mud line.

5.4.4 Flooded Member Detection (FMD) Surveys

Flooded members are generally the result of through-thickness fabrication flaws, corrosion, mechanical damage and/or fatigue. The database contains records from approximately 295 FMD surveys containing 5,773 FMD readings on 244 platforms. Table 5.8 shows the distribution of FMD surveys by platform vintage along with the number of members that tested positive for flooding.

Platform Vintage	Platforms Surveyed*	Positive/Total # Readings	Platforms with Positive Readings	% of Platform Vintage Population
Modern-RP2A	44	9 / 899	5 (11%)	<1%
Early-RP2A	73	167 / 1258	24 (33%)	6%
Pre-RP2A	124	1426 / 3512	77 (62%)	11%

(1) Three FMD surveys were performed on platforms without known installation dates.
(2) FMD data is generally poorly reported in the database. In many instances, only flooded members are reported and, therefore, the percentages of flooded members being detected as a percentage of the total tested cannot be reliably established.

Table 5.8: FMD Survey Results by Platform Vintage

Generally, the FMD findings are supportive of the general trends indicated by the mechanical damage and weld/joint surveys considered above. Analysis of the FMD data is hampered by the overall poor quality of reporting. For example, in many instances, only flooded members are reported as having been tested and in most cases the cause of flooding is not investigated, or at least not reported.

As would be expected, the number of platforms with positive flooded member readings increases with the age of the platform. Over half of the pre-RP2A platforms surveyed had positive FMD readings, and nearly a quarter of the early-RP2A platforms surveyed had positive FMD readings. One or more flooded members were detected on 11% of the modern-RP2A platforms. The following subsections provide more detail on the results of the surveys recorded in the database.

Modern-RP2A Vintage Platforms

As seen in Table 5.8, five of the modern-RP2A platforms had a total of nine positive FMD readings. The table below gives the general location and cause of flooding for the five platforms.

Platform	# FMD Readings	# Positive Readings	Location of Flooded Members	Cause of Flooding
1	11	3	at or near 1st bay elevation (1); between 1st bay and mudline (2)	no cause found
2	33	2	at or near 1st bay elevation	bow with dent
3	18	1	at or near 1st bay elevation	no cause found
4	1	1	at or near mudline	dent with hole
5	60	2	at or near mudline	dent

Table 5.9: Modern-RP2A FMD Survey Results

Two of the five platforms had flooded members with no cause found, and the other three platforms had flooding due to mechanical damage (bows, dents, and/or holes) most likely caused by dropped objects and/or vessel impact. The FMD data is consistent with pother observations that Modern-vintage platforms are not seeing fatigue damage. It also indicates the potential application of the technique to detection of through-wall mechanical defects.

Early-RP2A Vintage Platforms

A shown in Table 5.9, twenty-four early-RP2A platforms had positive FMD results. Three of these platforms had CGF fatigue defects and a further three general fatigue defects detected by close-visual examination. Approximately 55% of the flooding at the 1st CGF and above was due to cracks, the other flooding was due to repair, anode standoffs and unknown causes. Of the flooded members detected below the 1st CGF, nearly 90% was caused by crack indications; other causes of flooding included corrosion and dents.

Pre-RP2A Vintage Platforms

As expected, the pre-RP2A vintage platforms had the largest number positive FMD results. Seventy-seven of the 124 platforms tested had one or more flooded members detected, a total of 1,426 flooded members. Thirteen of the 77 platforms had 1st bay CGF fatigue confirmed by close-visual examination and a further seventeen general fatigue defects similarly confirmed.

The majority of member flooding (about 75%) on platforms with known CGF defects was caused by cracks near the 1st CGF elevation. Other causes of flooding included bows, dents and separated members. In the case of platforms with known general fatigue damage, approximately 87% of member flooding was caused by crack indications. Other causes of flooding included dents and holes.

Generally, FMD data is poorly recorded in the database. In many instances, only flooded members are reported and, therefore, the percentages of flooded members being detected as a percentage of the total tested cannot be reliably established from the JIP database.

5.5 Corrosion

5.5.1 Defect Types

Corrosion is responsible for 17% of reported defects in the JIP database as illustrated in Figure 5.1. Corrosion damage has been categorized as a number of specific defect types, as follows: -

***Uniform*:** General corrosion that is defined as an attack in a uniform fashion over the entire exposed area of a surface. General corrosion is defined as patches of uniform corrosion over a wider area.

***Pitting*:** Localized corrosion that usually forms circular holes that will grow deeper into the material with time.

Hole: An advanced state of through-wall uniform or pitting corrosion.

***Crevice*:** Corrosion that is typically found in welded joints. This type of corrosion tends to manifest as thin long lines parallel to the weld.

***Fretting*:** Corrosion caused by abrasion of metal due to physical contact, such as a steel cable rubbing against a member in the structure.

Figure 5.22 shows the relative proportion of the various types of corrosion defect types in the database and identifies those within and without the splash zone. The majority of recorded corrosion defects occur in the splash zone, especially pitting corrosion and holes.

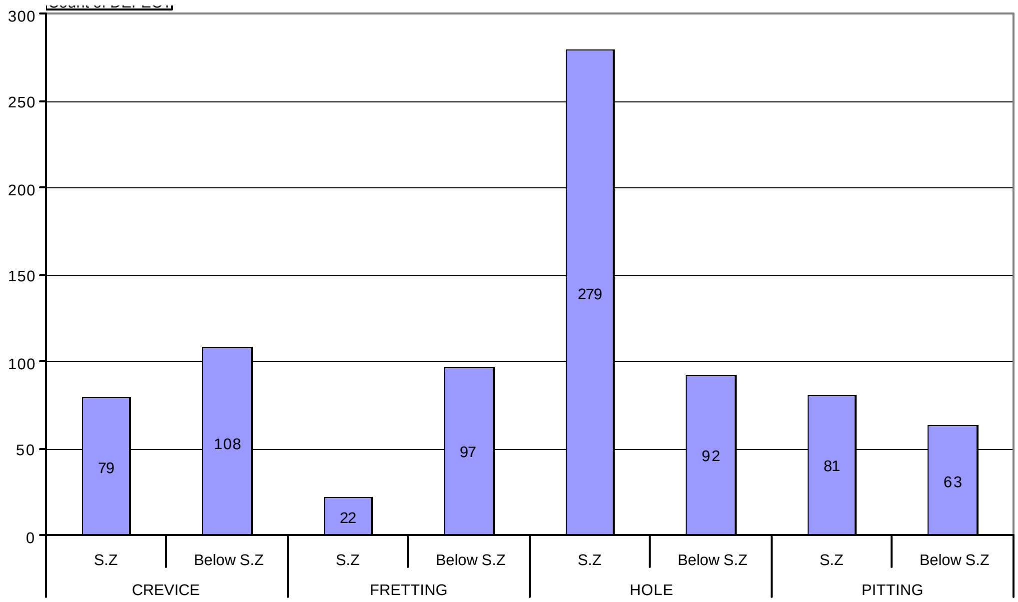


Figure 5.22: Corrosion Defects

5.5.2 <u>Assessment of Cathodic Protection and Extent of Corrosion</u>

The cathodic protection system is not effective in the splash zone; the degree of corrosion in this region is related to the quality and condition of the coating system. Generally, some allowance for corrosion is considered in design through the provision of additional component wall thickness through the wave zone. Splash zone corrosion may result in the loss of brace members with consequent reduction in jacket redundancy. In a number of cases corrosion of the leg to pile weld has occurred resulting in failure of the weld and 'dropping' of the jacket down the legs.

A number of complimentary techniques are used to assess the effectiveness of the cathodic protection system and/or the extent of corrosion of the submerged portion of a platform. Two non-visual techniques used are dropped cell measurement and anode surveys, both briefly described below.

Dropped Cell Measurements

API Level-I inspections require an above-water visual inspection to determine effectiveness of the corrosion protection system and to detect deteriorating coating systems and excessive corrosion. Below-water verification of the performance of the cathodic protection system by dropped cell or other method is also required. The database contains dropped cell CP readings from the annual Level-I inspections of all 2,024 platforms for which underwater inspection-data is available.

Anode Surveys

API Level-II inspections require a general underwater visual inspection by divers or ROV to detect excessive corrosion and measurement of cathodic potentials of pre-selected critical areas using divers or ROV. Typical level-II surveys in the Gulf of Mexico include anode-surveys where the percentage depletion of some or all anodes is estimated in addition to CP measurements.

Table 5.10 shows the number of platforms with ineffective cathodic protection systems (at the time of their inspection) based on anode surveys and dropped cell measurements. Also shown is the number of platforms within the MMS damage database reported to be unprotected at the time of inspection.

Assessment Technique	# Platforms with ineffective CP systems	Definition of ineffective
Anode survey	46	At least 40% anode readings out of spec.*
Dropped cell measurement	162	At least 40% cell readings out of spec.*
MMS damage database	121	As reported by platform operator

* Readings outside the range –850 mV to –1150 mV

Table 5.10: Platform with Recorded/Reported Ineffective CP Systems

Correlation between the platforms reported by the different techniques as having ineffective protection systems is difficult to establish. The failure of the CP system will not affect the likelihood of corrosion in the splash zone region and above. It is in this region that the majority of corrosion defects occur.

Close Visual (CV) Surveys

Close visual surveys provide an additional method to assess the state of corrosion of offshore platforms. API Level-III inspections involve cleaning of pre-selected areas of the platform, usually member intersection joints, facilitating a close visual survey of the region for corrosion monitoring. This method of corrosion inspection is reported by third-party inspection providers as being a rapid and reliable method for assessing the extent and severity of corrosion on the platform. The method is, however, highly subjective and the nature of the data recording varied, ambiguous and often incomplete.

Corrosion Level	General	Uniform	Pitting	Crevice	Fretting
Light	1835	2250	1251	368	14
Moderate	564	201	136		
Heavy	387	22	36		
Undefined	23	20	3961		

Table 5.11: Joint Corrosion Reported from Close Visual (CV) Surveys

Table 5.11 shows the reported extent of joint/weld corrosion from close visual inspections of over 11,000 welds. The pie chart of the data, Figure 5.23, shows that 4% of inspected welds are reported to have heavy corrosion of one sort or another. The high proportion of data with undefined level of corrosion and the lack of any definition of the levels reduces the reliability/usefulness of this data.

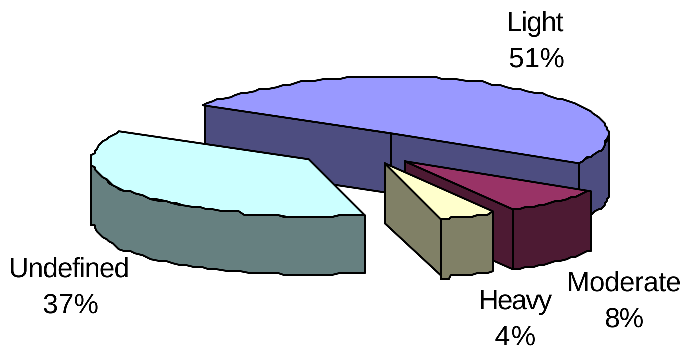


Figure 5.23: Reported Corrosion Levels from CV Surveys of Joints

Ultrasonic wall-thickness measurement (WT-UT)

Ultrasonic wall-thickness measurements are another possible method for the assessment of the extent of platform corrosion. From an investigation of 605 WT-UT measurements (where four readings were taken at the clock point positions around the circumference), very few data showed any variation in wall thickness outside the specification of supplied pipe. One explanation is that the more corroded the member the less reliable the tool. To achieve a reliable reading on a highly corroded surface it is usually necessary to lightly grind smooth a small area on which to set the probe. The procedure used in the tests recorded in the source data is not provided but it is thought unlikely that pre-grinding was used.

5.5.3 <u>Corrosion and Fatigue</u>

Drop cell readings are available for each of the platforms in the database and, therefore, these readings were initially used as an indicator of the degree of corrosion for the purposes of correlation of corrosion with fatigue damage. Two criteria were investigated to define unprotected platforms, as follows:

Criteria 1: At least 40% of recorded dropped cell readings outside the range -850 mV to -1150 mV.

Criteria 2: At least 40% of recorded dropped cell readings outside the range -800 mV to -1150 mV.

Platform Vintage	# Total Platforms	Unprotected (Corroded) Platforms*		Corroded platforms* with fatigue crack indications	
		#	%	#	%**
Modern-RP2A	657	33	5%	0	0%
Early-RP2A	429	22	5%	5	23%
Pre-RP2A (<100 ft)	581	59	10%	2	8%
Pre-RP2A (>100 ft)	139	3	2%	1	33%

*At least 40% of the dropped cell readings outside the range –850 mV to –1150 mV
**Indicates % of the population of platforms with suspected fatigue cracks (including 1st bay CGF)

Table 5.12: Correlation of Corroded Platforms with Cracked Platforms-Criteria 1

Table 5.12 shows that using Criteria 1, 23% of early-RP2A vintage platforms with suspected fatigue cracks have experienced some period during which the cathodic protection system did not function as intended. The value falls to 8% for pre-RP2A platforms. The figures appear to indicate that excessive corrosion increases a platforms susceptibility to fatigue cracking amongst early-RP2A vintage platforms but is wholly inconclusive for older platforms where, it might be expected that a greater correlation should exist.

Platform Vintage	# Total Platforms	Unprotected (Corroded) Platforms*		Corroded platforms* with fatigue crack indications	
		#	%	#	%**
Modern-RP2A	657	20	3%	0	0%
Early-RP2A	429	11	3%	2	18%
Pre-RP2A (<100 ft)	581	22	4%	0	0%
Pre-RP2A (>100 ft)	139	2	1%	0	0%

*At least 40% of the dropped cell readings outside the range –800 mV to –1150 mV
**Indicates % of the population of platforms with suspected fatigue cracks (including 1st bay CGF)

Table 5.13: Correlation of Corroded Platforms with Cracked Platforms-Criteria 2

Table 5.13 shows similar figures using Criteria 2. In this case, 18% of early-RP2A vintage platforms with suspected fatigue cracks appear to have experienced some period during which the cathodic protection system did not function as intended. The value falls to 0% for pre-RP2A platforms. These findings appear unreliable and are inconsistent with previous theories on the correlation of corrosion and fatigue cracks.

Tables 5.12 and 5.13 indicate that dropped cell readings are not a good predictor of the corroded state of the platform at least for purposes of correlation to fatigue crack indications.

An alternative indicator of the corroded state of a platform is the close-visual survey. Such surveys have been performed on a large number of platforms in the Gulf of Mexico and, as discussed above, 4% of such surveys reported the presence of 'heavy' corrosion. Table 5.14 compares the heavily corroded platforms to those with fatigue crack indications.

Platform Vintage	**# Total Platforms**	**Corroded Platforms***		**Corroded platforms* with fatigue crack indications**	
		#	%	#	%**
Modern-RP2A	657	3	0.5%	0	0%
Early-RP2A	429	10	2%	1	10%
Pre-RP2A (<100 ft)	581	25	4%	3	12%
Pre-RP2A (>100 ft)	139	27	19%	7	26%

*CVI indicates "heavy" corrosion
**Indicates % of the population of platforms with suspected fatigue cracks (including 1st bay CGF)

Table 5.14: Correlation of Corroded Platforms with Cracked Platforms by CVI

Table 14 shows an increasing level of corrosion with age and a good correlation between the level of corrosion and the presence of fatigue crack indications. As expected there are no modern vintage platforms and few early vintage platforms that are both corroded and have fatigue crack indications. Of the pre-RP2A platforms, the majority of the corroded/fatigued platforms are in water depths greater than 100 feet.

In conclusion:

i) Historic dropped cell survey records are not a reliable indicator of the level of existing corrosion.

ii) Close-visual examination appears to provide a reliable indicator of the overall general level of platform corrosion. This is supported by evidence provided by inspection divers.

iii) Heavily corroded platforms are more likely to suffer from fatigue damage.

5.6 <u>Platform Anomalies</u>

In Section 4.2, a distinction was made between defects and anomalies. A defect was defined as an imperfection, fault, flaw or blemish in a component of the platform, which falls into one of the categories defined in Section 4.2. A number of underwater surveys, however, result in anomalous readings that cannot be defined as defects. These surveys, include marine growth-surveys, scour-surveys and debris-surveys. Consistent with the wording of API RP2A, these surveys are routinely carried out during Level II inspections and large amounts of data are contained in the JIP database. For a variety of reasons, however, anomalies are seldom reported.

5.6.1 Marine Growth Surveys

The JIP database contains 9,239 marine growth measurements from 2,268 API Level II inspections of 1,194 platforms. Of the 9,239 measurements, only 38 were flagged as anomalies in the inspection reports, however, numerous spurious readings were recorded some reporting thickness measurements in excess of 12 inches. In most cases the measurements differentiate between hard growth and soft growth. Unfortunately, the method used to estimate thickness is not defined in the database. The reliability of many of the readings is, therefore, questionable. In the following, averages have been used wherever possible to avoid reliance on what appear to be numerous unreliable readings.

Variation with geographic location

The potential for a variation of marine growth thickness across the Gulf of Mexico was explored using the JIP database. The black circles in Figure 5.24 show the location of all platforms for which marine growth data has been recorded excluding platforms where the marine growth survey was carried out less than five-years after installation. These platforms have been excluded to ensure growth had reached a stable level to avoid bias from immature growth. In the figure, the blue triangles represent platforms where hard growth thickness measurements in zone 1 have been recorded in excess of 4 inches. In Figure 5.25, the black circles show the same platform population. The red triangles show hard growth thickness measurements in zones 2, 3 and 4 in excess of 3 inches. The marine growth zones are defined in Table 5.15.

Zone 1	LAT	to	-40	(ft)
Zone 2	-40	to	-110	(ft)
Zone 3	-110	to	-170	(ft)
Zone 4	-170	to	Mudline	(ft)

Table 5.15: Marine Growth Depth Zones

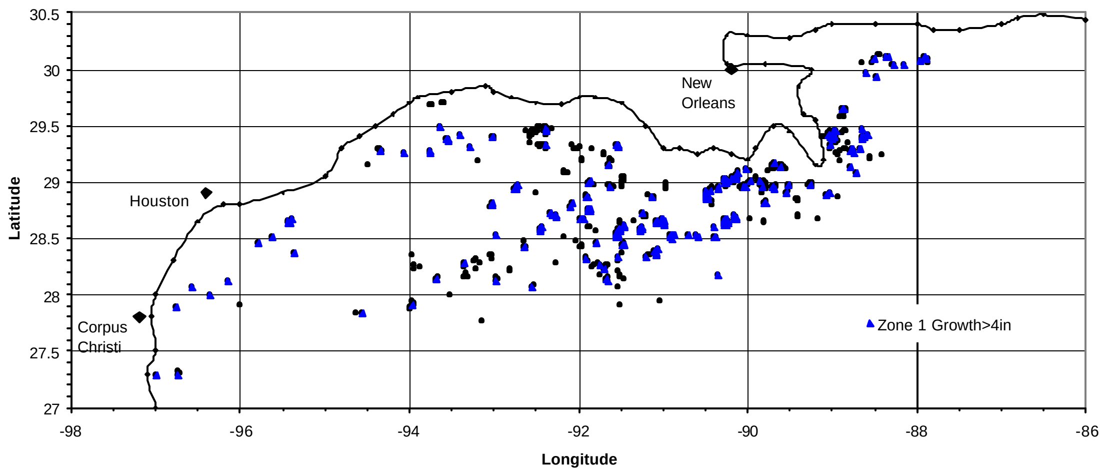


Figure 5.24: Marine Growth Anomalies – Zone 1

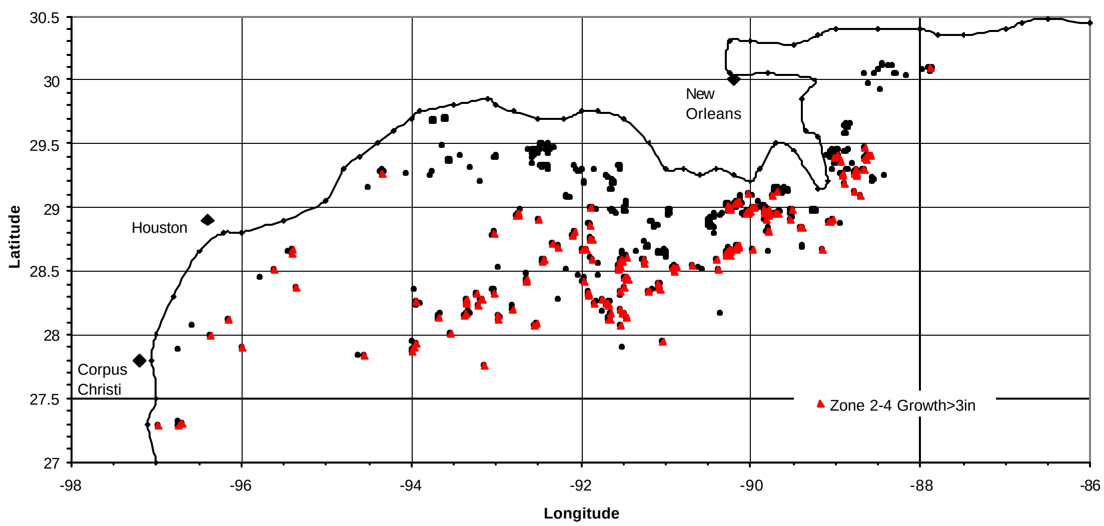


Figure 5.25: Marine Growth Anomalies – Zones 2, 3 and 4

No clear geographical variation in marine growth thickness is evident from the figures. However, the following observations may be relevant: -

- Marine growth anomalies beyond zone 1 are unusual in the coastal waters, north of latitude 29º, and west of New Orleans (longitude –90º) most probably due to the reduced water clarity.
- Marine growth measurements in excess of design levels are widespread throughout the Gulf of Mexico.

Variation with time

Marine growth thickness variation with time for four platforms in the Gulf of Mexico is shown in Figure 5.26. Each depth zone is shown independently for each platform. The locations of the platforms in the Gulf are shown in Figure 5.27.

