HSE
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Executive

Review of current inspection practices for topsides structural components

Prepared by **MSL Engineering Limited**
for the Health and Safety Executive

OFFSHORE TECHNOLOGY REPORT

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Mr J Bucknall
MSL Engineering Limited
5-7 High Street
Sunninghill
Ascot
Berkshire
SL5 9NQ
United Kingdom

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FOREWORD

This document summarises a study undertaken by MSL Engineering Limited for the Health and Safety Executive to review the existing and draft codified practices for the inspection of topsides. The study encompassed inspections during both fabrication and in-service. The inspection approaches recommended by the various codes and practices were critically appraised to determine the type and level of inspection required for topside structural components.

The objective of the study was to assist HSE in developing guidelines for improving performance standards for fabrication and in-service topside inspection.

CONTENTS

1. EXECUTIVE SUMMARY

This report addresses the review of Codes, Standards and Specifications that pertain to the inspection of topsides structures. A search of indices was made and a range of documents were selected for review. Fifteen were selected including a cohesive group of NORSOK standards that are treated as a single entity for most purposes in this study.

Each of the documents was studied to gain an appreciation of purpose for which it was written and to locate text that related to inspection. To gain a clear insight into the reasons for the inclusion or exclusion of types of content it is necessary to understand the context in which a Standard was written. Section 4- Overview of Codes and Standards has been prepared to provide a suitable context for each of the standards reviewed.

The relevant text was then studied and categorised with respect to specific criteria including the relationship of materials inspection, fabrication inspection and in-service inspection to structural criteria including component and connection complexity and functional criticality.

Changes in the factors affecting the design, construction and inspection of offshore topside structures over the last 10 years have also been reviewed in an attempt to identify quantifiable trends. The post Cullen safety regime, changes in design codes, methods of analysis and analysis tools, material strength, substructure geometry and interpretation of NDT were all identified as issues. These issues are discussed in Section 6.

A number of general conclusions drawn from comparing the various approaches have been identified with respect to both fabrication and in-service inspection. These are presented in Section 7. Notwithstanding the findings from these general conclusions. It is evident that more guidance is available with regard to fabrication inspection than is associated with in-service inspection requirements.

The overall conclusions of the study are that both fabrication and in-service inspection would benefit from a more systematic approach. A higher level of safety could almost certainly be achieved with similar and probably less effort than is currently deployed. The most significant area of deficiency is in relationship to assigning appropriate levels of criticality to structural elements that interface with the process plant. It is also likely that too much effort is assigned to elements that are large for reasons of transient loads and do not have a critical structural role in-service.

2. INTRODUCTION

2.1 General

Significant effort and progress has been directed to providing guidance on underwater in-service inspection and structural integrity management including collation of platform and inspection data and their evaluation to develop an inspection for the substructure. The substructure provides support for the superstructure, conductors, risers and other appurtenances. However, less attention appears to have been focused on the superstructure itself. A topside survey, in many instances, consists only of an annual general visual survey where deviations from as-built drawings are considered.

From the standpoint of inspection of topside structural components, the following areas of concern and uncertainty exist at the present time:

- There is a wide range of codes and standards (i.e. regional standards and national standards). The available practices are diverse. Further, many of them have been developed, in the main, to deal with substructure inspection.
- The dominant research on inspection over the past decades has focused on jacket structures. The applicability of these research efforts to topside components has yet to be fully examined.
- Extrapolation of present-day relevant practices to cover inspection of topsides details has not been examined in any detail.
- Extrapolation of present-day information on geometries, weld details, material properties and loading for topside components has not been examined in any detail.

Following discussions, HSE commissioned MSL Engineering to carry out a short study, the objectives and scope of work of which are given below.

2.2 Objectives

In light of the above issues, there is a need to critically appraise the inspection approaches recommended by the various codes and adopted in practice in determining the type and level of inspection required for topside structural components. The objectives of this study were as follows:

- To review existing codes and/or standards on topsides inspection during fabrication and in-service and identify areas of uncertainties where the various practices differ significantly in their approach to inspection (e.g. techniques and procedures) and categorisation of components.

- To identify changes in inspection practices which may have occurred over the past decade with a view to developing an understanding of the changes to inspection requirements which may be important for the assessment of both new and existing (particularly ageing) structures.

- To identify changes in design of topside structural details which have occurred over the past decade to develop an understanding of the changes to inspection requirements which may be important for the assessment of both new and existing (particularly ageing) structures.

- To classify topside structural details into categories of importance from the standpoint of inspection requirements for ensuring continuing integrity.

- To define the current status of topsides inspection and to recommend improvements to present-day practices.

2.3 Scope of Work

The scope of work is summarised below:

- Undertake critical appraisal of current codes/standards (UK, US and Norwegian and proposed ISO provisions) for inspection of topsides during fabrication.

- Undertake critical appraisal of current codes/standards (UK, US and Norwegian and proposed ISO provisions) for inspection of topsides during service.

- Identify and rank importance of inspection requirements relating to criticality of topside structural details and overall structural integrity of platform.

- Identify areas of uncertainty and make recommendations.

2.4 Methodology

A search was made of technical indices and reference sources to identify codes and standards that may have been or could be used for the specification, design, fabrication and inspection of offshore structures. As historical practice has involved the use of onshore design codes (or modifications of them), a number of recently developed onshore codes were also included. These were also considered a relevant benchmark, as it is arguable that many structural components of an offshore platform topsides are no different to those in an onshore coastal refinery. The results of the search revealed a few surprises, in particular **ISO/FDIS 10721-2 Steel structures - Part 2: Fabrication and erection,** the Scope of which includes the following statement: *"...specifies the requirements for fabrication, erection and inspection of structural steelwork in buildings designed in accordance with ISO10721-1,……..also applicable to bridges, **offshore** and other civil engineering and related structures, but for such structures it may be necessary to consider other requirements".* As it can be said with some confidence that at least 95% of engineers working in the offshore sector are not even aware of the existence of this code, it would be interesting to ascertain the means by which the code drafters audited this assertion. The codes selected for inclusion in the review were:

1. API RP2A – LRFD
2. EEMUA Publication No. 158
3. NORSOK Standard M001
4. NORSOK Standard M101
5. NORSOK Standard M120
6. NORSOK Standards N001 to N005
7. NORSOK Standard S001
8. NORSOK Standard Z001
9. ISO 13819-1

10. ISO 13819-1.3
11. ISO 13819-2
12. DD ENV 1993-1-1:1992 Eurocode 3
13. DD ENV 1090-1: 1998 Execution of Steel Structures
14. ISO/FDIS 10721-2 Steel structures - Part 2: Fabrication and erection

Full titles and details of all these reference Codes, Standards and Specifications are given in the References section.

The NORSOK Standards form part of a comprehensive suite of standards specifically written for offshore platforms and are treated as a cohesive group within this report.

The ISO Standards, while also forming parts of a unified standard, have been treated individually and in more depth as they should ultimately supersede all other national and regional codes.

Before reviewing the various documents a appreciation of the types of topside structural details that have evolved over the past 30 years is presented in Section 3.

Each of the selected documents was reviewed to obtain a clear appreciation of its objectives and philosophy. This was considered necessary because standards and specifications may be written from a wide range of perspectives and with different intents. It would not be constructive to approach a critical review and conclude that a document has shortcomings that are unrelated to its intended purpose. Section 4 gives an overview of the codes.

Each document was then examined to provide an understanding of the level to which it addressed the following attributes in relation to the inspection requirements relating to the fabrication and then to the in-service condition:

i. Material classification – in relation to component duty
ii. Inspection techniques, procedures and qualification
iii. Criticality classification (how)
iv. Complexity identified (how)
v. Extent of inspection and how allocated.

This part of the study is summarised in Section 5. From the information addressed in Section 5 comparisons between the various codes have been conducted, the details of which are given in Section 6. Not surprisingly relatively little information is provided for in-service issues.

Following the review an attempt has been made to draw some practical conclusions and make suggestions for a more systematic approach that may be adopted to the categorisation of structures for fabrication and in-service inspection. These are presented in Section 7.

3. TYPICAL TOPSIDE STRUCTURAL DETAILS

3.1 Evolution of Structural Form

The overall form of topsides structures has seen a most significant change over the last 30 years and this is mainly due to the developments in the North Sea. Most of the early platforms in the North Sea were derived from concepts used in the Gulf of Mexico. However, the comparatively hostile environment of the North Sea urged the use of heavier structures and more robust production equipment. Also the use of separate jacket platforms for drilling/production and accommodation, as sometimes seen in the Gulf of Mexico, was found impracticable; and commercial considerations favoured the use of platforms that could service the maximum number of wells. In short, the North Sea fuelled the need for single jackets supporting larger superstructures.

However, in the early days of North Sea production, offshore crane capacity was rather limited (eg. Maximum of 2000 tons in 1973) and this led to the topsides being built up in small modules (glorified containers) with extensive offshore hook-up activities. Each Module was designed with small truss members. They were typically stacked two or three high and were all supported on a module support frame (MSF). The MSF is typically fabricated with plate girder construction.

With the advent of higher offshore crane capacity (now at 14,000 tons), integrated decks became more common. These tend to have much more stockier members in the framing, typically larger column sections, rolled tubes or square hollow sections.

As design experience has grown, more optimal designs and economic construction techniques have arisen, associated with overall weight reduction. For example, over the last ten years deck plating has been increasingly used as a structural element in orthotropic plate construction, and module walls have been made to fulfil a structural role in stressed-skin designs.

The net effect of these changes is that whereas the percentage of the topsides weight was 50% structural for earlier MSF configurations, it is now about 35% for integrated decks.

3.2 Materials

Carbon steel is generally ubiquitously used for topside construction. However, alternative materials have been used over the last 15 years or so where technical or economic advantage has favoured their use. Technical advantages include weight saving and better corrosion resistance. For example, some platforms have incorporated aluminium stair towers and helipad supporting structures, others have used various grades of stainless steel for module skins and blast walls. Fibre-reinforced polymers may also be found as in floor gratings. Nevertheless, these alternative materials have really only been used for secondary structural applications, carbon steel remains the only effective choice for primary structure.

Improvements in steel-making, and in particular those over the last two decades, have resulted in higher strength steels. In topsides, buckling of members or fatigue consideration are rarely the governing design criteria and therefore advantage can be taken of the greater strength of these steels. Increasing use is being made of steels having specified yield stresses around 450 MPa.

One issue that has been of more concern for offshore structural steelwork than onshore constructions (where bolted construction is more common) is through-thickness properties. This applies both to hot rolled sections and to steelwork fabricated from plate. At all major nodal connections, flanges and or/webs tend to be cut out and replaced with plate having guaranteed through-thickness properties.

3.3 Welding

As mentioned above, topsides tend to be of all welded construction, exceptions being secondary steelwork and lattice towers. This facilitates sealing all internal voids and spaces against possible corrosion by running fillet welds. However, the welds across load paths in joints and connections tend to be full penetration even where, structurally, there is no necessity for a full strength connection. In part, this is due to time constraints on the designer who will specify full penetration welding so as to avoid calculation. Associated with this the designer may also call for 100% NDT inspection using ultrasonic and/or MPI where again it may not strictly be required. The fabrication sequence is normally the responsibility of the fabricator. In this respect, having the fabricator involved early in the project is advantageous. For minimum structures, where the lead time for steel procurement takes up a greater proportion of the fabrication schedule, early involvement is especially important as the fabricator may have steel already available in the yard which could be used in the design.

Greater use is now being made of automated welding techniques than was the case in the early days of North Sea development.

3.4 Detailing

It is important that joints are well engineered as they represent a major cost element in topside construction. However, design houses tend to use their own standard details from job to job. Different design houses (and fabricators) have different preferences such as some preferring the use of stiffeners to gusset in-fill plating and vice versa. Standard details cover items such as beam to beam and beam to column connections, for the range of sizes and member types (eg. rolled sections, tubulars, plate girders, etc.) that are found in practice.

The major structural joints or nodes in the topside structure may be complex with multiplanar horizontal and diagonal members framing into the node. Practice is to make them non-overlapping, for reasons of facilitating fabrication although subsequent inspection is an obvious additional benefit. If the vertical member is a tubular leg, ring stiffening may be provided to resist the large tensile and compressive forces acting in the flanges of the horizontal members. The joints between other member sections also usually require some form of reinforcement. The choices are stiffeners or gusset plates, and here the preference of the design house or fabricator will dictate which option is selected.

Stiffeners are usually designed so that the full capacity of the incoming member can be realised. Although the calculations are simple, stiffeners require some effort from the fabricator to shape them for a close fit within the member. Gussets, on the other hand, need more design effort but are relatively easy for the fabricator to fit. In fatigue prone areas, such as the MSF, the gusset plates may be curved so that stress concentration factors are reduced.

Supports for pipework, whilst often considered as secondary steelwork, deserve specific mention as there is potential for escalation in the event that one fails. Practice is to use standard details from job-to job. Small diameter pipework, and associated supports, are often run in the field.

4. OVERVIEW OF CODES AND STANDARDS

4.1 Philosophy

For each selected Standard this section summarises issues of a general "philosophical" nature. Not all the standards set out to cover the same scope or are written to meet the same objectives. It is necessary to relate inspection and testing to the Scope and objectives of the document and to place them in the correct context. It is interesting that the document used as the principal reference for most existing platforms (API RP2A) is not a normative standard.

API RP2A – LRFD

This is a "Recommended Practice" and worded in informative terms. It, and earlier (WSD) versions, form the original source documents for most offshore design and construction practice. A clear attempt is made to assign material and inspection requirements during construction in relation to service duty, material thickness, restraint and structural redundancy. Topside functions are however treated in a relatively cursory and dismissive manner (Ref. Clauses I.1.1, I.1.3.1). In-service surveys are specifically provided for in Section O with the guidance that "During the life of the platform, in-place surveys that monitor the adequacy of the corrosion protection system and determine the condition of the platform should be performed in order to safeguard human life and property, protect the environment, and prevent the loss of natural resources". This sound philosophy is diluted somewhat by the subjective classification of "more critical areas" in section O.3.1. as "deck legs, girders, trusses, etc".

