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Recommendations for design life extension regulations

PETROLEUMSTILSYNET
PETROLEUM SAFETY AUTHORITY NORWAY

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Summary
A study has been undertaken for PSA to identify the elements of ageing that could affect the safety of installations, to review existing information for other types of structure in other industries and reviews of the existing offshore regulations, other standards and guidelines and other information. The work has included an industry workshop and a review of recommendations made to UK HSE on life extension for fixed structures, from a separate study. In addition the study included the development of an underlying philosophy for regulating ageing installations and life extension in the Norwegian sector.

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1 Introduction

There are an increasing number of older installations in use on the Norwegian Continental shelf. The regulation of these older installations are a part of the Petroleum Safety Authority's (PSA) responsibility, with the intention of ensuring that older installations can also be regarded as safe. Inspection is a key issue in ensuring the safety of older installations, and the inspection intervals, inspection methods and their reliability are clearly influencing the safety of the installations.

There are two key aspects in a life time extension program. The first focuses on operational and time dependent degradation issues. This is to provide understanding of the impact of ageing related degradation mechanisms and to confirm that the equipment and systems can continue to be operated within their original safety margins.

The second aspect of the life extension programs focus on the regulatory process. This involves a process to effectively and systematically evaluate the information on the operational and time de-pendent degradation issues and to determine if continued safe operation is warranted.

In the work with design life extension regulations PSA has initiated a project to gather experience and lessons learned from other industries and countries related to the development and application of regulatory requirements and guidelines for the safe operation of systems and facilities beyond their original design life. Possible focus areas in this context can be the nuclear power industry, commercial aviation sector. PSA feel that the following questions are relevant:

- What are the main hazards associated with life extension?
- What experiences, and methods used in offshore life time extension, can be conveyed to the Norwegian petroleum industry?
- How do different industries deal with aging?
- How are the issues related to ageing documented?

2 Background –existing regulations

Many offshore installations in the North Sea are now reaching or have exceeded their original anticipated design life of typically around 25 years, (see Figure 1) but have a continued requirement to produce oil or gas, either from the original fields or to serve as a base for neighbouring subsea completions. Hence life extension is a necessary phase in the life cycle of many offshore installations in the both the UK & Norwegian Sectors of the North Sea.

Ageing processes such as fatigue, corrosion, scour and accumulated damage can affect the structural integrity of an installation, with the risk of failure increasing with time unless properly managed. Demonstration of safe performance beyond the original design life through assessment of the structural safety critical components is thus necessary.

