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REASSESSMENT ISSUES IN LIFE CYCLE STRUCTURAL INTEGRITY MANAGEMENT OF FIXED STEEL INSTALLATIONS

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ABSTRACT

There is an increasing number of ageing installations in UK waters, many of which are being or will be operated beyond their original planned service life. This important trend, in combination with (a) the introduction of risk-based goal-setting regulations which require the maintenance of life cycle integrity as a key target, (b) the development of guidelines in the draft ISO standard for offshore structures, ISO 19902, and (c) significant technology advances in recent years (e.g. in loading, fatigue, fire and blast integrity and system integrity), makes reassessment an important consideration in the structural integrity management of offshore installations.

The paper outlines procedures in place for reassessment, including those in the draft ISO standard, and reviews recent technical advances relevant to this area. The important role of inspection and maintenance for existing structures is assessed and related to both current practices and target requirements. The need for reliable and comprehensive inspection data is important for reassessment and the status of this is reviewed. An overall framework for reassessment is developed in the light of the above issues.

INTRODUCTION

In offshore locations around the world many installations are approaching or have exceeded their original design lives. Hence, reassessment is a key consideration and the criteria for this process are becoming established. These criteria are sufficiently different for large manned installations, often operated in the North Sea, compared with smaller unmanned installations typical of those found in the Gulf of Mexico. Reassessment is a relatively new concept in codes and standards with API RP 2A introducing a new section in 1997 [1]. This has been significantly expanded and modified in the development of the ISO 19902 standard [2] with a specific section devoted to this topic. The importance of reassessment was highlighted in the wake of Hurricane Andrew in 1995 which led to many platforms in the Gulf of Mexico requiring reanalysis.

Life cycle structural integrity has been given an important status in the Design & Construction Regulations [3], introduced into the UK in 1996. Reassessment is also recognised as a key aspect of this with the growing number of ageing installations in the UK sector, with over 80 platforms now older than 20 years (see Figure 1). To date, experience for the UK sector of the North Sea amounts to approximately 4000 platform years, during which there has been no major collapse of an installation

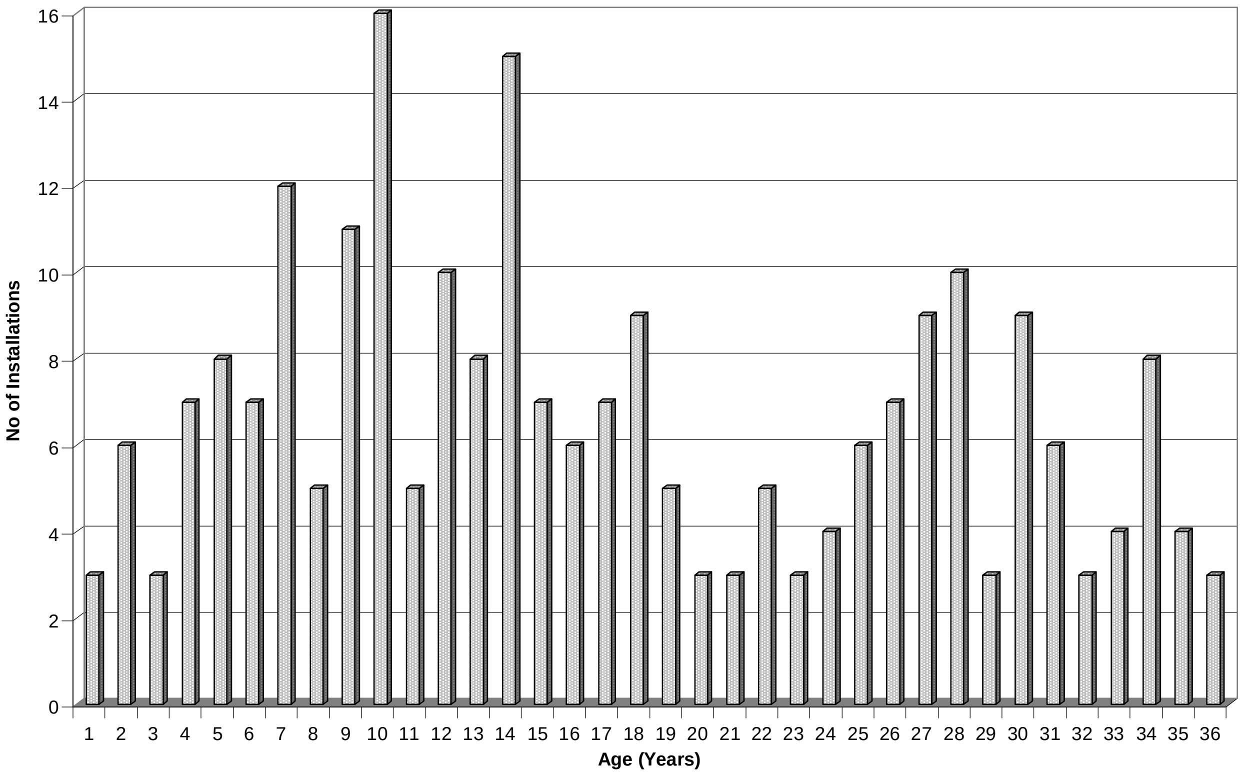

Figure 1: Histogram of fixed steel installations on UKCS by age

due to structural failure alone, although several installations have needed urgent repair to enable them to withstand subsequent winter storms. Further information on deterioration of fixed platforms on the UKCS is given below.