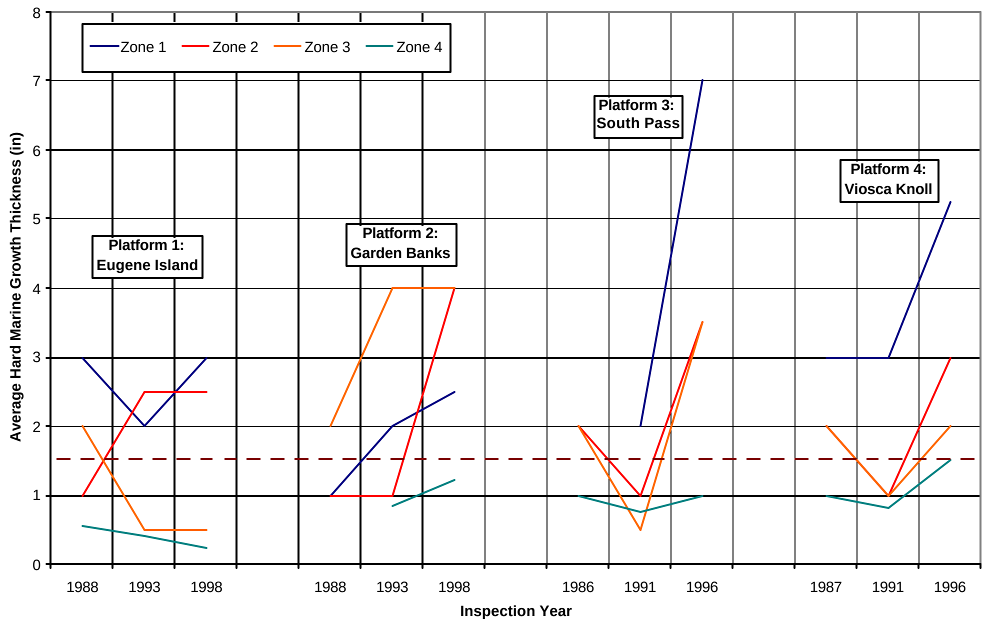


Figure 5.26: Marine Growth Thickness Variation

Figure 5.26 shows an erratic pattern of measured marine growth thickness with time. The figure indicates that thickness of growth varies year-to-year, depending on conditions, but does not continue to increase indefinitely. The seven-inch reading, at location 3, is considered unreliable. It was not recorded as anomalous in the inspection report.

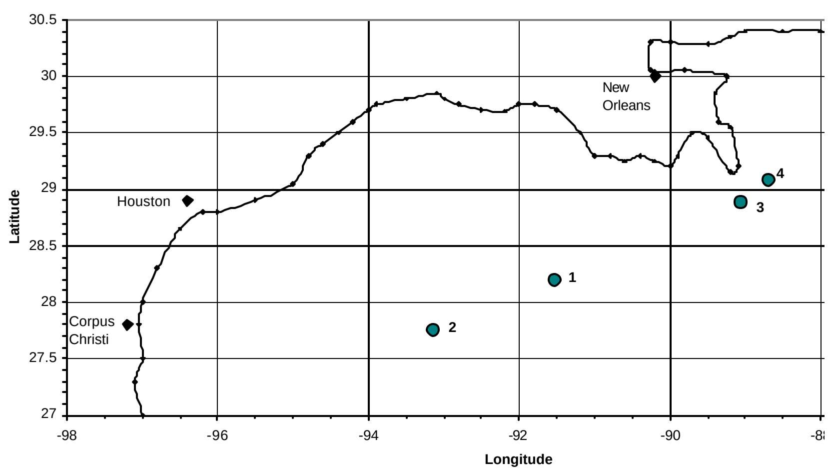


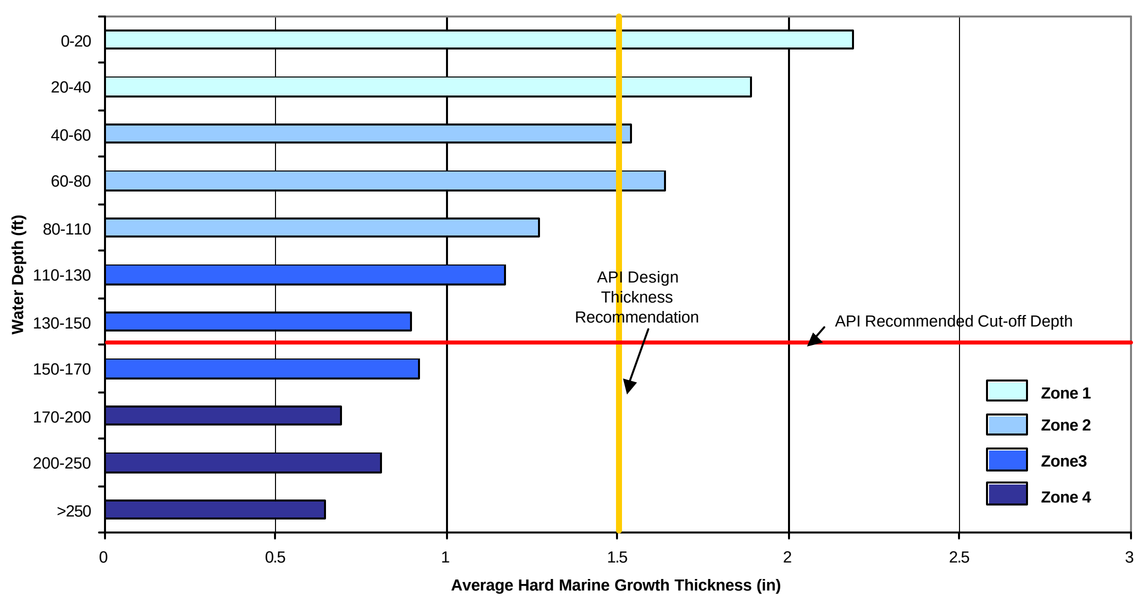
Figure 5.27: Location of the above Platforms in the Gulf of Mexico

It is evident that a consistent approach to the measurement and recording of marine growth thickness is needed to improve the reliability of recorded data for input into platform design, assessment and inspection planning.

Comparison with design guidance

The 20th Edition of API RP2A provides guidance on the consideration of marine growth, thickness and extent, in the design of platforms. In the Gulf of Mexico, the code recommends the use of a thickness of 1.5 inches from Mean Higher High Water (MHHW) to 150 feet water depth unless a smaller or larger value is appropriate from site-specific studies. The code also recommends that any members with more than a very light coating of marine growth should be considered to be hydrodynamically rough and recommends a cut-off at 150 ft. in lieu of site-specific data.

The design thickness and depth recommendations have been considered in relation to the average of the readings contained in the JIP database, for hard growth. Figure 5.28 shows the



average measured thickness (for hard growth alone) across four depth zones.

Figure 5.28: Measured Average Hard Marine Growth Thickness

The following observations may be relevant: -

- A varying marine growth thickness profile may be more appropriate for consideration in platform design.
- The marine growth profile appears to extend beyond the recommenced 150 ft. water depth to beyond 250 ft.

5.6.2 Bottom/Scour Surveys

Scour is the removal of seafloor soils by current and/or wave action. The phenomenon is caused either by natural geological processes or by structural elements interrupting the natural flow regime near the seafloor. Generally, the process requires a loose sandy seafloor. There are two main forms of scour affecting offshore platforms: global scour; shallow scoured basins of large extent around the structure and local scour; steep-sided scour pits around structural elements such as piles and legs. Scour can result in the degradation of vertical and lateral support for foundations potentially leading to unwanted settlements and/or overstressing of the foundation.

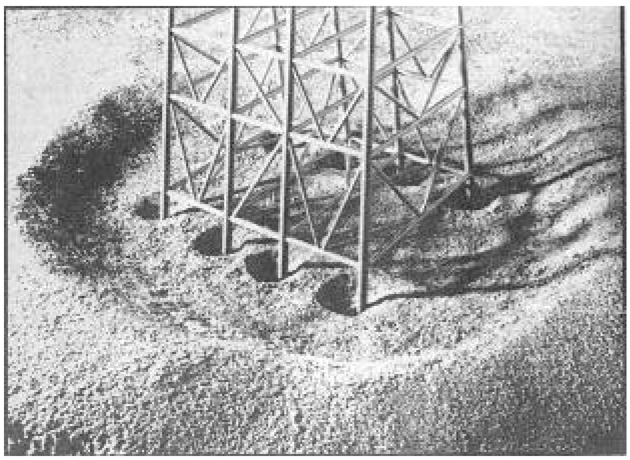


Figure 5.29: Laboratory Model Showing Local and Global Scour

In accordance with the wording of API RP2A, bottom/scour surveys are routinely conducted during Level II surveys in the Gulf of Mexico; in fact, they are the most common of all surveys recorded in the JIP database with data collected during over 2,400 underwater inspections. Analysis is restricted due to incomplete data recording, inconsistencies in soil descriptions, lack of differentiation of local and global readings, and undefined procedures. Attempts have been made to rationalize soil classifications based on available information and the scour readings are summarized in terms of these classifications in Table 5.16.

		Level of scour (ft)							
Sand	**Total**	**0 - 1**	**1 - 2**	**2 - 3**	**3 - 4**	**4 - 5**	**5 - 6**	**6 - 7**	**7 - 8**
Loose	-	-	-	-	-	-	-	-	-
Medium	2082	96.8%	1.7%	0.9%	0.2%	0.1%	0.1%	0.1%	-
Dense	115	92.2%	1.7%	3.5%	1.7%	-	-	-	0.9%
Clay									
Soft	4499	95.5%	2.9%	1.1%	0.2%	0.1%	0.2%	-	-
Medium	1095	97.7%	1.5%	0.6%	0.0%	0.1%	0.1%	-	-
Stiff	1843	95.7%	3.0%	0.7%	0.5%	0.1%	0.0%	0.1%	-
Other									
Shell	1864	97.5%	1.5%	0.7%	0.1%	0.1%	0.1%	-	0.1%
Unknown	1226	98.5%	0.7%	0.6%	-	-	0.1%	-	0.1%
	Overall:	**96.5%**	**2.2%**	**0.9%**	**0.3%**	**0.2%**			

Table 5.16: Summary of over 12,000 Scour Measurements in the Gulf of Mexico

Consistent with expectations, the table indicates that scour is not generally a problem for platforms in the Gulf of Mexico due to the generally cohesive nature of the soils and the absence of high bottom currents. However, the table does indicate a number of isolated examples of deep scour. It is possible that these reading are associated with short duration seafloor movements during severe storms or hurricane events. It is also likely that many of the higher scour readings are the result of sit-up during platform installation or inaccurate data recording.

5.6.3 Debris Surveys

Debris typically results from objects dropped or discarded overboard during operations, including construction operations, on or around the platform throughout its service life. Debris surveys are routinely carried out during API level II platform inspections. The database contains records from approximately 1,800 such inspections, where over 14,000 items of debris have been catalogued. There are no anomalous readings cited from debris surveys, this is perhaps due to uncertainty in the definition of an anomaly. Figure 5.30 shows the types of debris that have been recoded in the database. It is assumed, in lieu of other information, that 'miscellaneous debris' is some combination of the other types identified in the figure.

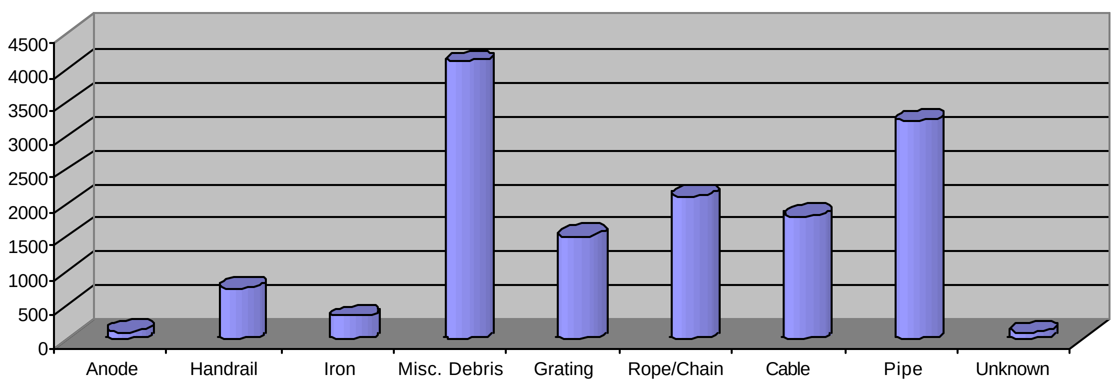


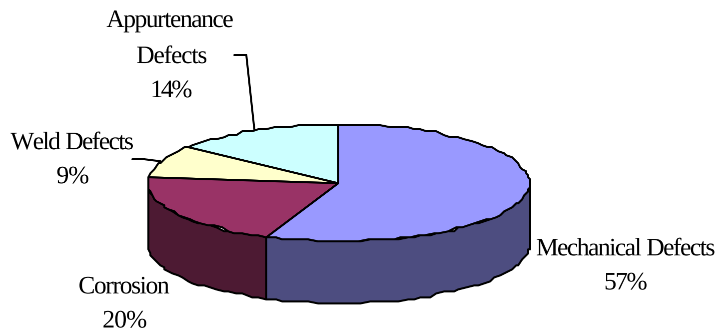
Figure 5.30: Debris Surveys by Type

Of the 14,000 items recorded in the database less than 4% were ever recovered or removed from the structure. The database indicates that debris associated with platform is not generally detrimental to the structural integrity of the facility. There are at least two notable exceptions. One is discarded wires, cables, grout-lines etc., which may cause fretting corrosion. The database contains a number of instances of such debris being catalogued on successive inspections of the same platform without removal. The second includes metallic objectives in contact with the structure, which may interfere with the corrosion protection system. These types of debris should be removed. In addition, debris resting on the structure posing a potential hazard during the inspection should also be removed or secured.

5.7 Conclusions

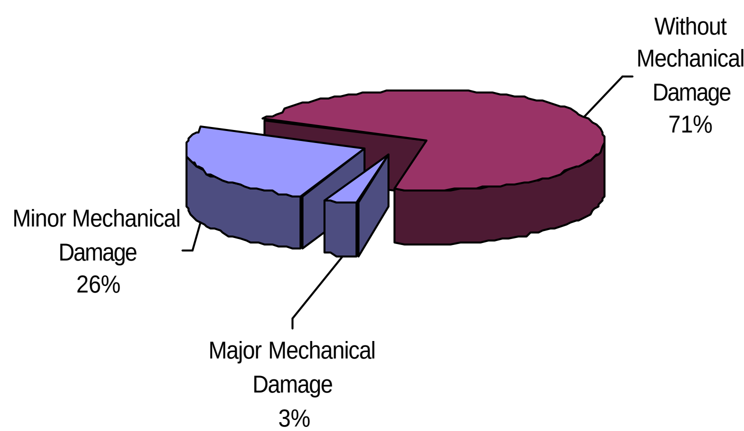
Platform Defects

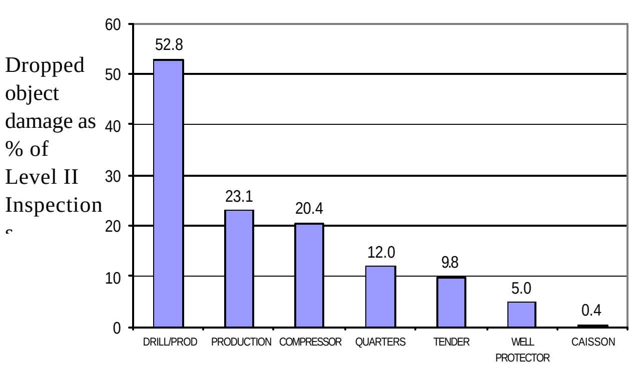
Damage found during underwater inspections of platforms in the Gulf of Mexico can be divided into four categories. The categories and their relative occurrence are shown in the figure. Neglecting non-structural defects, mechanical damage is responsible for two-thirds of the defects reported on platforms in the Gulf of Mexico.



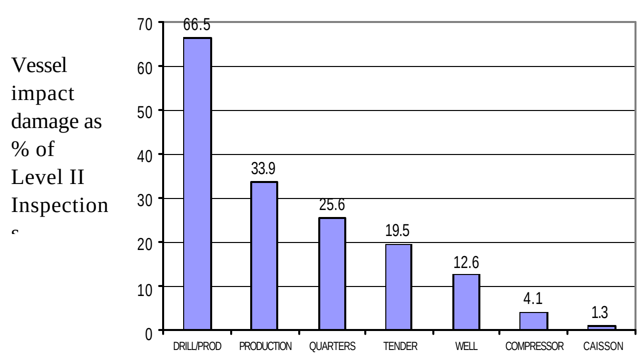
Mechanical Damage

Mechanical damage includes dents, bows, gouges and separated members. The figure summarizes the extent and severity of mechanical damage amongst the platform population in the Gulf of Mexico. The two primary causes of mechanical damage are vessel impact and dropped objects. The function/ type of a platform, as shown in the bar graphs below, influences its susceptibility to mechanical damage.





Dropped Object Damage by Platform Type



Vessel Impact Damage by Platform Type

Weld/Joint Defects

Weld/joint defects consist of cracks, fabrication defects and joint overload failures. Defects of this type correlate closely to platform vintages, and to identifiable subsets of platforms within vintages.

The following conclusions have been drawn with relation to the occurrence of weld/joint defects on platforms in the Gulf of Mexico.

i) Weld/joint defects occur on less than 1% of modern-RP2A vintage platforms and are associated with installation damage, fabrication defects and poor design/repair details such as welded stiffener/doubler plates.

ii) In both early-RP2A platforms and pre-RP2A platforms, approximately 80% of weld/joint defects result from a combination of fatigue damage and collateral damage from vessel impact.

iii) Fatigue damage in early-RP2A platforms is dominated by damage to the conductor guide frame at the first elevation below the water surface. This damage affects approximately 2% of the vintage population.

iv) General fatigue cracks have been found in around 1% of the early-RP2A platform fleet.

v) Early-RP2A vintage platforms where a failure of the CP system has been recorded at some time in the service life i.e. more heavily corroded platforms, are at increased risk of general fatigue damage.

vi) Conductor bay fatigue amongst the population of pre-RP2A platforms is consistent with early-RP2A vintage platforms. It occurs in a little over 3% of the vintage population; the relative increase being a function of the increased time of exposure.

vii) General fatigue damage is more widespread in pre-RP2A platforms than it is in early vintage platforms, affecting about 5% of the vintage population.

viii) Pre-RP2A platforms most susceptible to general fatigue damage are those installed in the latter part of the era in relatively (for the vintage) deep water, generally water depths of 100 feet or greater. The damage occurs mostly in primary joints close to the mud line.

ix) Joint overload failure defects occur at the mud line of pre-RP2A platforms that have inadequate deck heights (by modern criteria) and have been subject to extreme event loading.

Corrosion

Corrosion defects consist of pitting/holes, crevice corrosion, fretting and general/uniform corrosion. The majority of corrosion damage occurs in or above the splash zone.

i) Pitting corrosion and holes are the most common corrosion defects found on platforms in the Gulf of Mexico.

ii) Approximately 8% of the platform population has experienced interruption in the effective operation of the corrosion protection system although it was found that such interruption is not a good indicator of the level of corrosion on the platform.

iii) Inspection data indicates that close-visual joint inspection is a reliable indicator of the general corroded state of the platform. This finding is consistent with reports from underwater diving inspectors.

iv) More heavily corroded platforms, as defined by reported heavy visual corrosion of the steel surface, have an increased susceptibility to general fatigue damage.

Platform Anomalies

i) Marine growth measurements in excess of the API recommended design levels are widespread in the Gulf of Mexico.

ii) Marine growth anomalies beyond 40 feet water depth are rare in the coastal waters north of latitude 29° and west of New Orleans (longitude –90°).

iii) Marine growth thickness does not appear to increase indefinitely; a stable thickness is reached after a few years. Annual/seasonal variations in thickness do occur.

iv) Measured data indicates that a variable marine growth profile may be preferable in design to the constant 1.5 inches recommended in API RP2A and that marine growth should be considered, in design, beyond the 150 feet depth presently recommended in API RP2A. The impact of these findings is expected to be small.

v) Seafloor scour is not a concern for the large majority of Gulf of Mexico platforms due to the generally cohesive nature of the soils.

vi) Scour may occur because of temporary seabed movements during severe storms or hurricane events.

vii) Debris is not generally detrimental to structural integrity. Exceptions are; hanging objects that lead to fretting corrosion and metallic objects contacting the structure and reducing the efficiency of the CP system.

Data recording and defect reporting in the database is often of poor quality. Considerable subjective interpretation of information and screening of large amounts of incomplete data from the trend analyses was necessary. In future, clearer definition of reportable defects and improved data collection and reporting procedures will result in better allocation of valuable inspection resources and collection of data necessary for the continued integrity management of the platform fleet.

6. INSPECTION STRATEGY & GUIDELINES

6.1 Introduction

A key deliverable from the JIP is a set of In-service Inspection Guidelines. The Guidelines will be available for use by JIP participants, as an integral part of their structural integrity management system, to plan inspections and define appropriate intervals for Gulf of Mexico platforms. The Guidelines were developed through the application of the structural integrity management philosophy, outlined within ISO clause 24, to the Gulf of Mexico platform population.

The inspection strategy provides the basis for defining the detailed inspection scope of work and frequency of inspections. The inspection strategy is developed through a process of assessment and evaluation of all available data including inspection data, damage data, repair data, and all other data relevant to the structural integrity of the platform(s). The strategy must also consider a number of other issues, as follows:

- The motivation for inspection e.g. regulatory requirements, operator requirements, platform reuse/decommissioning and incident planning.
- The availability of inspection techniques (application and reliability).
- Scheduling flexibility.

Knowledge from the evaluation of the underwater inspection data for the Gulf of Mexico fleet is the single most important contributor to the development of the inspection strategy and guidelines contained herein. Other essential considerations in the development of the strategy include likelihood and consequence of platform failure and present condition. The likelihood of platform failure is influenced by a number of factors, as follows:

a) Robustness and Damage tolerance e.g.
   - Vintage (encompasses age and original design criteria)
   - Configuration of primary brace framing
   - Number of legs
   - Joint details
   - Skirt piles versus leg piles versus grouted leg piles

b) Present condition

c) Deck elevation

d) Water depth

e) Damage susceptibility

f) Similarities among platforms

Platform specific analyses, at least for Gulf of Mexico platforms, are not always necessary to be able to reliably assess the relative robustness or damage tolerance of different platforms. Industry experience of extreme storm events such as Hurricane Camille in 1969 and Hurricane Andrew in 1992 has improved understanding in these areas. Numerous analytical studies have further extended industry knowledge to the point where suitably qualified engineers can, based on an understanding of certain platform structural parameters, reasonably assess the relative robustness and damage tolerance of different platforms. This approach has been adopted in the inspection strategy and in the subsequent development of the In-Service Inspection Guidelines and inspection programs.

The present condition of the platform will also influence the inspection strategy. The present condition should be established, in the first instance, through the conduct of a baseline inspection of the platform. Baseline inspections are discussed in the Guidelines. Subsequent routine inspections will ensure the present state of each platform is updated at a suitable interval consistent with the overall inspection strategy for the platform, or type of platform, in question. It is important that inspection data is fed back to the data management system, suitable engineering evaluation carried out, and the inspection strategy adjusted accordingly. The evaluation process may indicate that damage is benign, however, this data should remain in the data management system as part of the platform damage register. This should ensure that future damage is evaluated in the light of existing damage. Evaluation 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.