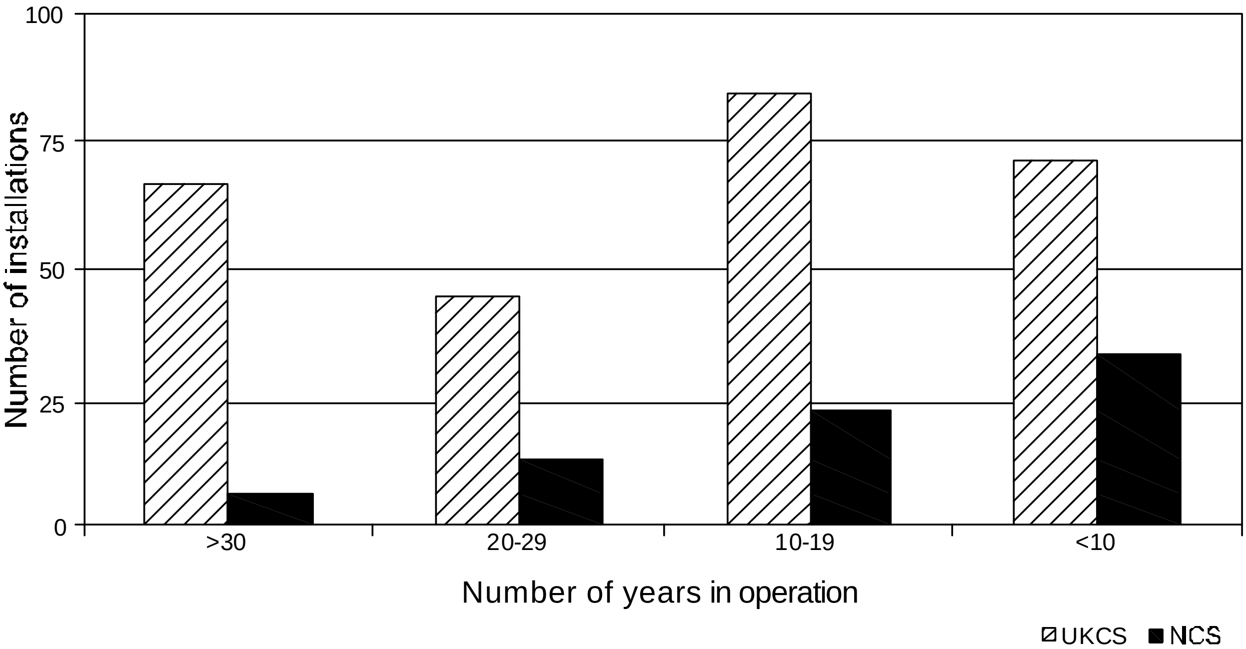

Figure 1 - Age of offshore installations in the UK and Norwegian sectors of the North Sea (courtesy G. Ersdal)[1]

Formal approval to extend life it is already a requirement under the Norwegian Petroleum Directorate Regulations. ISO 19900 (general requirements for offshore structures) [2] lists exceedance of the original design life as an initiator for platform assessment, and the forthcoming ISO 19902 (fixed steel offshore structures) [3] follows ISO 19900 in this respect.

Since the time of the original design, improved data and knowledge have resulted in many changes in offshore engineering, codes of practice and environmental criteria. Many offshore structures have been reanalysed against these new criteria and appropriate action taken to ensure fitness for purpose taking into account the new guidance. However the process of assessment is relatively new, which began as section 17 in API RP 2A in 1997 [4]. This section has subsequently been extended and updated in the ISO FDIS 19902 [3], which is expected to become the international standard for assessment of existing structures.

Specific concern has been expressed about ageing semi-submersibles. In 2003, both the UK and Norwegian regulators issued a safety notice on the need for reassessment of ageing semi-submersibles [6]. DnV has also published an additional section to their code for floating structures (OSS-101) [5] with special provisions for ageing units, which introduced the fatigue utilisation index, the ratio between the effective operational time and the documented fatigue life, as an indicator for further action.

The significance of the prior history of environmental loading on structures and the effect of gross errors has been examined by Ersdal, Sørensen and Langen [7].

3 Report on industry workshop

3.1 General

This is a summary report of the Workshop on ageing installations and life extension, held at PSA Offices, Stavanger on Sept. 28th 2006

The Attendees were from the following organisations:

- Talisman Energy Norge AS
- Statoil
- Aker Kværner Offshore Partner
- Sjøfartsdirektoratet, Oslo (Norwegian Maritime Directorate)
- BP
- Total E&P Norge
- ConocoPhillips
- Luftfartstilsynet (Civil Aviation Authority Norway)
- Shell
- Poseidon
- Petroleumstilsynet

3.2 Introduction:

The introduction to the workshop was given by G. Ersdal (PSA). In this he noted:

- NPD recommended NORSOK AGn to start developing guidelines for life extension in 2000.
- NPD proposed that work-groups be established in ISO TC67 in 2002.
- There had been an initiative on ageing rigs from HSE and NPD
- PSA had requested a summary from operators on installations and their status with respect to design life and the need for life extension.
- PSA had requested an initiative from OLF towards developing procedures for life extensions.
- A figure showing the number of installations in both the Norwegian and UK sectors was also shown (see section 3)

He also explained that PSA had four current projects associated with life extension which were:

- Chockie Group – Review of experience from nuclear industry with respect to life extension
- J.D. Sørensen – Inspection of ageing structures
- DnV – Review of ageing of materials
- Poseidon - Developing Recommendations for Design Life Extension Regulations

As background he gave examples of experiences with respect to life extension from Conoco-Phillips(Norway), Civil Aviation Authority (Norway) and NMD (see annex 3 for details).