Most UK platforms were designed and installed under the Certificate of Fitness (CoF) Regime [4], which ended in 1998. Under this prescriptive regime the responsibility for issuing the CoF lay with one of six certifying authorities (CA). The certificate was renewed every 5 years, which provided the framework for reassessment at that time. Each CA had their own approach to managing structural integrity, based on the published HSE Guidance Notes [5]. These Guidance Notes were recognised as the cornerstone for the technical requirements, although the emphasis was mainly on design aspects. Each CA held a large amount of data on each platform for which they were responsible which provided an opportunity for benchmarking performance. As noted earlier, at that time most codes and standards did not address re-assessment until API introduced a new section in 1997.

The goal-setting safety case approach [6] to managing safety is based on assessment of hazards and managing the associated risks. Structural failure is one of the hazards for which the consequences can be very serious, particularly for manned platforms and hence deserves special attention. As a result, safety cases address this and appropriate performance standards for the safety critical elements (SCEs) are set to manage the risk to ALARP levels. However for most UK installations to date the setting of suitable performance standards for the structural SCEs (e.g. jacket, topsides, helideck, etc.) is still developing and in many safety cases these are not yet well demonstrated. Verification of the SCEs is now part of the current UK scene, although priority has been given to those aspects associated with the hazards of fire and explosion.

An international OMAE workshop on platform requalification was held in Lisbon in 1998 [7]. This included several significant papers focusing on the reassessment of platforms in US, Mexican and Norwegian waters. As a result of the workshop, a number of key management and engineering issues were identified including:

- improved knowledge of current structural and environmental conditions

CAUSE	DAMAGE (JACKETS)							
	Severance	Through crack	Dent (>50mm)	Bow (>100mm)	Tear	Hole	Crease	Total
Boat impact	10	13	22	23	1	2	-	71
Dropped objects	3	2	6	-	1	-	-	12
Fatigue	5	41	-	-	-	-	-	46
Fatigue from fabrication defect	1	11	-	-	-	-	-	12
Installation		10	2	2	-	2	1	17
Other / unknown	1	2	13	1	1	4	-	22
Total	20	79	43	26	3	8	1	180
No. of repairs								105

Table 1: Data on 180 incidents in period 1972 - 1991 from a review of 174 platforms

- development of platform performance characteristics
- identification of mitigation and performance measures
- development of common acceptance criteria
- development of reassessment standards and procedures
- improved knowledge communication on reassessment.

Concerns arising from recent changes to current practice have been highlighted in [8]. These include several issues relevant to reassessment with the identification of various needs, i.e.

- UK inspection practices under the new goal-setting regulations to be suitable for the large population of ageing structures in the North Sea
- improved definition and modelling of the total process of managing structural integrity, including underwater inspection
- a better understanding of the major factors associated with inspection planning, particularly with respect to inherent defects during fabrication and their influence on in-service fatigue life, and the static and fatigue performance of components developing large cracks
- recognition of the increasing importance of operator reliability and competency in inspection planning and execution and the need for suitable training and competency standards.

Although some progress has been made in advancing the above issues, it is noteworthy that the management framework for continuing or extended operation (i.e. reassessment) still remains an issue and the wider adoption of best practice validated by benchmarking remains to be progressed.

Recent technological developments have enabled re-assessment and life cycle integrity to be managed more effectively. In particular, the development of software for prediction of system strength has provided a means of measuring the performance of structural systems, and the estimation of reserve capacity, now recognised as one of the key parameters in managing integrity. In addition, a better understanding of extreme wave loading and requirements for air gap has enabled limit states to be better defined. A more recent development is the recognition that human factors and competence are as important as the technical aspects of design and offshore operations in some contexts. Techniques are emerging to measure human factor performance, both individually and organisationally in safety aspects, such as design, although this approach has yet to be developed in depth for reassessment.

This paper addresses life cycle structural integrity with particular emphasis on reassessment, identifying the many changes that have occurred in recent years that affect this.

HISTORICAL DATA ON DAMAGE OR DETERIORATION OF PRIMARY STRUCTURAL COMPONENTS (SCEs)

Historical damage and deterioration data can provide valuable information on and verification of the structural integrity management system and is an essential input to the reassessment process. Structural deterioration is a direct consequence of operation over a sustained period of time in a hazardous environment, both from natural processes and accidental events. Such deterioration needs to be minimised by appropriate design and managed through regular inspection and maintenance.

For reassessment, the availability of quality data on damage and subsequent repairs is an essential requirement but is not always available. Historical data on damage to UK offshore fixed platforms exist for the period up to 1991 but more recent data, particularly for the period post 1996 when the DCR regulations were introduced, are very limited for the UK sector, which is a significant disadvantage.

There are two main sources of data on structural damage. Data were obtained by HSE from a research project reviewing damage to 174 installations over the period 1972-91 [9]. Details of 180 incidents leading to 105 repairs are given in Table 1, below. This also shows that accidental causes were responsible for 83 damages (46% of the total), whilst earlier stages of the life cycle caused damage in 29 cases (16%).