6.2 Proposed Inspection Guidelines and Commentary

The Guidelines, presented below, are consistent with the philosophy within both API and ISO existing recommendations and have been laid out to reflect API RP2A Section 14 format to assist comparison therewith. A commentary to the Guidelines is provided to assist with interpretation and provide supplemental information for specific surveys.

14 IN-SERVICE INSPECTION

14.1 GENERAL

The purpose of in-service above water and underwater structural inspection is to detect, within a reasonable level of confidence, the existence and extent of deterioration, defects or damage. Data collected during an inspection is needed to verify the structural integrity of the platform.

The recommendations contained herein should be part of an on going structural integrity management (SIM) process. Data collected during the in-service inspection is integral to the SIM process. These guidelines have been developed from the partial application of the SIM methodology to the Gulf of Mexico Platform fleet.

14.1.1: Definitions

Inspection: An inspection is defined as the visit to the platform for purposes of collecting data important to its structural integrity and continued operation.

Survey: A survey is defined as a specific visual or non-destructive examination of one or more platform component. Collectively, the surveys make up the complete inspection.

Defect: Imperfection, fault, flaw or blemish in a component of the platform. Some suggestions on defect categorization are provided in commentary, Section C14.1.1.

Anomaly: An anomaly is defined as a survey measurement outside specification. Suggested thresholds for common surveys are discussed in the commentary, Sections C14.3-F to C14.3-I.

14.1.2: Inspection Types

a) Baseline Inspection

Baseline inspections are conducted to benchmark the initial platform condition for items not included in fabrication or pre installation inspections and to detect any early appearance of defects or deterioration.

b) Periodic Inspection

Periodic inspections should be used to identify deterioration/degradation and unknown defects over time. The periodic inspection strategy is made up of the inspection interval and scope of work, which may vary over time, depending on the evaluation results, during the service life of the platform.

c) Special Inspection

Special inspections may be required in certain circumstances as follows:

- To monitor repairs or known damage
- Prior to platform assessment or reuse*
- Post occurrence of extreme event (storm/earthquake/mudslide)**
- Post accidental event (impact/explosion)**

*In many cases, the structural integrity management process should identify assessment requirements and reuse candidates in sufficient time to permit adjustment of the periodic inspection scope of work.

**Subject to evaluation, special inspections may be planned to coincide with the periodic inspection with the scope adjusted accordingly.

Special inspections should be developed based on evaluation of all available data. Key elements of special inspections are the definition of objectives, selection of appropriate surveys (including tools/equipment) and timing.

14.2 PERSONNEL QUALIFICATIONS

The inspection program should be compiled and approved by a qualified and suitably experienced engineer familiar with the structural integrity aspects of the platform/s. The engineer should be involved in all phases of the structural integrity management cycle.

Offshore execution of the inspection program requires supervisors, divers, ROV operators and data recorders who are qualified in their assigned tasks. It is suggested that these qualifications should include:

- Qualification to international or equivalent regional standards.
- Knowledge of how and where to look for damage and situations that could lead to damage.
- Familiarity with the platform owner's/operator's data validation and quality requirements.
- Training and experience in the methods employed.
- For operatives/divers who will be performing NDE, accredited training/qualifications or underwater pre-qualification trials.

14.3 UNDERWATER SURVEYS

Platform surveys are required to detect, measure and record platform defects and anomalies. Platform defects may include excessive corrosion, weld/joint damage (including overload and fatigue damage) and mechanical damage in the form of dents, holes, bows and gouges. Platform anomalies may include, non-operating or ineffective corrosion protection system, scour, seafloor instability, hazardous or detrimental debris and excessive marine growth.

14.3-A: General Visual (GV) Survey

The GV survey should consist of a thorough underwater visual examination of the platform, including:

a) Structural Elements

- Primary structural framing
- Leg/pile connections
- Conductor guide framing
- Other secondary framing and appurtenances

b) Non-structural elements and supports

- Pipeline risers and supports
- J-tubes and supports
- Service caissons and supports
- Riser guards
- Boat landings and fenders

Commentary C14.3-A provides suggestions for performing GV surveys and data recording.

14.3.B: Anode Survey

The anode survey should consist of a thorough underwater visual examination of all (full survey) or some (part survey) of the platform sacrificial anodes.

Commentary C14.3-B provides suggestions on performing full and part anode surveys including depletion assessment and data recording.

14.3-C: Flooded Member Detection (FMD) Survey

The FMD survey should employ appropriate underwater non-destructive equipment to assess whether a platform member is 'dry', 'flooded' or 'partially-flooded'.

Commentary C14.3-C provides suggestions on performing FMD surveys including the extent of the survey, data recording and procedures in the event of the detection of 'flooded' members.

14.3-D: Visual Corrosion Survey

The visual corrosion survey should consist of localized cleaning and close visual examination of the steel surface of a platform element to assess the extent of corrosion.

Commentary C14.3-D provides suggestions on performing visual corrosion surveys including the extent and method of cleaning, location selection and data recording.

14.3-E: Weld/Joint Survey

The weld/joint survey should consist of a thorough underwater examination of the weld/joint. The location should be sufficiently cleaned of marine growth to permit thorough examination.

Commentary C14.3-E provides suggestions on performing weld/joint surveys including weld/joint selection, examination techniques and data recording.

14.3-F: Cathodic Potential (CP) Survey

The CP survey should consist of underwater measurements of the electrical potential of elements at selected locations either throughout the platform (full survey) or at selected locations (part survey).

Commentary C14.3-F provides suggestions on performing full and part CP surveys including location selection and data recording.

14.3.G Debris Survey

The debris survey should consist of an underwater visual search of the platform to locate debris that is either hazardous to personnel or potentially detrimental to platform structural integrity.

Commentary C14.3-G provides suggestions for performing debris surveys including debris classification and procedures for reporting and removal/retrieval.

14.3-H: Scour Survey

The scour survey should consist of the measurement of the seafloor relative to the platform's installed elevation. The scour survey may include local scour measurements, around platform legs/piles, and/or global scour measurements, of the seabed surrounding the platform.

Commentary C14.3-H provides suggestions on performing both local and global scour surveys including data recording.

14.3-I: Marine Growth Survey

The marine growth survey should consist of the measurement of the compressed marine growth thickness (CMGT), or approved alternative, at pre-selected locations, either throughout the platform (full survey) or at selected locations (part survey).

Commentary C14.3-I provides suggestions on performing full and part marine growth surveys including data recording.

14.3-J: Appurtenance Inspection

Appurtenance inspections should consist of selected surveys of non-structural elements and their supports including risers, caissons and j-tubes.

Commentary C14.3-J provides suggestions on performing appurtenance inspections including suggested surveys for specific appurtenance types.

14.4 ABOVE WATER INSPECTION

The above water inspection should consist of a general visual (GV) survey (see Section 14.3-A) of the platform structure located above the mean water level, including the splash-zone. The visual inspection should determine the effectiveness of the corrosion protection system and detect deteriorating coating systems and excessive corrosion.

The inspection scope should include below-water verification of the performance of the cathodic protection system by dropped cell or other method.

14.5 INSPECTION LEVEL (SCOPE)

14.5.1 Baseline Inspection

A baseline inspection should be performed as soon as practicable after the platform installation and commissioning. The minimum scope of work should consist of the following unless the data is available from the installation survey:

- A GV survey of the platform from the mud-line to top of jacket (members and joints) including coating integrity through the splash zone.
- Anode count (verify presence and integrity)
- Appurtenance survey.
- Measurement of the mean water surface elevation as-installed, with appropriate correction for tide and sea state conditions.
- Tilt and platform orientation.
- Riser and J-tube soil contact.
- Scour survey (seabed profile).

14.5.2 Periodic Inspection

The scope of work for periodic underwater inspection depends on the platform susceptibility to defects and anomalies, its robustness and its present condition. The platform consequence of failure may also play a part in determining the final scope of work at the discretion of the planning engineer.

Application of the structural integrity management process to Gulf of Mexico platforms has identified three inspection scopes appropriate for periodic inspections:

Level II – Green inspection
Level III – Yellow inspection
Level IV – Red inspection

Figures 14.5-1 and 14.5-2 should be used to determine the suggested inspection scope for the platform(s) under consideration.

SUSCEPTIBILITY TO MECHANICAL DAMAGE	SUSCEPTIBILITY TO WELD/JOINT DEFECTS: Pre-RP2A – Corroded or Unknown CP History and/or >100'	Pre-RP2A – Inadequate Deck Elevation	Pre-RP2A – Pre	Early-RP2A – Corroded or Unknown CP History	Early-RP2A – Early	Modern-RP2A
HIGH Drilling	IV	IV	IV	IV	IV	III
MEDIUM Other	IV	IV	III	IV	III	II
LOW Caisson Well Prot.	IV	III	III	III	III	II

Figure 14.5-1: Guideline Inspection Scopes

Reference	Defect Surveys	Inspection Level II	Inspection Level III	Inspection Level IV
14.3-A	General Visual	X	X	X
14.3-B	Anode	X	X	X
14.3-C	Flooded Member Detection		X^P	X^P
14.3-D	Visual Corrosion	(1)	X	
14.3-E	Weld/Joint			X
14.3-F	Cathodic Potential		X^P	X
Reference	**Anomaly Surveys**			
14.3-G	Debris	X	X	X
14.3-H	Scour	(2)	(2)	(2)
14.3-I	Marine Growth			X
Reference	**Appurtenance Surveys**			
14.3-J	Riser / J-Tubes / Caisson	if present		

X^P Part survey
(1) Not required if a continuous annual drop cell record so indicates.
(2) If seafloor is conducive (loose sand) or seafloor instability is known/suspected.

Figure 14.5-2: Guideline Scope of Work

The commentary provides additional guidance on survey techniques, tools and applications.

14.5.3 Special Inspections

Initiators for a special inspection are identified in section 14.1.2. Surveys should be selected consistent with the nature of the event. Particular attention should be given to detecting damage and indirect signs of damage, such as localized areas of missing marine growth.

14.6 INSPECTION FREQUENCY

The time interval between platform inspections should be determined in accordance with the overall structural integrity management philosophy. Figure 14.6-1 provides guidance on the selection of intervals between routine platform inspections. The ranges presented are taken from existing guidance provided in API RP2A 20th Edition Supplement 1.

The selection of an appropriate interval from the applicable range should be initially based on the platform's vintage (with additional sub-categories for pre and early vintage platforms) as shown in Figure 14.6-1. The vintage definitions are based on extensive evaluation of Gulf of Mexico underwater inspection data and are intended to be indicative of the relative robustness and damage tolerances of different platform generations.

Appropriate engineering judgment on the relative robustness of alternative platform configurations (e.g. # of legs, framing, joint details etc.) and associated analytical data or assessment information will support the selection of extended intervals towards the upper bounds of the ranges provided in Figure 14.6-1.

	SUSCEPTIBILITY TO DEFECTS				
	Pre-RP2A		Early-RP2A		Modern-RP2A
Exposure Category Level	Corroded or Unknown CP History and/or >100'	Pre*	Corroded or Unknown CP History	Early	Modern
1	3-5 yrs		5-10 yrs		10 yrs
2	5-10 yrs		10 yrs		10-15 yrs
3	5-10 yrs		10-15 yrs		15 yrs

Figure 14.6-1: Guideline Inspection Intervals

Exposure category levels indicated in Figure 14.6-1 are defined in the existing guidance provided in API RP2A 20th Edition Supplement 1.

14.7 PRE-SELECTED AREAS

During platform design and any subsequent assessment, critical elements should be identified to assist in focusing future platform surveys. Selection of critical areas should be consistent with the overall structural integrity management process and should be based on such factors as:

- Data collected from the baseline survey.
- Familiarity with relevant information about the specific platform(s) under consideration.
- Knowledge of general inspection findings in the offshore industry.
- The significance of members and joints to the platform system capacity.
- Knowledge of the platform damage tolerance.
- Joint and member stresses and stress concentrations.
- Joint fatigue lives.

14.8 DATA RECORDS

Records of above water and underwater platform inspections should be maintained by the owner/operator, within a managed system for the archive and retrieval of such data and other pertinent records, for the life of the platform. Such records should include the inspection level performed and detailed accounts of the surveys carried out including photographic evidence, measurements and other recorded data.

Detected defects and anomalies should be thoroughly documented and included with the survey results together with the subsequent engineering evaluation and any resulting repairs or specified monitoring requirements.

C14 IN-SERVICE INSPECTION

C14.1 GENERAL

The objectives of an underwater survey are to detect and properly measure any evidence of damage or distress, to carry out routine inspection and measurement of items that affect structural integrity and performance and to record and report all findings and measurements in a standard and meaningful manner. Consistency, accuracy and completeness of inspection records are important since these data form an integral part of the structural integrity management system.

C14.3 UNDERWATER SURVEYS

For each survey identified in Section 14.3 of the Guidelines, a suggested scope of work is presented below together with suggestions for data recording and for defect and anomaly reporting. The defect and anomaly reporting systems are intended to ensure that sufficient data is collected for an effective engineering evaluation to be carried out.

Where a defect or anomaly is discovered an additional scope of work may be necessary and additional reporting requirements may come into effect. For anomaly surveys, including debris surveys, scour surveys and marine growth surveys acceptance criteria are suggested to establish thresholds for the definition of anomalies.

C14.3-A: General Visual (GV) Survey

The object of the GV survey is to detect signs of mechanical damage such as missing or separated members, dents, gouges and bows, and major joint/weld defects including large cracks, separation and distortion, visible without marine growth removal. The survey generally extends up to the high water mark, however, if new damage is observed above this level, then this should also be reported. The survey should include visual examination of appurtenances to detect loose or missing items and/or other obvious signs of deterioration. The survey will normally be carried out by ROV below the air diving range.

Indications of missing marine growth or coating scuffing may be evidence of impact damage. Such indications should be closely investigated for both primary and collateral damage. Close attention should also be given to platform nodes to identify large cracks or visible distortion.

Data/Defect Recording: Records from the GV survey should include details of the extent of coverage. In particular, data records should identify regions or elements of the platform, including appurtenances, not examined in the GV survey. An explanation why the region or element was excluded should be provided.

Defects detected during the GV survey should have their location accurately identified and should be appropriately measured in accordance with a standardized procedure. Defects will generally be classified as follows:

- Variations from the platform database (e.g. missing members).
- Mechanical damage: Dents, gouges, bows, holes and distortion should be suitably measured and recorded. Collateral damage should be identified as such, where discernable. Records should include the location and extent of the defect and close-up photographic documentation.
- Weld/Joint Defects: The location, size and extent of cracks/separation should be suitably measured and recorded. Records should include the location and extent of the defect and close-up photographic documentation.
- Corrosion: Evidence of heavy uniform corrosion, heavy pitting and/or any fretting or abrasion corrosion should be recorded. Records should include the location and extent of the defect and close-up photographs of the corroded surface.

Measured data should be sufficient to permit subsequent engineering evaluation of the defect/s, for example:

Dents – measurements shall determine the general shape of the dent, depth and location of maximum depth (clock position), maximum length and maximum width. The edge sharpness should also be determined.

Bows – measurements shall record the bow profile, maximum deflection and orientation relative to the member axis.

Holes – measurements shall determine the location and shape of the hole. Multiple holes shall be carefully measured.

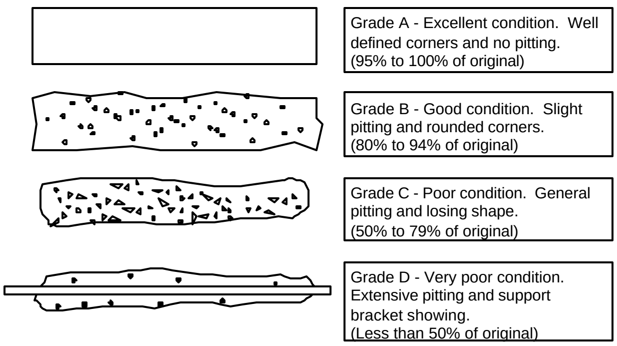
Gouges – measurements shall determine the general length, depth and location of the gouge.

Minor impact damage to boat fenders or riser guards need not be reported in detail. It is suggested that for fender damage a photographic record is sufficient. The integrity of structural supports should, however, be carefully checked.

Data recording for anode, debris and platform appurtenances are identified in Sections C14.3-B, C14.3-G and C14.3J, respectively.

C14.3-B: Anode Survey

The object of the anode survey is to locate, count and estimate depletion of platform anodes. Anode depletion may be graded by their condition as follows:



This system is preferred to a percentage depletion estimate since it is not as reliant on prior knowledge of the original shape and size of the anode, however, it is subjective.

Depending on the results of the annual above-water CP survey and the extent and results from other surveys used to assess the level of corrosion e.g. the underwater CP survey (14.3-F) and the visual corrosion survey (14.3-D) either a full or part anode survey may be required.

Full Survey: A full anode survey includes all platform anodes.

Part Survey: A part anode survey typically includes anodes associated with one or more specified legs or as specified in the detailed inspection scope of work.

Data Recording: Data recording from the anode survey should identify the location (member to which the anode is fixed and position thereon) and grade of the platform anodes. If known (or discernable) anodes should be identified as being either original or retrofit.

Anomaly Reporting: Grade D anodes should be reported as anomalous. Anodes identified as loose, damaged or missing should also be recorded as anomalous.

C14.3-C: Flooded Member Detection Survey

The object of the flooded member detection (FMD) survey is to determine whether platform underwater members are 'flooded', 'partially-flooded' or 'dry'. FMD is performed using either ultrasonic (UT) or radiometric (RT) techniques. RT FMD is more typically performed by ROV and may be preferred below air diving depths or where heavy corrosion is anticipated, which may reduce the reliability of UT techniques. Both UT and RT FMD can reliably determine member flooding provided an appropriate specification is used, based on established and tested practice.

Flooding of members may be indicative of through-wall fatigue cracking in welded joints or attachments and, therefore, flooding checks provide a useful screening of members considered prone to such damage, in particular, members in or supporting the conductor-guide frame (CGF) within approximately 100 ft. of the water surface. Flooding may also result from other through-wall defects associated with fabrication, mechanical damage or corrosion.

Caution is advised in the application of the technique to primary structural members framing into platform legs. These connections are not prone to fatigue damage in most platforms, however, if fatigue cracks do occur they are more likely to develop on the chord-side of the weld and may not result in flooding of the brace.

The strategy for the extent of coverage for the FMD survey should be consistent with the overall structural integrity management philosophy being applied.

Part Survey: A part FMD survey should be confined to the CGF members and support structure to a specified depth of approximately 150 ft. and other members specified in the detailed scope of work.

Full Survey: A full FMD survey should include the CGF and either, all primary-framing members, or selected members based upon their importance to the continued integrity of the platform.

Data Reporting: All members checked for flooding should be clearly identified as 'dry', 'flooded' or 'partially-flooded'. Suitable procedures should be employed to detect the water level in 'partially-flooded' members and this should be recorded.

Defect Reporting: All 'flooded' or 'partially-flooded' members should be reported as anomalies.

In the event of flooding being detected, the cause of flooding should be established and recorded as a defect in the survey report. The member and its end joints shall be visually examined for signs of through-wall defects such as corrosion (pitting or fretting), mechanical damage, cracks/separation or perforation at anode or other attachments. If necessary, marine growth should be removed to assist visual inspection. If the cause of flooding is not detected after cleaning then this should be recorded since the cause of flooding is likely not detrimental to structural integrity.

C14.3-D: Visual Corrosion Survey

The visual corrosion survey should consist of local manual cleaning (brush/scraping tool or similar) of the steel surface and close visual examination to determine the level of corrosion. The cleaning need expose no more that a six-inch square. The selected location/s for the check should be continuously submerged i.e. not within the splash zone. It is suggested that two locations are generally sufficient to establish the overall level of corrosion. One location should be at a member end weld, the other at any convenient location along a primary member. This survey should be carried out ahead of any non-destructive testing since knowledge of the general level of platform corrosion will assist data interpreters of UT inspection equipment, including wall-thickness gauges and UT FMD tools.

Data Reporting: For each location the survey report should include close-up photographic record of the steel surface condition. Uniform surface corrosion should be graded as light, medium or heavy and color photographs should be provided in the survey specification to assist the data recorder with selection of the appropriate grade. If pitting is present the maximum depth should be measured using a suitable gauge.

Defect Reporting: ‘Heavy’ uniform corrosion and pitting greater than 3mm depth shall be considered as a defect and identified as such in the inspection report.

C14.3-E: Weld/Joint Survey

The objective of the weld/joint survey is to confirm or otherwise the integrity of selected welded joints on the platform and to detect, quantify and report associated defects. Joints may be selected in a number of ways, including:

- The known historic susceptibility of similar joints on similar platforms to fatigue or overload damage.
- Knowledge of existing damage at, or adjacent to, the joint (includes damage monitoring).
- The critically of the joint to the platform integrity during occurrence of the extreme event.

The joint selection strategy should be consistent with the overall structural integrity management philosophy adopted.

Weld/joint surveys should include complete removal of marine growth and close visual examination of the weld. A visual corrosion survey should also be carried out using the guidelines of Section 14.3-D.

<u>Initial Cleaning</u>: The initial cleaning should remove marine growth by cleaning to black-oxide to a distance of at least six-inches from the weld.

<u>Close Visual Examination</u>: Close visual examination should be undertaken for the detection of major cracks, holes, separation or distortion of the brace-end or chord wall.

Depending on the inspection strategy, it may also be required to clean the weld and HAZ to bright metal (e.g. using a low-pressure grit blaster) and to examine the weld with a non-destructive technique e.g. Magnetic Particle Inspection (MPI). Factors involved in this decision include the planned inspection interval, the fatigue sensitivity of the joint and the tolerance of the platform to defects at the joint location, all of which should be addressed in the inspection strategy. Where non-destructive techniques are used, detailed specifications should be provided and the testing undertaken by suitably qualified and experienced personnel. Procedures should include guidance for the confirmatory grinding of indications and remedial grinding and crack-arrest drilling for confirmed cracks.

Data Recording: Joint/weld survey reports should include details of the weld and establish a datum and reference for reporting of all observations and defects. A complete photographic mosaic of the weld should be provided with a continuous reference from datum along the full length of the weld. Photographic recording of both visual and NDE defects is required. Defect recording is discussed below. In addition, data should be recorded on non-defect fabrication flaws and confirmatory grinding.

Defect Reporting: All weld/joint defects should be reported including, accurate location, detailed measurement and photographic record. Defects include cracks, holes, member separation, distortion of the brace-end or chord wall and certain fabrication flaws (incomplete welds, lack of fusion and porosity and undercut greater than 2mm).

Corrosion defect reporting should be consistent with the requirements 14.3-D and shall include location, and measurement of any detected crevice corrosion

C14.3-F: Cathodic Potential (CP) Survey

The objective of the cathodic potential survey is to confirm or otherwise the correct operation of the platform corrosion protection system. Annual CP surveys should be carried out using drop cell or comparable techniques as part of the above-water inspection.