He explained that the plan for later in the workshop would be to organise the attendees into 5 breakout groups for detailed discussion on selected topics which are listed below. A report from each group would then be made at the end of the workshop.

Title of the proposed breakout groups

1. How should life extension procedure look like and what standards could be used

2. Main outstanding issues regarding life extension, including:

    - Ageing of materials
    - Damage accumulation from dropped objects, ship collisions etc. Is this recognized and how is it dealt with?
    - Gross errors due to human and organizational failures … loss of structural safety. How are these addressed in reassessment?

3. Quality of DFI and the inclusion of repair work and modifications. Impact on safety factors.

4. Cost of life extension – how to decide what is safe enough

5. Maintenance philosophy – why, how to define intervals, techniques to meet life extension requirements, cost of inspection for ageing systems. What about uninspectable items.

3.3 Presentation on Ageing and Life Extension:

Professor Sharp (Poseidon) gave a presentation on ageing and life extension, with particular attention to structural integrity, based on a study which had been sponsored by the UK Health & Safety Executive, for which he had been one of the authors [8]. He explained that the approach had been biased toward the UK legislation (e.g. safety cases). The main points are outlined below, a more detailed account of the presentation is given in section 11.1.1.

The aims of the study were to:

- Review current industry practice for the operation of offshore installations beyond their original design life; and treatment of life extension in other related industry sectors.
- Identify (a) deficiencies in current approaches, and (b) needs for the development of a risk-based best practice for safe operation offshore.
- Develop a framework for the management of life extension.
- Propose minimum requirements, including Performance Standards for safety critical elements, to inform regulatory review of installations operating beyond their original design life.

The study addressed life extension of jackets, jack-ups and semi-submersible structures used for drilling and/or production operations but excluding FPSOs. The focus was on the primary substructure. He explained that the main activities were to:

- Review approaches in codes and standards;
- Review current industry practice in the North Sea;
- Consider treatment of life extension in a selection of UK sector safety cases;

- Review the treatment of life extension in different regulatory regimes (Norwegian sector, Gulf of Mexico) and in other industries, review relevant literature, including workshop reports on life extension, requalification;
- Contact key personnel in selected oil companies for inputs on life extension;
- Identify gaps in current technology and associated research.

A framework for life extension, proposed requirements and recommended good practice had been developed as part of the study. This addressed data collection, assessment for fatigue, corrosion, scour & subsidence, environmental overload, inspection & maintenance planning. ISO 19902 [3] has been identified as representing good practice for the assessment of fixed installations in the life extension phase, with several amendments and additions which were outlined. Overall the main conclusions were:

- Life extension is an ongoing requirement;
- Procedures to manage life extension are required, via a long term safety review;
- For fixed structures ISO 19902 is a good basis, with additions and amendments.

3.4 Presentations by Civil Aviation Authority, NMD

Brief presentations were given by Knut Magnar Bjorsvik and Evelyn Vestbo (both Civil Aviation Authority, Norway) and a representative of NMD.

- Civil Aviation: Knut Magnar Bjorsvik asked the question as to whether aircraft were old or not well maintained. He described an incident in the 1980's where there had been a corrosion problem in an aircraft less than 20 years old, which had resulted in the top part of the cabin being blown off, resulting in one fatality. Aircraft are inspected on a regular basis, with more substation inspections at several stages in their life, usually based on number of hours flown. There is a common approach across Europe, with a maintenance steering group for each aircraft type. Evelyn Vestbo explained the procedure for helicopters and helidecks. Survey programmes were part of the maintenance of helicopters. Preventive maintenance programmes were in place for helidecks. A plan is being developed for management of the lifetime of helidecks.
- NMD explained that there were no NMD regulations for life extension in drilling rigs and FPSOs, but they had been involved in a joint approach with PSA on drilling rigs. Fatigue was a potential problem which was still under review. The IMO code did not include any requirements associated with life extension or ageing. One key point was the dry dock inspection every 5 years. Structural issues were discussed with the Classification Societies.