MTD undertook a survey of repairs to platforms, covering the period from 1966 to 1991 [10]. For this period details of 158 repairs were obtained and reviewed. 42 repairs (27% of the total) were required due to accidental causes (ship impact, dropped objects), whilst 49 repairs were required due to fatigue or corrosion. In addition, design faults (original or upgrades) led to a further 20 repairs during operation and faults occurring during fabrication or installation caused a further 24 repairs. It is noteworthy that these 44 repairs (28% of the total) were needed due to problems in the early stages in the life cycle (design, fabrication, installation etc.), showing the importance of all stages in managing platform integrity.

UK historical data [9] indicate that the probability of underwater fatigue cracking is approximately 2×10^{-2} p.a., which is high. The MTD study of repairs [10] showed that out of 158 repairs analysed 39 were due to fatigue (representing a frequency per structure year of 0.01). Good data for cracking exist for the Norwegian sector [11] and these have been reviewed recently, with an estimate of 3.5×10^{-3} for each member and node in the jacket, based on historical data (approximately 5×10^{-2} p.a.).

In terms of reassessment, damage due to earlier stages in the life cycle is important but in most cases will have been addressed during the previous operational life. The exception is fatigue where fabrication defects are known to act as initiators of cracking.

Accidental damage due to, for example, ship impact should have been located at the time of the incident although the MTD review of repairs showed that in 15**%** of cases this damage was only found by chance or at the time of the next routine inspection. With current inspection concentrating mainly on flooded member detection it is unclear whether such damage would now be found unless causing major cracking. In only a very few of the instances listed in Table 1 would a formal reassessment have taken place, on the basis that the installation possessed sufficient redundancy that damage to one member would be unlikely to lead to structural collapse. Knowledge on platform redundancy is a key factor in this decision and as noted earlier improved software enables assessments to be made of this characteristic.

Good structural data are an essential requirement for reassessment and since the demise of the certficate of fitness regime the availability of such data is limited. One of the priorities of HSE is to encourage better data collection and sharing of such data to encourage benchmarking.

CODES & STANDARDS

To date guidance on reassessment is contained in various codes and standards. However, the topic as a management activity is only just gaining recognition. The principal sources of guidance on reassessment are API RP 2A [12], ISO 19901 [13], ISO 19902 [2] and NORSOK [14].

Some guidance is given in the ISO standard with Part 1, ISO 19901 (now published) [13], covering General Requirements and the draft ISO 19902 (originally Part 2) [2] giving more detailed information. The criteria for when a reassessment should be conducted to determine fitness for purpose are stated in ISO 19901 as when an installation:

- has exceeded its intended design life
- has deteriorated or been damaged significantly
- will be used in a manner that will invalidate the original design assumptions
- has departed from the original basis of design
- the original design criteria are no longer valid.

ISO 19901 also states that when a condition assessment is undertaken:

- it cannot be assumed that the platform condition and the gravity, environmental and seismic actions originally used remain valid
- new information from installation, construction, operations should be reviewed and taken into account in the assessment (including the latest environmental data)
- records from inspection and maintenance and repairs are available as necessary inputs to the reassessment process

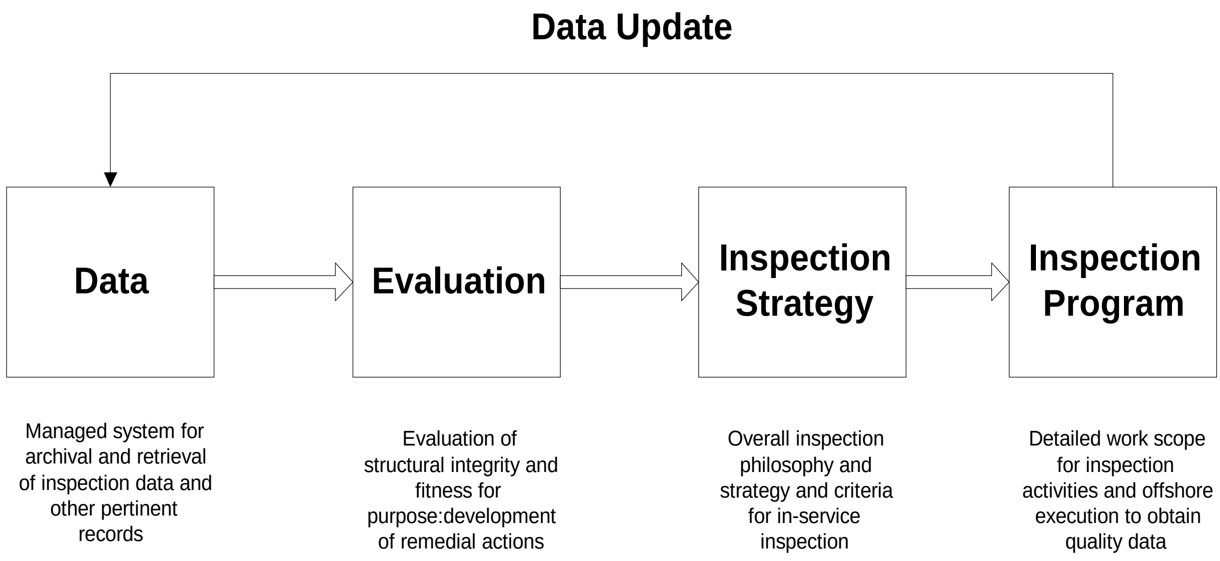

Figure 2: ISO procedure [2] for development of inspection plan

- additional inspections to establish the condition of the structure may be required when existing inspection records are insufficient
- current standards for resistance calculations should be used, not those at the time of the original design.