An underwater CP survey may also be required depending on the results of the annual above-water survey and other underwater surveys such as the visual corrosion survey and the anode survey. These other indicators of the effectiveness of the corrosion protection system may also be used to define the extent of the underwater CP survey.

Full Survey: A full survey is designed to provide full coverage of the underwater structure and will typically require readings are taken on jacket legs at each framing (node) level, LAT and halfway between these framing levels on the outside of the legs. Readings should also be taken half way along all adjoining braces and at other locations specified in the detailed scope of work.

Part Survey: A part survey typically consists of readings on a single leg at each framing (node) level, LAT and halfway between these framing levels on the outside of that leg only.

CP surveys may also be carried out during appurtenance surveys e.g. riser, conductor, caisson and J-tube surveys, see Section 14.3-J.

Data Recording: Electrical potentials shall be measured in millivolts with reference to Ag/AgC1 half-cells. The location and value of every reading should be recorded.

Defect Recording: Any and all potential readings outside the range of –850mV to –1150mV should be reported as anomalous. If the average of all readings lies outside the same range, this should be additionally reported as a separate anomaly.

C14.3-G: Debris Survey

The objective of the debris survey is to locate debris on the mud-line members of the structure or snagged in the upper structure. Debris should be removed from contact with the platform if it is hazardous to personnel, metallic or obstructs inspection activities. Large items, which cannot be moved, shall be recorded.

When large or heavy items of debris are discovered, the structure above should be checked for mechanical damage. The structure shall be checked for fretting or abrasion damage where debris is found in contact with the platform.

Data Recording: The location and identification of all debris on mud-line members of the structure or snagged in the upper structure should be recorded. The record shall state if the debris was removed. Photographic record shall be provided for all debris that is not removed.

Defect Recording: Any items of debris on mud-line members of the structure or snagged in the upper structure, which are hazardous, metallic or may obstruct future inspection activities, and were not removed, shall be reported as anomalies.

C14.3-H: Scour Survey

The objective of the scour survey is to detect and report seafloor movements relative to the jacket. Care should be taken to ensure that measurements are compared to a confirmed datum level. Two types of scour can be identified. Global scour consists of shallow scoured basins of large extent around the structure. Local scour is usually seen as steep-sided scour pits around structural elements such as piles and legs. In the Gulf of Mexico scour is not generally found due to the cohesive nature of the soils. It may however be a concern if the platform is located on loose sandy soils or where seabed movements are possible during severe storm events.

Full survey: The scope of work is designed to detect and record both local and global scour. Measurements should be taken at the outside of each leg and from the underside of the perimeter horizontal bracing to the mudline.

Part survey: The scope of work is designed to detect either local or global scour. Measurements should be taken on the outside of corner legs as specified in the detailed scope of work.

Data/Defect Recording: Physical measurements should be taken at platform legs and beneath the bottom horizontal bracing and all measurements shall be recorded. Physical measurements (i.e. measuring rule) are preferred to diver depth-gauge readings. If the depth-gauge is used it should be calibrated to some platform datum and the calibration so recorded.

The occurrence of any gravel dumps around the platform should also be reported, as should any sandbagging of pipelines.

C14.3-I: Marine Growth Survey

The object of the marine growth survey is to measure and record the thickness of marine growth fouling on the structure. In the Gulf of Mexico marine growth rarely extends below 200 ft. Details of the type of growth are not normally required.

Marine growth thickness should be measured and recorded as a compressed marine growth thickness (CMGT). CMGT is determined by wrapping a broad tape (3"- 4" wide) around member growth and pulling it tight to record the measurement. Care should be taken to avoid hang-ups with the measuring tape so that an accurate reading is achieved.

Part Survey: A part marine growth survey should include measurements both above and below all major elevations of the platform down a single leg.

Full Survey: A full marine growth survey should extend to additional legs and associated bracing. Measurements may also be taken along a representative conductor.

When taking measurements in a specified area, a representative zone of marine growth thickness should be chosen.

Data Reporting: The location and value of all CMGT readings should be reported. Photographs showing the fouling make-up should be provided for each measurement site. The measurement tape should be in-place and the compressed growth reading should be visible in the photograph.

Anomaly Reporting: CMGT readings indicating marine growth thickness in excess of that used in the most recent design/assessment should be reported as anomalies. In the absence of such information a thickness of two-inches is suggested as the anomaly threshold for Gulf of Mexico platforms.

C14.3-J: Appurtenance Inspection

Non-structural platform appurtenances including risers and J-tubes, caissons and conductors should be included within other platform surveys as appropriate. In particular, appurtenance inspection should include GV and debris surveys. Consideration should also be given to other platform surveys as follows:

- Visual corrosion survey
- Cathodic potential survey
- Marine growth survey

A number of appurtenance-specific surveys may also be included in the scope of work as follows:

Riser Coating: The riser coating should be examined to determine type, integrity and depth of termination. At damage locations UT wall thickness readings should be taken, see C14.3-D.

Support Clamps: Support clamps and guides should be sufficiently cleaned and visually examined to determine their integrity and that of their fasteners. Loose or missing fasteners should be tightened or replaced.

Caisson Intakes: The lower section of the caisson around the intake should be cleaned and any blockages removed.

Pipeline Spans: The riser inspection should extend to the bury-point or anchor-point or to a reasonable alternative distance from the platform (e.g. 50ft.). Any suspension of the pipeline should be measured and recorded.

Data Recording: Data recording should be consistent with the requirements of the surveys undertaken; in addition, the location and extent of any suspensions of the pipeline should be measured and recorded.

Defect Reporting: Defect reporting should be consistent with the requirements of the surveys undertaken; in addition coating damage, lack of clamp integrity (loose bolts, slippage, liner loss or excessive degradation), pipeline spanning and caisson blockages not removed should be recorded as defects.

7. BENCHMARKING

7.1 Objectives

Several platforms were used to "benchmark" the proposed inspection Guidelines. The objectives of the benchmark task were to test the guidelines for applicability and completeness and update as necessary.

The benchmark platforms also provide useful examples of the application of the guidelines and provide a "go-by" of minimum requirements for Participants when developing inspection plans for their own platforms.

7.2 Selected Platforms

Six platforms of different types and configurations were used for the benchmarking process as summarized in Table 7.1. A variety of platform types (drilling, quarters, etc.), configurations (caisson, 4-leg, 8-leg, X braced, etc.), and installation dates were used in order to demonstrate applicability of the guidelines over a range of typical platforms found in the Gulf of Mexico. The platforms were taken from the dataset of platforms provided by the JIP participants. The platform information was appropriately desensitized and some changes made to operation and configuration issues in order to demonstrate use of the guidelines.

ID	Type	Year	General Configuration	Bracing Scheme	Damage Susceptibility	Defect Susceptibility	Other Issues
1	Caisson	'95	Caisson	Braced	Low	Modern	
2	Drilling	'90	4 pile	X	High	Modern	(1)
3	Drilling	'75	4 pile	X	High	Early	
4	Quarters	'75	8 pile	X	Medium	Early Corroded	(2)
5	Tender	'68	8 pile	Diagonal	Medium	Pre	
6	Compressor	'68	4 pile	X and Diagonal	Medium	Pre >100 ft WD	

Notes:
(1) Future wells planned
(2) Existing damage (corrosion and flooded-member)

Table 7.1: Summary of Benchmark Platforms

Figure 7.1 shows how the benchmark platforms fit into the inspection 'scope of work' matrix from the Guidelines. The benchmark platforms were selected to test a range of Green, Yellow and Red inspection scenarios. Most emphasis has been placed on Red inspections as these are generally more complex and, therefore, require validation that is more thorough.

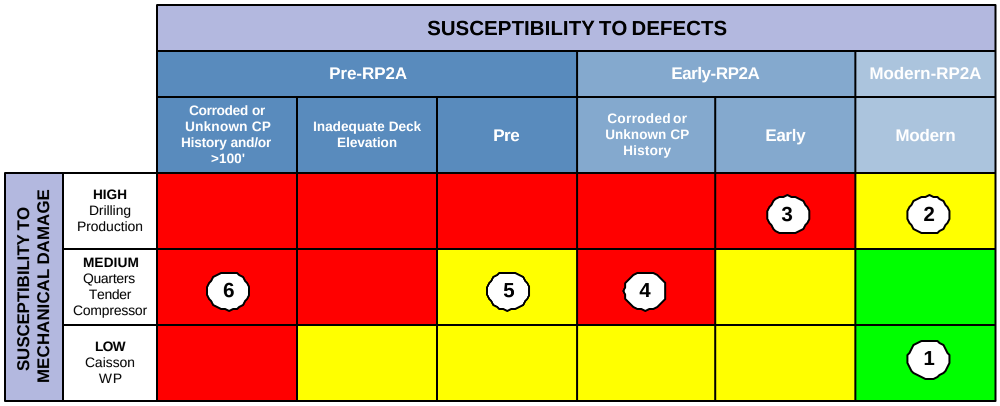


Figure 7.1: Locations of the Benchmark Platforms in the Inspection Scope Matrix

7.3 Benchmark Case Descriptions

The following sections provide a brief description of each of the benchmark cases and the resulting findings. A specific figure and summary table for each case is provided at the end of each case description. The summary table identifies the type of inspection used, identifies the guideline reference section and provides a brief description/clarification of the inspection. Note that in all cases, a 'general visual survey' and 'anode survey' are carried out during the inspection of the platform.

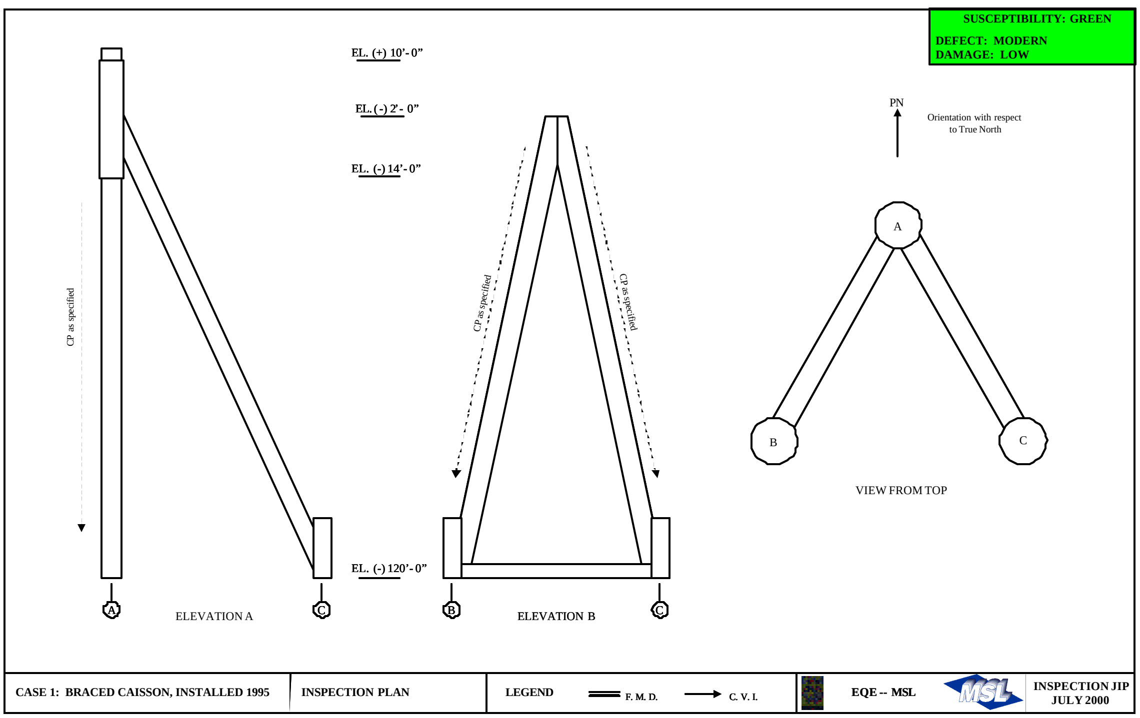
Case 1 - Braced Caisson, Installed 1995

This is a Modern-Vintage/Low-Consequence platform. A Level II (green) inspection is required as indicated in Figure 7.1.

Per the guideline, there are no FMD checks or Joint/Weld inspections. A corrosion check is used to assess the surface condition of the structure's steel. This is the only cleaning of the structure required. Although not required per the guideline, a 'full CP' survey was selected for this braced caisson (a form of special structure). This was felt prudent since the pile-top portion of the vertical diagonal members is located at a good distance from the caisson, where the CP system may not be fully effective. In addition, there is no access to the pile tops via the yearly drop cell CP readings, hence a full-CP survey is called out.

CASE 1: BRACED CAISSON
SCOPE OF WORK

PLATFORM INSPECTION	TYPE	GUIDELINE REFERENCE	SURVEY DESCRIPTION
DEFECT SURVEY			
General Visual	FULL	14.3-A	All members, joints, appurtenances, and appurtenance connections.
Anode Survey	FULL	14.3-B	Survey all anodes. Anodes to be graded.
Flooded Members	NONE	14.3-C	None required.
Corrosion Check	PART	14.3-D	Clean 6" square patch on caisson at (-) 10 ft or lower and CVI to determine steel condition.
Joint/Weld Inspection	NONE	14.3-E	None required.
Cathodic Potential	FULL	14.3-F	Readings to be taken at: LAT, (-) 50' and (-) 100' on the caisson; (-) 50' and (-) 100' on the braces; and at midway between the botton and top of the pile guides.
ANOMALY SURVEY			
Debris Survey	FULL	14.3-G	To be done as part of General Visual. The seabed immediately surrounding the structure. Remove any hanging debris if safe to do so.
Scour Survey	NONE	14.3-H	None required.
Marine Growth	NONE	14.3-I	None required.
APPURTENANCE INSPECTION			
Risers Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.
Caisson Survey	NONE	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.



Case 2 - 4-Pile Drilling Platform, Installed 1990

This is a Modern-Vintage/High-Consequence platform. A Level III (yellow) inspection is required as indicated in Figure 7.1.

Per the guideline, there is an FMD survey but no joint/weld survey. A 'part FMD' is used on the platform, omitting the mud-line braces, which are not critical for strength in most jackets, and the horizontal braces, which are not critical for X-braced structures due to their "robust" configuration. As described in the inspection techniques section, X-braced structures are particularly suitable for FMD when other, more intensive checks, such as close-visual surveys, are not used. The X-brace configuration provides a high degree of redundancy, and even if the FMD checks are in error, there are sufficient alternative load paths to rely on FMD alone to assure adequate integrity. Since it is a four–pile platform, the full FMD survey was reasonably extensive since it is relatively easy to FMD a platform of this size by diver.

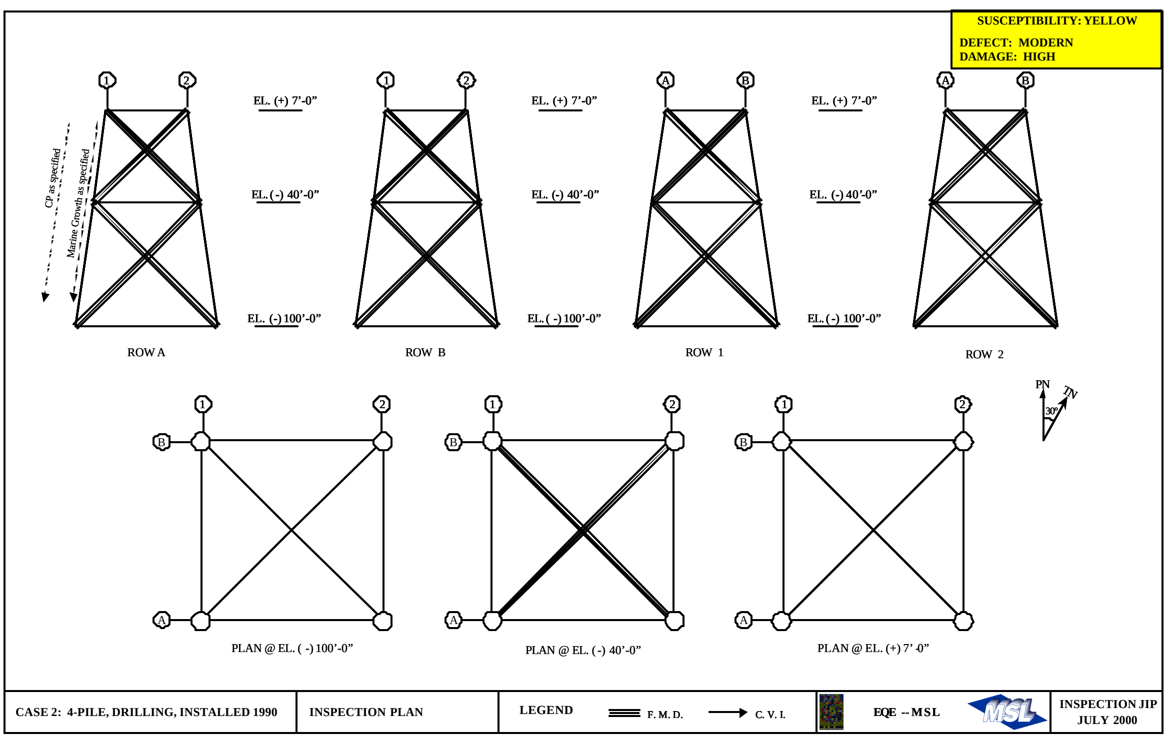
A Corrosion Check is used to determine the existing condition of the structure's steel on one of the legs by cleaning a small patch and performing a close-visual survey.

A 'part CP' survey is used to check potential readings along one leg.

Since the diver is going to be in the water for the CP survey, a marine growth survey is also taken along leg A1. Although not specifically required by the guideline, for a "yellow" inspection, the marine growth data was collected since several future wells are planned for the platform and a structural assessment per API RP 2A Section 17 will have to be performed. The marine growth survey will allow the use of actual field conditions for the assessment.

CASE 2: 4-PILE, DRILLING, INSTALLED 1990
SCOPE OF WORK

PLATFORM INSPECTION	TYPE	GUIDELINE REFERENCE	SURVEY DESCRIPTION
DEFECT SURVEY			
General Visual (GV)	FULL	14.3-A	All members, joints, appurtenances and appurtenance connections.
Anode Survey	FULL	14.3-B	Survey all anodes. Anodes to be graded.
Flooded Members	PART	14.3-C	All vertical diagonals, and horizontal diagonal framing at (-) 40' as shown in drawing.
Corrosion Check	PART	14.3-D	Clean 6" square patch on any leg at (-) 10 ft or lower and CVI to determine steel condition.
Joint/Weld Inspection (CV)	NONE	14.3-E	None required.
Cathodic Potential	PART	14.3-F	Readings to be taken on the outside of A1 leg at each framing (node) level, LAT and halfway between the framing levels.
ANOMALY SURVEY			
Debris Survey	FULL	14.3-G	To be done as part of General Visual. The seabed immediately surrounding the structure. Remove any hanging debris if safe to do so.
Scour Survey	PART	14.3-H	Measurements to be taken on the outside of each leg.
Marine Growth	PART	14.3-I	Measurements of compressed marine growth to be taken on A1 leg above and below all major elevations.
APPURTENANCE INSPECTION			
Riser Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.
Caisson Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.



Case 3 - Four-Pile Drilling Platform, Installed 1975

This is an Early-Vintage/High-Consequence platform. A Level IV (red) inspection is required as indicated in Figure 7.1. The structure is the same as that used in Case 2, except that it was installed 15 years earlier in the Early-RP2A era.

Per the guideline, the inspection includes FMD and joint/weld surveys. The FMD survey is a 'full' survey with the exception of the mud-line braces, which are not critical for strength. No separate corrosion check is performed since the joint/weld surveys will provide a suitable visual indication of the level of corrosion on the platform.

Four joints were selected for close-visual inspection. These are located at the member ends of a combination of compression and tension members along orthogonal sides of the platform. Typically, in the Gulf of Mexico, hurricane extreme waves (which are the most concern to the structure) progress from a Westerly heading to a Northerly heading. On the subject platform, Row B is approximately aligned east-west and Row 1 approximately aligned north-south.

The combination of compression (bottom bay) and tension (top bay) braces provides a check on the most heavily loaded members of the platform (compression) as well as the members that contribute the most to platform robustness. Robustness relates to the amount of damage that a platform can tolerate. The tension members of an X-braced frame provide the robust nature of the platform that allow it to take the highest loads (after failure of the compression brace) and are the members that determine the reserve strength of the platform. In other words, the compression members may fail in a storm, but ultimately the tension-members prevent collapse, hence their importance to structural integrity. Note that only the member ends of these braces are selected for cleaning and close-visual examination, other braces connecting to the node do not need to be cleaned. The upper and lower vertical diagonals are both cleaned and inspected at the (-) 40 ft. elevation on Leg A1 and Leg B2 so that the diver can perform the cleaning of two member ends at a single node.

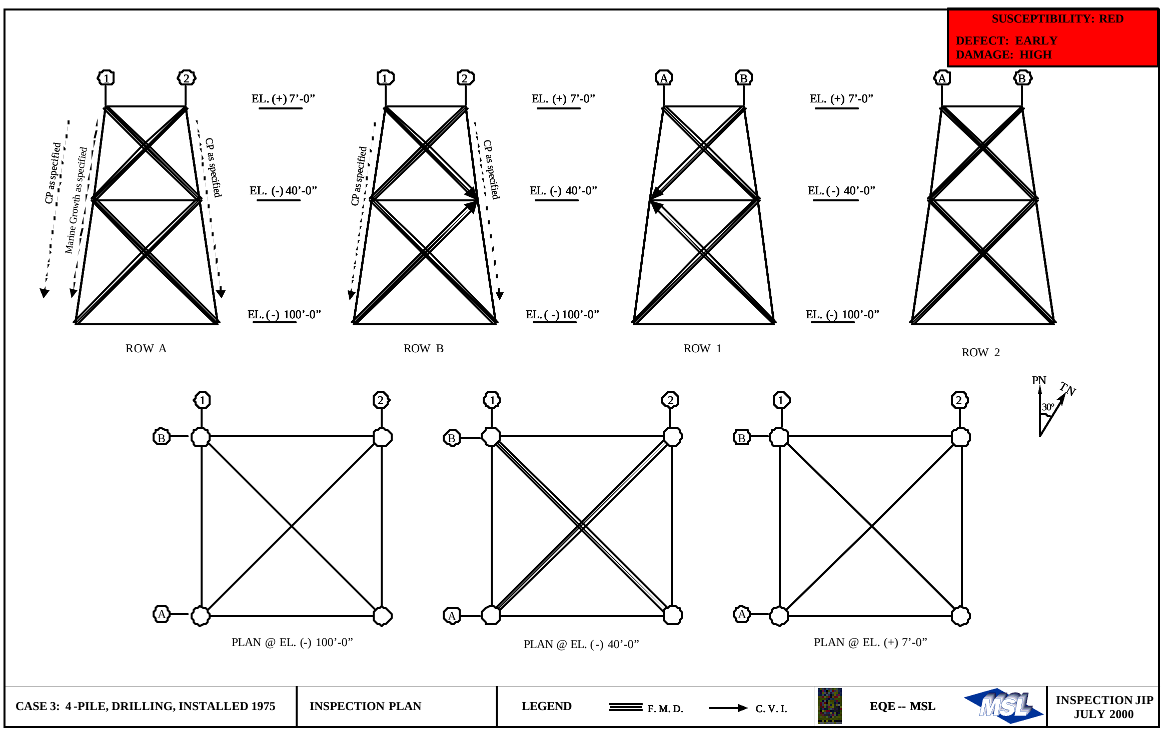
The selection of the particular braces for this case is based upon work done elsewhere (Gebara, et. al., 1998, EQE, 2000). As stated in the guidelines, engineering input should be used to define the inspection and references of this nature may be used by the operator to justify node selection in lieu of structural analysis. The operator could also have performed structural analyses to make such a decision, for example, based upon a design level strength check to determine the braces with the maximum loading under extreme wave conditions, or pushover analysis to determine the critical members that determine the RSR and collapse.