EEMUA Publication No. 158

This Specification is a Construction Specification for Offshore Steel Structures and thus more limited in Scope but more extensive in detail than API RP2A. It is intended for use by Purchasers of Facilities and is normative in content. It pre-supposes a Contract with a high level of Purchaser supervision and assumes Purchaser expertise and approval at a detailed level. It is considerably more detailed than API RP2A in the requirements for construction with more than 100 pages covering a scope that is represented by 7 pages in API RP2A. Aspects, which should ideally be highlighted in a Clause on general principles, are buried in sub-clauses, particularly issues that relate design to inspection level.

NORSOK Standards M001, M101, M120, N001/N005, S001 and Z001

These Norwegian Standards are considered here as a group for the purposes of this study. They represent the most extensive and developed public sector standard(s) covering the requirements for inspection during fabrication and operation. They are normative and prescriptive in nature. They clearly identify the link between design knowledge and inspection requirements and give detailed direction on component and joint classification relative to inspection requirements. Within the standards there are a large number of normative references - so many that the realistic ability of a contractor to comply must become questionable. The requirements for topside structures are dealt with more extensively than in other standards but the bias in identifying risk is clearly transferred from substructure design and the issue of system interaction poorly covered.

ISO 13819-1 Petroleum and Natural Gas Industries - Offshore Structures – Part 1: General Requirements

This document specifies general principles. Section 3.2 states "Maintenance shall include the performance of regular inspections, inspections on special occasions (e.g., after an earthquake or other severe environmental event)" but then proceeds to state "Durability shall be achieved by either: a) a maintenance program, or b) designing so that deterioration will not invalidate the state of the structure in those areas where the structure cannot be or is not expected to be maintained." The implications for this statement are clarified further by the following paragraph: "In the first case above, the structure shall be designed and constructed so that no significant degradation is likely to occur within the time intervals between inspections. The necessity of relevant parts of the structure being available for inspection - without unreasonable complicated dismantling - should be considered during design. Degradation may be reduced or prevented by providing a suitable inspection system." The possibility of designing and fabricating to completely avoid in-service inspection is identified here. This is however contradicted in section 8 (see Requirements during Operation - extent of Inspection). A note at the end of section 3.2 says: "Structural integrity, serviceability throughout the intended service life, and durability are not simply functions of the design calculations but are also dependent on the quality control exercised in manufacture, the supervision on site and the manner in which the structure is used and maintained".

ISO 13819-1.3 Petroleum and Natural Gas Industries - Offshore Structures – Part 1.3 Topside Structures

The draft reviewed is not yet at Committee Draft status. The draft was made available by the technical author working with the editing panel and is an unofficial copy undergoing development and amendment. The philosophy for inspection and its relationship to design, fabrication and in-service conditions is clearly stated (in clauses 6.8 and 6.9) as follows:

> **"6.8 DESIGN FOR FABRICATION AND INSPECTION**
>
> The designer should be familiar with, and anticipate the various methods of fabrication, welding, and erection that may be used to execute his design and he shall provide a design which accommodates these through the provision of appropriate material thicknesses, clearances, access and stability at all stages of construction.
>
> The responsible engineer shall ensure that the design intent is followed during construction and shall ensure that variances are resolved without compromising the design intent.
>
> The designer shall clearly communicate the extent, type and rejection criteria for all non-destructive inspections. Where performance level (e.g. fatigue performance) depends on the achievement of particular standards in construction the designer shall ensure that these are clearly communicated and verified.

6.9 DESIGN CONSIDERATIONS FOR STRUCTURAL INTEGRITY MANAGEMENT

During the design, fabrication, inspection, transportation and installation of the topsides, sufficient data shall be collected and compiled for use in preparing in-service inspection programmes, possible platform modifications etc. Where a topsides has fatigue sensitive components the critical areas shall be identified and this information used in the preparation of in service inspection programmes."

ISO 13819-2 Petroleum and Natural Gas Industries - Offshore structures – Part 2 Fixed Steel Structures

Clause 6.1.2 quotes from ISO 13819-1 (the note at the end of section 3.2). From this is drawn the philosophy that "…during the planning stage a philosophy for inspection and maintenance should be developed. The design of the structure as a whole, as well as the structural details, should be consistent with this philosophy." A systematic classification of "life safety" and "consequence of failure" are proposed to provide a matrix of "exposure levels" that may be used to determine criteria for design. Alternative philosophical approaches to material selection, i.e. Material Category (MC) or Design Class (DC), are proposed.

DD ENV 1993-1-1:1992 Eurocode 3. Design of Steel Structures

Except by reference to "Reference Standards", EC3 contains little relevant to inspection and maintenance of structures. Clause 2.4 - Durability lists one criterion as "the likely maintenance during the intended life". Clause 7.2 - Project Specification states that the designer shall provide, or adopt, a Project Specification. The Project Specification shall contain adequate details of any special requirements for fabrication, erection, inspection and acceptance. Clause 17.8 refers to "the Relevant Reference Standards". The Reference Standards in the UK National Application document are BS 5950: Pt 2, BS 4604: Pt 1 and Pt 2, BS 5135 and BS 5531. None of these give guidance for in-service inspection. (It is apparent that DD ENV 1090-1 will become the "Relevant Reference Standard" for EC3.)

DD ENV 1090-1: 1998 Execution of Steel Structures - General Rules and Rules for Buildings. + ENV 1090-3: 1997 Supplementary Rules for high yield strength steels + ENV 1090-5 : Supplementary rules for bridges

The standard "..gives requirements for execution of steel structures in order to ensure adequate levels of mechanical resistance and stability, serviceability and durability." It specifies "general requirements for execution of structural steelwork ….. detailed requirements for structures which are not significantly susceptible to fatigue. ...in particular those which are designed to according to ENV 1993-1-1". The standard (Cl. 4) requires that "All necessary information and technical requirements for execution shall be set out in the project specification". Some subsequent clauses leave such a wide range of discretion to the project specification that structures fabricated to this standard can be so variable in reliability as to make the standard ephemeral. For example, the only mandatory weld inspection is visual, all other testing is at the discretion of the project specification. On this basis structures built with zero NDT could claim to be in accordance with ENV 1090-1. This specification is also a good example of the problems faced by engineers in attempting compliance. It lists no less than 113 normative references. To obtain clarity from section 3 (Definitions) reference to seven other ISO or EN standards is required. In the real world compliance will be impossible. There is a need to challenge the protocols that make any standard so cumbersome to use. The document is both ephemeral in terms of standard and almost impossible to comply with in practice.

ISO/FDIS 10721-2 Steel structures - Part 2: Fabrication and Erection

The introduction states "This part of ISO 10721 establishes a common basis for drafting national standards for the fabrication and erection of steel structures, in order to ensure an adequate and consistent treatment of safety and serviceability compatible with ISO 10721 - 1. The specific and numerate requirements for the achievement of structures which are optimal with respect to the state of the economy, development and general values of a nation are given in the appropriate national standard." This paragraph appears to contain a degree of logical contradiction. The Scope includes the following: "...specifies the requirements for fabrication, erection and inspection of structural steelwork in buildings designed in accordance with ISO 10721-1,……..also applicable to bridges, **offshore** and other civil engineering and related structures, but for such structures it may be necessary to consider other requirements". The text of this specification contains normative requirements - generally relevant and sound. However, for weld inspection, reference is made for guidance to Annex D - Informative (but which contains much normative language), and for Qualifications of Personnel, clause 10.2.5 states that all personnel **shall** be suitably qualified for the tasks for which they are appointed, in accordance with Annex C (Annex C is Informative!). Notwithstanding the above semantic difficulties this document does contain much which is worth considering for normative inclusion in more detailed application documents.

4.2 Coverage

Each selected code was studied to identify clauses relevant to:

i. Material classification issues
ii. Categorisation of components
iii. The extent of inspection requirements during the fabrication stage
iv. The recommended inspection techniques including procedures, inspector qualifications and reject/acceptance criteria
v. In-service inspection requirements.

A summary of the findings are given in Section 5 and comparisons between the various codes are presented in Section 6.

Here only a general overview is given, see Table 4.1. The table indicates whether the code has anything relevant to the above items and if so, to what qualitative level of detail does the code address the item. The levels of detail in Table 4.1 are as follows, starting with the least coverage.

No
The codes makes no mention of the item.

Little
The item is mentioned as an aspect that needs consideration but little guidance is given within the code.

Limited
There is some guidance given but it is not particularly detailed. It may, for instance, give a list of issues that are involved but without any weighting as to the importance of the issues.

Detailed
As the name implies, the guidance is detailed and more or less complete. Typically tables of categories are presented within the code.

It can be seen from Table 4.1 that the extent of coverage by the codes is quite variable. The NORSOK set of standards and the forthcoming ISO 131819-2 offer the most coverage. Both of these codes are new codes. The most prevalent offshore code, API, has something on all items but is rather limited in depth. In-service inspection is poorly represented with most codes having nothing or only little to say on this aspect. Only ISO 13819-3 (the topsides Annex) attempts to give some practical guidance on in-service inspection but even then it is limited.

Table 4.1
Coverage of various Codes according to selected subject matters

Document	Material Classification	Component Classification	Extent of Fabrication Inspection	Inspection Techniques	In-service Inspection
API RP2A	Limited	Limited	Limited	Little	Little
EEMUA No.158	Limited	Limited	Detailed	Detailed	No
NORSOK	Detailed	Detailed	Detailed	Detailed	Little
ISO 13819-1	No	No	Little	No	Little
ISO 13819-3	Limited	Little	Little	No	Limited
ISO 13819-2	Detailed	Detailed	Detailed	Limited	Little
DD ENV 1993-1-1	Little	Little	Little	Little	No
DD ENV 1090-1	Little	No	Little	Limited	No
ISO/FDIS 10721-2	Little	Little	Detailed	Detailed	No

5. INSPECTION ALLOCATION AND REQUIREMENTS

5.1 General

This section summarises the main aspects of each of the various codes and standards with respect to the extent of inspection that is required and how this inspection is allocated. The extent of inspection and allocation encompasses the following areas:

- Extent of inspection: Including the type of and intensity of NDT with respect to the function and criticality of elements.
- Inspection techniques: Encompassing both method and qualifications.
- In-service Inspection: As opposed to fabrication inspection.

The above can be influenced by a number of factors including the following:

- Material classification: With particular emphasis on the relationship of material grade, testing and certification to the duty of the structural element to which it is assigned.
- Component criticality: By which the component or connection are classified by their construction to overall structural integrity.
- Component complexity: Including the reliability with which the true stress in a component or connection can be predicted, accounting for constraint during welding and complex geometry.

From the overview of codes and standards undertaken in Section 4 it was apparent that some of the codes provided more details than others on the above (see Table 4.1). Emphasis in this section was given to those codes and standards which provided sufficient information to enable the above items to be addressed in some detail. A review of both the fabrication and in-service inspection requirements have been undertaken and are presented separately.

5.2 Fabrication Inspection

This section reviews the requirements of fabrication inspection.

5.2.1 ISO 13819-2 Petroleum and Natural Gas Industries - Offshore Structures – Part 2 Fixed Steel Structures

Clause 18 of the above clearly links the extent of inspection to the following areas:

i. Criticality of member or joint
ii. Effect on global integrity
iii. Consequence of failure
iv. Degree of redundancy
v. Stress state complexity
vi. Strength level
vii. Thickness
viii. Degree of plastic straining
ix. Exposure to fatigue loading

x. Service temperature

Two approaches based on either a global level (Material Class, MC) approach or joint/component level (Design Class, DC) approach as designated by the Owner are available. Clause 18 emphasises that once the Owner has decided on the classification approach to be adopted then this approach shall be followed throughout without switching between approaches.

Design class approach

In the case of the DC approach the designer is allowed to select the appropriate steel quality by component. The code emphasises that this approach should only be used for highly engineered structures where the designer studies the stress patterns in the members and joints and has engineers that are experienced in the application of DC principles. The main criterion for determining the design class of a joint or component is the significance with respect to global integrity and consequence of failure of the joint or component. In addition items highlighted above (i.e. degree of redundancy, geometrical complexity etc.) will also influence the DC selection.

The consequences of such selection therefore has a direct bearing on not only the material strength, toughness selection but also on the inspection requirements (i.e. NDT technique used and extent of coverage). The code provides a number of inter-related tables within Clauses 18 and 20 for determining the selection of material steel grade, toughness and minimum inspection requirements, including minimum extent of inspection and percentage coverage of each inspection technique used. A closer examination of these requirements has been carried out and the most important features relating to the inspection requirements are presented in Table 5.1. An examination of Table 5.1 reveals the following aspects relating to the inspection requirements:

- Consequences of structural failure (with respect to life, pollution, asset and residual strength)
- Toughness requirements (related to steel yield strength selection)
- Five design classes DC1- DC5 (linked to consequence of failure and joint complexity)
- Joint complexity (high or low, inspectable or non-inspectable)
- Joint criticality (high or low with respect to fatigue and tensile stress utilisation)
- Five Inspection Categories A, B, C, D and E (related to type of weld, NDT method and coverage).

The following observations from Table 5.1 can also be made:

i. The number of inspection methods include visual inspection, Ultrasonic(UT) Radiography (RT) and Magnetic Particle testing (MT).
ii. For all components regardless of DC, 100% visual inspection shall be performed.
iii. The use of NDT inspection techniques UT, RT and MT inspection and the extent of coverage (i.e. 0-100%) using each of the techniques is dependent on the DC and the consequence of failure. The extent and type of NDT inspection undertaken increases with increase in consequences of failure.
iv. Five categories of inspection are provided ranging from categories A-E respectively for each weld type. Category A provides the highest extent of testing with respect to number of NDT techniques used and % coverage of each technique, whilst Category E provides the lowest extent of testing (i.e. visual only).
v. Inspection of Butt welded, T connections and Fillet welded/Partial penetration welds are considered.

vi. Joints which are categorised as being non-inspectable (i.e. welds or part of welds with no access for in-service inspection or repair) require a higher degree of inspection than those which can be inspected/repaired. The designated inspection category for these cases increase by one inspection category level (e.g. from inspection categories B to A, C to B and D to C respectively).
vii. Joints designated as having high fatigue utilisation have different inspection categories depending on whether the dominating stress is in the direction of the weld or transverse to the weld. Welds with direction of stress transverse to the weld require a higher degree of inspection.
viii. Joints designated as having a high degree of fatigue utilisation require a higher degree of inspection depending on the degree of tensile stress transverse to the weld and degree of shear stress (i.e. the higher the tensile stress utilisation and shear stress the higher the extent of inspection required). For joints with tensile stress utilisation greater than 0.6 the coverage is similar to joints designated with high fatigue utilisation.
ix. Inspection requirements of connections designated as Fillet welded/Partial penetration do not include/require UT inspection as part of the overall inspection coverage.
x. In general the toughness requirements increase with increasing consequences and increase in yield strength of material selected.
xi. Some relaxation in the coverage of weld inspection is allowed provided that the defect rates that are obtained in the last 100mm of weld are consistently low.