In considering component failures as a result of reassessment it is stated that limited individual failures may be acceptable provided there is sufficient reserve against overall system failure (as demonstrated for example by pushover analyses). However, when it is shown that the structure is not acceptable by analysis then strengthening or repairs may be required. When this is not possible operational limits may be needed on the platform (e.g. demanning when extreme weather is imminent). The adequacy of fatigue life for the intended remaining life should also be reviewed and this should be taken into account when planning repairs and future inspection schedules.

ISO 19902 [2], concerned with fixed installations, is now at its final draft stages, following development by a committee with strong international representation. Section 25 (*Assessment of existing structures*) includes a more detailed approach to develop assessment procedures to demonstrate that existing installations are 'fit for purpose'. The formal assessment process includes six main elements which are:

- selection (initiation)
- screening criteria
- condition assessment
- action assessment (i.e. loads)
- resistance assessment
- prevention & mitigation.

When developing screening criteria, several factors are identified for consideration in the draft standard. These include:

- remaining service life
- availability of structural condition monitoring records
- long term loading environment
- degree of confidence in modelling assumptions
- sensitivity to analysis assumptions
- redundancy and collapse behaviour
- potential structural deformation affecting lifesaving equipment, escape routes, etc..

It is also recommended that performance criteria are established against which the adequacy of the screening criteria can be monitored for later assessment. To date, this assessment process has not been in widespread use for UKCS structures as the current draft of ISO is still at the DIS stage and further editing work is in hand. However, it is expected that, when finalized, this standard will form the basis for managing structural integrity. It will also fill an important role formerly taken by the HSE Guidance Notes [5] prior to their withdrawal in 1998.

A parallel section in the draft ISO standard is also important for re-assessment, concerned with in-service inspection and structural integrity management, which are key aspects of life cycle integrity. The ISO procedure includes collation of platform and inspection data and their evaluation to develop an inspection plan, as illustrated in Figure 2.

For North Sea structures on the UKCS, preparation of an inspection plan is now a requirement of Regulation 8 of the DCR [3]. This requires that the duty holder ensures that suitable arrangements are in place for maintaining the integrity of the installation, through periodic assessments and carrying out any remedial work in the event of damage or deterioration. The ISO draft standard [2] includes a substantial new section on these items which is expected, in due course, to provide an international framework for this subject. The plan will identify the inspection programme which, when completed, will feed back new data into the in-service database (see Figure 2). The inspection programme includes:

- a baseline inspection once the platform has been installed
- periodic inspections to monitor any deterioration (e.g. from fatigue)
- special inspections following any accidental damage or extreme loading events.

The NORSOK standard on Design of Steel Structures [14] also contains a section on reassessment, which includes recommendations to demonstrate 'fitness for purpose' when conditions similar to those specified in the ISO standard exist. The NORSOK section covers several topics in more detail, such as extension of fatigue life, material properties, corrosion allowance, foundations, damaged and corroded members, cracked members and joints, repaired and strengthened members and joints and plates and shells with dents and permanent deflections. However, limited data are available on the residual strength of damaged structural components.

REASSESSMENT FRAMEWORK

Reassessment Triggers

The draft ISO 19902 standard [2] specifies five criteria for reassessment reflecting the requirements of ISO 19901 (see Figure 2):

- extension of service life beyond the original calculated design life
- damage or deterioration of a primary structural component
- change of use that violates the original design or previous integrity assessment
- departures from the original basis of design (e.g. increased loading or inadequate deck height)
- original design criteria are no longer valid.

In the UK it is also required that the safety case be updated periodically to reflect changing knowledge and conditions [6]. This trigger is to ensure that safety cases remain working documents and safety measures are continuously revised and improved.

Extension of service life
The service life of many offshore installations has been extended to enable recovery of additional oil/gas resources and in particular to enable satellite wells to be established using the main platform as a base for treatment and offshore loading via pipeline or tanker. The key factors in life extension are the management of hazards associated with long term processes such as corrosion and fatigue. These are addressed below.

Damage or Deterioration of Primary Structural Components
Following the discovery of significant damage during structural inspection it is necessary to carry out reassessment of the structure in the damaged state, recognising the influence of component failure on the overall system strength. This may indicate that repairs are required to restore the structural integrity to an acceptable level. Several codes, e.g. ISO and NOROSK, provide guidance on the treatment of damaged components. This trigger is only activated as a result of the implementation of an appropriate and timely inspection programme.

Change of Use Affecting Original Design
This topic has received little attention to date with respect to structural integrity. However, the main hazards in this area are weight management and greater risks for fire and explosion arising from change of process requirements, etc.. Performance standards for weight management have been prepared for some platforms as part of the safety case, relating to leading indicators.