A 'full CP' survey is conducted at the four corner legs per the guidelines for a red-inspection.

A Marine Growth survey is taken along one of the legs as required for a Red inspection.

CASE 3: 4-PILE, DRILLING, INSTALLED 1975
SCOPE OF WORK

PLATFORM INSPECTION	TYPE	GUIDELINE REFERENCE	SURVEY DESCRIPTION
DEFECT SURVEY			
General Visual	FULL	14.3-A	All members, joints, appurtenances and appurtenance connections.
Anode Survey	FULL	14.3-B	Survey all anodes. Anodes to be graded.
Flooded Members	PART	14.3-C	All vertical diagonals, and horizontal diagonal framing at (-) 40' as shown in drawing.
Corrosion Check	NONE	14.3-D	None required.
Joint/Weld Inspection	PART	14.3-E	Four member ends per drawing.
Cathodic Potential	FULL	14.3-F	Readings to be taken on the outside of the jacket legs at each framing (node) level, LAT and halfway between the framing levels. Readings also to be taken halfway along all adjoining braces.
ANOMALY SURVEY			
Debris Survey	FULL	14.3-G	To be done as part of General Visual. The seabed immediately surrounding the structure. Remove any hanging debris if safe to do so.
Scour Survey	PART	14.3-H	Measurements to be taken on the outside of each leg.
Marine Growth	PART	14.3-I	Measurements of compressed marine growth to be taken on A1 leg above and below all major elevations.
APPURTENANCE INSPECTION			
Riser Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.
Caisson Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.



Case 4 - 8-Pile Quarters, Installed 1975

This is an early vintage/medium-consequence platform with heavy uniform corrosion observed during previous close-visual surveys. A Level IV (Red) inspection is required as indicated in Figure 7.1.

Per the guideline, an FMD survey is specified. A part-FMD survey is chosen; focused on Row A, Row 1 and Row 2. This is because Row B, Row 3 and Row 4 were surveyed with FMD in the last inspection and the operator chose not repeat the inspection at this cycle. With an eight-leg jacket there are many members to inspect, particularly taking into account the X bracing and the fact that there is only one "through" member. Hence, unlike the four-leg platforms, it was decided to rotate between inspections the Rows that warrant FMD survey. An additional FMD has been requested on the previously identified "flooded member" on Row B, with the intent of confirming that the member is flooded and, if necessary, invoking a more rigorous examination to determine the cause.

Fatigue induced cracking of conductor guide framing in the upper most levels below the waterline is a concern due to vertical wave kinematics combined with the large 'sail' area in the conductor guides. This problem can be readily detected with FMD, since the cracks occur at the ends of the intermediate horizontals that tie into the main horizontal bracing (Rows 3 and 4 in this case). Since all of these members are buoyant at these nodes, FMD will identify a flooded member whether cracks occur on the brace or chord side of the joint. This is contrary to main diagonal bracing that ties into a leg, where a crack on the chord (leg) side is not detectable by FMD. For this platform, the conductor guide framing at both the (-) 40 ft. and the (-) 100 ft. elevations are inspected with FMD at each inspection. Even though it is the second conductor guide frame below the waterline, the framing at (-) 100 ft. is also inspected with FMD since these types of cracks have been found to occur down to (-) 140 ft.

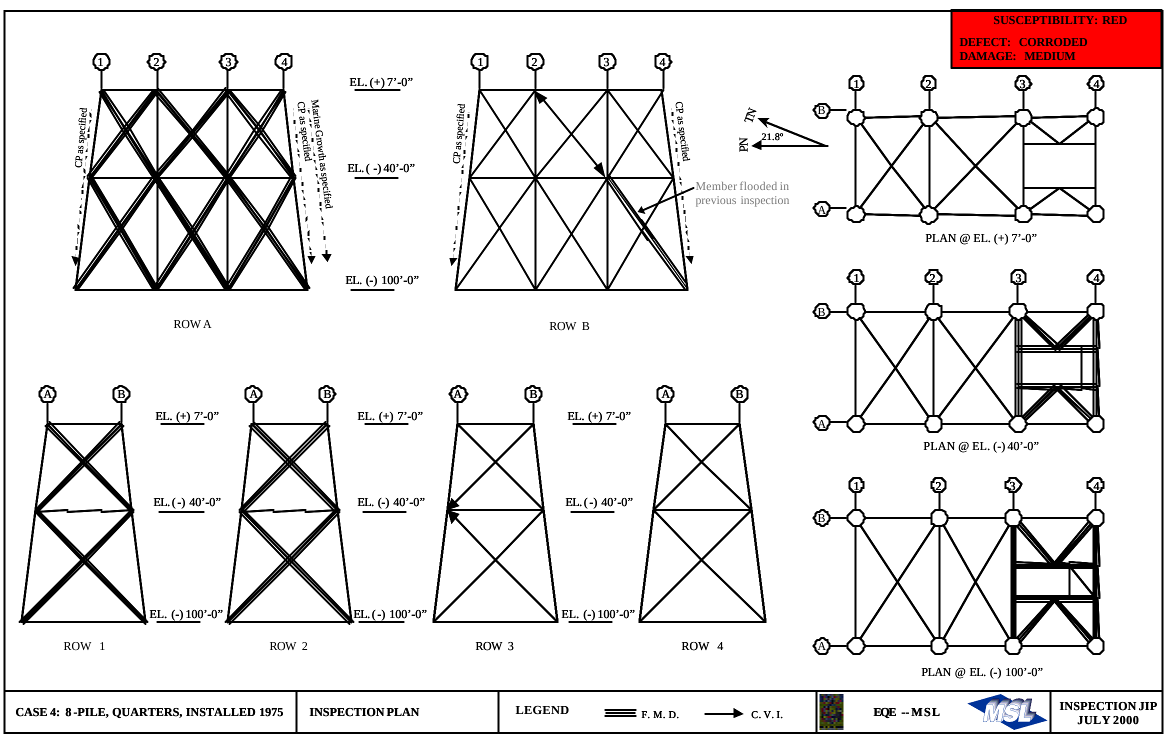
A corrosion check is used at each leg to determine the extent of corrosion across the platform. Ultrasonic wall thickness measurements are defined for the members that will receive joint/weld inspections to further understand the extent of corrosion. These members were selected since divers will be operating at these locations for other tasks.

Four joint/weld surveys are identified. The logic for selection of the specific nodes is based upon strength and robustness and is similar to that described for Case 3. In this case, the platform may be considered more robust since it has eight legs instead of four. For the eight-leg structure, it was decided to check joint/welds in the conductor region (Row B and Row 3) since hydrodynamic loading is highest at this location.

A Full CP survey is conducted at the four corner legs per the guidelines for a Red inspection. A Marine Growth survey is taken along one of the legs as recommended for a Red inspection.

CASE 4: 8-PILE, QUARTERS, INSTALLED 1975
SCOPE OF WORK

PLATFORM INSPECTION	TYPE	GUIDELINE REFERENCE	SURVEY DESCRIPTION
DEFECT SURVEY			
General Visual	FULL	14.3-A	All members, joints, appurtenances and appurtenance connections.
Anode Survey	FULL	14.3-B	Survey all anodes. Anodes to be graded.
Flooded Members	PART	14.3-C	Members on Row A, Row B, Row 1, Row 2, and Els. (-)40' and (-)100' in conductor guide region as indicated on drawing. Row B, Row 3, and Row 4 had FMD during previous inspection.
Corrosion Check	FULL	14.3-D	Clean 6" square patch on each leg at (-) 10 ft or lower and CVI to determine steel condition.
Joint/Weld Inspection	PART	14.3-E	Four member ends per drawing.
Cathodic Potential	FULL	14.3-F	Readings to be taken on the outside of the jacket legs at each framing (node) level, LAT and halfway between the framing levels. Readings also to be taken halfway along all adjoining braces.
ANOMALY SURVEY			
Debris Survey	FULL	14.3-G	To be done as part of General Visual. The seabed immediately surrounding the structure. Remove any hanging debris if safe to do so.
Scour Survey	PART	14.3-H	Measurements to be taken on the outside of each corner leg.
Marine Growth	PART	14.3-I	Measurements of compressed marine growth to be taken on A4 leg above and below all major elevations.
APPURTENANCE INSPECTION			
Riser Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.
Caisson Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.



Case 5 - 8-Pile un-manned Tender, Installed 1968

This is a pre-vintage/medium-consequence platform. A Level III (Yellow) inspection is required as indicated in Figure 7.1. The structure is the same as Case 4 except that it has single diagonal bracing and no previously reported anomalies.

Per the Guideline, an FMD survey is specified. A part-FMD survey is selected, which includes all vertical diagonal braces but excludes horizontal framing except at the conductor guide framing at (-) 41 ft. and (-) 103 ft., for reasons described in Case 4. In this case it was decided to use FMD on all main vertical diagonals, since with a diagonal bracing scheme there are fewer members and the FMD survey can proceed rapidly (compared to the X-braced platform in Case 4). In addition, a diagonal framing scheme is less "robust," and hence less damage tolerant than the X-braced framing. Thus if a member were to be damaged in the diagonal braced platform, there is a greater impact on the reserve strength of the platform and it is more critical to locate the damage during the periodic inspection. FMD is a good tool to supplement the General Visual survey in this case.

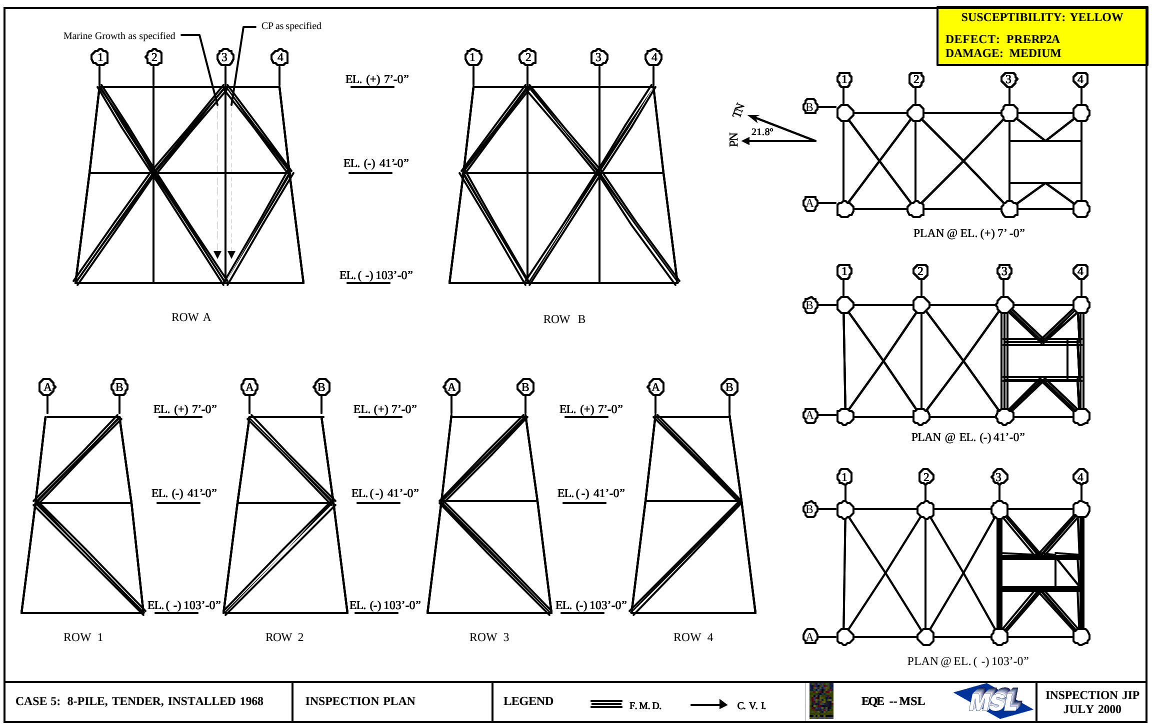
A corrosion check is used to determine the existing condition of the structure's steel on one of the legs.

A part-CP survey is used to check readings along one leg, and since the diver is going to be in the water, a marine growth survey is taken along this leg.

Per the Guideline, there are no joint/weld surveys.

CASE 5: 8-PILE, Tender, INSTALLED 1968
SCOPE OF WORK

PLATFORM INSPECTION	TYPE	GUIDELINE REFERENCE	SURVEY DESCRIPTION
DEFECT SURVEY			
General Visual	FULL	14.3-A	All members, joints, appurtenances and appurtenance connections.
Anode Survey	FULL	14.3-B	Survey all anodes. Anodes to be graded.
Flooded Members	PART	14.3-C	All vertical diagonals and conductor guide framing at Els. (-)41' and (-)103' as shown in drawing.
Corrosion Check	PART	14.3-D	Clean 6" square patch on any leg at (-) 10 ft or lower and CVI to determine steel condition.
Joint/Weld Inspection	NONE	14.3-E	None required.
Cathodic Potential	PART	14.3-F	Readings to be taken on the outside of A3 leg at each framing (node) level, LAT and halfway between the framing levels.
ANOMALY SURVEY			
Debris Survey	FULL	14.3-G	To be done as part of General Visual. The seabed immediately surrounding the structure. Remove any hanging debris if safe to do so.
Scour Survey	PART	14.3-H	Measurements to be taken on the outside of each corner leg.
Marine Growth	PART	14.3-I	Measurements of compressed marine growth to be taken on A3 leg above and below all major elevations.
APPURTENANCE INSPECTION			
Risers	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.
Caissons	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.



Case 6 - 4-Pile Compressor, 190 ft. WD, Installed 1968

This is a pre-vintage/medium-consequence platform located in a water depth greater than 100 ft. A Level IV (red) inspection is required as indicated in Figure 7.1. The platform has single diagonal bracing in the upper bays and X bracing in the lowest bay.

A part-FMD survey is selected including all of the main vertical bracing. The only horizontal bracing surveyed with FMD is located at (-) 45 ft. where several caissons and other appurtenances may cause collateral damage to the bracing. The horizontal bracing at the other elevations has a high level of redundancy (exterior framing and center X bracing) and is not considered critical for strength and, therefore, is not checked via FMD.

Four joint/weld surveys are identified. The logic for selection of the specific nodes is similar to that described for Case 3, with a combination of extreme storm compression braces and tension braces that contribute to robustness selected for inspection. As before, only the member ends of these particular braces are inspected. A member end of a vertical diagonal near the waterline was also selected for a joint/weld survey since the member is located near the boat landing and may be subject to dropped objects or other types of damage resulting from marine operations.

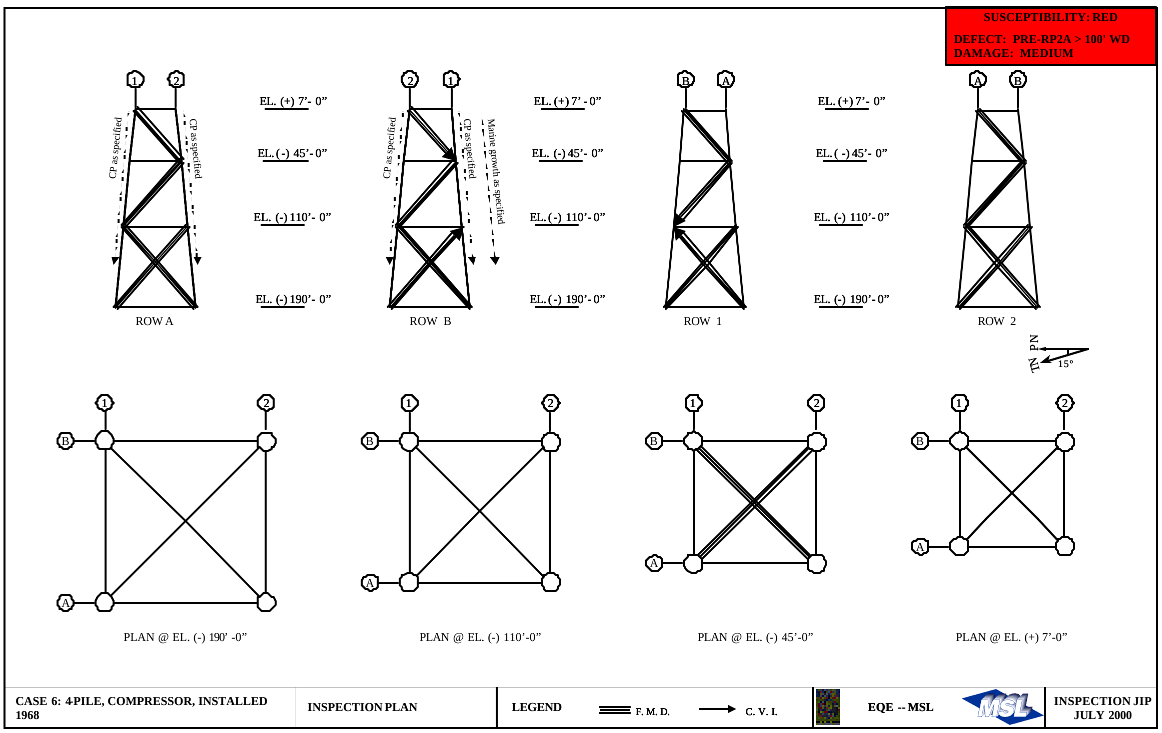
There is no corrosion check since the joint/weld surveys will provide a visual measure of the corrosion state of the platform.

A full CP survey is conducted at the four corner legs per the Guidelines for a Red inspection.

A Marine Growth survey is taken along one of the legs as recommended for a Red inspection.

CASE 6: 4-PILE, COMPRESSOR, INSTALLED 1968
SCOPE OF WORK

PLATFORM INSPECTION	TYPE	GUIDELINE REFERENCE	SURVEY DESCRIPTION
DEFECT SURVEY			
General Visual	FULL	14.3-A	All members, joints, appurtenances and appurtenance connections.
Anode Survey	FULL	14.3-B	Survey all anodes. Anodes to be graded.
Flooded Members	PART	14.3-C	All vertical diagonals, and horizontal diagonal framing at (-) 45' as shown in drawing.
Corrosion Check	NONE	14.3-D	None required.
Joint/Weld Inspection	PART	14.3-E	Four member ends per drawing.
Cathodic Potential	FULL	14.3-F	Readings to be taken on the outside of the jacket legs at each framing (node) level, LAT and halfway between the framing levels. Readings also to be taken halfway along all adjoining braces.
ANOMALY SURVEY			
Debris Survey	FULL	14.3-G	To be done as part of General Visual. The seabed immediately surrounding the structure. Remove any hanging debris if safe to do so.
Scour Survey	PART	14.3-H	Measurements to be taken on the outside of each leg.
Marine Growth	PART	14.3-I	Measurements of compressed marine growth to be taken on B1 leg above and below all major elevations.
APPURTENANCE INSPECTION			
Riser Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.
Caisson Survey	FULL	14.3-J	Not part of JIP – Guidance can be found in the relevant section of the guidelines.



8. INSPECTION TECHNIQUES INCLUDING FMD

8.1 Introduction

Offshore platforms require underwater inspection during their lifetime in order assess their integrity and thereby ensure their safe and reliable continued operation. This primarily involves inspection of the individual platform elements using a variety of techniques. The inspection can be performed by diver or by Remotely Operated Vehicle (ROV) or by a combination thereof.

Many methods are available for conducting inspections including a wide range of nondestructive examination (NDE) techniques. The effectiveness and the cost of these methods in detecting potential structural damage and degradation can vary widely. Examples of NDE techniques include General Visual Inspection (GVI), Close Visual Inspection (CVI), and Flooded Member Detection (FMD).

This section summarizes common NDE techniques and the applicability to underwater inspection planning. The section focuses specifically on FMD techniques and the reliability of this method and how it can be used for effective inspections, since this is the prime focus of this portion of the project.

8.2 Summary of NDE Methods

8.2.1 Type of Methods Worldwide

Many NDE methods exist for underwater inspection. A list of inspection techniques commonly used worldwide is shown below. A description of each technique is provided below.

- *Visual Inspection – GVI or CVI*
  - Diver, ROV
- *Non destructive examination (NDE) focused on crack detection and sizing*
  - Magnetic Particle Inspection (MPI)
  - Eddy Current (EC)
  - Ultrasonic Testing (UT)
  - Alternating Current Field Measurement (ACFM)
  - Remotely Excited Field Measurement (REFM)
- *NDE focused on identifying members with cracks and other through thickness damage*
  - Flooded Member Detection (FMD)
- *Continuous monitoring*
  - Acoustic Emission

Other techniques exist such as Radiography, Radiographic tomography, Robotics and automation, Neutron backscatter, Thermography and Holography. However, these specialty techniques are not used on a regular basis for routine platform inspection and, therefore, will not be further discussed here.

8.2.2 Descriptions of NDE Techniques

The following gives brief descriptions on the NDE methods listed in Section 8.4.1. Use and limitations for each of these methods are discussed. Note that FMD is treated separately in Section 8.4.

Magnetic Particle Inspection (MPI)

- Used for locating indications of exposure to overloading, i.e., early failure or fatigue cracking.
- Commonly used for detecting surface-breaking defects in welds, easily carried out by trained divers – well proven.
- Typical problems:
  - Particles falling into or bridging discontinuities.
  - Dispensing particles to the work piece.
  - Quality control.
  - Recording inspection data.

UT - Ultrasonic Amplitude Techniques

- Characterize crack-like defects once they have been detected by other inspection methods.
- For optimum defect detection it is essential that the correct ultrasonic probes are used (angle, beam and frequency) and the procedure is appropriate for defects to be detected.
- Experimental test programs indicate that accuracy is dependant on the skill of the operator, as well as on parameters such as equipment characteristics, defect position and shape.
- Main disadvantages:
  - Contact pressure on UT probe must be constant.
  - Changes in cross-section area of the defect cause changes in result.
  - False and misleading indications may result if the defect is unfavorable oriented.
  - Slight twisting of the probe during scanning can lead to false indications.