It should be noted from the information summarised in Table 5.1 that Clause 18 does provide minimum design class designations, toughness requirements and minimum inspection categories with respect to different components of the substructure/jacket (i.e. leg nodes, bracing). However, information relating to the superstructure/topsides does not appear to be available. The only information found relates to the classification for joints with high joint complexity (i.e. DC1 and DC3 respectively). In these cases high joint complexity is defined where the geometry of connected elements and weld type leads to high restraint and to triaxial stress patterns (e.g. typically multiplanar plated connections with full penetration welds). From examining Clause 18 further it would appear that further information can be found when adopting the MC approach.

Material class approach

In the case of the MC approach the inspection approach is described once the global criticality designation has been made by the Owner. The selection of components having already been evaluated on the basis on overall structural significance. Three MC classes are available:

MC1- This category is generally used for L1 structures
MC2- This category is generally used for L2 structures
MC3- This category is generally used for L3 structures

Where the designations of structure types L1-L3 are dependent on both the consequences of failure (i.e. high, medium and low) and life safety category (i.e. manned-non evacuated, manned evacuated and unmanned) as described in clause 6.6 and presented in Table 5.2 of this report.

The MC approach defines the strength level, toughness class and hence extent of minimum fabrication inspection required. Table 5.3 summaries the main important features of the extent of inspection to be carried out. As in the case of the DC approach the percentage coverage, type of NDT technique used are provided. However inspection categories (i.e. A to E) are not defined as in the case of using the DC approach. To aid in the comparisons between the two approaches similar inspection categories have been assigned where they are similar to the DC approach. In some cases the inspection coverage using the MC approach is different to the DC approach (i.e. inspection categories A, B, etc. are not applicable). In these cases, to aid comparisons arbitrary defined categories (defined as a subset of the main categories A, B, C etc.) have been used and assigned to the appropriate MC.

The following observations from Table 5.3 can be made:

i. The numbers of inspection methods include visual inspection, Ultrasonic(UT), Radiography (RT) and Magnetic Particle testing (MT).
ii. For all components regardless of the MC adopted 100% visual inspection shall be performed.
iii. Inspection categories A, C and E similar to that observed for the DC approach are noted. However, further categories have been defined (i.e. A^1, A^2, C^1, C^2, C^3) which reflect the different extent of inspection method used and % coverage of each inspection technique.
iv. The number of NDT methods (i.e. UT/RT and MT) used and extent of coverage (i.e. 0-100%) for each technique increases for inspection of deck/girder components as the degree of consequence increases (i.e. as the selection of MC changes from MC3 to MC1 respectively).
v. For components involving lifting points, crane pedestal and vent/flare towers similar inspection requirements are noted irrespective of the allocated Material Class category. Furthermore, the inspection requirements for each of these components require a high inspection category - Category A.
vi. Inspection of full penetration, partial penetration and fillet welds are considered.
vii. Inspection percentage values shown in brackets are reduced values which can be used provided defect rates observed are low.
viii. Toughness requirements generally increase with degree of consequences observed. Mandatory CTOD testing is required for components greater than 50mm thick.

In the case of both the DC and MC approaches, weld inspection and weld acceptance criteria are noted as being to a recognised international code (such as API RP2X and AWS D1.1) for each of the inspection NDT techniques (i.e. UT, RT, MT). However, for UT inspection involving the use of API RP2X the code states that for TKYX tubular joints Level C criteria shall apply and for butt welds and other critical welds as specified by the designer (e.g. welds where brace footprints cross stiffener locations and welds which are ground to improve fatigue life) Level A criteria shall be used. In the case of visual inspection the code states that either the acceptance criteria defined in Table 20.9 of the code, the details of which have been summarised in Table 5.4 (i.e. details of the type of defect and the permitted maximum defect size allowed), should be adopted or a recognised international code with equivalent requirements shall be used.

5.2.2 ISO 13819-1.3 Petroleum and Natural Gas Industries - Offshore Structures – Part 1.3 Topside Structures

Clauses 6.8 and 6.9 place a clear responsibility on the designer to define, communicate and ensure verification of the level of NDT. Clause 15 refers to the fabrication minimum inspection requirements for topsides. The clause clearly identifies that inspection should be carried out in accordance with ISO 13819-2, Section 20.8 which reflects the approaches described previously. Additional information is also provided in Annex A (informative section) where it is stated that the requirements of ISO 13819-2 may not cover all situations that can occur in a topside structure. Emphasise is particularly noted with respect to Table 20.2 of ISO 13819-2 (see also Table 5.3 in this report) where components relating to equipment support that may be critical to safety because of the potential of fire or explosion are not included. Designers are informed that they should ensure that the inspection requirements for such components are appropriate to the component criticality.

5.2.3 EEMUA Publication 158

Inspection and NDT requirements are covered under Section 7 of EEMUA 158. A number of tables linking the extent and type of minimum inspection that should be carried out is included. The main important features from these tables have been collated and are summarised in Table 5.5 of this report. Although not included in EEMUA 158 an inspection category designation similar to that adopted in ISO 1318-9 Part 2 (i.e. A, B C etc.) has been included for comparison purposes. The following observations from Table 5.5 can be made:

i. Five inspection categories, namely I-V, are defined and relate to the stress state of the weld and also the extent of cyclic loading applied
ii. For each of the five categories the areas of application (e.g. jacket nodes, topside structural columns, lifting padeyes/padears, crane pedestals etc.) are defined
iii. The number of inspection methods considered include visual inspection (V), Ultrasonic (UT), Radiography (RT) and Magnetic Particle testing (MT)
iv. For all areas of application regardless of the inspection category assigned 100% visual inspection shall be performed
v. Inspection categories A and C are similar to that observed for the DC approach included in ISO 13819-2
vi. The number of NDT methods (i.e. UT/RT and MT) used and extent of coverage (i.e. 0-100%) of each technique is lower for welds which do not involve any significant cyclic loading
vii. Reduced percentages of inspection coverage noted can be allocated depending on whether a consistent low repair rate is achieved.

Ultrasonic and visual inspection acceptance criteria are provided within EEMUA, the details of which have been summarised in Tables 5.6 and 5.7 of this report. It should be noted as shown in Table 5.6 that in the case of visual inspection defect types (i.e. undercut, excess penetration, shrinkage grooves and root concavity, reinforcement shape, overlap and linear misalignment) are covered within the criteria. This criteria appears to be similar to that adopted in ISO 13819-2, albeit ISO 13819-2, Table 20.9 (see Table 5.4 herein) appears to cover more defect types (i.e. includes cracks, lack of fusion, craters, fillet welds and porosity).

5.2.4 API RP2A - LRFD

The extent of minimum inspection requirements are identified in Table N 4.1, the details of which have been summarised in Table 5.8 of this report. The extent of inspection covers jacket/substructure components in some detail, whilst topside components are covered under the single heading "deck members" where inspection of topside components are related to welds which are either full penetration welds, partial penetration or fillet welds. From Table 5.8 the following observations can be made:

i. The number of inspection methods considered include visual inspection (V), Ultrasonic (UT), Radiography (RT) and Magnetic Particle testing (MT).
ii. For all areas of application regardless of the inspection category assigned 100% visual inspection shall be performed.
iii. Either 100% (UT) or 100% (MT) inspection can be used to inspect full penetration welds, (i.e. suggests that UT can be used as an alternative to MT for any topside weld).
iv. For partial penetration and fillet welds visual inspection only is normally required with the provision that either MT or PT (liquid penetrant technique) may also be considered.

The cursory nature of RP2A with respect to topsides was considered to be a major driver for a separate topside annex. Interestingly, API RP2A addresses in a single paragraph (i.e. Section N.4.3.1) a number of important issues regarding NDT method selection which include similar features noted in ISO 13819-2 (i.e. influence of joint geometry, applied stress (type and magnitude), thicknesses of components and discontinuities). The section also recommends that co-ordination between designer, fabricator, inspector, and owner together with consultation with an NDT specialist is essential in order to select the most appropriate technique for a particular application.

Acceptance criteria are also noted in Section N.4.3.2 where it is noted that UT inspection of welds shall be in accordance to the criteria given in API R2X - "Recommended Practice for Ultrasonic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Ultrasonic Technicians" and to ANSI/AWS D1.1-"Structural Welding Code-Steel, American Welding Society Specification" for other NDT inspection methods.

5.2.5 NORSOK

NORSOK Standard N-004 - "Design of Steel Structures", Section 5 provides a clear link between the selection of steel quality and requirements for inspection. The main criterion for the systematic classification of welded joints is related to the structural significance and complexity (i.e. stress predictability) of joints and the significance with respect to consequence of failure of the joint. The selection is based on similar principles to the DC approach of ISO 13819-2 in which the DC class assigned is related to the significance with respect to consequences of failure of the joint in relationship to loss of life, pollution and asset. An examination of Section 5 of NORSOK N-004 reveals that the approach follows closely that adopted in ISO 13819-2 (or visa -versa) involving the allocation of five different DC classifications. A number of tables providing links between the consequences of failure, design class and selection of inspection categories for each design class are similar to those presented in Section 20 of ISO 13819-2, and hence similar to details presented previously in Table 5.1 of this report. However, NORSOK Standard N-001 - "Structural Design" does provide some general guidance on the selection of components for the different DC categories and identifies examples applicable to topsides as follows:

i. DC1 should be regarded as a special case selection and should not be used indiscriminately (i.e. complexity of joint is high with regards to geometry and stress predictability). Examples are: complex topside footing connections, complex main steel joints where high tensile through thickness stresses are expected which would otherwise have been classified as DC2.

ii. DC2 should be used for majority of joints which are essential for the overall integrity of the structure (i.e. complexity of joint is low with regards to geometry and stress predictability). Examples are topside footing connections, main truss nodes, bridge supports and flare tower supports.

iii. DC3 is a special case selection and should not be used indiscriminately (i.e. complexity of joint is high with respect to geometry and stress predictability). Only applicable for extreme complex joints which would otherwise be classified as DC4.

iv. DC4 is applicable for main secondary structures in general. Examples are joints in trusses, deck beams, stiffeners, large pipe supports and large equipment supports.

v. DC5 is applicable for all other joints and members in less significant load bearing structures. Examples are outfitting structures, pipe and equipment supports in general.

Section 9, Table 9.1 of NORSOK Standard M-101- "Structural Steel Fabrication" defines the minimum extent of NDT testing for each inspection category. As previously noted above the requirements in this section are similar to the requirements provided in Table 20.8 of ISO 13819-2 using the DC approach, as presented in Table 5.1 of this report, where inspection Categories A, B, C, D and E are defined for different types of connections (i.e. Butt welds, T-Connections and Fillet/Partial penetration welds). However, whilst ISO 13819-2 provides acceptance criteria explicitly for visual inspection only (see Table 5.4) which are the same irrespective of the inspection category adopted, NORSOK Standard M-101 provides acceptance criteria for visual/MT, UT and RT for each of the different inspection categories. The details of these different acceptance criteria have been summarised and are presented in Tables 5.9 to 5.11 of this report for each of the different inspection techniques respectively.

5.2.6 DD ENV 1090-1: 1998 Execution of Steel Structures

Section 12 of DD ENV 1090-1 provides information relating to inspection requirements. The standard states that visual inspection of all welds should be made (i.e. normative) but all other methods and the extent of coverage are left to the project specification and may - or may not - be specified. Table 8 of the standard (the details of which are presented in Table 5.12 of this report) provides frequency of NDT testing (non-mandatory) and this is modified in ENV 1090-3 but still remains non-mandatory. Further tables are provided within the standard which show proposed "Fields of application for NDT". The main features of which have been summarised and presented in Table 5.13 of this report. It can be seen from Table 5.13 that UT, MT and RT inspection techniques are applicable for full penetration welds, whilst for fillet/partial penetration only MT is considered. The standard also indicates that acceptance criteria for welds shall be stated in the project specification. The standard provides guidelines for limits of weld imperfections in Annex H.

5.2.7 ISO/FDIS 10721-2 Steel structures- Part 2: Fabrication and erection

Clause 11.1 states that the extent of inspection shall be determined according to the importance of a connection in the structure. Annex D (informative) provides further details stating that the procedures for testing and inspection of welded structures depend on many factors which are related to a number of variables such as material quality, strain rate, type of detail and workmanship. Annex D identifies four main stages for testing and inspection to control weld quality namely procedure qualification, welder qualification, production weld testing and final acceptance. It is clearly intended that these details be converted to normative where they are appropriate.

Detailed proposals on the appropriate use of NDT methods are given in Section D.5 of Annex D for final acceptance of welds. Section D.5 states that all welds should be visually inspected. In addition to this, NDT testing using UT, RT and MT inspection techniques should be applied in accordance with Table D2 of the standard, the main features of which are presented in Table 5.14 of this report. It can be seen from Table 5.14 that the inspection requirements are dependent on the following:

i. Weld type (butt full/partial penetration welds and fillet welds)
ii. Joint types (butt, Tee, cruciform, lap, corner)
iii. Welding procedure (single-sided, double sided or single sided with backing strip).

It is also noted that areas are clearly identified where NDT testing using either UT, RT or MT are mandatory depending on the inspection quality level, a) normal quality - assumed for statically loading buildings, and b) fatigue quality level which is related to the relevant fatigue class of the joint. However, details on the actual extent of coverage using the different techniques are not defined.