Departures from the Original Basis of Design
Departures from the original basis of design include [2,13]:

- additional reduction of personnel or facilities such that the platform category is changed
- more onerous environmental criteria
- more onerous component or foundation resistance criteria

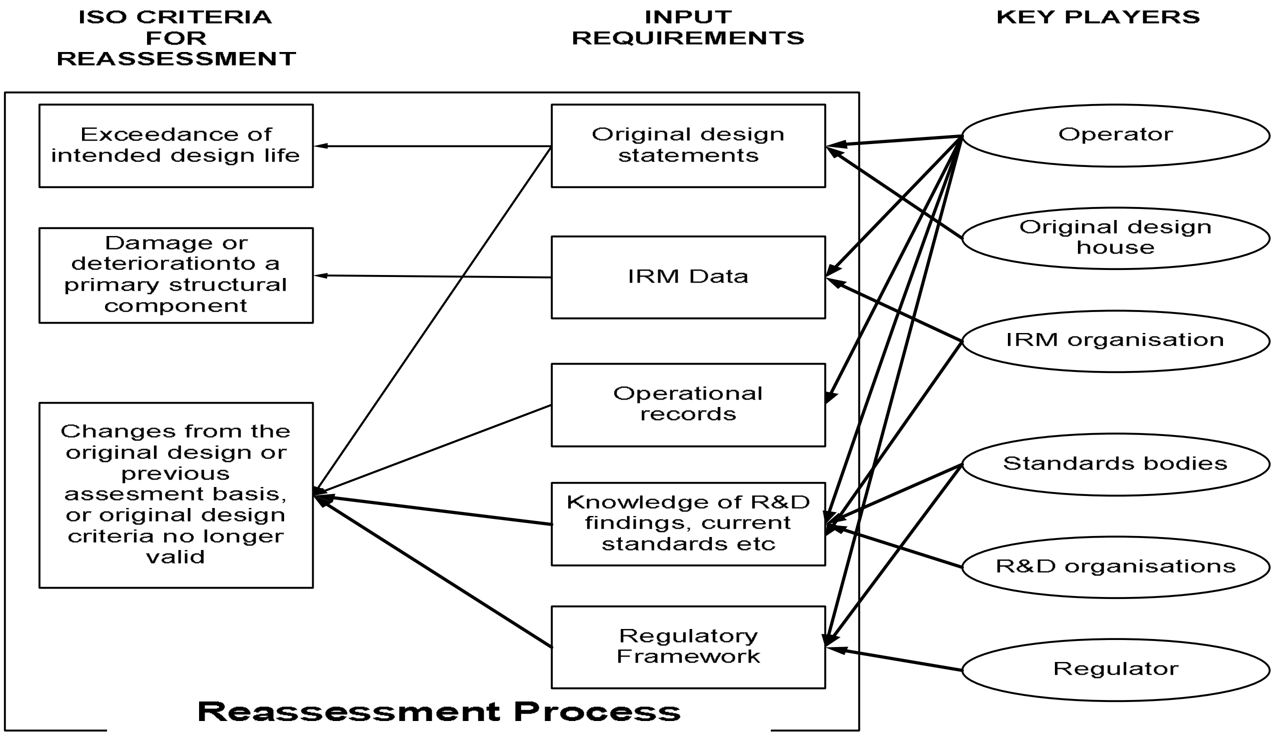

Figure 3: Reassessment process showing criteria, relevant input data requirements and key players

- physical changes to the platform's design basis (e.g. scour or subsidence)
- inadequate deck height leading to wave impact on the deck not previously considered.

It is expected that reassessment will be based on the most recent data available for the structure. Loading data may need to be revised according to the latest metocean data and analysis, as specified in the most recent relevant standard. Foundation data may also be updated according to findings during installation and data from adjacent structures, or from any structural monitoring system deployed. The water depth may need to be revised according to measured data and scour and settlement reports. The latter information is very important for air gap considerations.

<u>Original Design Criteria No Longer Valid</u>

Many installations have been designed to earlier versions of structural codes and standards which have subsequently been updated to reflect improved knowledge and experience. Hence, design criteria based on the original version of the code may now be unconservative and no longer valid and reassessment is necessary. The principal documents that have been used in the structural design of offshore installations operated on the UKCS during the last 30 years are API RP 2A [12] and the HSE Guidance [5]. During this long period, they have been revised substantially with over 20 different editions of API RP 2A and four main editions, with various amendments, of the HSE Guidance. This has resulted in several different categories of design of offshore structures ranging from those early shallow water designs which did not include fatigue to large deep water designs to modern codes. These changes are described in [8].

Reassessment Stages

There are four main stages to reassessment, which are:

- criteria for selection of platform for reassessment (see above);
- assembly of input data, followed by analysis process using appropriate tools and competent persons;
- criteria for acceptance / failure;
- decision and actions to be taken.

These are illustrated in Figure 3 where the key players are shown. It is apparent from Figure 3 that

Quality of data	Original design assumptions	Loading	Resistance	Effect on safety margins
High	Well documented, good materials data available.	Current environmental data established, wave history fully documented, including incidences of deck loading	IRM data fully documented and assessed, joint and member assessments known against current codes	Can be assessed as per design basis in current codes / standards
Medium	Some gaps in documentation of design and materials data	Some gaps in knowledge of current environmental data	Gaps in IRM data, lack of design analysis of joints & members against current codes	Some additional safety margin required over current design levels
Low	Poorly documented, materials data not well recorded	Limited knowledge of current environmental data, poor records of wave history, (e.g. encounters with deck)	IRM data poorly established or assessed	Considerably higher safety margins required than in original design. Increased IRM is required. May require urgent inspection to establish relevant data before reassessment process

Table 2: Input data requirements linked to safety margins

reassessment is a complex process involving a large number of organisations and with a requirement for a significant amount of technical, operational and regulatory data, both historic and current, and hence the importance of the overall management framework.
Whilst the reassessment process is not well formalised in codes and standards, the draft ISO standard includes some guidelines for assessing the effectiveness of the process, as previously described.