3.5 Norwegian Operators Experience (G. Ersdal)

Gerhard Ersdal outlined several examples where Norwegian operators were taking action with regard to life extension. These included Statoil, BP, Conoco/Phillips. Susana Hoshovde (Conoco-Phillips) explained the procedure they had taken with respect to life extension of the Bravo platform in the Ekofisk field, installed in 1972. Life extension studies had been undertaken on the Bravo platform, based on a facilities gap analysis and taking account of requirements in Norwegian regulations. This approach provided a list of requirements for satisfying the regulations, which provided an excellent framework. The first obligation operators have is to document their own processes. Gerhard Ersdal said that the learnings from this work would be valuable for other operators.

3.6 Breakout sessions

In practice four breakout sessions were held with the topics for sessions 1 and 3 being combined. Reports of these four breakout sessions are contained in section 11.1.

3.7 Summary

Gerhard Ersdal summarised the workshop and outlined the next steps which were:

- Reporting from this meeting (draft to be circulated for comment);
- OLF work;
- PSA report on ageing and life extension (available Dec. 2006);
- Current projects (Chockie, Poseidon, J.D. Sørensen);
- Possible JIP projects;
- Need for a second workshop?

Gerhard Ersdal also showed a slide based on the "bath-tub" curve suggesting drivers for inspection at different stages, including the life extension phase (see Figure 2 below).