Section D.2 of the standard indicates that acceptance levels should be carried out in accordance with appropriate national standards to demonstrate that any weld discontinuities present do not exceed the limits specified. In the absence of appropriate standards, acceptance levels for procedure trial welds should be selected such that they are generally higher than those required for final acceptance of the production welds. Detail information on the acceptance criteria for final acceptance of production welds are presented in Table D.3. Acceptance criteria are provided for four different categories namely overall weld geometry, profile discontinuities, surface breaking defects and subsurface discontinuities. For each of these categories a number of are considered which influence the acceptance criteria as follows:

i. Overall weld geometry (location, weld type)
ii. Profile discontinuities (throat thickness, leg length, toe angle, excess weld metal incomplete groove, misalignment)
iii. Surface breaking discontinuities (undercut, lack of root penetration, porosity, lack of fusion, cracks)
iv. Subsurface discontinuities (lack of fusion, root gap, porosity, cracks, lamellar tears).

The above are further influenced by the type of weld that is examined (e.g. butt, fillet etc.) and by the required weld class that is to be achieved (i.e. normal level or fatigue class level).

5.3 In-Service Inspection

As highlighted in Section 4 the codes and standards reviewed had relatively little content on in-service inspection and much that does exists appears to be based on or attached closely to the associated inspection of the sub-structure. This section highlights the main features relating to in-service inspection requirements from each of the various codes and standards reviewed.

5.3.1 ISO 13819-1 Petroleum and Natural Gas Industries - Offshore Structures- Part 1: General Requirements

Clause 8.2.3 states "Following installation, the structure shall be re-inspected to confirm that it conforms to the design, for example, air gap, pile penetration, ballast, anchor tensioners …….". Clause 8.3 (In-service inspection, maintenance and repair) states "Inspection shall be undertaken at regular intervals to check for possible damage or deterioration. Maintenance should be specified accounting for the importance and use, knowledge of the durability of the components, environmental conditions and the protection against external actions. Structural components that are essential to the stability and resistance of a structure should, as far as possible, be accessible for inspection".

5.3.2 ISO 13819-2 Petroleum and Natural Gas Industries - Offshore Structures – Part 2 Fixed Steel Structures

Inspection during operation is identified as a principal issue from the planning phase. Section 24, In-service inspection and structural integrity management (Cl. 24.8) states that "The inspection strategy should identify the general type of tools/techniques to be used". Specific techniques are discussed in the commentary but this is entirely directed at the substructure. The following methods are discussed: visual inspection, flooded member detection (UT or RT), eddy current inspection, alternating current field measurement (ACFM), alternating current potential drop (ACPD), UT and RT. Criticality classification is discussed under risk assessment in Cl. 24.4.1. Component complexity is not explicitly discussed but should be identified by the required review of design data.

This standard recommends inspection according to a platform specific "structural integrity management plan" in accordance with clause 24.5 and also provides an alternative default inspection programme in Cl. 24.7.1.3 which addresses the concerns of safeguarding human life and the environment only. The default inspection programme consists of four different periodic inspection levels: level I, level II, Level III and Level IV, the details of which have been summarised in Table 5.15 (a) and Table 5.15 (b) of this report. These periodic inspections are to be carried out within defined periods and are directly linked to the exposure levels of the structure (e.g. L1, L2 or L3) relating to safety of personnel and consequence of failure as shown in Table 5.16.

5.3.3 ISO 13819-1.3 Petroleum and Natural Gas Industries - Offshore Structures – Part 1.3 Topside Structures

Section 16 identifies the needs for in-service inspection and structural integrity management. Clause 16.2 clearly states that the structural integrity management plan for the installation should include a structural risk assessment to identify safety-critical components, the failure of which could significantly reduce structural integrity. In assessing safety criticality consideration should be given to components that are subject to high loading, including cyclic loading, corrosion and other defects and the availability of alternative load paths where a structural component may be defective. Clause 16.3 lists areas that need to be taken into account in the case of topside structures. The list appears to be extensive and includes areas such as corrosion protection systems, fire protection systems, supports for equipment including safety critical items, shock/vibration loading, access routes, including floors and gratings, difficult to inspect areas, etc. Emphasise on topside components which require special attention are noted in Section A.16.3 (informative) which includes a number of items as follows:

i. Main deck girders - highly stressed panels
ii. Leg transitions to substructures - fatigue in highly stressed stiffened panels
iii. Module trusses and support units
iv. Accommodation module - anti vibration mountings and support units
v. Drilling rigs - shock loading, wind turbulence
vi. Bridges - bearing fatigue, support for both safety critical and hazardous equipment
vii. Flare booms and vent stacks - supports to the main deck structure, vortex shedding, strength reduction due to heat

viii. Cranes - highly stressed pedestals, fatigue, attachments to main deck structure
ix. Helidecks - wind turbulence due to obstruction from surrounding structures and equipment and thermal effects from turbine exhausts
x. Lifeboats and other evacuation, escape and rescue equipment - fatigue cracking of davits
xi. Changes to equipment weights and support location points and deck loads.

Clause 16.5 provides alternative default minimum inspection requirements to be used in the absence of a platform specific inspection plan consisting of a baseline inspection and periodic inspections. It is clear from Clause 16.5 that the requirements of Clause 24.7 of ISO 13819-2 relating to periodic inspections should be followed. However, it is noted that these requirements are somewhat simplified for topsides for which the main features have been summarised in Table 5.17 of this report. It can be seen from Table 5.17 that the emphasise on periodic inspection is mainly confined to the following areas:

i. The continued effectiveness of coating systems (i.e. corrosion protection systems, fire protection systems), without the removal of paint and coatings.
ii. Vulnerability of safety critical equipment and supports to damage from shock or vibration loading
iii. Assessment of missing, bent or damaged members.

It can be also be observed from Table 5.17 that a baseline inspection shall be conducted as soon as possible after installation and no later than one year after installation. The basis of this inspection involves visual inspection only, although it is not clear whether this is to be form of a general or close visual inspection. It can be seen from Table 5.17 that general visual inspection is required for all periodic inspection levels, whilst close visual inspection is confined to Level II and III only. From Table 5.17 it can be seen that NDT inspection requirements are confined to level II or level III inspections and in the case of level II inspection a minimum of 10% inspection of safety critical elements is required, whilst for level III inspection all safety critical elements are required to be inspected. Reference is made in Clause 16.4 and in the informative Section A.16.4 on the suitability of NDT inspection techniques to be used (i.e. UT, MT and eddy current based techniques). However, the extent of NDT testing and the acceptance criteria is not defined. This may be important particularly for example where safety critical components identified have protective coatings. In such cases the application of certain NDT inspection techniques (e.g. MT) may not be suitable. Furthermore, issues such as whether coatings should be removed to perform inspection, or whether reliance should based on techniques which do not require coating to be removed, may be significant in determining the inspection program to be carried out. Furthermore, certain areas of topsides may be difficult to inspect because of their function and location (e.g. flares, drilling derricks and areas hidden by plant and equipment).

5.3.4 EEMUA Publication No. 158

In-service conditions are beyond the scope of this document.

5.3.5 API RP2A – LRFD

In-service inspection is specifically covered in Section O. The Approach of Section O, clause O.5 is sound, correctly proposing that critical areas for inspection should be identified in design but the general bias of Clause O towards substructure would make its application to topsides less likely in practice. The lack of any direction as to the contents of a design report in any other section of API RP2A is clearly a weakness in this respect – as this would be an essential document to ensure compliance. Section O includes the guidance that "During the life of the platform, in-place surveys that monitor the adequacy of the corrosion protection system and determine the condition of the platform should be performed in order to safeguard human life and property, protect the environment, and prevent the loss of natural resources". This sound philosophy is diluted somewhat by the subjective classification of "more critical areas" in section O.3.1.

Clause O.3 provides details on the extent of the surveys that are to be carried out. These requirements follow a similar format to the default requirements of ISO 13818-2 in that four periodic inspection levels at certain time intervals are defined. Details of these requirements have been summarised in Table 5.18 and 5.19 respectively of this report. It is noted in Clause O.4 that the time intervals stated, as shown in Table 5.18 are not to be exceeded unless experience and/or engineering analyses indicates otherwise. If different intervals are to be implemented then justification for doing so is to be documented and retained by the operator. In producing this documentation a number of factors should be taken into account as follows:

i. Consequence of failure to human life, property, the environment, and/or conservation of natural resources
ii. Manned or unmanned platform
iii. Wells (naturally flowing, sour gas high pressure, etc.)
iv. Original design criteria
v. Present structural condition
vi. Service history of platform (condition of corrosion protection system, results of previous inspections, changes in design operating or loading conditions, prior damage and repair, etc.)
vii. Platform structural redundancy
viii. Criticality of the platform to other operations.
ix. Platform location (frontier area, water depth, etc.).

5.3.6 NORSOK Standards

NORSOK standard N-005 provides the basis for condition monitoring of loadbearing structures throughout the lifetime until decommissioning. The standard is applicable to all types of offshore structures used in the petroleum activities, including bottom founded structures as well as floating structures. The standard is applicable to condition monitoring of complete structure including substructures, topside structures, vessel hulls, foundations and mooring systems. The objectives of condition monitoring are to ensure that an adequate level of structural integrity is maintained at all times. The standard provides a number of Normative Annexes (B to E), which give additional conditional monitoring requirements specific to jacket structures, Column stabilised units, Ship-shaped units and Concrete structures respectively. Information specific to topsides is not provided although as stated above the main normative section of N-005 is intended to be applicable for topsides.

The IMR (In-service Inspection, Maintenance and Repair) prepared during design should give clear direction relating to the effect of complexity and criticality on inspection assessment and shall cover, as a minimum, the areas such as overall structural redundancy, provisions of critical areas and components, consequences of failure, accessibility, possible repair methods, extent of inspection and inspection methods. Inspection is mandated to be developed on a platform specific basis (see N-005 Cl. 5). The detail condition monitoring programme depends on the design and maintenance philosophy, the current condition, the capability of the inspection methods available and the intended use of the structure. The condition monitoring should determine, within reasonable confidence the existence, extent and consequence of the following items on human life, the environment and assets:

i. degradation or deterioration due to fatigue or other time dependent structural damage
ii. corrosion damage
iii. fabrication or installation damage
iv. damage or component weakening due to strength overloading
v. damage due to man-made hazards
vi. excessive deformation

The condition monitoring is to be continuously updated as it may involve factors in the nature of uncertainty such as environmental conditions, failure probabilities, damage development. In addition a revised programme may be necessary as a result of new tools and methods.

An initial condition survey during the first year of operation is recommended followed by a "framework programme" for inspections on a 3-5 year cycle (Cl.5.3.1), which is based on the experience obtained from Norwegian petroleum activities. Based on the information gained in the first period of operation and knowledge of the application of new analysis techniques and methods within condition monitoring and maintenance, the interval may be altered. However, a change in the duration of the framework programme should be based on maintaining an adequate level of safety and appropriate documentation shall be provided to show this.

Detailed inspection planning is discussed with the proposition that “It may, when appropriate, be practical to differentiate between condition monitoring in the atmospheric zone and in the submerged zone”. The splash zone is separately discussed with the exhortation “Needs for splash zone inspection should therefore be reduced to a minimum”. Alternative Instrumentation based Condition Monitoring (IBCM) is highlighted as being an alternative to conventional inspection methods. The IBCM is considered to be suitable to areas with limited accessibility for performance of condition monitoring and maintenance. Typical applications of ICBM highlighted are strain monitoring of jacket structures, foundation behaviour during extreme storm, etc. Methods for topsides inspection are not specified but must be suitable to meet the objectives.

The standard provides information in the form of an informative Annex A on use of inspection methods for in-service inspection for above water and below water. For above water inspections general visual and close visual inspection are noted as being required before carrying out any further NDT. Although UT, MP and EC methods are mentioned, caution is noted with regards to use of MT where removal of coatings would be necessary. For surface breaking defects, crack detection may be detected by means of MT or by EC methods. In areas where fatigue resistance needs to be confirmed or where the consequences of developing a crack is unacceptable the use of EC rather than MT are preferred. Information on the use of most widely used methods, (e.g. visual, EC, UT/RT, MP, FMD

(Flooded Member Detection), etc.) their capabilities, features and limitations are provided for below water inspection only.

5.3.7 DD ENV 1993-1-1:1992 Eurocode 3. Design of Steel Structures

This document says nothing of significance with respect to in-service inspection.

5.3.8 DD ENV 1090-1: 1998 Execution of Steel Structures

This document says nothing of significance with respect to in-service inspection.

5.3.9 ISO/FDIS 10721-2 Steel structures - Part 2: Fabrication and Erection

This document says nothing of significance with respect to in-service inspection.