Where the quality of data available is limited it is likely that a conservative approach to reassessment will be required, which provides a stong motive to maintain an efficient structural integrity management database.

The margin of safety required is clearly related to the level of confidence in the input data and modelling assumptions. Knowledge of the redundancy and collapse behaviour is also very important in deciding on acceptance criteria and the role of individual components in mainitianing overall integrity, particularly if codes and standards have become more onerous since the platform was built. This is illustrated in Table 2.

It can be seen from Table 2 that there are considerable penalties for poor data management prior to reassessment. The importance of a managed system for IRM data is reflected in the flow diagram included in the ISO draft section on 'in-service inspection and structural integrity management', shown in Figure 2.

KEY FACTORS IN REASSESSMENT

The need to reassess offshore installations is determined mainly by the ageing process associated with exposure to severe environmental and operational conditions. Reassessment is facilitated by technological developments which enable more rigorous assessment of structural integrity to be undertaken. They also act as a trigger to initiate the reassessment process as a result of improved knowledge of structural performance since the original design.

Ageing Processes

Ageing is characterised by deterioration caused mainly by fatigue and corrosion. Any structural deterioration due to ageing should be taken into account in the reassessment process. It is therefore important to have accurate knowledge of both the condition of a structure with respect to fatigue and corrosion and knowledge of the response of the structure to the ageing process for the reassessment process to be performed effectively.

Fatigue
Fatigue life is an important structural integrity performance criterion for offshore structures, with fatigue failure defined as the occurrence of a through-thickness crack. However, there is considerable uncertainty in the assessment process and it is recognised that cracking can occur within the design life, particularly if defects from the fabrication process remain. The importance of fatigue was demonstrated in the section addressing historical data which indicated that there has been a high probability of fatigue cracking underwater, with an annual probability rate of 2×10^{-2}.

The consequences of fatigue failure are initially through-thickness cracking of welded joints, followed by member severance and loss of stiffness in that part of the structure. This will lead to other components being more heavily loaded, possibly resulting in more rapid fatigue cracking, i.e. multiple cracking, and, depending on the level of redundancy, structural collapse. Such damage is called 'widespread fatigue damage' in the aircraft industry and its use as an indicator may also be relevant to North Sea structures and hence to the reassessment process. Examples of multiple cracking have already occurred in North Sea structures, such as conductor framing cracking as a result of fatigue at poor design details. Extreme wave loading or accidental ship collision could also lead to local collapse in areas with significant amounts of prior fatigue cracking. However, it should be noted that few studies have considered multiple cracking as might occur towards the end of life of a jacket structure.

Corrosion
The consequence of corrosion is loss of member thickness, leading to reduced static strength, buckling capacity and possible local structural collapse. Corrosion of riser supports can lead to more rapid fatigue damage to the riser and cracking which, in the extreme, could lead to a hydrocarbon leak. It follows that corrosion performance and the consequences of inadequate control are important considerations in the reassessment process.
Most platforms use sacrificial anode systems, with a distribution of anodes provided to give sufficient protection over the structure. In addition, it is also common practice to provide a 'corrosion allowance' for members located near mean sea level (often between 6-12 mm) where corrosion rates are higher. Steel exposed to sea spray is also vulnerable and in the splash zone epoxy or similar paints are often used to provide corrosion protection, since the CP system is ineffective in this zone.

Normal underwater inspection programmes include a condition survey of the anodes, as well as corrosion potential monitoring of areas of the jacket structure. Through this, anodes can be identified and subsequently replaced to ensure an adequate level of cathodic protection is provided for the life of the structure.

Overprotection (i.e. potentials more negative than -1100mV Ag/AgCl) can be damaging to fatigue (i.e. it can increase fatigue crack growth rates significantly) and to epoxy or similar coatings, with the possibility of bonding to the steel being lost. Hence, design of the anode system is important to minimise this effect and regular monitoring of potentials is also essential to reduce this problem in practice.

Technology Developments

Recent developments in analytical capability have offered opportunities for improvements in integrity assessment and reassessment.

A substantial amount of research has been funded by the offshore industry and HSE with the overall aim of providing a better understanding of the structural integrity performance of offshore installations, both at the component and at the system levels. Key areas which have received a considerable amount of attention include fatigue performance, system strength, extreme wave loading, accidental damage including fire and blast, inspection (both technology and management) and reliability technology. In particular, the development of software for the prediction of system strength has provided a means of measuring the performance of structural systems and the estimation of reserve capacity, now recognised as one of the key parameters in managing integrity. It is appropriate that these developments should be considered in the reassessment process.

System Strength
The process of reassessment has been enhanced considerably by the development of system strength analysis. In recent years there has been increasing interest in developing an understanding of the behaviour of the whole structure (i.e. system strength). This is particularly relevant with the current trend towards reliance on flooded member detection (FMD) as the primary inspection technique for fixed steel installations in the North Sea. The concept of residual strength is very important in assessing the capacity of a structure containing damage, e.g. a large fatigue crack.