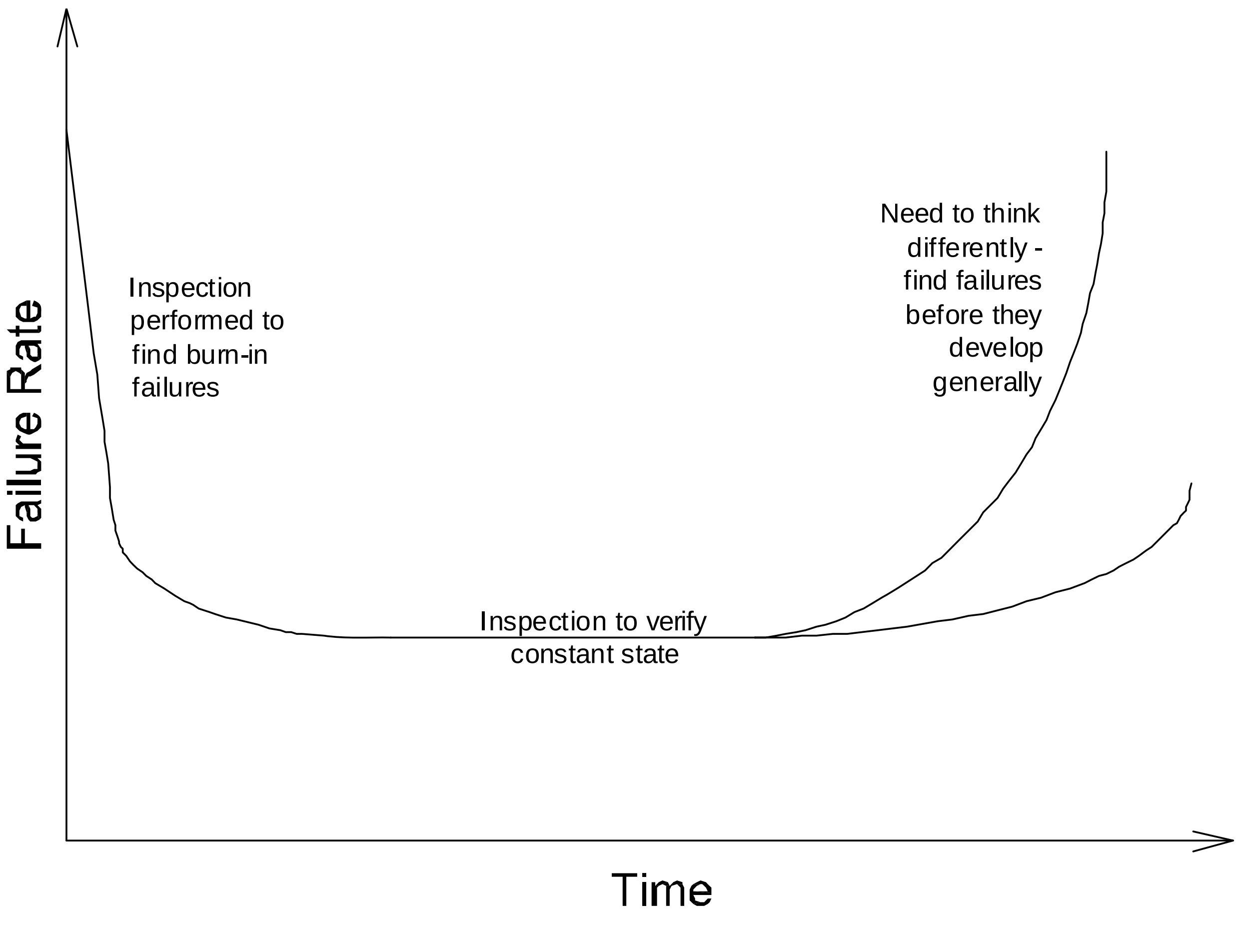

Figure 2 - Bath-tub curve showing drivers for inspection at different stages

Gerhard Ersdal queried whether the group needed to meet again as he felt that the workshop had been a success. This could be decided once the summary notes of this meeting had been circulated.

4 Identification of elements of aging that affect the safety of installations

4.1 Fatigue

Fatigue cracking of welded structural components is a recognised time dependent hazard, although several offshore structures have already suffered from cracking due to poor design, resulting in expensive repairs. It is recognised that the North Sea wave climate is one of the more damaging offshore regimes for fatigue cracking.

It is expected therefore that fatigue cracking could be a significant threat to the life extension of offshore installations beyond their original design life. Single cracks are unlikely to threaten the integrity of an offshore fixed structure due to its inherent redundancy, provided that they are repaired, but accumulating widespread fatigue cracking, as can occur in ageing aircraft, could have more serious implications.

Fatigue cracking starts by small cracks usually initiating at the toe of the weld, growing to through thickness, (detectable by flooded member detection), developing to visible cracking (detectable by either close or gross visual inspection) and finally to member severance and loss of load carrying capacity. This could result in neighbouring members or joints carrying additional loadings from waves, which may develop or enhance further cracking.

Fatigue is normally a design criterion, often based on a “fatigue limit state” and a design life. Factors of safety are recommended by codes and standards varying from 2 for a conventional welded joint inspectable in service to 10 for a critical non-inspectable joint (e.g. piles and brace to chord welds in the splash zone (see Figure 3). However very few early designs incorporated the larger factors and hence do not meet current code requirements in this respect.