UT - Ultrasonic Time-of-Flight Diffraction (TOFD)

- Relies on the measurement of signal time differences between known paths and those of defects.
- Places little or no reliance on signal amplitude and so is less sensitive than amplitude techniques with respect to the condition of the steel surface or operator performance.

- Ultrasonic pulse is introduced into the steel at one point and diffracted signals are received, recorded and interpreted by receiver place at the same or different point.
- Particularly useful for the sizing of known defects such as surface-breaking cracks, but can also be used with considerable benefit in a "search" mode to locate unknown defects.
- Detects defects over a wider range of orientations than conventional UT.

Eddy Current

- Well established technique onshore for detecting surface breaking and buried defects. Not as well established offshore.
- Based on the principle of electromagnetic induction, when a coil (EC probe) carrying an alternating current is placed close to or on the surface of a conductor (steel) eddy currents are induced.
- Considered secondary to MPI for crack detection, but with sufficient confidence may eventually replace MPI.
- Equipment is calibrated by examining a test piece containing a series of surface notches of known dimensions.
- No special experience or training in eddy current testing is required for the diver.
- Surface operator must be trained.
- Uses include:
  - Measurement of paint coating thickness.
  - Metal identification.
  - Defect detection.

Acoustic Emissions

- Continuous monitoring system.
- Relies on sounds emitted from stressed materials.
- Sounds are detected, measured and interpreted and measured by specialized sensors and computer based equipment.

ACFM (Alternating Current Field Measurement)

- Can be used to detect and size fatigue cracks in air and under water.
- Uses theoretical interpretation of the magnetic field perturbations for sizing.
- Calibration used with other techniques is not necessary with ACFM, making technique more reliable.
- Does not require as much cleaning as other techniques (e.g., MPI).

REFM (Remotely Excited Field Measurement)

- Allows the detection of defects without cleaning operations.
- Consists of inducing an alternate electric current in the structure and analyzing corresponding localized perturbations of the current at defects.

8.3 <u>**NDE Techniques Used in the Gulf of Mexico (GOM)**</u>

NDE techniques commonly used in the GOM are general visual inspection (GVI), close visual inspection (CVI), flooded member detection (FMD), ultrasonic wall-thickness testing (UT-WT) and magnetic particle inspection (MPI). The general relationships between these five methods are illustrated in Figure 8.1. The range of inspection detail and the relative cost for these methods are also shown in the figure.

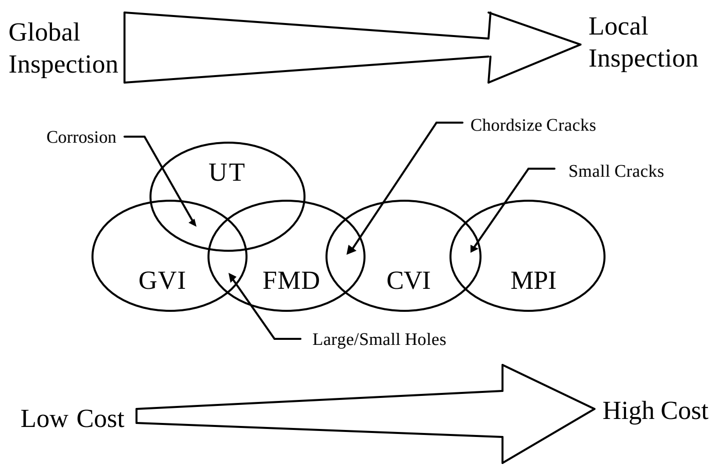


Figure 8.1: Relationships Between GVI, CVI, UT, FMD and MPI

8.3.1 <u>Visual Inspections</u>

The major part of any underwater inspection program is usually based on visual examinations. It may be further subcategorized into general visual inspection (GVI) and close visual inspection (CVI).

General Visual Inspection (GVI)

GVI corresponds to Level II inspection as described in API Recommend Practice 2A. The main function of GVI is to detect:

- Missing/separated members
- Large holes/cracks
- Large dents
- Bowed members
- Extent of marine growth
- Debris build-up

GVI is conducted either by divers or ROV. The advantages and disadvantages between these two alternatives is summarized in Table 8.1

	Advantage	Disadvantage
GVI - ROV	▪ Greater endurance ▪ Better mobility than divers	▪ Two-dimensional view ▪ No sense of touch to backup visual ▪ Need correction for color presentation ▪ Camera resolution limits the detail of inspection ▪ Currents may make it difficult for the ROV to stay on station ▪ Two-dimensional view
GVI – Divers	▪ Three-dimensional view ▪ Sense of touch can be used to backup visual ▪ Can see natural color ▪ Multiple task ability (e.g. measuring while inspecting) ▪ Can detect damage around the inner face of structural members	▪ Diver endurance and environmental conditions can limit effectiveness

Table 8.1: Comparison between ROV and Divers for General Visual Inspection

Close Visual Inspection (CVI)

CVI corresponds to the Level III survey as described in the API Recommend Practice 2A. CVI is conducted on areas of known or suspected damage. Such areas should be sufficiently cleaned of marine growth and permit thorough inspection. CVI is usually carried out by divers and its intent is to detect smaller dents/holes, and smaller cracks visible to the trained naked eye.

	Advantage	Disadvantage
CVI	▪ Detect smaller dents, cracks and holes.	▪ Cleaning required ▪ Depends more on inspector's skill

Table 8.2: Advantages and Disadvantages of CVI

Ultrasonic Testing (UT)

Measurement of steel wall thickness underwater is normally carried out using ultrasonic pulse-echo compression-wave techniques and equipment. Application of the technique for spot checking of wall thickness is normally done with a digital instrument.

The instruments required the steel surface to be cleaned to a smooth surface, although some instruments are capable of taking readings through a surface coating.

	Advantage	Disadvantage
UT	▪ Efficient for measuring wall thickness using digital thickness meter ▪ Easy to carry out	▪ Cleaning required ▪ For wall thickness measurement only ▪ Can't apply on rough surfaces with severe corrosions

Table 8.3: Advantages and Disadvantages of UT

Magnetic Particle Inspection (MPI)

The magnetic particle inspection (MPI) method of inspection has been used under water for many years. It is the most commonly used NDE method for detecting surface-breaking defects in welds and is easily carried out using equipment that is well proven. In theory, defects of 0.1"-0.2" in length can be detected. In practice, many factors affect the detectability, including:

Magnetic flux

- Adequacy and position within the test material
- Strength
- Orientation with respect to the likely direction of cracks

Indicating particles

- Size
- Permeability
- Retentivety

Viewing and illumination conditions

- Background contrast
- Ambient lighting
- Particle illumination

The major choices of techniques in use for MPI are electromagnetic yokes (AC and DC) and coils (AC and DC). AC current is significantly more sensitive than DC current in detecting surface breaking defects regardless of magnetizing technique. AC electromagnetic yokes and coils have the same reliability for detecting discontinuities. However, compared to yokes, equipment for coils is heavier and more difficult to transport to the underwater inspection site and set-up time is longer.

	Advantage	Disadvantage
MPI	▪ Well proven technique ▪ Reliability data is well quantified in literature.	▪ Cleaning required ▪ Depends more on inspector's skill

Table 8.4: Advantages and Disadvantages of MPI

8.3.2 Reliability of NDE Techniques used in the GOM

The objective of an inspection program is to enhance the reliability of structural components by detecting flaws that can degrade the strength of the components. Having detected flaws that are of structural significance, corrective actions can then be taken to prevent service failures.

Given that real NDE systems perform imperfect inspections, a number of measures are commonly used to quantify the reliability of a given NDE system (e.g., equipment, personnel, and procedures) for a given application. These include Probability of Detection (POD), False Call Probability (FCP), Relative Operating Characteristic Concepts (ROC), sizing accuracy, and others. Of all the reliability measures listed above, POD is the most relevant one for this study. The other measures either do not apply to the methods discussed in this section, or their quantification studies have yet to be carried out in sufficient detail for the underwater inspection industry

POD is defined as the ratio of number of flaws actually detected to the number of flaws that would have been detected given a perfect NDE system. Flaws must be of some minimum size before detection becomes possible. Above this threshold size, the detection probability increases with flaw size.

The following subsections provide a brief description of the general reliability of GOM NDE techniques.

Reliability of Visual Inspections

General visual inspections are used to detect large-scale damages. For the grossest types of damage: missing/separated members, large dent/bow and large hole/crack, visual inspections are reliable means of detection. For smaller damages, the reliability of detection reduces and the extent of reliability depends significantly on underwater environment. Ambient lighting and degree of marine growth are factors among which inspection reliability may depend upon for both divers and ROV. For divers in particular, factors such as underwater temperature and wave conditions can be significant to affect the divers' inspection reliability.

The reliability of close visual inspection depends on the degree of surface preparation which in term depends on the water or grit blasting system used to clean the member or joint. The cleaning threshold of hard marine growth with calcareous basal plates on steel is in the vicinity of 7-10 KPSI. Cleaning with pressures at or above this range should be used in order to obtain a clean surface for good reliable visual inspection.

Reliability of UT

A rough surface, e.g. a severely corroded or pitted surface, reflects a large portion of the input energy and may mean that measurements are impossible with standard equipment. When the differences in height of the surface irregularities are less than 1/3 of the sound wave length, the surface can be regarded as smooth and UT may be effective in measuring wall thickness in this range.

The probe on standard ultrasonic equipment is not able to physically reach the bottom of a corrosion pit in order to make good contact with the member, and hence cannot make measurements of the pit or the remaining steel wall thickness under it. This makes it particularly difficult to obtain good thickness readings in regions of high pitting. Since pitting is a sign of corrosion, this would be a region where reliable wall thickness readings are required. UT can be used, but reliability may be an issue. In this case, the diver may also take readings with a gauge or on some cases, if warranted, cast on site a replica of the pit which, when brought to the surface, can be studied and measured in detail.

Reliability of MPI

A survey of operator opinions showed that the mean length of the shortest crack that could reliably be detected was 1.1". This is many times the theoretical minimum detectable size (the theoretical minimum size is 0.1" - 0.2"), but it does still show a fairly high degree of confidence among operators that they can detect significant defects in areas examined by the MPI method.

A careful scrutiny by close visual inspection is essential before and during MPI, as weld undercut, interbead grooves, and other fabrication defects are often mistaken for cracks. The effective operation of MPI is therefore heavily dependent on the skill of the inspector. A good practice to avoid mistaking weld undercut for crack is to grind 0.08" before performing MPI.

A series of studies conducted at the Underwater NDE Center of University College London have demonstrated that the probability of detection (POD) came to its maximum (around 90%) at crack length around 0.08".

8.3.3 Summary Review of Common GOM NDE Methods

The following table presents a summary for the four NDE methods mentioned in the previous sections. The table presents the use of the methods, their limitations and relative cost. Note that FMD is treated separately in Section 8.4.

Type	Use	Limitations	Cost
General Visual Inspection (GVI) - ROV	Can show evidence of gross structural deformation, missing members, separated members and large dents/holes	Only the grossest types of damage can be identified	Minimal
General Visual Inspection (GVI) - Diver	All of the use above, plus divers can see the inside of members and divers are actively in contact with members	Only the grossest types of damage can be identified	Minimal
Close Visual Inspection (CVI)	Can show evidence of cracks visible to the naked eyes, dents/holes covered by marine growth and damages on the inside of member	Small cracks may be missed.	More expensive than GVI
Magnetic Particle Inspection (MPI)	Can aid visual examinations by revealing near-surface flaws such as cracks, voids, inclusions, and other material and geometric changes	Requires adequate cleaning	Slightly more expensive than CVI for limited cleaning. Complete cleaning is more expensive
Ultrasonic Testing (UT)	For member thickness measurements	Reading becomes difficult when the surface is rough, for example, corrosion	Minimal for measuring member wall thickness

Table 8.5: Summary Review of Four NDE Methods

Table 8.6 shows a comparison of reliability and costs for CVI and MPI. Note that some operators prefer to use SVI almost anywhere that a CVI inspection is called for, since the joint has already been cleaned. The MPI increases the confidence that the joint has no cracks al of the way done to 4" long and 0.001 inches wide. As shown in Table 8.6, this approach can be justified on a cost basis since the relative cost of MPI is only about 20 % of the total cost including cleaning.

	CVI Limited Cleaning (Black Oxide)	CVI Complete Cleaning (Bare Metal)	MPI Limited Cleaning (Black Oxide)	MPI Complete Cleaning (Bare Metal)
Detectable Crack Length	12” and greater	12” and greater	1” and greater	1” and greater
Detectable Crack Width	0.006” and greater	0.002” and greater	0.001” and greater	0.001” and greater
Detectable Crack Depth	0.03” and greater	0.03” and greater	0.03” and greater	0.03” and greater
Cleaning Time	3-5 min/ft ^{2}	10-30 min/ft ^{2}	3-5 min/ft ^{2}	10-30 min/ft ^{2}
Estimated Relative Cost per Foot	1.0	1.8	1.2	1.9
Reliability of Detecting Crack 4”Lx0.001”Wx0.03”D	5%	20%	80%	90%
Reliability of Detecting Crack 12”Lx0.01”Wx0.03”D	75%	80%	90%	90%
Reliability of Detecting Crack 24”Lx1”Wx3/8”D	90%	90%	90%	90%

Source: SeaTest Services

Table 8.6: Reliability and Cost Estimate for CVI and MPI

8.4 Flooded Member Detection (FMD) Reliability

The previous section described the most prevalent underwater inspection techniques in the Gulf of Mexico, including their application, advantages and disadvantages and general reliability. This section focuses on Flooded Member Detection (FMD) in particular, with emphasis on the reliability of the technique and how it is best used in the Gulf of Mexico.

8.4.1 Why Use FMD?

The presence of a flooded member on a platform typical indicates an anomaly of some type that has allowed water to ingress to the normally buoyant enclosed region of the member. Examples of anomalies include holes caused by dropped objects, corrosion pitting that has developed into a hole, cracks at a member end (Figure 8.2), or other strength or fatigue prone areas. Thus a flooded member indicates the potential for a structural problem in the platform that needs to be further investigated.

Figure 8.2: Crack that Results in a Flooded Member

Note that in some cases the member may be flooded for a reason that is not an anomaly. This includes members that are intentionally flooded during the installation process, members that hold liquids required for topside operations or members that may be fully or partially flooded due to rain water that entered the member during fabrication and then was sealed during subsequent fabrication. A proper FMD inspection includes procedures to determine if such a pre-existing condition exists (e.g., inspecting the member in multiple places, checking design data for members used for storage, etc.).

The FMD check is relatively quick to implement on a platform. It effectively tests an entire tubular member in one measurement. For example, all of the main framing members on a four leg platform in 150 ft water depth can be checked for FMD by diver in about ½ to 1 day. The presence of a flooded member indicates a possible problem – but does not pinpoint the cause. However, taking in this sense, FMD is a cost effective approach for global inspection and "screening" of the platform to identify potential problem areas. The alternative approach of specific member and joint CVI, MPI and other inspections as described in the prior section provides a better understanding and pinpointing of problems; however, it is cost prohibitive to apply these approaches to every major member on the platform. Instead, the operator will apply these more intensive inspection approaches to a select few areas that are deemed most likely to have damage or are the most critical strength members for the platform as determined by qualified engineers.

Hence, by using FMD in a proper manner, the operator can screen through the many members of a platform to identify those that are damaged (by being flooded). Unfortunately, FMD is not 100% reliable to identify all potential anomalies on a platform. Specific concerns about FMD reliability include:

- False readings that may indicate that a member is not flooded when in fact it is (flooded members are usually checked in several places to ensure that the member is indeed flooded, and to what extent).
- Cracks on the chord side of a weld for major framing that is connected to the leg – since the leg is flooded, the major framing member will still be buoyant when in fact there is a crack at a joint. In fact, about 60% of cracks are on the chord side of a weld.
- A FMD check does not determine how close to failure that a member may be, only if it has failed – in some low redundant platform this may not be acceptable.
- An initial non-critical fabrication flaw such as an incomplete weld may have caused the flooding (Figure 8.3).
- Locating a flooded member and then not being able to determine what has caused the flooding. How do you resolve this anomaly?
- Other issues pertinent issues.

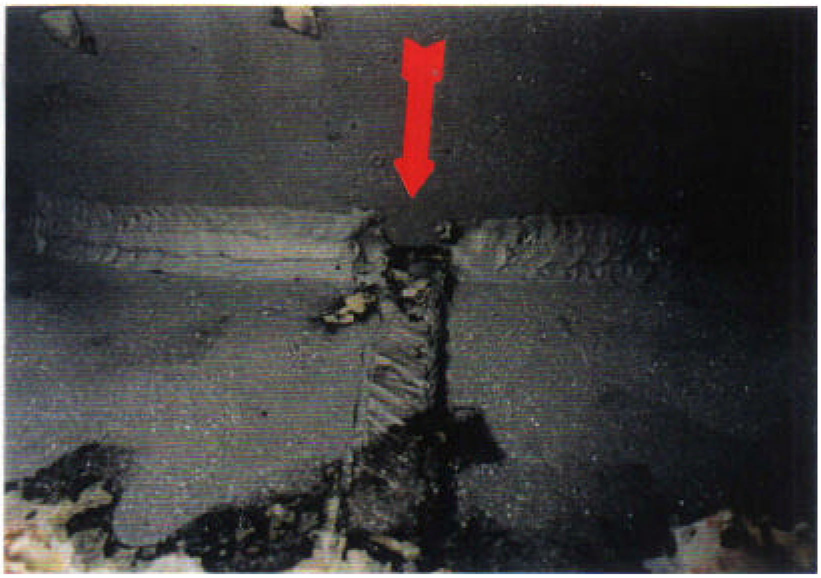


Figure 8.3: Incomplete Weld that Results in a Flooded Member

The objective of this effort is to investigate the reliability of FMD, taking into account the above issues as well as other pertinent information identified in the process. Then, based upon this data, make recommendations on using FMD as an integral part of an underwater inspection program.

8.4.2 Description of Techniques

There are three basic types of methods that can be used for FMD:

- Ultrasonic – this involves sending an acoustic signal through the member to determine the presence of water.
- Gamma Ray – this involves sending a radioactive signal through the member to determine the presence of water.

- Thermal – this involves heating the member to determine the presence of water (a flooded member takes longer to heat).

Ultrasonic and Gamma Ray are the most often used worldwide and are described further below. Thermal testing is uncommon and is therefore not described further.

Ultrasonic

Ultrasonic FMD works by placing a transducer on the outer portion of a member and passing an acoustic signal through the member. If the member is not flooded, then the acoustic signal reflects off the member wall thickness since air is a poor conductor of ultrasonic signals. If the member is flooded, then the signal also travels through the water in the flooded member and reflects off of the opposite side. The longer travel distance for the signal indicates a flooded member.

Figure 8.4 shows a schematic of a typical ultrasonic setup. This consists of a diver or ROV to hold the probe on the member and an operator for the topside unit where the reading is actually performed. Figure 8.5 shows an ultrasonic probe that is placed on the member by a diver and is commonly used in the Gulf of Mexico.

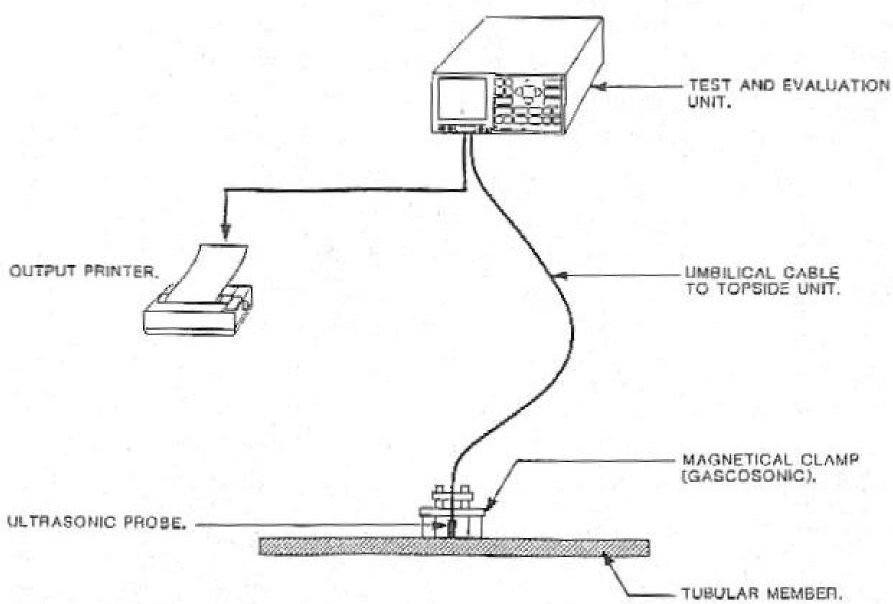


Figure 8.4: Schematic of a Typical Ultrasonic FMD Setup

Figure 8.5: Ultrasonic FMD Probe Typical of the Gulf of Mexico

The diver can rapidly check a number of members form basically one position by descending to a node and then checking all or most of the members connected to the node using FMD for flooding. In this manner, the diver can move from node-to-node around the platform performing FMD checks in an efficient manner as he/she also conducts the General Visual Survey.

The ultrasonic method has a fail-safe reading of a not flooded member. If the device is not working properly then the member will read as not flooded. This is one of the drawbacks for this approach since if diver obtains a not flooded reading, he/she will typically move on to the next member to be checked and the anomaly will go unreported unless found by other inspection methods (for example, cleaning and CVI of one of the member ends).

The ultrasonic method is the most commonly used FMD approach for the Gulf of Mexico. The ultrasonic method has been used in the North Sea, but is seldom used at this time.

Gamma Ray

Gamma ray works by placing a source of gamma radiation on one side of the member and a radiation detector on the opposite side of the member. The amount of radiation that is transmitted through the member is then measured. The amount of radiation transmitted through a not flooded member is more than is transmitted through a flooded member due to radiation absorption by the water in the flooded member.

Figure 8.6 shows a schematic of a typical gamma ray setup. This consists of a device for holding the radioactive source and detector on the member, which is usually an ROV since the radioactive source is hazardous to divers. A diver can only handle such a radioactive source for less than 1 hour underwater before an hazardous condition exists. An operator for the topside unit makes the reading.