Table 5.1
ISO 13819-2, Part 2: Design Class Inspection Requirements

Consequences of Structural Failure	Design Class	Toughness Requirements: Yield Strength (<400) MPa	Toughness Requirements: Yield Strength (>400) MPa	Joint Complexity: Inspectable= INSP Or Non Inspectable= NINSP		Joint Criticality: Low Fatigue Utilisation (Lives > 3 Required(3)) Tensile Stresses/Design >0.85	0.85-0.6	< 0.6	High Fatigue Utilisation (Lives < 3 Required(3)) (1)	(2)	Extent and Type of Inspection: V = Visual; MT = Magnetic particle; UT = Ultrasonic based; RT = Radiography (coverage, Butt welds, T-conn, Fillet/ Partial Penetration)
High with Respect to Life, Pollution, Asset and Structure Possessing Limited Residual Strength	DC 1	CV2 or CV2Z 36J	CV2 or CV2Z 42J	HIGH	INSP	A	B	C	A	B	A = 100% V, 100% UT, 10% RT (For Butt Welded Joints)
					NINSP	A	A	B	A	A	B = 100% V, 50%(25%)UT, 100% (50%) MT
	DC 2	CV2Z or CV 1 36J or 27J	CV2Z or CV1 42J	LOW	INSP	A	B	C	A	B	C = 100% V, 20% (10%) UT, 20%(10%) MT Note: For Fillet Welded Joints/Partial Penetration, no UT Inspection for categories A, B and C.
					NINSP	A	A	B	A	A	
High with Respect to Life, Pollution and Asset, due to Residual Strength	DC3	CV2Z or CV1 36J or 27J	CVZ or CV 1 42J	HIGH	INSP	B	C	D	B	C	A, B, C as above. D = 100% V, 5% MT
					NINSP	A	B	C	A	B	
	DC4	CV2Z or NT 36J or 27J	CV2Z or NT 42J or 27J	LOW	INSP	B	C	D	B	C	Note: % values in ( ) above for categories B and C are reduced values, depending on % defect rate being low in last 100mm of weld.
					NINSP	A	B	C	A	B	
Failure will be without Substantial Consequences to Life, Pollution and Asset	DC5	NT 27J	NT 27J	ANY	ANY	D – For all Load Bearing Joints E – For all Non-Load Bearing Joints			D	E	D as above E = 100% V

Notes:
1. Welds with the direction of the dominating dynamic principle stress transverse to the Weld (between 45^0 and 135^0)
2. Welds with the direction of the dominating dynamic principle stress in the direction of the Weld (between -45^0 and 45^0)
3. Required fatigue life is Design Fatigue Life multiplied with the Design Fatigue Factor (DFF)

Table 5.2
ISO 13819-2, Part 2: Exposure Level

Life Safety Category	Consequence of failure category		
	High Consequence of failure	Medium Consequence of failure	Low consequence of failure
Manned-non-evacuated	L1	L1	L1
Manned – evacuated	L1	L2	L2
Unmanned	L1	L2	L3

Table 5.3
ISO 13819-2, Part 2: Material Class Inspection Requirements

Component	Weld Type	L1 Structures					L2 Structures					L3 Structures				
		MC 1					MC 2					MC 3				
		Toughness Requirements	Inspection Type			Inspection Category	Toughness Requirements	Inspection Type			Inspection Category	Toughness Requirements	Inspection Type			Inspection Category
			Visual	UT/RT	MT			Visual	UT/RT	MT			Visual	UT/RT	MT	
Deck	Full Penetration (Trusses)	CV2ZX-CV1 Mandatory CTOD if >50mm thick	100%	100%	100%	A	CV2Z-NT	100% (100%)	100% (10%)	- -	A[1] (C[2])	CV2-NT	100%	10%	-	C[2]
	Full Penetration (Others)		100% (100%)	100% (10%)	100% (10%)	A (C)		100%	10%	-	C[2]		100%	-	-	E
	Partial Penetration/ Fillet Welds		100% (100%)	- -	100% (10%)	A (C)		100%	-	10%	C		100%	-	-	E
Girders/Web to Flange	Full Penetration (Major Brace Connections)	CV2ZX-CV2 Mandatory CTOD Testing if >50mm thick	100% (100%)	100% (100%)	100% (10%)	A (C[1])	CV2Z-NT	100% (100%)	100% (10%)	10% (10%)	A[2] (C)	CV2-NT	100%	10%	-	C[2]
	Full Penetration (Others)		100% (100%)	100% (100%)	100% (10%)	A (C[1])		100%	-	10%	C[3]		100%	-	-	E
	Partial Penetration/ Fillet Welds		100% (100%)	-	100% (10%)	A (C[1])		100%	-	10%	C		100%	-	-	
Lifting Points (Padeye/ Lifting Aids/ Heavy Lift Frames)	Full Penetration	CV2ZX Mandatory CTOD if > 50mm thick	100%	100%	100%	A	CV2Z	100%	100%	100%	A	CV21	100%	100%	100%	A
	Partial Penetration/ Fillet Welds		100%	-	100%	A		100%	-	100%	A		100%	-	100%	A
Stiffeners/ Rings	Full Penetration	CV2-CV1	100% (100%)	100% (100%)	100% (10%)	A (C[1])	CV1	100% (100%)	10% (10%)	100% (10%)	A C	CV1	100%	-	10%	C[3]
	Partial Penetration/ Fillet Welds		100%	-	100%	A		100%	-	10%	C		100%	-	10%	C
Crane Pedestal	All	CV2ZX Mandatory CTOD if >50mm thick	100%	100%	100%	A	CV2Z	100%	100%	100%	A	CV2	100%	100%	100%	A
Vent/ Flare Tower	All	CV2ZX Mandatory CTOD if >50mm thick	100%	100%	100%	A	CV2Z	100%	100%	100%	A	CV2	100%	100%	100%	A

Table 5.4
ISO 13819-2, Part 2: Acceptance Criteria for Visual Inspection (continued…)

Defect Type	Permitted Maximum
Undercut	Undercut shall be no more than 0.25 mm (0.01”) deep when its direction is transverse to primary tensile stress in the part that is undercut, nor more than 1 mm (0.04”) for all other situations
Shrinkage grooves and root concavity	As for undercut, depth shall not exceed 1.5 mm (0.06”)
Excess penetration (double sided girth welds only)	3 mm (0.12”) maximum. Occasional local excess is allowable
Reinforcement shape	The reinforcement shall blend smoothly with the parent metal. Dressing is not normally required provided the shape does not interfere with the specified non-destructive testing technique
Overlap (as defined in ANSI/AWS D1.1)	Not permitted
Linear misalignment –prior to welding	Joint misalignment on tubulars and skid beams shall not exceed the following: • For double sided joints: the lesser of 6 mm (0.25”) and 10% of the joint thickness, except that a 2 mm (0.08”) misalignment is permitted regardless of thickness • For single sided joints: the lesser of 3 mm (0.12”) OR 10 % of the joint thickness, except that a 2 mm (0.08”) misalignment is permitted regardless of thickness • Joint misalignment on sections other than those above shall not exceed the lesser of 5 mm (0.20”) and 12 % of the joint thickness, except that a 2 mm (0.08”) misalignment is permitted regardless of thickness
Linear misalignment – weld shape post welding	All misalignments greater than 2 mm (0.08”) or 10% of the wall thickness whichever is greater, in butt welds shall be build up with weld deposit to give a cross taper of 1:4
Cracks	The weld shall have no cracks
Fusion	Through fusion shall exist between adjacent layers of weld metal and between weld metal and base metal
Craters	All craters shall be filled to the cross section of the weld, except for the ends of intermittent fillet welds outside of their effective length

Table 5.5
ISO 13819-2, Part 2: Acceptance Criteria for Visual Inspection (…continued)

Defect Type	Permitted Maximum
Fillet welds	A fillet weld in any single continuous weld shall be permitted to under run the nominal fillet weld size specified by 1.6 mm (0.06") without correction, provided that the undersize portion of the weld does not exceed 10% of the length of the weld. On the web-to-flange welds on girders, no under run is permitted at the ends for a length equal twice the width of the flange
Piping porosity – fillet welds	The frequency of piping porosity in fillet welds shall not exceed one in each 100 mm (4") of weld length and the maximum diameter shall not exceed 2 mm (3/32") Exception: for filet welds connecting stiffeners to web, the sum of diameters of piping porosity shall not exceed 10 mm (0.375") in any linear inch of weld and shall not exceed 19 mm (0.75") in any 305 mm (12") of weld
Piping porosity – complete penetration welds	Complete joint penetration groove welds in butt transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds, the frequency of visible piping porosity shall not exceed one in 100 mm (4") of length and the maximum diameter shall not exceed 2 mm (3/32")
Inspection Timing	Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for Group III (i.e. yield strength 400-455 MPa) and higher strength steels shall be based on visual inspection performed not less than 48 hours after completion of the weld

Table 5.6
EEMUA 158: Inspection Requirements

Inspection Category	Definition	Areas of Application	Inspection Requirements				Inspection Category (as defined in ISO 13819-2, Part 2)
			Visual	Ultrasonic	RT	Magnetic Particle	
I	Applicable to highly stressed welds which have relatively low calculated fatigue lives	All jacket node welds: welds in main topside structural columns except longitudinal and flange web joints: flange splices: crane pedestal welds: lifting padeye/ padear welds	100%	100%	-	100%	A (T-conn)
II	Applicable to less highly stressed welds which have relatively high calculated fatigue lives	Some circumferential brace welds remote from nodes: structural installation aids	100%	100%	(a)	100%	A (Butt/T-conn)
III	Applicable to low stressed welds, welds in shear, welds with relatively high calculated fatigue lives	Longitudinal welds in tubular members of jackets or topsides structural columns: flange web joints: welds for sea fastenings	100%	100% (b)	20% (e)	100% (b)	A (Butt) (C) (Butt)
IV	Applicable to low stressed welds which are not subject to any significant cyclic loading	Welds in module structure other than main columns, lifting points, crane pedestals, and other designated areas	100%	20% (c)	(a)	20% (c)	C (Butt)
V	Applicable to temporary attachments but excluding module lifting padeye/padear attachments	Welds for temporary attachments and pile grout beads. Non structural attachments	100%	-	-	100% (a)	A (Fillet/Partial Pen)

Notes:

(a) For t≤ 11mm, radiography shall be substituted for ultrasonics and for 11mm <t≤ 25mm radiography may be substituted for ultrasonics when agreed by the Purchaser.
(b) This may be reduced to 20% when the Contractor has been able to demonstrate to the satisfaction of the Purchaser that a consistently low repair rate is being achieved.
(c) 20% examination is defined as examination of 20% of the length of each weld, unless the length of the weld is less than one metre, in which case 20% of all similar welds shall be inspected.
(d) Alternative inspection requirements may be specified for pile grout beads.
(e) Required on all tubulars less than 50 mm w.t., prior to erection, on longitudinal seam ends and circumferential seam intersections.

Table 5.7
EEMUA 158: Acceptance Criteria for Visual Inspection

VISUAL INSPECTION ACCEPTANCE CRITERIA	
Defect Type	**Permitted Maximum**
Undercut	Slight intermittent undercut permitted, depth should not exceed approximately 0.5mm.
Shrinkage grooves and root concavity	As for undercut, depth should not exceed 1.5mm.
Excess penetration (girth welds only)	3mm maximum. Occasional local slight excess is allowable.
Reinforcement shape	The reinforcement shall blend smoothly with the parent metal. Dressing is not normally required provided the shape does not interfere with the specified non-destructive testing techniques.
Overlap	Not permitted.
Linear misalignment	If the joint misalignment on tubulars and skid beams exceeds the following; for double sided joints, the lesser of 6mm and 10% of the joint thickness, except that a 2mm misalignment is permitted regardless of thickness. Single sided joints, the lesser of 3mm and 10% of the joint thickness, except that a 2mm misalignment is permitted regardless of thickness. If the joint misalignment on other sections exceeds the lesser of 5mm and 12% of the joint thickness, except that a 2mm misalignment is permitted regardless of thickness.

Table 5.8
EEMUA 158: Acceptance Criteria for UT Inspection

ULTRASONIC INSPECTION ACCEPTANCE CRITERIA	
Defect Type	**Acceptance Level**
Three Dimensional Defects (i.e. slag, Porosity)	a) Indications greater than 100% of the reference curve shall be reported and limited to a maximum length of t/3 or 20 mm, whichever is the lesser b) Indications less than 100% but greater than 50% of the reference curve shall be reported, and limited to a maximum length of 2t or 50 mm, whichever is the lesser c) Indications less than 50% of the reference curve are acceptable
Two Dimensional Defects other than Cracks (i.e. Lack of Side Wall Fusion, Lack of Inter-run Fusion)	a) Not acceptable if the defect indication exceeds the reference curve or lies within 6 mm of either surface, regardless of amplitude b) Indications more than 6 mm from the surface which are less than 100% but greater than 50% of the reference curve shall be reported, and limited to a maximum length of t/3 or 20 mm, whichever is the lesser c) Indications more than 6 mm from the surface which are less than 50% of the reference curve are acceptable
Cracks or Suspect Cracks	Not acceptable
Incomplete Penetration or Lack of Root Fusion in Single Sided Welds	Not acceptable
Single Point Reflectors: (Indications which show Pattern I behaviour in both directions, as per BS 3923 Appendix L)	If separated by a distance of 25 mm or greater, acceptable regardless of amplitude. If separated by less than 25 mm, indications with an amplitude greater than 100% of the reference curve shall be reported.

Table 5.9
API RP2A-LRFD: Inspection Requirements

Component	Extent of Inspection %	Inspection Method
Structural Tubulars		
Longitudinal Weld Seam (L)	10*	UT or RT
Circumferential Weld Seam (C)	100	UT or RT
Intersection of L and C	100	UT or RT
Tubular Joints		
Major brace-to-chord welds	100	UT
Major brace-to-brace welds	100	UT
Misc. Bracing		
Conductor Guides	10*	UT (or MT)**
Secondary bracing and subassemblies, i.e. splash zone, and/or mudline secondary bracing, boat landings etc.	10*	UT (or MT)**
Attachment weld connecting secondary bracing/subassemblies to main members	100	UT or MT
Deck Members		
All primary full penetration welds	100	UT or MT
All partial penetration welds	100	Visual***
All fillet welds	100	Visual***

Notes:

* Partial Inspection should be conducted as 10 percent of each piece, not 100% of 10% of the number of pieces.
Partial inspection should include a minimum of three segments randomly selected unless specific problems are known or suspected to exist. All suspect areas (e.g. areas of tack welds) shall be included in the areas to be inspected. If rejectable flaws are found from such 10% inspection, additional inspection should be performed until the extent of rejects has been determined and the cause corrected.