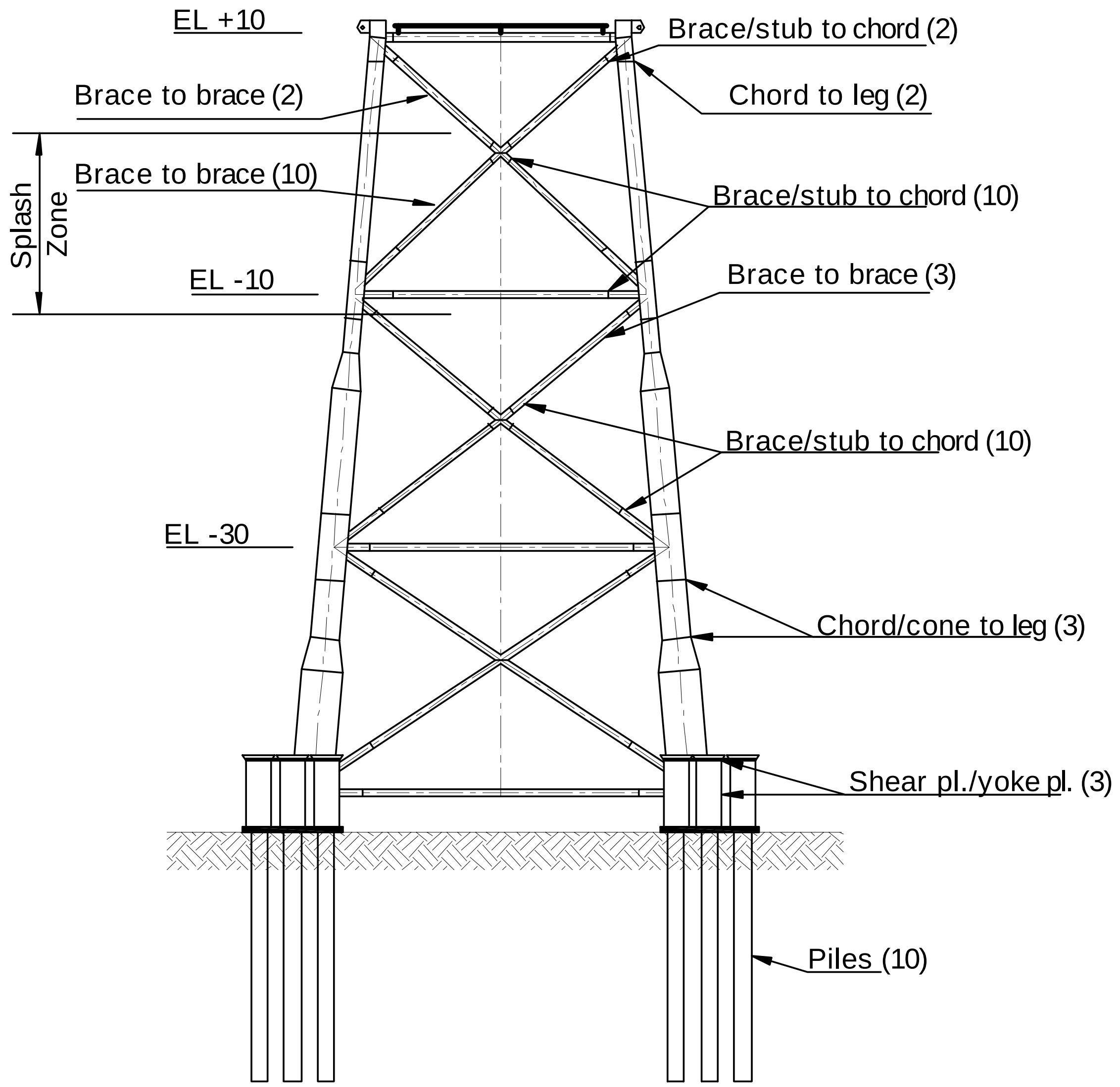

Figure 3 - Fatigue design factors for structural components on a fixed platform (from NORSOK N-004, Annex K [9])

Identification of fatigue cracking in service is managed by periodic inspections of critical welded connections. This was originally by using techniques such as magnetic particle inspections or eddy current methods which could detect cracks at an early stage, but current practice is to use flooded member detections which relies on the cracks having grown to the through thickness stage, with minimal life remaining. This is usually backed-up by gross visual inspection from an ROV which can detect major cracking or member severance.