Existing codes and standards are based on satisfying component adequacy and hence structures are normally designed on a component basis. However, fixed offshore platforms generally have a multiplicity of load paths so that failure of one component does not necessarily lead to catastrophic structural collapse. The ability of alternative load paths to carry applied loads when damage is present determines the residual strength of the installation and the concept of 'robustness' is sometimes used to describe this capacity. A systems analysis provides an indication of the 'reserve capacity' and the identification of critical components in the structure and thus has the benefit of enabling design and inspection to be optimised. It also enables any available reserve strength to be exploited to overcome identified shortcomings in component performance, e.g. in reassessment. Software has been developed to enable the reserve strength to be determined, using 'pushover' type analyses.

The presence of a single large crack in a single tubular joint is generally unlikely to lead to overall structural collapse due to redundancy in the structure. However, two or more cracks in joints within the same load path could have more serious effects on platform integrity. As noted earlier, the concept of widespread fatigue damage, as used in the aircraft industry, could be an important indicator of significant reduction in integrity. Thus, an estimate of reserve strength alone may not be sufficient to demonstrate the true reserve capacity of a structure. The capacity after the first component failure may be important, particularly if first component failure leads to system failure. Many codes and guidance documents require, not surprisingly, that accidental or other damage to part of an installation should not lead to progressive collapse of the whole structure. However, most analyses of the damaged state do not allow for more than one component suffering damage at any one time.

Platform configuration is a key factor to be considered in reassessment. It is widely recognised that X braced panels are more 'ductile' in that they offer alternative load paths compared to, for example, K bracing where once a member fails there is no alternative load path through the frame. Thus, the potential reduction in static strength of a joint in K-based framing is likely to be more damaging than a cracked joint in X-braced framing and this needs to be reflected in the level of reassessment of system strength.

Significant progress in the understanding of system performance has been achieved through the Frames joint industry projects [15] in which pushover tests were performed on large scale two-dimensional frames initially and more recently on a large scale three-dimensional representation of an offshore jacket containing both X- and K-braced frames in which the mechanisms of load redistribution which contribute to system reserve strength were investigated. The various phases of this work are described in [15]. In addition to providing important information on the behaviour of offshore structures, the results of the Frames projects have enabled the calibration and enhancement of numerical analysis procedures, via benchmarking exercises, thus providing improved confidence in the analysis of offshore structures.

The project was a major undertaking and achieved its objectives. The results are particular relevant to both the design and reassessment of offshore installations enabling the development of guidelines on best practice both for systems behaviour and numerical analysis.

Integrity Inspection and Monitoring

In-service inspection practices will determine the nature and extent of the reassessment process to demonstrate structural integrity. Hence, the reassessment process needs to take into consideration the changes in inspection practices that have taken place in recent years as these have implications on the approach to structural integrity assessment. The use of FMD as the principal inspection method applied to primary and secondary members in steel jacket structures has been an important development with respect to structural integrity assessment because it has brought about an acceptance that significant damage must occur for the damage to be detected. The method has moved integrity away from the detailed weld inspection approach to one in which more is known about the overall integrity of the structure as total reliance on FMD is not necessarily sufficient to ensure structural integrity.

In low redundancy structures the damage necessary for FMD to be effective may result in a reduction in ultimate strength and an associated, unacceptably high risk of structural collapse. For low redundancy structures, it is theoretically possible for such structures to exist in a seriously damaged condition in the interval between inspections. This possibility represents a very high exposure to the risk of catastrophic structural failure. For high redundancy structures, damage may have less serious consequences on structural integrity. Thus, the change in inspection practices requires the understanding of system strength technology and the availability of analytical models to enable an assessment of the damage in the context of the overall structural integrity. These are necessary inputs at the reassessment stage.

However, this approach based on the reliance on FMD necessitates a significant amount of complex analyses and the identification of the most probable failure paths. This may not necessarily correspond to actual failure modes as a result of changes in fatigue life arising from load redistribution in the damaged state and unexpected failures.

On-line monitoring (OLM) has the advantage of providing a continuous check on integrity and may remove the need for underwater inspection. The technique is based on the principle that in low redundancy structures, the annual probability of failure is dominated by a few critical members. The significant effect of critical members on structural strength implies that their failure would also have a significant effect on structural stiffness and hence a structure's response to periodic loading (i.e. wave loading). If this is the case then the failure of critical members could be detected immediately by a sufficiently sensitive on-line monitoring scheme. This would (a) enable assessment to be targeted at damage as soon as it occurs (directly relevant to one of the five reassessment triggers), and (b) reduce the time to repair and therefore minimise the damage caused to adjacent members due to load redistribution.

On-line monitoring methods have been investigated in the past [16] and have had some success in a few cases where the operator has incorporated the concept into the overall integrity management system. This has been done, for example, where a platform has had a record of member severance.

Two particularly important recent initiatives are the establishment of SIMoNet [17], Structural Integrity Monitoring Network, and a joint industry project (JIP) [18] which is nearing completion. The aim of the project is to demonstrate the types of structures and structural members for which on-line monitoring may be used to assure structural integrity. The specific objectives are:

- to establish the relationship between the reduction in ultimate strength and the change in frequency for a range of structures.
- to develop guidelines on how to use a structural monitoring system for substructure integrity assurance.