** Depending upon design requirements and if specified in the plans and specifications MT may be an acceptable inspection

*** May include MT and/or PT.

Table 5.10
Norsok M-101: Acceptance Criteria for Visual and MT Weld Inspection (continued…)

Welding	**Acceptance criteria**	
Type of defect	**Insp. cat. A, B**	**Inspection category C, D, E**
Cracks	Not acceptable	Not acceptable
Incomplete penetration or lack of fusion	Not acceptable	Single - side weld: Length < t/2, max 10 mm Defects shall be regarded as a continuous defect if the distance between them is < t.
Undercut	Max depth 0.5 mm Continuous undercut is not permitted	Maximum depth 0.75 mm Continuous undercut is not permitted
Surface porosity Exposed slag	Not acceptable	Not acceptable. However, the following defects may be acceptable if it does not conflict with surface treatment requirements: Accumulated pore diameters in any area of 10 x 150 mm is not to exceed 15 mm. Max. size of a single pore is t/4 or 4 mm, whichever is the smaller.
Concave root	Max. concavity 0.5 mm if the transition is smoothly formed.	
Excessive pen. [1)]	Max. 3 mm	
Roughness of weld (fig. 1)	"U" shall be less than 2.5 mm. Weld surface shall be smooth, without sharp transitions. The bottom of roughness in butt welds shall not be below the base material surface.	
Misalignment of butt welds (fig. 2)	Max. misalignment (M), 0.15 x t or max. 4 mm, whichever is the smaller.	
Reinforcement of butt welds (fig. 3) [1)]	"t" less or equal to 10 Max reinforcement "C" 2 mm "t" greater than 10, up to 25 Max reinforcement "C" 3 mm "t" greater than 25, up to 50 Max reinforcement "C" 4 mm "t" greater than 50 Max reinforcement "C" 5 mm	
Reinforcement of fillet/partial pen. welds (fig.4) [1)]	"a" less or equal to 10 Max reinforcement "C" 2 mm "a" greater than 10, up to 15 Max reinforcement "C" 3 mm "a" greater than 15, up to 25 Max reinforcement "C" 4 mm "a" greater than 25 Max reinforcement "C" 5 mm	
Symmetry of fillet welds (fig. 5)	"a" less or equal to 6 Max difference, b - h: 3 mm "a" greater than 6, up to 13 Max difference, b - h: 5 mm "a" greater than 13 Max difference, b - h: 8 mm	
Grinding arc strikes etc. Removal of temporary attachments [2)]	Grinding of base material shall not exceed 7% of the wall thickness or max. 3 mm. Repair welding and inspection shall be performed if removal of the base metal exceeds the specified requirements.	
Sharp edges	Minimum 2 mm radius (Clause 6.4 of M-101)	

Table 5.11
Norsok M-101: Acceptance Criteria for Visual and MT Weld Inspection (…continued)

Notes:

1. Localised reinforcements exceeding the above requirements are acceptable.

2. Temporary attachments shall be cut min. 3 mm from the base metal and ground smooth. The ground area shall be visually inspected and MT shall be performed in accordance with the inspection category in question.

3. When required (Refer to Clause 6.11 of M-101), grinding of the surface shall be specified. Typical examples of grinding requirements are given in annex A of Norsok Standard M-101.

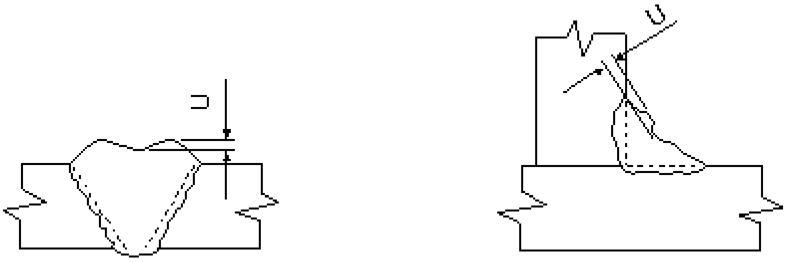

Fig. 1 Roughness of weld

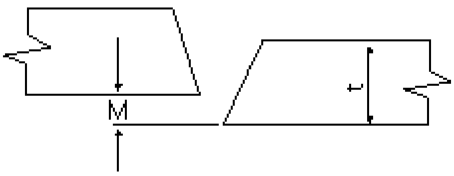

Fig. 2 Misalignment of butt weld

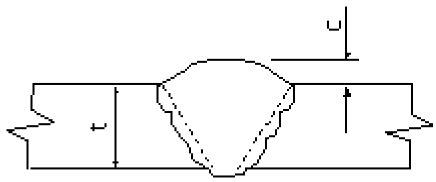

Fig. 3 Reinforcement of butt weld

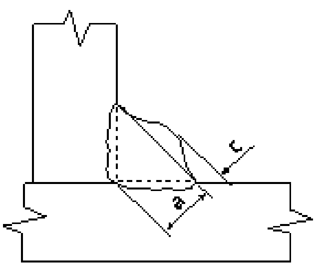

Fig. 4a Reinforcement of fillet weld

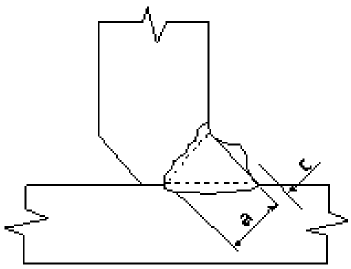

Fig. 4b Reinforcement of partial pen. weld

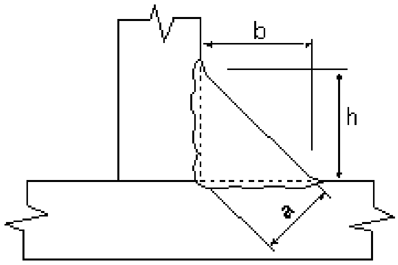

Fig. 5 Symmetry of fillet weld

Table 5.12
Norsok M-101: Acceptance Criteria for UT Weld Inspection

Description	Inspection category A + B	Inspection category C, D, E	Notes
General	If the type of defect can not be ascertained with certainty the defect shall be repaired when the length exceeds 10 mm and the echo height exceeds the reference curve.		1 2 3 4
Cracks	Unambiguous cracks are unacceptable regardless of size or amplitude.		
Lack of fusion or incomplete penetration	Internal defects: I: The echo height exceeds the reference curve:		1 2 3 4 5
	Max length t, max 25 mm	Max length 2t, max 50 mm	
	II: The echo height is between 50 and 100% of the reference curve:		
	Max length 2t, max 50 mm	Max length 4t, max 100 mm	
	Surface defects are not acceptable except: For root defects in single sided welds, the max length for which the echo height exceeds the reference curve shall be:		
	Max length t, max 25 mm	Max length 2t, max 50 mm	
Slag inclusions	When echo height exceeds the reference curve:		
	Max length 2t, max 50 mm	Max length 4t, max 100 mm	1 2
Porosity	Repair is required if porosity may mask other defects.		1

Notes:

1. Type of defect shall be decided by:

   I: Supplementary non-destructive testing.

   II: The ultrasonic operator's assessment of the defect, using his knowledge of the welding process, signal geometry, defect position etc.

2. If elongated defects are situated on line and the distance between them is less than the length of the longest indication, the defects shall be evaluated as one continuous defect.

3. Defect length shall be determined by the 6dB drop method from the end of the defect (for defects larger than the beam) or by the maximum amplitude technique (for defects smaller than the beam).

4. With UT performed from only one side of the weld with only one surface accessible, the acceptable echo heights are reduced from 100% to 50% and from 50% to 20%, respectively.

5. With "internal defects" it is meant defects which are located more than 6 mm from the nearest surface. A defect is classified as a "surface defect" if any part of the defect is located less than 6 mm or t/4, whichever is smaller, from the nearest surface.

Table 5.13
Norsok M-101: Acceptance Criteria for RT Weld Inspection

Type of defect	**Inspection category**	
	A, B	**C, D, E**
Internal porosity (Note 1)		
Isolated:		
Pore diameter	max t/4, but max. 6 mm	max t/3, but max. 6 mm
Cluster:		
Pore diameter	max 3 mm	max. 4 mm
Scattered:		
Accumulated pore diameters in any 10x150 mm area of weld	max 20 mm	max. 25 mm
Slag inclusions, or piping porosity (Note 2)		
Width	t/4, max. 6 mm	t/3, max. 6 mm
Length (Note 3)	2t, max 50 mm	4t, max. 100 mm
Incomplete penetration, lack of fusion		
Length (Note 2)	t, max. 25 mm	2t, max. 50 mm
Cracks	Not acceptable	Not acceptable

Notes:

1. If more than one pore is located inside a circle of diameter 3 times the pore diameter, the pores are to be considered as a cluster.
2. Defects in a line where the distance between the defect is shorter than the longest defect shall be regarded as one continuous defect.
3. No length limitation for width $\leq$ 2 mm for t $\geq$ 20 mm and for width $\leq$ 1 mm for t < 20 mm.

Table 5.14
DD ENV 1090-1: Frequency of NDT Testing

CATEGORIES OF JOINT TYPES			Visual Inspection	Additional NDT if required by the project specification: SHOP WELDS	Additional NDT if required by the project specification: SITE WELDS
Connection Zones				First 5 identified joints of each type having the same basic dimensions, material grades, weld geometry and welded to the same procedures. Thereafter 1 in 5 joints of each type (if the first 5 have complied with subclause 12.4.2.5)	All identified joints
Member zones	Built-up members	Transverse butt welds in web and flange plates before assembly Transverse fillet welds at end of lap joints	100%		
		Longitudinal welds	100%	0,5 m in each 10 m or parts thereof, of all identified joints, including 1 in 4 weld ends	Double the frequency of shop welds
	Secondary attachment weld	Eg. for fixing purlins. Side rails, buckling stiffners, etc	100%	1 in 20 attachments	

Table 5.15
DD ENV 1090-1: Fields of Application for NDT Inspection Methods

Weld Type	Joint Type	Application of NDT Methods		
		Visual	**MT [(3)]**	**UT [(1)]**
Full Penetration	Butt	√	√	√ (t ≥ 10[(2a)] mm and t ≥ 20 [(2b)] mm)
	"T" and Cruciform Joint	√	√	√ (t ≥ 10mm)
	Corner Joint	√	√	√ (t ≥ 10mm)
Fillet and Partial Penetration	Lap Joint	√	√	-
	Tee, Cruciform and Corner Joints	√	√	-
	Butt	√	√	-

Notes:

(1) UT can be carried out with some reservation regarding root defects detection
(2a) RT may be used instead of UT for detection if thickness t<30mm for single sided and double sided joints
(2b) RT may be used instead of UT for detection if thickness t <30mm for single sided with backing strip
(3) Liquid penetration testing may be used as a substitute for MPI if MPI is not possible

Table 5.16
ISO/FDIS 10721-2: Inspection Requirements

Weld Type	Joint Type	Welding Procedure	NDT Method/Quality Level					
			Normal Quality			Fatigue Quality 71 to 140		
			Thickness t (mm)			Thickness t (mm)		
			MT	UT	RT	MT	UT	RT
Butts Full and Partial Penetration	In-Line Butt	S/S	t<10(1)	t≥10(2)	NMF,t<8	All	t≥8	NMF,t<8
		D/S And S/S + B	t<12(1)	t≥12(2)	NMF,t<8	All	t≥8	All
	Tee and Cruciform	S/S	t≥20	t≥20	NM	All	t≥12	t≥12
		D/S And S/S + B	t≥20	t≥20	NM	All	NM	NM
	Corner	All	t≥20	t≥30	NM	All	t≥12	NM
Fillet	Lap	All	t≥20	NM	NM	All	NM	NM
	Tee, Cruciform and Corner	All	t≥20	NM	NM	All	NM	NM

Notes:

(1) RT testing may be used instead of MT for detection. MT may be needed to assist evaluation
(2) RT testing may be used instead of UT for detection if t>20mm. UT may be needed to assist evaluation.
(3) Fatigue Quality: Where the fatigue strength requirements is in excess of 56N/mm^2 at an endurance of 2x10^6 cycles, one of four fatigue qualities 71, 90, 112 or 140 should be specified as follows:

Quality	Required Fatigue Strength at 2x10^6 cycles
FAT 71	57 N/mm^2 to 71 N/mm^2
FAT 90	72 N/mm^2 to 90 N/mm^2
FAT 112	91 N/mm^2 to 112 N/mm^2
FAT 140	113 N/mm^2 to 140 N/mm^2

NM = Not Mandatory **NMF** = Not Mandatory For
S/S = Single Sided **D/S** = Double Sided **S/S+B** = Single Sided plus Backing Strip

Table 5.17(a)
ISO 13819-2, Part 2: In-service Baseline Inspection Requirements

Baseline Inspection
A baseline inspection shall be conducted as soon as practical after the major platform installation, and commissioning. The minimum scope shall consist of: (a) a visual inspection without marine growth cleaning that provides full coverage from mudline to top of jacket of the platform structure (members and joints), conductors, risers, and various appurtenances. This includes benchmarking the seabed conditions at the legs/piles and checking for debris and damage (b) a set of CP readings that provides full coverage of the underwater platform structure (members and joints), conductors, risers, and various appurtenances (c) visual confirmation of the existence of all sacrificial anodes, electrodes and any other corrosion protection material/equipment (d) measurement of the actual mean water surface elevation relative to the as installed platform structure, with appropriate correction for tide and sea state conditions (e) tilt and platform orientation (f) riser and J-tube soil contact (g) seabed soil profile

Table 5.17(b)
ISO 13819-2, Part 2: In-service Periodic Inspection Requirements

Periodic Inspection			
Level I	**Level II**	**Level III**	**Level IV**
A visual Inspection without marine growth cleaning of the top of jacket region CP readings of at least one jacket leg using a drop cell or other suitable equipment	The default scope for Level II periodic inspection shall consist of the same scope as the default Level I inspection plus a general visual survey of the full structure with particular attention to members, joints, appurtenances, and appurtenance connections	The default scope for Level III periodic inspection shall consist of the same scope specified for the baseline inspection, plus the following additional items: (a) Flooded member detection (FMD) of the following components that are located underwater and were designed to be unflooded: at least 50% of all primary structural members, plus key support members for risers, J-tubes, conductors (first underwater framing level only), service caissons, and other appurtenances. (Note: A Level IV periodic inspection, as described below, may be substituted in lieu of this FMD requirement) (b) In lieu of the FMD requirements in a) above, marine growth cleaning and close visual inspection of at least 20 or 5 % of the total population (whichever is smaller) of primary member end connections including a minimum of five primary brace to leg connections (c) Marine growth measurements on selected members at a representative set of elevations from mean sea level to the mudline (d) For platforms with sacrificial anodes: An estimate of the approximate percent in depletion of 100% of anodes (e) For platforms with impressed current systems: Visual survey of the state of the anodes and reference electrodes. Dielectric shields shall also be thoroughly inspected to ensure that they are undamaged, free from discontinuities, and satisfactorily bonded to the structure	The default scope for a Level IV periodic inspection shall consist of the same scope as a Level III default inspection, excluding the Level III requirements a) and b), plus: (a) Marine growth cleaning (as required) and detailed inspection of selected welds at nodal joints (member and connections) and other critical locations using NDE techniques. 100% of the weld length shall be inspected. The degree of marine growth cleaning shall be sufficient to permit thorough inspection