There is a considerable uncertainty in designed fatigue life due to the lack of precision in the input parameters, particularly loading and stress concentration factors, and cracking can occur at lives much shorter or longer than the predicted design life. The treatment of life extension regarding fatigue is addressed in the DnV recommended practice for semi-submersibles [5] and is based on a combination of the original design life and evidence for cracking in service.

The elements of a fixed offshore installation for which fatigue cracking could be an issue in life extension are listed in Table 1. The table also shows the crack management measures and the consequences of failure.

Table 1- Structural elements susceptible to fatigue cracking

Element	Risk management measures	Consequences of failure	Issues for life extension
Sub-structure – welded joints	Planned fatigue life at the design stage, periodic inspections	Joint failure, possibility of widespread fatigue cracking which could lead to loss of structural integrity	Range of design fatigue lives, extent of cracking in joints, possible need for repair
Welded piles	Planned fatigue life during design, minimise fatigue damage during pile driving, difficult to inspect in service	Pile failure could lead to platform tilt, damage to pipework and risks to personnel	Design fatigue lives, fatigue damage due to pile driving, possible need for some degree of inspection
Structural supports for risers underwater	Design fatigue life, periodic inspection	Riser vibration, fatigue and local failure, possibly leading to gas/oil release	Results from recent inspections
Topside structural supports	Design fatigue life, periodic inspection	Failure of support systems for plant, cranes, flare tower accommodation.	Results from recent inspections

4.2 Corrosion

Steel immersed in seawater can suffer enhanced corrosion unless protected either by coatings or by cathodic protection. For the steel sub-structure most platforms are protected by sacrificial anodes. The design of these includes an assessment of the life required and the additional weight and cost of adding anodes to an installation. Sacrificial anodes are consumed during life and their inspection is part of normal periodic platform inspections. Hence consideration needs to be given to their effectiveness in life extension situations.

Piles are also vulnerable to corrosion, both in the soil and particularly at the seabed interface. Unfortunately piles are difficult to inspect in service.

Corrosion in the splash zone, with higher corrosion rates, is particularly difficult to manage in practice, as cathodic protection is less effective in this zone and regular inspections are difficult in practice due to access problems. Members in the splash zone are usually coated using epoxy or similar paints to limit corrosion but such coatings can be damaged in service and result in enhanced local corrosion. A "corrosion allowance" in steel thickness is usually made at the design stage, based on expected life and predicted corrosion rates. Consideration of life extension should include an assessment of the state of any coatings and the remaining corrosion allowance in wall thickness.

Corrosion is also a major hazard for topside steelwork, usually protected by paint and coatings. Maintenance of such coatings is an essential part of planned topside maintenance. The state of these coatings is also an issue for life extensions, since loss of steel wall thickness could lead to possible structural collapse.

Table 2 shows the elements at risk from corrosion, the management measures and consequences of failure.

Table 2 - Structural elements vulnerable to corrosion

Element	**Risk management measures**	**Consequences of failure**	**Issues for life extension**
Steel Sub-structure	Design of cathodic protection system. Regular inspection, measurement of CP levels, replacement of anodes (if required)	Member or joint failure from reduced wall thickness	State of CP system and anodes, CP levels. Replacement of anodes if required
Welded piles	CP system, partially effective, difficult to inspect	Pile failure causing topside tilt or collapse, with risks to personnel	Difficult because of problems of in-service inspection
Steel structure in splash zone	Design thickness allowance, coatings, regular inspections	Member or joint failure from reduced wall thickness	Results from recent inspections, state of coatings, measurements of wall thickness if required (to assess loss of design allowance),
Structural supports for risers underwater	Design of cathodic protection system. Regular inspection. Coatings in some cases	Riser vibration, fatigue and local failure, possibly leading to gas/oil release	Results from recent inspections
Topside structural supports	Paintings, coatings, inspection, maintenance of coatings as required	Loss of wall thickness, member strength, possible local collapse	Results from recent inspections

4.3 Geological and Geotechnical Hazards

These hazards can be divided into two groups, as follows:

- Installation foundation hazards:
  - Pile pull-out in tension;
  - Pile punch-through in compression;
  - Degradation of pile capacity due to cyclic loading.
- Geological hazards:
  - Differential settlement;
  - Seabed scour;
  - Subsidence and slope instability.