Further research in OLM concerns the automation in FMD and acoustic monitoring [19].

<u>Reliability</u>

The last decade has seen a major investment in research concerning reliability issues for offshore installations. This research has enabled the uncertainty associated with more traditional design approaches to be more fully understood and the margins of safety delivered by existing practice to be explored. As such, reliability analysis methods provide an additional tool for reassessment. A high competence factor is required in using these techniques and they are also best used in conjunction with advanced analysis so that the engineering parameters can be modelled closely.

Guidelines for carrying out reliability analysis have been published [20] and the framework for carrying out structural reliability analysis for offshore structures is summarised in [21]. A recent initiative, ASRANET [22], Advanced Structural Reliability Network, has been set up to encourage the integration of reliability analysis with advanced structural analysis in an attempt to provide more accurate and realistic measures of failure and hence provide some technical basis for dealing with ageing infrastructures.

Fire & Blast Integrity

A significant amount of work (including full scale testing) has been undertaken concerning the science and engineering of fire and explosion loads and effects on offshore structures. The reassessment and design framework for this work is currently being considered as the industry moves to standardise and harmonise matters associated with these hazards. In some instances, strengthening of components and topsides systems has been undertaken.

Sensitivity of topsides structures to fire and explosions has been investigated [23] and the importance of realistic modelling of steel panels is emphasised in experimental work reported in [24]. The strengthening of structures to enable them to withstand large explosions requires a better understanding of ultimate capacity performance and escalation prediction. This has resulted in increased activity on the investigation of high temperature and strain rate effects on materials plasticity and fracture behaviour.

Environmental Criteria

The environmental criteria are key inputs to the design process. The significant and complex environmental loading criteria which are also subject to changing patterns require regular re-evaluation and may be a trigger for reassessment. The risk-based regime requires that conditions beyond the design capacity are assessed to understand and achieve quantification of true failure probabilities. The technology for this is developing and further work is required but certain issues have been identified:

- the inappropriateness of the 1.5m air gap provision and the development of improved understanding of wave in-deck load effects [25]
- the issues of reconsideration and re-evaluation of the design criteria in the light of a longer historical record
- concerns over climate change
- newer technology for dealing with uncertainties and reliabilities.

The evaluation of metocean criteria has received considerable attention but needs to be disseminated more widely. The outcome of this work is to be found in a re-evaluation of waves/winds around the UK [26] and the forthcoming long term North Sea hindcasts via the NEXT project [27].

Offshore Industry Organisational Changes

In recent years, the offshore industry has undergone some major organisational changes, partly affected by the significant variations in the oil price and other cost-reducing factors. These economic issues have led to the need for restructuring which have, in turn, resulted in substantially more partnering and alliancing. Thus, in many cases, this has led to many of the basic engineering and technical skills being contracted out of the duty holder organisation. As a result, the flow of information in the system has undergone significant change [28]. This places strong emphasis on the need for robust and well-defined organisational management of safety to ensure that risks are controlled to an appropriate level throughout the installation life cycle. A further issue is the associated problem of assuring continuity in structural integrity management with respect to knowledge and experience previously held by key personnel and the certifying authorities. Furthermore, as indicated above, the delay in finalising the ISO standard for offshore structures since the withdrawal of the HSE Guidance has exacerbated this problem.

CONCLUSIONS

- The reassessment of structural integrity for offshore installations is an area of increasing relevance as there is a growing need to consider life extension for many installations now approaching or exceeding their original design life. In addition, there is a need to demonstrate life cycle integrity in safety case revisions and to refocus on integrity issues such as in-service inspection. This is part of HSE's forward plan.
- The importance and relevance of reassessment has been recognised by the offshore industry with the introduction of guidance on this area in codes and standards. In particular, the emerging ISO standard has a specific section on reassessment based on the API RP2A procedure introduced in 1997.
- The ISO standard specifies five triggers for reassessment which have been reviewed in this paper and are considered to be comprehensive. However, an additional requirement of the UK regime is the demonstration of continuous improvement via the safety case regime.
- The reassessment process involves several key players providing various inputs to the overall activity. It is important that this complex process is managed rigorously to ensure good practice. This aspect requires further development.
- Key factors relevant to the reassessment process include ageing, technology developments (e.g. in inspection, accidental loads and damage) and acceptance criteria. The reassessment of the ever increasing population of ageing installations is facilitated by significant technology developments which have provided a much better understanding of structural performance. However, ageing offshore installations are complex structures and, despite recent progress, require further study.
- Many installations have been designed to older versions of existing structural codes, e.g. API RP 2A, and may not therefore be always able to demonstrate the same level of safety as more modern structures. This requires that suitable measures are taken during operation, entailing an appropriate inspection regime and recognition of necessary remedial measures.
- It has been shown that organisational changes, combined with the complexity of technology issues, clearly call for reassessment to have emphasis on quality management of the process.
- A major point for deliberation is the quality of the inputs and the appropriate acceptance criteria. For example, where there are large uncertainties in the input data, there must be suitable penalties on safety criteria.
- There is a need for the offshore industry to adopt a common approach reassessment. The ISO framework is a good basis for this.

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