Table 5.18
ISO 13819-2, Part 2: Periodic Inspection Intervals for different exposure levels

Exposure Category	Maximum Inspection Interval			
	Level I	Level II	Level III	Level IV
L1	annual	3 years	5 years	As required from Level III
L2	annual	5 years	10 years	As required from Level III
L3	annual	5 years	(none required)	(none required)

Table 5.19
ISO/CD 13819-1.3: In-service Inspection Requirements

Baseline Inspection	Periodic Inspection (Exposure Levels/Consequence of Failure)			
	Level I	Level II	Level III	Level IV
A baseline inspection to benchmark the installed condition of the topsides structure shall be conducted as soon as possible after first emplacement and commissioning of the topsides facilities, and no later than one year after emplacement. The objective of this inspection is to identify any defects with the potential to impair the integrity of the structure and equipment so as to allow these to be assessed and repaired if necessary before the first periodic inspection. The minimum scope of inspection shall consist of: 1) A visual inspection without removal of paint and coatings of all parts of the topsides structure including facilities structures to check that: i) All Parts of the structure are intact and undamaged, ii) All fixings between structures and between structures and equipment, including gratings and handrails, are secure, iii) Paintwork and protective coatings are not damaged. 2) A walkdown survey to assess the vulnerability of safety-critical equipment and supports to damage from shock loading and strong vibration induced by actions from extreme environmental events and accidental loadings.	The minimum scope shall consist of a visual survey to determine: – The continued effectiveness of coating systems – Any signs of excessive corrosion – The existence of any bent, missing, or damaged members – The survey should identify indications of obvious overloading, design deficiencies and any operational usage that is inconsistent with the original design intent of the installation. – The survey should include a general visual inspection of all areas of structure that have been identified as safety-critical. Should the Level 1 survey indicate that damage might have occurred, level II inspection should be conducted as soon as conditions permit.	The minimum scope shall consist of: – A general visual inspection without removal of paint and coatings of all parts of the topsides structure including facilities (as described in Level 1 inspection). – A close visual inspection of all components identified as safety-critical – Detailed non-destructive examination of a selection of safety-critical components and comprising not less than 10% of all safety-critical structural components. If damage is detected, non-destructive testing of the suspect area should be used where visual inspection alone cannot fully determine the extent of damage.	The minimum scope shall consist of: - A general visual inspection without removal of paint and coatings of all parts of the topsides structure including facilities structures (as described in Levels I and II inspection). - A close visual inspection of all components identified as safety-critical (as described in Levels I and II inspections.). - Detailed non-destructive examination of all safety-critical components	There is no requirement for a Level IV inspection of topsides structures

Table 5.20
API RP2A- LRFD: Guideline Survey Inspection Intervals

Level	I	II	III	IV
Manned	1 yr	3 thru 5 yrs	6 thru 5 yrs	*
Unmanned*	1 yr	5 thru 10 yrs	5 thru 10 yrs	*
Well Protectors/Caissons	1 yr	5 thru 10 yrs	*	*

Note:

* Surveys should be performed as per Level II and Level III

Table 5.21
API RP2A- LFRD: In-service Periodic Inspection Requirements

Periodic Survey Levels			
Level I	**Level II**	**Level III**	**Level IV**
The effectiveness of the corrosion protection system employed should be checked and an above water visual survey should be performed annually to detect deteriorating coating systems, excessive corrosion, and bent, missing or damaged members. This survey should identify indications of obvious overloading, design deficiencies and any use, which is inconsistent with the platform's original purpose. This survey should also include a general examination of all structural members in the splash zone and above water, concentrating on the condition of the more critical areas such as deck legs, girders, trusses, etc. If above water damage is detected, nondestructive testing should be used when visual inspection cannot fully determine the extent of the damage. Should the Level I survey indicate that underwater damage may have occurred, a Level II inspection should be conducted as soon as conditions permit.	A Level II survey consists of general underwater visual inspection by divers or ROV to detect the presence of an or all of the following: Excessive corrosion Accidental or environmental overloading Scour, seafloor instability, etc Fatigue damage Design or construction deficiencies Presence of debris Excessive marine growth This survey should include the measurement of cathodic potentials of preselected critical areas using divers or ROV. Detection of significant structural damage during a Level II survey should become the basis for initiation of Level III survey. The Level III survey, if required, should be conducted as soon as possible.	A Level III survey consists of an underwater visual inspection of preselected areas and/or, based on results of the Level II survey, areas of known or suspected damage. Such areas should be sufficiently cleaned of marine growth to permit thorough inspection. Pre-selection of areas to be surveyed should be based on an engineering evaluation of areas where repeated inspections are desirable in order to monitor their integrity over time. Detection of significant structural damage during a Level III survey should become the basis for initiation of a Level IV survey in those instances where visual inspection alone cannot determine the extent of damage. The Level IV survey, if required, should be conducted as soon as conditions permit.	A Level IV survey consists of underwater nondestructive testing of preselected areas and/or, based on results of the Level III survey, areas of known or suspected damage, Level IV should also include detailed inspection and measurement of damaged areas.

6. A COMPARISON OF FABRICATION AND IN-SERVICE INSPECTION PRACTICES

6.1 Historical issues

It is just over 10 years since Lord Cullen's Report on the Piper Alpha Disaster was published. In parallel the industry has commenced using LRFD design methods and adopted CRINE approaches to cost reduction. Substructure design has been refined – with a significant reduction in the number of support points available to the topsides. Large integrated decks on 4 support points have become increasingly common. The industry has also increased its use of steels with yield stress >400N/mm^2. Over the same time the computer resources available for structural analysis have increased by orders of magnitude and the use of fracture mechanics to define acceptable defect sizes and/or minimise the requirement for PWHT have expanded. These processes have initiated a sequence of changes in platform design but from the viewpoint of structural components, connection design and inspection methods the impact has been neither universal nor dramatic.

Some of the influences have worked against each other. Increasing requirements to design for accidental events – particularly blast with high overpressures – has increased the reserve strength available to resist operational loads and consequentially increased redundancy of both components and systems. The ability to perform more sophisticated analyses cheaply and quickly has allowed designers to consider global plastic collapse and more reliably predict the ultimate capacity of structures – rationalising component strength to match system capacity.

Major operators utilise their own detailed specifications to supplement or replace national codes. Some operators have adopted LRFD methods while others have been deliberately avoiding them. The basic NDT methods used for fabrication have not changed dramatically, but the increased sophistication in the analysis of UT signals has made methods more consistent – less operator dependent and capable of sizing defects more reliably. More sophisticated techniques have become available for use offshore – including such methods as ACPD and ACFM and methods monitoring changes in resonant response of structural systems. The extent to which these are deployed and their reliability have not been determined in this study.

The complex interaction of the issues discovered in this review make it impossible to draw reliable conclusions that would inform a differential approach for structures relative to their age.

All the standards reviewed contained some degree of mandatory inspection during the fabrication process although for some of the generalised onshore codes this could – at least in theory – be limited to visual inspection. The level of detail provided varies enormously. This variation can be accounted for in part by the different objectives of the Standards. It probably also reflects historical practice and, it is suspected, the particular degree of knowledge and experience of the authors of the codes.

The best practice for inspection clearly relates all inspection activities to the design process from the earliest planning stage. The objective must be to achieve the appropriate level of safety at the lowest overall cost. For offshore topside structures where in-service inspection is always expensive and usually difficult to perform there is a clear need to consider the benefits of designing to avoid the need for in-service inspection as far as is practicable. This approach has a clear resonance with the approach of inherently safe design. Key parameters in this review will be the impact on capital cost, the lowest net present cost of a facility and the avoidance of cost step functions involving platform installation. (As a general rule minimising inspection will increase weight.) For a platform topside concept which is not close to an “installation cost step”, designing the structure for “zero” inspection and zero maintenance should be practicable and could potentially yield both cost and safety benefits. To achieve this objective clearly requires a systematic approach to design, fabrication and fabrication inspection.

6.2 Comparison of Fabrication Inspection Standards

The codes that include specific fabrication requirements for offshore structures generally contain a high level of detail – specifying standards for qualification of inspectors, equipment, frequency of inspection and acceptance criteria standards. Where appropriate information presented in Section 5.2 has been used to assist in the comparisons between the various standards. A number of factors which have a direct bearing on the inspection process have been identified as follows:

i. Consequences of failure
ii. Joint complexity and fatigue/tensile stress utilisation
iii. Inspection techniques, extent of coverage and accessibility
iv. Acceptance criteria

Each of the above are discussed as follows:

6.2.1 Consequences of failure

The codes currently under development appear to provide a more rational basis of linking fabrication inspection to design. In the case of the provisions developed under ISO 13819-2 and NORSOK N-004 the inspection process is linked to material selection (i.e. parent material, weld metal and heat affected zone toughness), joint type (geometrical complexity and stress predictability), weld type (i.e. butt, fillet etc.), inspection methods (i.e. NDT method and extent of coverage) and inspection access. These aspects are clearly linked to the consequences of failure involving human life, pollution and asset as shown previously in Tables 5.1 and Table 5.2 respectively.

Using ISO 13819-2 Part 2, two approaches are available (i.e. MC or DC approach), whilst NORSOK N-004 appears to be similar to the DC approach of ISO 13819-2. Using the MC approach minimum inspection requirements as shown in Table 5.3 are given for different topside components. In contrast using the DC approach of ISO 13819-2, minimum inspection requirements for the substructure are provided. The NORSOK approach although similar to ISO 13819-2, does not give minimum inspection requirements for either the substructure or topsides. However, as described in Section 5.2.5 it does give some general guidance on linking the various DC classifications to specific substructure/topside components.

ISO13819-1.3 refers to the requirements of ISO 13819-2. However, it is clear from ISO 13819-1.3, that certain areas identified (i.e. safety critical supports) are not covered by ISO 13819-2.

The EEMUA 158 standard although not directly linking consequences of failure to inspection requirements addresses the importance of inspection by defining five different inspection categories which are related to the stress state of the weld (i.e. depending on whether the weld is highly stressed and/or whether welds have low or high fatigue lives). This categorisation appears to be similar to part of the overall selection process adopted in ISO and NORSOK where the five DC classifications are linked to the degree of fatigue and tensile stress utilisation. For example as shown in Table 5.5, it can be seen that the inspection categories follow a similar trend to those adopted in ISO 13819-2 where welds which are highly stressed etc., in that higher inspection requirements/categories are assigned to them.

API makes reference to the importance of material class and toughness requirements for the selection of components by linking selection to the requirements of the component (i.e. use, degree of redundancy, complex stresses, degree of constraint etc.). However, the inspection requirements are classified with respect to components being either primary or not and welds being full penetration or not.

6.2.2 Joint Complexity - fatigue and tensile stress utilisation

ISO 13819-2 and NORSOK Standard N-004 recognises that joint complexity influence the selection of material, toughness and inspection coverage (i.e. components with high complexity/stress predictability require higher classification and hence increased inspection requirements than those with low complexity).

It can be seen from Tables 5.1 and Table 5.2 that ISO/NORSOK link the inspection requirements to the importance of fatigue life utilisation and/or tensile stress utilisation when adopting the DC classification approach. Using this approach the inspection requirements are then further divided into whether the fatigue life of the component is above or below 3 times the required life. For joints which have lives above three times the required life the inspection category is further categorised depending on whether the tensile stress utilisation is above or below a certain level a) greater than 0.85, b) between 0.85 and 0.6 and c) below 0.6 respectively. As expected the level of inspection increases as the degree of fatigue and tensile stress utilisation increases. However, it is not clear as to why fatigue life factors of above and below 3 and various tensile utilisation factors have been selected as the criteria.

In the case of EEMUA 158 selection is similar in broad terms to the above in that a distinction is made between welds that are highly fatigued and/or stressed when defining the inspection category as shown in Table 5.5. However, fatigue criterion defining high/low fatigue life etc. are not provided, albeit information on areas of intended application for these situations (i.e. type of components) are noted for both jacket and topside components.

In the case of ISO/FDIS 10721-2 it can be seen from Table 5.14 that a distinction between non-fatigue (i.e. normal class) and fatigue class is made when determining the level of inspection that is required. However, the inspection requirements are not linked to the degree of complexity etc. of the component.

6.2.3 Inspection techniques - methods used and extent of coverage

Most of the codes recognise the need to undertake inspection of welds using various NDT methods. However, the degree of coverage and the methods used varies between each of the codes. The most detail coverage is provided by ISO/NORSOK where both inspection coverage and number of techniques used depend on the weld type being examined (i.e. butt, T-connection or fillet/partial penetration), joint complexity and joint criticality. The extent of coverage increases as the joint complexity and criticality increases. For example for highly complex and critical welds inspection would involve not only 100 % visual but 100% UT and 100% MT inspection.

When comparing all the various codes it is noted that only ISO/NORSOK appear to clearly distinguish between joints which are inspectable and non-inspectable. For joints which are non-inspectable an increase in the inspection requirements (during fabrication) is required. As noted in Section 5.2 and shown in Table 5.1 and Table 5.3, for these situations the inspection category increases by one category (i.e. a weld that is inspectable and classed as category B will be assigned class A. etc.) when using the DC approach. However, when using the MC approach in ISO 13819-2 the DC inspection categories (i.e. A, B, C, D and E) are not used. As stated in Section 5.2 and presented in Table 5.3 attempts to provide similar categories to those used in the DC approach were used. However, in a number of instances the same categories could not always be used and other arbitrary sub set categories (i.e. A^1 etc.) of A, etc. were defined. It may be useful if the inspection requirements of both the MC and DC approach could follow a similar approach when defining the inspection categories adopted for inspection.

API defines the inspection requirements of deck components by distinguishing between components that are considered to be either primary or not in nature and also whether welds are either full penetration or not. For primary butt welds, API allows the use of either 100% UT or 100% MT to be used, whilst for other weld types (i.e. partial penetration or fillet welds) only visual inspection is required.

EEMUA 158 appears to be broadly in line with the provisions of ISO 13819-2, recognising that welds which are more highly stressed require higher coverage and hence involve 100 % visual, UT and MT inspection. However, inspection is classified with respect to areas of application (i.e. different components) and no distinction between the different types of weld is noted.