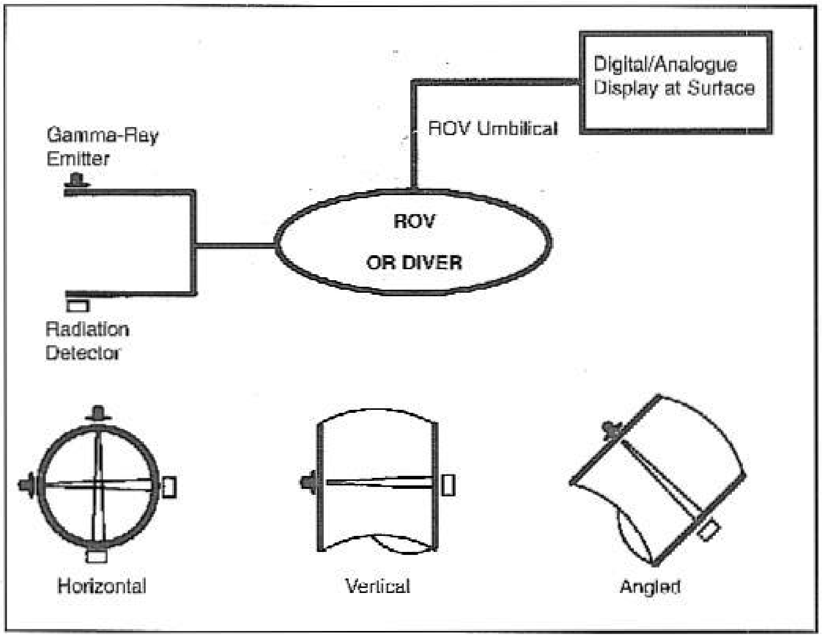


Figure 8.6: Schematic of a Typical Gamma Ray FMD Setup

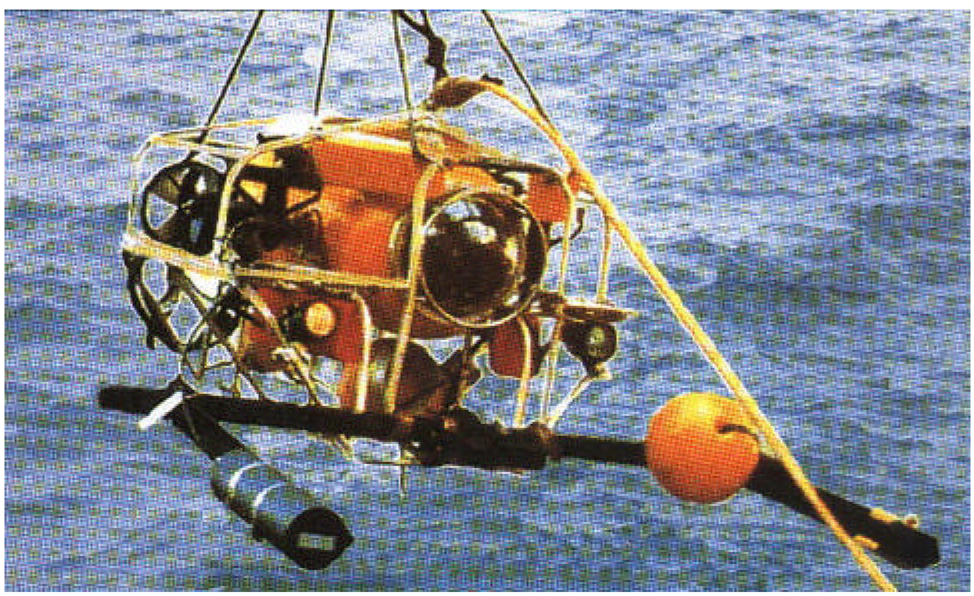


Figure 8.7: Gamma Ray Equipped ROV

Figure 8.7 shows an ROV equipped with a gamma ray FMD device. The gamma ray FMD source and detector are mounted on the parallel ends of the fork, which is placed around the member at the location for the FMD check. The fork width is adjustable for a range of tubular diameters. In some cases this adjustment can be made automatically with the ROV underwater.

In other cases the ROV must be brought to the surface and the fork diameter adjusted. If this is the case, then the ROV will typically perform the FMD check on all of the members within the same/similar group size, say 16 to 24 inch diameter. The ROV would then be brought to the surface, fork width increased, and the ROV placed back in the water to check larger diameter members. Once the fork is located with the member in the middle, then the gamma readings take between approximately 5 to 20 second to obtain.

The gamma ray method has a fail-safe reading of a flooded member. If the device is not working properly then the member will read as flooded. This typically prompts for further checks and increase the probability of determining that there is an error and taking corrective action.

The gamma ray method is the most commonly used FMD approach for the North Sea. The gamma ray approach is seldom used in the Gulf of Mexico.

8.4.3 Making FMD Checks on Platform Members

Over the years, experience has been gained on the proper locations to make checks for flooded members, whether the ultrasonic or gamma approach is used. These can be summarized as follows:

Horizontal members. Readings are generally taken at one or both of the member ends in the 6 o'clock to 12 o'clock direction. This allows water in the lower portion of the horizontal member to be identified. An additional "horizontal" reading between the 3 o'clock and 9 o'clock direction may also be taken to further confirm a dry member.

Vertical and vertical diagonal members. One reading is taken towards the lower end of the member as close as possible to the weld. This is because a member will only flood a certain amount depending upon where the hole or crack is located. If a crack is located at the bottom of a vertically oriented member, then the member will flood to a point where the air above the crack (which has no means of escape) will compress depending upon the differential pressure based upon water depth. Hence the member will be flooded at the bottom but void at the top. Thus the requirement to make the FMD check near the bottom. If the member is found to be flooded, then additional checks are made along the length of the member, starting at the bottom and moving upward, until either a void region is located or the entire member is found to be flooded. The location of the void region, if any, can help determine where the whole or crack is located. If the entire member is flooded, then the crack is likely located near the upper node.

8.4.4 Comparison of Key Issues – Ultrasonic versus Gamma Ray

A comparison of key issues for each FMD approach is shown in Table 8.7 below.

Issue	Ultrasonic	Gamma Ray
Fail safe reading	Non-flooded	Flooded
Cleaning required	Diver can brush away rough growth by hand. Hammer or wire brush may be required in some cases	None
ROV compatible	Yes – but ROV must be able to clean member and hold probe steady on member	Yes – in fact, requires ROV
Speed – time spent on-site performing FMD on a platform	Diver can rapidly test numerous members at a joint	Reading is quick, however, numerous readings may be slow in order to position ROV for each member
Handling	No special handling of equipment	Special handling of radioactive source is required
Training	Required	Required, including stringent procedures for handling and storage of radioactive source
Effect of corroded surfaces – internal or external	Can be significant and lead to false readings	None
Sensor alignment	Reading is sensitive to sensor (transducer) alignment	Reading is less sensitive to alignment
Overall safety	Typical diver safety issues apply	Diver safety not an issue since ROVs are used, however safety related to handling the radioactive source is a concern
Capability for partially flooded members	Possible false readings	Good
Capability at congested joints (access requirements)	Good – diver can maneuver freely. Probe is hand held and small.	Poor – problems moving ROV around. Two sided access required. Overall FMD package is large.
Capability in currents	Good	Poor – environment must be suitable for ROV operations
Water depth limitations	None for the device, but divers are typically limited to 300 ft or less water depth. FMD of deeper members will have to be performed via ROV	None
Regulatory based certification?	None	None
Topside calibration/test prior to underwater application	Yes	Yes

Table 8.7: Comparisons of Key Issues between Ultrasonic and Gamma Ray FMD

8.4.5 Reliability to Detect Flooded Members

The previous sections described some of the general issues associated with performing FMD in terms of difficulty in preparation, handling the device, taking the reading, etc.

This section addresses the issue of the ability of the devices to take accurate readings. In other words, if the FMD test indicates that a member is not flooded – is this indeed the case?

Data Sources

Several international public as well as private data sources available to MSL/EQE and available via some of the participants were used to provide background information and reliability data on FMD.

The project also performed an extensive literature search to identify other documents available in the public domain. Appendix B provides a listing of the contents of the data search.

Key sources of information were as follows:

- The Reliability of the FMD Method in the Testing of Offshore Structures, Confidential Joint Industry Project, 1997.
- ICON project – InterCalibration of Offshore NDT – An extensive and in-depth European Union / Industry project of all types of underwater inspection techniques via diver and ROV funded by numerous companies and completed in 1996.
- Underwater Weld Inspection Philosophy – Sea Test Services, performed for Exxon, 1987.

Of these data sources, the ICON tests fro FMD provide the most definite results and are the basis for the findings on reliability. The ICON FMD results are summarized in the following sections.

Ultrasonic Testing by Diver

Table 8.8 shows results of the ICON FMD trials using ultrasonic tests by diver, using a "Gascosonic" brand device. The left column indicates that real water fill level of the test member. The top row values are the reported fill level per the FMD test. A 100% success rate would be represented by figures on the diagonal only.

	Fill Level Reported by Ultrasonic FMD Device			
Actual Fill Level	**0%**	**10%**	**50%**	**90/100%**
0%	9	1		
10%	3	2	4	1
50%				1
90/100%				12

Table 8.8: ICON Results for Ultrasonic FMD by Diver

The ultrasonic FMD tests performed quite well when the member was 90/100% filled, or basically completely flooded.

However, the ultrasonic tests did not perform well for partially flooded members. For example, three FMD test showed the test member to be 10% filled, when in fact it was 0% filled. Similarly, four tests showed the test member to be 50% filled when in fact it was 10% filled.

Ultrasonic Testing by ROV

Table 8.9 shows results of the ICON FMD trials using ultrasonic tests by ROV, using the same "Gascosonic" brand device as used in the diver test. In this series of tests, the test members were mounted in a vertical orientation and in a diagonal orientation.

	Fill Level Reported by Ultrasonic FMD Device			
Actual Fill Level	**0%**	**10%**	**50%**	**100%**
0%	1			
10%	3			
50%			2	1
100%				3

Table 8.9 ICON Results for Ultrasonic FMD by ROV

Similar to the ultrasonic diver FMD tests, the ROV FMD tests performed quite well when the member was completely flooded. However, the ROV ultrasonic tests also did not perform well for partially flooded members.

Figure 8.8 and 8.9 show the ICON results for ultrasonic ROV FMD further broken down according to vertical or horizontal members. Data points on the 45 degree line would indicate perfect readings. These results indicate that ultrasonic ROV FMD testing is generally more accurate for vertical members than for horizontal members.

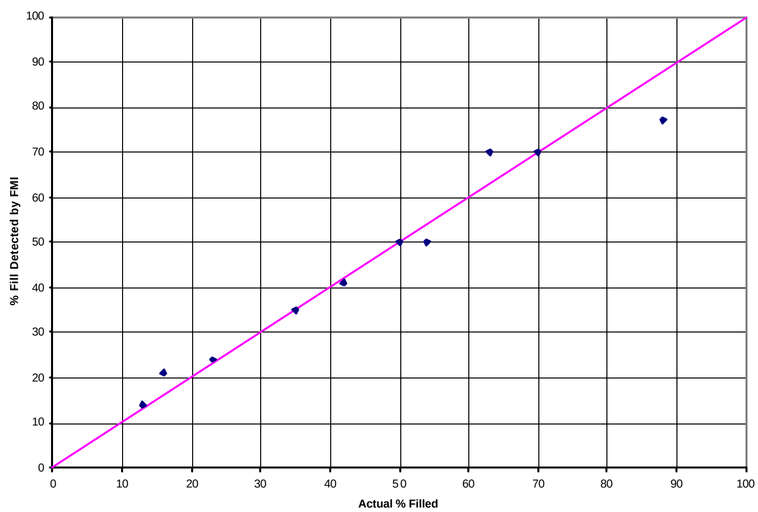


Figure 8.8: ICON Results for Ultrasonic FMD by ROV Tests on Vertical Members

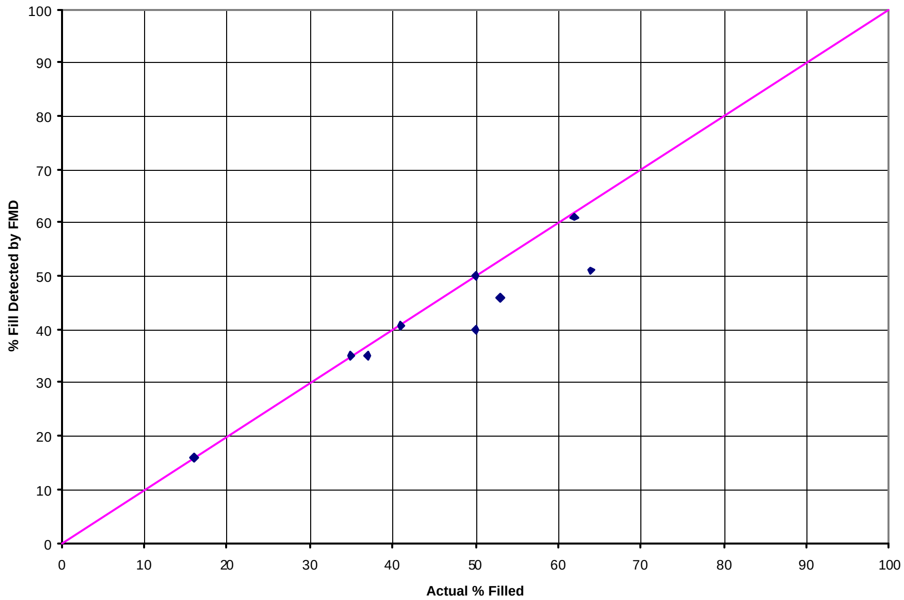


Figure 8.9: ICON Results for Ultrasonic FMD by ROV Tests on a Diagonal Member

Gamma Ray Testing by ROV

Table 8.3 shows results of the ICON FMD trials using gamma ray tests via ROV, using an "ICI Tracerco" brand device. The testing occurred on both horizontal and vertical members. Gamma ray test were only conducted via ROV since divers are seldom if ever used for this test due to the use of a radioactive source.

	Fill Level Reported by Gamma Ray FMD Device			
Actual Fill Level	**0%**	**10/25%**	**40/60%**	**100%**
0%	4			
10%		5		
50%			5	
90/100%				5

Table 8.10: ICON Results for Gamma Ray FMD

The test results show that the gamma ray ROV FMD tests had 100% accuracy and detected the correct flood level on both partially and fully flooded members.

8.4.6 Conclusions on Reliability of Detection

Ultrasonic tests show good results by diver or ROV when the member is nearly completely flooded, but accuracy reduces substantially for partially flooded members. Diver ultrasonic tests accurately detected as filled all members filled 50% or greater. ROV ultrasonic tests were not as accurate and detected all fills of 50% or over as filled and 70% of those at 10% as filled.

Gamma ray tests are about the same reliability as ultrasonic for completed flooded members. For partially flooded members, gamma ray tests are much better than ultrasonic. The gamma ray tests detected accurately the water fill level in 19 of 19 measurements for a 100% accuracy. Gamma ray FMD is used by ROV only.

In summary:

- Ultrasonic FMD by diver or ROV can be considered to be accurate for completely flooded members. However, this accuracy drops to 70% for partially flooded members.
- Gamma ray FMD can be considered to be nearly 100% reliable for all levels of flooded members.

8.4.7 FMD and Structural Reliability

The reliability studies of detecting the presence of flooded members show excellent accuracy for fully flooded members whether the tests were performed via ultrasonic or gamma ray, using diver or ROV. For partially flooded members, particularly less than 50% flooded, the accuracy drops using ultrasonic FMD, the typical technique used in the Gulf of Mexico. In most cases, and over an extended period, the member will likely flood to greater than 50% if there is a through wall thickness anomaly. Based upon this, it can be concluded that the FMD has a good chance of finding damaged members.

However, "reliability" of the FMD technique, in the broad sense, needs to also account for many other factors that come into play when inspecting and evaluating an entire platform with its many members (versus an inspection of a single member). In fact these are the real issues when it comes to FMD reliability and how it can be used effectively in an inspection program.

If the FMD technique (say ultrasonic) is 100% accurate, how does the reliability change from this starting point? Consider the following previously mentioned issues and how they impact the "accuracy" of finding or not finding a damaged member via FMD:

Crack is on the chord side of the weld for a main vertical diagonal connected to the legs (see example shown in Figure 8.10). The member is shown to be not flooded via FMD. Since the crack is on the leg (which is flooded and not capable of being checked via FMD), the member will not be flooded, and the inspection program will erroneously conclude that the member is not damaged, when in fact it is. Since approximately 60% of weld cracks are at the weld toe chord side – FMD checks may miss over ½ of cracked members that connect to the legs – which are the critical members in the platform. In this case, the FMD device is indeed accurate and shows that the member is not flooded, however a problem does exist and therefore the FMD check is providing a false sense of a no damage condition.

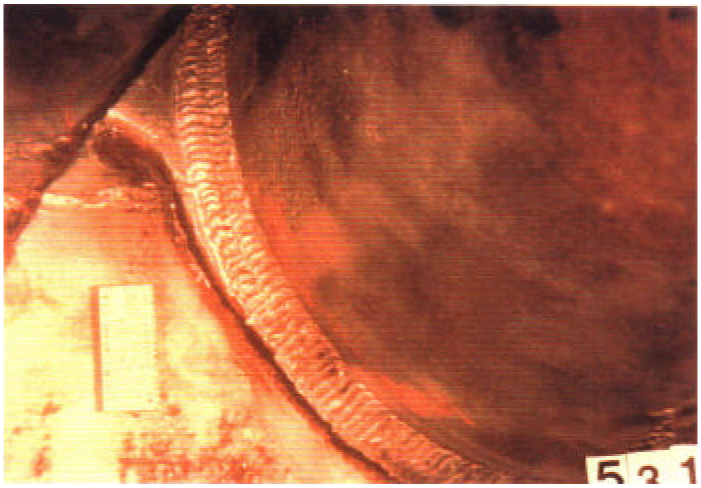


Figure 8.10: Crack on chord side of member (member is not flooded)

(a) A member may have a crack that has not progressed to the through-crack stage at the time of the FMD check, and therefore, the member will be found to be not flooded. But the member is damaged. Depending upon crack growth rate, environmental conditions, and other factors, the damage may propagate to a more fully developed and hazardous stage prior to the next inspection. Again, FMD in this case would provide a false sense of a no damage condition. Figure 8.11 shows a schematic of how crack growth progresses and the ability of different types of inspection techniques to identify the problem based upon remaining life of the member. FMD obviously will not find the crack until the member has flooded, whereas, MPI would have found the crack before it reached the through thickness stage.

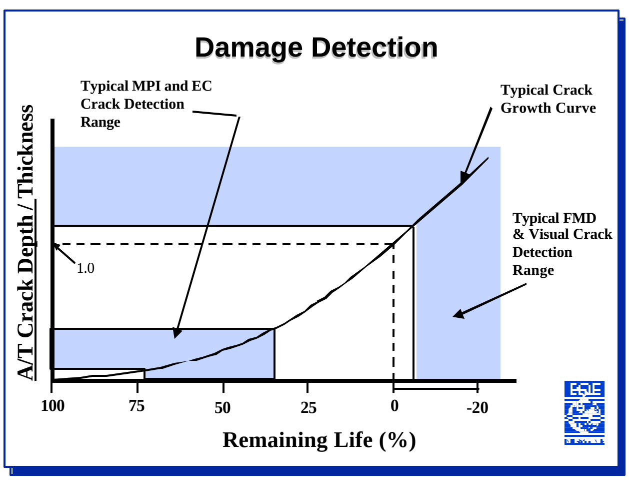


Figure 8.11: Ability to detect a crack in member for different NDE techniques

The FMD JIP recently completed by EQE (UK) investigated this issue in great detail and developed an approach to help an operator understand how to use FMD for different type of redundancy levels based upon the jacket framing scheme. That JIP concluded that FMD works well for redundant framing schemes. For example X-braced platforms, since even if a not through crack is missed via FMD (because the member is not yet flooded), there is sufficient redundancy such that the platform will be safe until the next inspection cycle when the damage has progressed to the point that the member is now flooded and will be found via FMD. Contrarily, a single diagonally braced platform is less redundant and when the crack appears, it may significantly reduce platform safety. In this case it may be "too late" to wait until the next inspection cycle to locate the damaged member. However, even for X-brace structures, the above approach does not address the issue of chord-side cracks. These cracks are the most frequently occurring and may not flood the member even at full separation.

Thus, FMD cannot be counted on to find and locate all of the potential defects in a platform. Instead, FMD is best utilized based upon platform susceptibility to damage, framing/redundancy (often called robustness) and in combination with other inspection techniques.

Some general guidelines for use of FMD are as follows:

- FMD can be used during any underwater inspection – it is up to the operator to determine how much effort and time should be spent inspecting the facility, perhaps based upon the platform's importance (or non importance). FMD can be used as a supplement to other inspection activities. For certain cases (as explained below), it can be one of the focused and main techniques of the inspection.

- In all cases, FMD should be supplemented with a well-planned and thorough general visual survey. In fact, FMD helps to ensure that a good visual inspection is performed by forcing the diver (or ROV) to spend more time at the platform nodes in terms of hands-on testing, than may occur in a typical "swim-by." The operator may in fact call out an FMD program just to ensure that a better quality GVI is performed.

- For robust structures, such as X-braced framing, FMD provides a good tool to check for problems that may have been missed by other techniques. If other inspection activities, such as close visual inspection (CVI), are specified for locations that are selected in error, or the CVI sample is too small, then FMD provides a safety net for any unknown damage occurring the jacket elsewhere. The operator may want to consider rotating the locations of the FMD from inspection to inspection such that all of the major framing in a platform is inspected over time (i.e., it may not be necessary to FMD every member at each inspection). In some cases for newer platforms, a qualified engineer may be able to specify FMD as the main inspection technique (but always in combination with GVI).

- For less robust structures, such as single diagonal and K-braced framing, FMD can be used – but it should not be considered to be the main inspection technique. It should be supplemented with other member specific inspections such as CVI on critical members. As described above, these types of structures are not as damaged tolerant as robust platforms and FMD may miss problems (such as small cracks) that may develop into a significant concern prior to the next inspection.

- The focus of FMD should be the main vertical diagonal framing – less emphasis should be placed on horizontal framing, since it plays a lesser role in the overall strength of a platform (other than horizontals associated with the conductor guide and conductor tray supports, see next bullet). One of the complaints with FMD is that if a flooded member is located, then a more thorough close-visual or non-destructive examination (e.g. MPI) is often specified at each end of the flooded member. Sometimes no problem is found. Thus if several horizontal members are found to be flooded, then a lot of time and money may be spent further investigating the problem – when in fact these members may not be critical for platform performance. The operator may have better spent the money inspecting more critical platform members.

- Conductor guide framing located near the water line is an excellent candidate for FMD on any platform. The effect of vertical wave forces creates an up-and-down motion on certain types of conductor guide framing (often called a "conductor tray") and can create cracks located at the 12 o'clock 6 o'clock joint locations of the conductor guide framing. Since this framing is typically "secondary" framing, both the brace and the chord are buoyant, and therefore, one or the other of these members will flood, regardless of the location of the joint crack (brace or chord side). Conductor trays that are most susceptible are those that tend to have a large amount of steel plating, which provides a significant "sail" area for vertical wave loads, which increases the up-and-down motions. Note that most modern platform designs having taken this problem into account by designing more streamlined trays with less sail area. This type of damage to conductor guide framing has been found in conductor trays down to (-) 150, and operators should perform FMD inspections on conductor trays down to at least this depth.