DD ENV 1090 recognises the applicability of different inspection techniques for different weld and joint types but the extent of coverage required and relationship with joint criticality etc. are not provided. This is also the case for ISO/FDIS although the need to undertake both UT and MT inspection is recognised in relationship to the thickness of components and fatigue strength.

6.2.4 Inspection acceptance criteria

Again both ISO 13819-2 and NORSOK M-101 recognise the need for acceptance criteria for each of the various inspection techniques. The provisions adopted in ISO 13819-2 indicate that acceptance criteria should be to recognise international standards, albeit that for visual inspection alternative criteria as shown in Table 5.4 can be used. It should be noted that the acceptance criteria are applicable to both MC or DC approaches and hence do not distinguish between the different inspection categories adopted when using the DC approach.

In the case of NORSOK M-101 detail acceptance criteria are explicitly provided for each of the inspection techniques (i.e. visual, MT, UT and RT). Furthermore, different acceptance criteria are provided for each of the inspection categories A, B, C, D and E respectively.

EEMUA 158 provides acceptance criteria for both visual and UT inspection respectively. As indicated in Section 5.2.3 the visual inspection criteria appears to be similar in nature to that adopted in ISO, albeit that it appears to cover less defect types etc. Again the criteria are not linked to any specific inspection category.

ISO/FDIS 10721-2 provides detail requirements for final acceptance of production welds. As noted in Section 5.2.7 these criteria are divided into four categories namely weld geometry, profile discontinuities, surface breaking defects and subsurface discontinuities. A distinction between different applications (i.e. normal class or fatigue class) is made within the acceptance criteria.

API RP2A- LRFD indicates that acceptance criteria for UT inspection of welds shall be in accordance to the criteria given in API R2X- "Recommended Practice for Ultrasonic

Examination of Offshore Structural Fabrication and Guidelines for Qualification of Ultrasonic Technicians" and to ANSI/AWS D1.1-"Structural Welding Code- Steel, American Welding Society Specification" for other NDT inspection methods.

It is clear that the codes provide varying degrees of acceptance criteria which are either to recognised codes or are explicitly provided. The extent of the criteria appear to vary in terms of defect type covered, maximum allowable defect size permitted and inspection category/class. A detailed comparison of the various criteria is beyond the scope of this study.

6.3 Comparison of in-service inspection

For in-service inspection of topside structures the standards provide far less guidance. This is not necessarily illogical. Following from the practice of onshore structural design, safety is very much a design and fabrication issue. It is implicit that the structure will operate without inspection or maintenance for the duration of its working life. Information presented in Section 5.3 has been used to assist in the comparisons.

All the codes written specifically for the overall engineering of offshore platforms require a "baseline" or "bench mark" inspection to be performed as soon as practicable after installation. This is generally defined as a substructure issue with a token "look-over" for the topsides. As presented in Section 5.3 several of the codes provide guidance on the inspection requirements of the substructure. Default periodic inspections during the planned life of the structure are noted in ISO 13819-2 and API RP2A-LRFD which are linked to the exposure level and/or type of structure (i.e. manned/unmanned etc.). For such cases the type of inspection involves mainly underwater inspections of the substructure, involving the use of divers/ROV and also for detail NDT inspection the use of techniques such as FMD. Hence, the nature of these types of inspection are therefore not applicable to the requirements for topsides.

The only standard which provides any form of a inspection programme for topsides is ISO 13819-1.3, as shown in Table 5.17, which follows a similar pattern to the ISO 13819-2, default programme (i.e. periodic inspection levels). As stated in Section 5.3.3, the default programme is linked to particular areas (i.e. coatings, safety critical elements and missing/damaged members). The standard emphasises the need to consider topside components which may require special attention but such details are given in the informative section. Furthermore and as noted in Section 5.3.3, limited guidance on selection of inspection techniques is given with respect to components that have protective coatings. The periodic inspections identified involving NDT inspection require different degrees of inspection of safety critical elements varying from 10% to 100% depending on the level of inspection required. The basis of the 10% value is unclear and further information to support this would be desirable.

NORSOK N-005 also defines that an initial condition survey during the first year of operation is recommended followed by a "framework programme" for inspections on a 3-5 year cycle (Cl.5.3.1), based on the experience obtained from Norwegian petroleum activities. Alternative Instrumentation based Condition Monitoring (IBCM) is also highlighted in NORSOK N-005 as being an alternative to conventional inspection methods. The IBCM is considered to be suitable to areas with limited accessibility for performance of condition monitoring and maintenance.

It is clear that with respect to the level of inspection required (i.e. extent and type of techniques) that no similar correlation with fabrication requirements are explicitly given. Therefore, one could assume that the type of technique(s) used and the extent of coverage may not be similar to the minimum requirements adopted during fabrication.

A particular issue in relationship to in-service inspection is that criticality is a time based variable. Some very large structural elements, critical to transport and lifting, may, once the platform is complete offshore, be redundant and have low levels of utilisation. Many large and impressive components of major platforms could in fact be removed completely after installation but are likely to be subject to considerably more offshore inspection than a support on a critical riser or process vessel. Most modern offshore platforms in the North Sea – even those on four main supports – could tolerate the loss of a support or the column or brace directly above it without initiating a life threatening event.

However, none of the codes give clear systematic guidance or instruction on the assessment of system interaction with the process plant and pipework although this issue is raised in the draft text for ISO 13819-1-3 (in Cl. 16). When one considers that the pipework can consist of up to 2 metre diameter tubes – an order of magnitude stiffer than some of the "supporting" structure – and may containing explosive liquids and gases at pressures exceeding 200bar, with complex routing, this omission is clearly undesirable. When one adds the practice of analysing the pipes and supporting structures in completely independent models with no systematic exchange of stiffness data the need to ensure high quality in the supporting systems is very clear. The supports on major pipes and vessels are likely to present considerably less redundancy and a more severe consequence.

7. CONCLUSIONS

A review of Codes, Standards and specifications to determine the inspection requirements for both fabrication and in-service pertaining to topside structures has been undertaken. A number of key factors influencing the inspection process have been identified. The main conclusions from this study are as follows:

7.1 Fabrication Inspection

- The approach to the determination of the fabrication inspection requirements for offshore topside structures is variable between codes. Member and joint classification draws heavily on the approach adopted for jacket structures although the codes currently being developed, particularly ISO 13819-1.3, show more recognition of the specific conditions for the topsides.

- The codes currently under development appear to provide a more rational basis of linking fabrication inspection to design. In the case of the provisions developed under ISO 13819-2 and NORSOK N-004 the inspection process is linked to material selection (i.e. parent material, weld metal and heat affected zone toughness), joint type (geometrical complexity and stress predictability), weld type (i.e. butt, fillet etc.), inspection methods (i.e. NDT method and extent of coverage) and inspection access. These aspects are linked to the consequences of failure involving human life, pollution and asset.

- For those codes written for offshore application the approach to member classification draws heavily on practice for substructures. Criticality and complexity almost invariably directly relate to structural functions. The codes currently under development provide different inspection criteria depending on the fatigue utilisation (i.e. high or low). The basis of these criteria is unclear.

- None of the codes give clear systematic guidance or instruction on the assessment of system interaction with the process plant and pipework although this issue is raised in the draft text for ISO 13819-1-3 (in Cl. 16).

- It is clear that all the codes examined provide varying degrees of inspection acceptance criteria. The requirements being either to recognised codes or in some cases explicitly provided for some inspection techniques used. Only NORSOK M-101 provides explicit inspection criteria for each of the various NDT inspection techniques namely visual, MT, UT and RT. Furthermore, NORSOK provides different acceptance criteria which are closely linked to the required inspection category

- The extent of the criteria appear to vary in terms of defect type covered, maximum allowable defect size permitted and inspection category/class. A detail comparison of the various criteria is beyond the scope of this study.

7.2 In-service Inspection

- The frequency of subsequent in-service inspections for topsides generally follows as an add-on to that for the substructure. This is likely to be both inefficient and ineffective for topsides. The “Structural Integrity Management Plan” would include requirements for topsides that relate specifically to the in-service criticality of components.

- The only standard which provides any form of a inspection programme for the topsides is ISO 13819-1.3, which follows a similar pattern to the ISO 13819-2 default programme (i.e. periodic inspection levels). The default programme is linked to particular areas (i.e. coatings, safety critical elements and missing/damaged members).

- ISO 13819-1.3 does emphasise the need to consider topside components which may require special attention, although such details are mentioned in the informative section only.

- ISO 13819-1.3, provides information on the different inspection techniques that can be used. However, details on which techniques should be used, and the extent of coverage to be undertaken are not given. Therefore, one could assume that the type of technique(s) used and the extent of coverage may not be similar to the minimum requirements adopted during fabrication.

- Most of the standards that were prepared for the design and fabrication of offshore structures include a specific provision for a "bench mark" inspection of the platform structure as soon as possible after installation. Such an inspection has several functions – included in which is a practical check on the integrity of the design. No QA system is foolproof. Even for a platform that has been designed and approved for zero in-service inspection this initial inspection has an intrinsic value that should not be dispensed with. Unfortunately none of the standards attempt to identify the timing of such an inspection with respect to the commissioning of the platform's equipment. The commencement of drilling operations and the on-loading of bulk materials, together with the thermal and dynamic loads in risers and process systems, could all initiate a hidden weakness in the structural systems that would not be evident otherwise. The requirements for the benchmark inspection of topsides should clearly address these issues.

- NORSOK N-005 also defines that an initial condition survey during the first year of operation is recommended followed by a "framework programme" for inspections on a 3-5 year cycle (Cl.5.3.1), based on the experience obtained from Norwegian petroleum activities. Alternative Instrumentation based Condition Monitoring (IBCM) is also highlighted as being an alternative to conventional inspection methods. The IBCM is considered to be suitable to areas with limited accessibility for performance of condition monitoring and maintenance.

- Selection of inspection techniques may need careful consideration particularly for components requiring inspection that have protective coatings.

- Consideration to critical pipework and supports is not dealt with in any detail. When one considers that the pipework can consist of up to 2 metre diameter tubes – an order of magnitude stiffer than some of the "supporting" structure – and may containing explosive liquids and gases at pressures exceeding 200bar, with complex routing, this omission is clearly undesirable. When one adds the practice of analysing the pipes and supporting structures in completely independent models with no systematic exchange of stiffness data the need to ensure high quality in the supporting systems is very clear. The system is critical, complex and poorly understood.

7.3 Way Forward

With the exception noted above the more recently derived standards written for the fabrication of offshore structures show a more logical approach than those from earlier documents. One could also conclude from the low reported incidence of structural failure offshore that the in-built conservatism in the overall design – including the interface with process systems and the quality of the fabrication – is generally fit for purpose. The lack of knowledge in relation to the reliability of structural systems at the interface with complex process systems is, however, a cause for some concern.

For all structural inspections for offshore topside structures, both during fabrication and in-service, there is a clear need for a more systematic approach than those generally identified within current codes and standards. The objective should be to achieve a higher and more consistent level of safety for less effort than currently deployed. The first step in the preparation of such an approach is to identify all the logical inputs to the process and Figure 7.1 presents inputs that could well be considered appropriate.

One possible way forward may be to perform a study that would permit the development of quantitative assessment of inspection class for topside components based on such a route as given in Figure 7.1. If this were calibrated against equivalent onshore structures – related to risk and consequence – it would permit a rational and consistent approach to be adopted. It would also permit the performance of rational cost/benefit assessments taking into account the cost of inspection versus the cost of reducing the "criticality index" by reducing component utilisation ratios, increasing design fatigue life, etc.

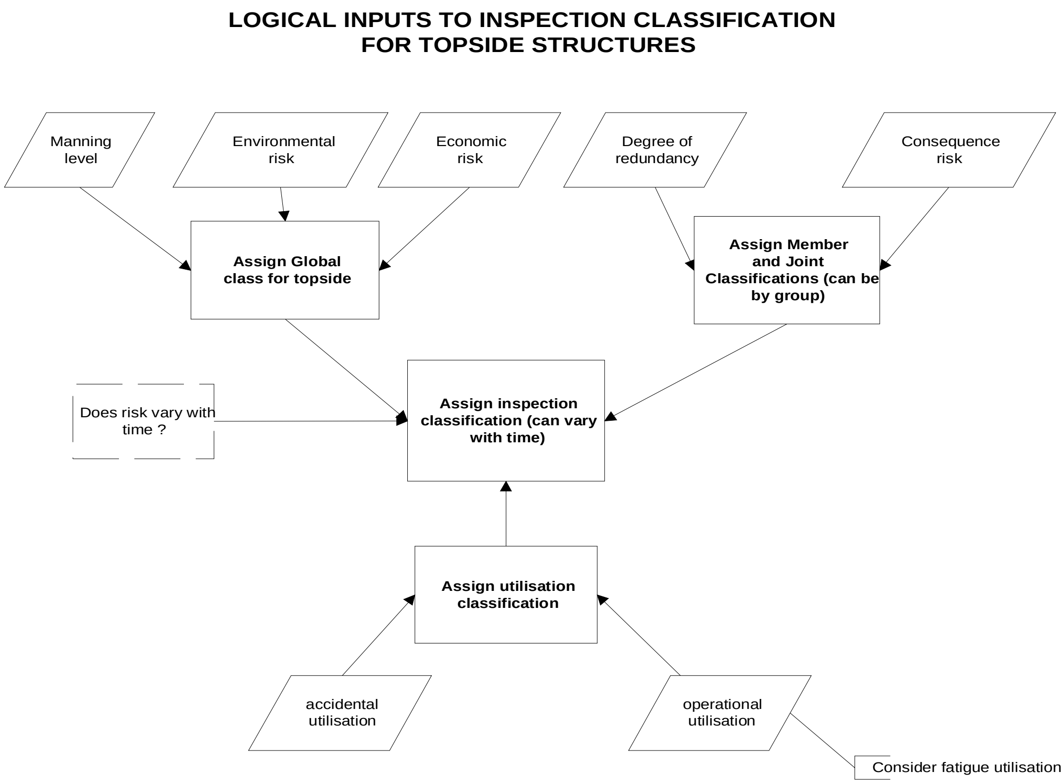

Figure 7.1
Logical Inputs to Inspection Classification of Topside Structures

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