- FMD should be considered for use in underwater areas that may be subjected to issues such as dropped objects or workboat impact. Critical members located near the boat landing or in an area that is often used for offloading materials, for example related to drilling operations (pipe and collars), are good candidates for FMD.

In all of these cases, it is important that a qualified engineer develop the inspection program. This is particularly true in terms of determining the robustness of a platform, selecting specific important members for FMD, and other structural design and performance related issues. The inspection plan should also consider the other portions of this project that have investigated issues such as type of platform (drilling, production, quarters) and how these operations impact inspection plans.

Data Sources

During the course of the JIP an extensive literature search and review was undertaken relating to inspection techniques in general and in particular to FMD. These documents are listed in the reference section, which follows. The documents are too numerous and large to be attached with this report, however, in most instances, they can be made available to Participants upon request. Reference 9 and 10 were specifically purchased for the JIP. The former represents a Recommended Practice for FMD developed by Sea Test Services. This Practice includes a procedure for implementation in the event that a flooded member is detected.

REFERENCES

(1) American Petroleum Institute (API), "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design", RP 2A-WSD, 20th Ed., 1993

(2) International Standards Organization (ISO), "ISO/TC67/SC7/WG3, In-service Inspection and Structural Integrity Management." ISO 13819-2, Draft C, Clause 18, 1997

(3) American Petroleum Institute (API), "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms", RP-2A, 19th Ed., 1991

(4) Norwegian Technology Standards Institution, Norsok Standard, "Condition Monitoring of Loadbearing Structures", N-005, Rev. 1, December 1997

(5) Hennegan, N. et al, "Inspections, Surveys and Data Management", International Workshop on Reassessment and Requalification of Offshore Platforms, New Orleans, LA, 1993

(6) Sea Test Services (STS), "Application and Reliability of Flooded Member Detection using Ultrasonic and Radiometric Techniques – Final Report", STS No. 88-018, 1989

(7) Kallaby, J., O'Conner, P.E., "An Integrated Approach for Underwater Survey and Damage Assessment of Offshore Platforms", Proceedings of the Offshore Technology Conference, paper OTC 7487, May 1994

(8) Versowsky, P. E. "Offshore Structural Inspection Intervals", IBS Conference on Inspection and Maintenance Strategies of the Offshore Industry, New Orleans, LA, 1998

(9) InterCalibration of Offshore Non-destructive testing (ICON), "Project Nos: OG/0098/90/FR/UK and OG/00149/93/FR/UK", Final Report, 1996

(10) Sea Test Services (STS), "Commentary and Recommended Practice; Flooded Member Detection", Revision 1, March 1995

(11) DeFranco, S.J. et al, "Development of a Risk Based Underwater Inspection (RBUI) Process for Prioritizing Inspections of Large Numbers of Platforms", Proceedings of the Offshore Technology Conference, 1999, (OTC 10846)

(12) Sharp, J. V., Stacey, A. and Wignall, C. M. "Structural Integrity Management Of Offshore Installations Based On Inspection For Through- Thickness Cracking", 17th ASME Offshore Mechanical & Artic Engineering International Conference, Lisbon, Portugal, 1998 (ISBN 0-7918-1952-3; OMAE98-2110)

(13) Choqueuse, D. and LaMarre, A. "Use Of Phased Array Ultrasonic Equipment For Fatigue Crack Characterization For Underwater Inspection Of Offshore Structures", 8th ISOPE Conference, Montreal, Canada, 1998 (ISBN 1-880653-38-9)

(14) Craig, M. and Goldberg, L. "State-Of-The-Art Practice of Underwater Inspection", U.S. Department of the Interior et al, Underwater Welding Of Marine Structures International Workshop, New Orleans, 1995 (ISBN 0-918062-77-2)

(15) Holdsworth, R. D. and Craig, M. J. K. "Further Developments on Standards, Specifications and Codes for Underwater Welding and Inspection", U.S. Department of the Interior et al, Underwater Welding Of Marine Structures International Workshop, New Orleans, 1995 (ISBN 0-918062-77-2)

(16) Mirshekar-Syahkal, D. and Sadeghi, S. H. H. "Advances In Surface Magnetic Field Measurement Technique For Detection And Sizing Of Surface- Breaking Cracks In Offshore Structures", 4th ISOPE Conference, Osaka, Japan, 1994 (ISBN 1-880653-14-1)

(17) Dover, W. D. and Rudlin, J. "Underwater Inspection Reliability Trials", International Association Of Underwater Engineering Contractors et al. International Offshore Contractors & Subsea Engineers Conference, Aberdeen, UK, 1992 (Proceedings Vol. 3, 1992)

(18) Giordano, P., Daste, S., Ittel, J. M., Guilhamat, B. and Huc, R. "Remotely Excited Field Measurement (R.E.F.M.) Method: A Contactless Ndt (Nondestructive Testing) Method For Crack Detection On Jackets", 1st Inst. Petrol et al Mediter Oil & Gas Conference (MOEX 92), Valletta, Malta, 1992

(19) Dover, W. D. "Weld Inspection: Crack Detection and Sizing", IBC Technical Services Ltd. Welding & Weld Performance in the Offshore Industry Conference, London, England, 1992

(20) Watt, A. M., Walther, K. G., Walther R. G. "Control Method Useful for Magnetic Particle Inspections", Offshore (Incorporating Oilman) (Int. Ed.) Vol 52, No. 3, Pp 41-42, March 1992 (ISSN 01436694)

(21) Giordano, P., LeMoine, L. and Cahouet, J. "Underwater Inspection: Defects Detection At High Lift Off By A New Electromagnetic Technique", 10th ASME OMAE Conference, Stavanger, Norway, 1991 (ISBN 0-7918-0719-3)

(22) Colombrita, C., Papponetti, M. and Ziliotto, F. "Impact Of Underwater Inspections Of Offshore Structures On Design And Maintenance - A Case Study: Revamping Of Loango Platforms", 9th ASME OMAE Conference, Houston, 1990 (ISBN 0-7918-463-1)

(23) Dover, W. "Probablility of Detection Trials for MPI (Magnetic Particle Inspection) and Eddy Current", Society of Underwater Technology Advancement in Underwater Inspection &

Maintenance International Conference, Aberdeen, Scotland, 1990, Vol. 21 Pp 129-140, (ISBN 1-85333-304-2)

(24) Collins, R., Niemiro, A. and Lewis, A. M. "Underwater Crack Measurement From Electromagnetic Field Measurements", Society of Underwater Technology Advancement in Underwater Inspection & Maintenance International Conference, Aberdeen, Scotland, 1990, Vol. 21 Pp 109-128, (ISBN 1-85333-304-2)

(25) Sandy, P. A. and Swain, N. "The Application Of Ultrasonic Creeping Waves For NDE (Non Destructive Evaluation) Of Welds In The Offshore And Related Industries", 22nd Offshore Technology Conference, Houston, 1990, (OTC-6456)

(26) Hughes, G. and Bond, L. J. "Progress towards Fatigue Crack Detection and Sizing through Partially Cleaned or Virgin Marine Deposits", 8th ASME OMAE Conference, The Hague, Netherlands, 1989, (Proceedings. Vol. 1, Pp 285-292)

(27) Gulliver, J. and Newton, K. "A New Eddy Current Instrument for Inspection of Welds on Steel Jackets", Offshore Conference & Exhibition Ltd. Offshore Inspection, Repair & Maintenance Conference, Aberdeen, Scotland, 1988

(28) Simpson, J. "Underwater Inspection of A TLP (Tension Leg Platform)", Offshore Conference and Exhibition Ltd. Offshore Inspection and Maintenance Conference, Aberdeen, Scotland, 1988

(29) Frieze, P. A. and Kam, J. C. P. "The Assessment Of The Reliability Of Non-Destructive Inspection Of Offshore Structural Defects", Offshore Conference and Exhibition Ltd, Offshore Inspection & Maintenance Conference, Aberdeen, Scotland, 1988

(30) Melegari, J. "A Systematic Approach to IM & R (Inspection, Maintenance and Repair) In Deep Waters", 4th Deep Offshore Technology (DOT) International Conference, Monte Carlo, Monaco, 1987, (Proceedings Vol. 2, PAP No. Vol.10B)

(31) Bressan, G. "A Systematic Approach to IM & R (Inspection, Maintenance And Repair) in Deep Waters – Technological Applications in U/W (Underwater) Optics, Acoustics And NDT (Nondestructive Testing) For IMR In Deep Waters", 4th Deep Offshore Technology (DOT) International Conference, Monte Carlo, Monaco, 1987, (Proceedings Vol. 2, PAP No. V10B)

(32) Goncalves, R. "Deep Subsea Production Equipment: Practical Aspects of Inspection and Maintenance", 4th Deep Offshore Technology (DOT) International Conference, Monte Carlo, Monaco, 1987, (Proceedings Vol. 2, PAP No. Vol. 4)

(33) Birring, A. S. "Overview of Factors Affecting Ultrasonic Inspection of Tension Leg Platforms", 6th ASME OMAE International Symposium, Houston, 1987, (Proceedings Vol. 2, PP 513-516)

(34) Chen, W. C. "Fracture Control Strategy for TLP (Tension Leg Platform) Tethers", 6th ASME OMAE International Symposium, Houston, 1987, (Proceedings Vol. 1, PP 1-8)

(35) Eikas, N. "Oil Company View of Future Operations - Inspection And Repair of Deepwater Structures", Society of Underwater Technology Submersible Technology International Conference, Aberdeen, Scotland, 1985, (Proceedings Vol. 5 Pp 271-281 ISBN 0-86010-771-X)

(36) Hawker, B. M. "Sizing Weld Defects in Sub-Sea Structures using the Harwell Ultrasonic TOFD (Time of Flight Diffraction) Technique", 5th Association of Offshore Diving Contractors, Offshore Inspection, Repair & Maintenance Conference, Aberdeen, UK, 1984, (Proceedings Pt 2, 16 PP, IRM 84)

(37) Mirshekar-Syahkal, D. and Collins, R. "Probe Development for Underwater Applications of the A.C.F.M. (Alternating Current Field Measurement) Technique", 4th ASME OMAE Symposium, Dallas, 1985, (Proceedings Vol. 2, Pp 446-450)

(38) Blanc, M. J. and Crohas, H. "Pressio-Detection for Permanent Jacket Structure Monitoring", 17th Offshore Technology Conference, Houston, 1985, (OTC-5043)

(39) Andrews, W. B. "Inspection Maintenance And Repair: Ultrasonic Imaging for Offshore Underwater Operations", Society of Underwater Technology, International Symposium, Brighton, UK, 1980, (Proceedings Tech., Pp19-28)

(40) Phillips, J. "New Ultrasonic System For Non-Destructive Testing", Ocean Vol., No., Pp52-53, June 1983 (ISSN 00298026)

(41) Fuller, M. D. and Rose, J. L. "Application of the Acoustic Emission Technique for Monitoring Offshore Structures", SPE of AIME Unsolicited Paper No. SPE-11869, 26 Pp, June 1983

(42) Stumm, W. "Magnetographic Weld Inspection System for Underwater Installations", Mater Evaluation Vol. 41, No. 4, Pp 586-588, April 1983 (ISSN 00255327)

(43) Burkle, W. S. "Method for Measuring Transducer Movement During Underwater Ultrasonic Evaluation of Weld Flaws", Mater Evaluation Vol. 41, No. 4, Pp 579-581, April 1983 (ISSN 00255327)

(44) Fuller, M. D., Nestleroth, J. B. and Rose, J. L. "A Proposed Ultrasonic Inspection Technique for Offshore Structures", Mater Evaluation Vol. 41, No. 4, Pp 571-578, April 1983 (ISSN 00255327)

(45) Allen, K. P. "Further Considerations For NDT (Non destructive Testing) Validity and Structural Integrity", Offshore Inspection Repair and Maintenance Conference, Edinburgh, UK, 1981 (Proceedings Pt. 1, Pp 9, IRM '81)

(46) Silk, M. G. "The Potential Use of Ultrasound for Sizing Defects in Offshore Structures", Offshore Inspection Repair and Maintenance Conference, Edinburgh, UK, 1982 (Proceedings Pt. 1, Pp 24, IRM '82)

(47) Dover, W. D., Rudlin, J. R. and LeMoine, L. "The ICON Project – Underwater Inspection Reliability", 5th Europe Union Hydrocarbons Symposium, Edinburgh, UK, 1996, (Proceedings Vol. 1, Pp 717-726 ISBN 0-9520079-8-3)

(48) Shetty, N. K., Gierlinski, J. T. and Smith, J. K. "Structural System Reliability Considerations in Fatigue Inspection Planning", 8th BOSS International Conference, Delft, Netherlands, 1997, (Proceedings Vol. 3, Pp 161-175 ISBN 0-08-042833-9)

(49) Majid, W. M. W. A. and Bin Embong, M. "Tubular Joints Reliability and Fracture Analyses for Development of Underwater Inspection of Offshore Steel Structures", 7th ISOPE Conference, Honolulu, 1997, (Proceedings Vol. 4, Pp 119-124, ISBN 1-880653-32-X)

(50) Frieze, P. A., Nichols, N. W., Sharp, J. V. and Stacey, A. "Detection of Damage to Underwater Tubulars and the Effect of Damage on Strength", 16th ASME OMAE International Conference, Yokohama, Japan, 1997, (Proceedings Vol. 3, Pp 331-345, ISBN 0-7918-1801-2)

(51) Saubestre, V., Ricci, F., Ellingsen, P. B., Eikanger, T. E. and Rasmussen, J. "Justifying Changes in Primary Structures Inspection Philosophy Based on Past Experience, New Analytical Tools and Development of Underwater Means", 5th ERA Technology Ltd. Offshore Structures - Hazard & Integrity Management International Conference, London, UK, 1996, (Proceedings Paper No. 3-1, Pp 30)

(52) Ganguly, P., Goldberg, L. and Wood, B. "The Pompano Subsea Inspection", 29th Offshore technology Conference, Houston, 1997, (OTC-8469)

(53) Rudlin, J. R. and Dover, W. D. "The ICON (Intercalibration of Offshore Nondestructive Testing) Database - Assisting Underwater Inspection", Journal of Offshore Technology, November 1996, (Vol. 4, No. 4, Pp 33-34, ISSN 0968784X)

(54) Rudlin, J. R. and Dover, W. D. "Defect Characterisation and Classification for the ICON (Intercalibration of Offshore Nondestructive Testing) Inspection Reliability Trials", 15th ASME OMAE International Conference, 1996, Florence, Italy, (Proceedings Vol. 2, Pp 503-508, ISBN 0-7918-1491-2)

(55) Topp, D. A. “The Use of Manual and Automated ACFM (Alternating Current Field Measurement) Techniques For Subsea And Topside Crack Detection And Sizing”, 10th AAPG Offshore South East Asia Conference, Singapore, 1994, (Preprints Pp 281-288, OSEA-94137)

(56) Spencer, J. “Flooded Member Detection by Gamma Ray Technique”, 27th Offshore Technology Conference, Houston, 1995, (OTC - 7808)

(57) Stirling, G., Hayward, G. and Pearson, J. “Evaluation of a Novel Ultrasonic Technique for Reliable Detection of Flooded Membersi Offshore Installations”, 2nd ISOPE Conference, San Francisco, 1992, (Proceedings Vol. 1, Pp 148-151, ISBN 1-880653-01-X)

(58) Dover, W. D. and Rudlin, J. R. “Inspection Reliability for Crack Detection and Sizing”, 10th ASME OMAE International Conference, Stavanger, Norway, 1991, (Proceedings Vol. 2, Pp 289-295, ISBN 0-7918-0718-5)

(59) Alers, G. A. “Electromagnetic Acoustic Transducers (EMATS) for Special Inspection Problems on Offshore Structures”, 9th ASME OMAE International Conference, Houston, 1990, (Proceedings Vol. 3, Pp 563-567, ISBN 0-7918-463-1)

(60) Newton, K. “The Development Of New Techniques For Underwater Inspection Of Offshore Structures”, 9th ASME OMAE International Conference, Houston, 1990, (Proceedings Vol. 3, Pp 547-553, ISBN 0-7918-463-1)

(61) Browne, W. “Advances in Subsea Ultrasonic Imaging”, Society of Underwater Technology Advances in Underwater Inspection & Maintenance International Conference, (Aberdeen, Scotland, 1990, (Proceedings Vol. 21, Pp 155-172, ISBN 1-85333-304-2)

(62) Newton, K. and Gulliver, J. A. “A New Eddy Current Instrument for Underwater Inspection”, Society of Underwater Technology Advances in Underwater Inspection & Maintenance International Conference, (Aberdeen, Scotland, 1990, (Proceedings Vol. 21, Pp 141-153, ISBN 1-85333-304-2)

(63) Eccleston, M. J. “Potential Application of Nuclear Remote-Handling Technology to Underwater Inspection and Maintenance”, Society of Underwater Technology Advances in Underwater Inspection & Maintenance International Conference, (Aberdeen, Scotland, 1990, (Proceedings Vol. 21, Pp 83-96, ISBN 1-85333-304-2)

(64) Zettlemoyer, N., Buitrago, J. and Wirsching, P. H. “Probabilistic Concepts for Offshore Fatigue Inspections”, 9th ASME OMAE International Conference, Houston, 1990, (Proceedings Vol. 2, Pp249-258, ISBN 0-7918-461-5)

(65) Miller, B. H. and Hennegan, N. M. “API Level III Inspection of Mississippi Canyon 194 "A" (Cognac) using an ROV (Remotely Operated Vehicle)”, 22nd Offshore Technology Conference, Houston, 1990, (OTC-6355)

(66) Walther, K. G. and Leonard, D. “Underwater Magnetic Particle Testing, How valid are the results? ”, 8th ASME OMAE International Conference, The Hague, Netherlands, 1989, (Proceedings Vol. 1, Pp 315-325)

(67) Fast, D. “Underwater Inspection - Current Methods and Applications”, American Society of Non Destructive Testing, Petroleum Industry Inspection Technology Topical Conference, 1989, Houston, (Proceedings Pp 87-90, ISBN 0-931403-87-1)

(68) Haugland, H. and Lovaas, S. “Underwater Detection and Monitoring of Fatigue Cracks on a Dynamic Loaded K-Node With Internal Stiffeners”, 20th Offshore Technology Conference, Houston, 1988, (OTC-5869)

(69) “New Underwater Cleaner Scours North Rankin Field Platform”, Ocean Ind. Vol. 23, No. 4, Pp. 19-20, April 1988, (ISSN 00298026)

(70) Allen, K. P. and Crawford, A. W. “Improving Subsea MPI (Magnetic Particle Inspection) Consistency”, Society of Underwater Technology Submersible Technology International Conference, Aberdeen, Scotland, 1986, (Proceedings Vol. 5, Pp 189-197, ISBN 0-86010-771-X)

(71) Newton, K. “The Transparency of Fatigue Cracks to NDT (Non Destructive Testing) Methods Used for the Inspection of Offshore Structures”, SPE Offshore Europe 87 Conference, Aberdeen, Scotland, 1987, (Proceedings Vol. 2, SPE-16576, Pp 18)

(72) Fish, J. F., Richards, B. and Low, G. “Ultrasonic NDT (Non Destructive Testing) by Remotely Operated Vehicles”, 5th Association of Offshore Diving Contractors, Offshore Inspection Repair & Maintenance Conference, Aberdeen, UK, 1984, (Proceedings Pt. 2, Pp 5, IRM 84)

(73) Goldberg, L. “Cost Effective Engineered Inspection Techniques for Use Underwater”, Oil Gas Dig Vol. 7, No. 5, Pp. 36-37, May 1985, (ISSN 07449399)

(74) Balmer, B. “Underwater Inspection For Corrosion”, Corrosion And Marine Growth On Offshore Structures (ISBN 0-85312-564-3) Ellis Horwood Ltd, West Sussex, England; Pp. 53-60, 1984

(75) Turner, J. “The Use of Photography in Underwater Inspection”, Society of Underwater Technology International Symposium, Brighton, England, 1980, (Technical Session G, Pp. 14-17, ("Diving Operations"))

(76) Crohas, H. “Pressio-Detection for Permanent Jacket Monitoring”, Deep Offshore Technology Conference, Palma DeMallorca, Spain, 1981, (Proceedings Vol. 2, Pp. 163-167)

(77) Sharma, J. N. “Marine Growth on the Hondo Platform in the Santa Barbara Channel”, 15th Offshore Technology Conference, Houston, 1983, (OTC-4569)

(78) “Magnetic Particle Testing in the Marine Environment”, Mater Evaluation Vol. 41, No. 4, Pp. 527, April 1983, (ISSN 00255327)

(79) Saebjornsen, K. and Forli, O. “Underwater NDE (Non Destructive Evaluation) Techniques”, Mater Evaluation Vol. 41, No. 4, Pp. 503-504,506-507, April 1983, (ISSN 00255327)

(80) “Maintenance and Inspection. Monitoring Bolsters Structural Confidence”, Offshore Vol. 43, No. 2, Pp. 65-66, February 1983 (ISSN 00300608)

(81) “Maintenance and Inspection. Maintenance Requires Scientific Skills”, Offshore Vol. 43, No. 2, Pp. 62-63, February 1983 (ISSN 00300608)

(82) Singh, A., Hasegawa, Y. and Brackett, R. L. “Underwater Thickness Measurement of Underwater Steel Structures”, 14th Offshore Technology Conference, Houston, 1982, (OTC-4361)

(83) Raine, G. A. “ROV (Remotely Operated Vehicle) Weld Inspection with a Mid Size ROV and an ACFM (Alternating Current Field Measurement) Array”, Marine Technology Society, Underwater Intervention Conference, Houston, 1997, (Proceedings Pp. 51-59, ISBN 0-933957-18-1)

(84) Trench, S. A., Hayward, G. Hononge, D. and Kuo, C. “A Focussed Ultrasonic Array System for Offshore Cleaning Applications”, 2nd ISOPE International Conference, San Francisco, 1992, (Proceedings Vol. 1, Pp. 137-141, ISBN 1-880653-01-X)

(85) Trench, S. A., Hayward, G. Hononge, D. and Kuo, C. “Ultrasonic Cleaning of Offshore Structures”, IBC Technology Services Ltd., Offshore Inspection & Maintenance Conference (OIM '92), Dyce, Scotland, 1992, (Proceedings Pp. 25)

(86) Barber, J. C. “Inspection and Maintenance Optimization”, IBC Technology Services Ltd., Offshore Inspection & Maintenance Conference (OIM '92), Dyce, Scotland, 1992, (Proceedings Pp. 35)