Foundation design includes the effects of both extreme environmental loads as well as consideration of cyclic loadings. However there are considerable uncertainties in determination of soil parameters and in calculating the capacity of piled foundations. There is also little redundancy in piled foundations for jacket structures, with up to 6 piles driven through the legs. Foundation failure can have serious consequences but few have been observed in practice.

The primary means of managing geological hazards are through the design and installation stage. This includes collecting site specific soil data and assessment of seabed conditions. In-service inspection for seabed scour, settlement and subsidence are also important measures for managing these hazards. Maintaining the air-gap is a major consideration because of the possibility of "wave-in-deck" at times of occurrence of extreme waves, with large increases in structural loading. Table 3 shows the main structural elements vulnerable to either geotechnical or geological hazards.

Table 3 - Structural elements vulnerable to geotechnical or geological hazards

Element	Risk management measures	Possible consequences	Issues relating to life extension
Steel sub-structure	Design of piling system, acquisition of soil data, knowledge of the seabed, optimise pile driving. Monitoring of seabed scour, settlement etc.	Loss of foundation capacity, loss of air gap, damage from extreme storms, topside tilt, platform collapse	Original design criteria, knowledge of soil data and seabed, pile driving records.
Recent inspection results for scour, air gap, platform tilt, settlement etc			
Topside structural supports	Design for extreme environmental event, regular inspection to locate damage and repair if required	Failure of support systems for plant, cranes, flare tower accommodation.	Results from recent inspections, platform tilt analyses

4.4 Accidental Damage

Structural damage in service can arise from accidental events such as ship collision or dropped objects. Fixed installations have a design requirement to resist ship impact (typically 2500 tonnes at 2.5 m/sec). In practice it is normal to identify such occurrences and introduce appropriate inspection measures to identify any damage following the event. Repair may be required depending on the level and location of the damage.

However the accumulation of damage over time, either minor in form and judged not to need repair or missed at the time of the event can lead to a reduction in structural load carrying capacity. This damage in the form of dents, cracks and bows can have a significant effect on member capacity and on the static capacity of tubular joints. Of particular concern are bows to members which are difficult to locate via periodic inspections and can result in significant reduction in bucking capacity [10]. The study indicated that bow damage, detectable from a routine inspection (rather than from a special inspection at the time of the event) could reduce member strength by as much as 68%.

This type of damage does need consideration in life extension considerations and may require specific inspections to locate areas of accumulated damage. Table 4 identifies those structural elements vulnerable to accumulated damage, the risk management measures and possible consequences.

Table 4 - Structural elements vulnerable to accumulated damage from accidental events

Element	Risk management measures	Possible consequences	Issues relating to life extension
Members in steel sub-structure	In-service inspection at the time of the accidental event, repairs as required	Members failure due to buckling,	Assessment of accidental events and repairs from platform records. Special inspections for accidental damage if required (e.g. bows)
Joints in steel sub-structure	In-service inspection at the time of the accidental event, repairs as required	Joint failure due to static collapse, initiation of fatigue cracking	Results from recent inspections.
Structural supports for risers underwater	In-service inspection at the time of the accidental event, repairs as required	Local riser failure, possibly leading to gas/oil release	Results from recent inspections.
Topside structural supports (from dropped objects)	In-service inspection at the time of the accidental event, repairs as required	Failure of support systems for plant, cranes, flare tower accommodation.	Results from recent inspections

4.5 Extreme Weather

The environmental loading on an installation due to extreme environmental events is a very important design factor and considered under the ultimate limit state design criterion. This is a result of a combination of wave, wind and current loadings on the structure, which can occur at given return periods, often 100 years. Checking for survivability under a 1 000 year or 10 000 year return period is also a requirement in certain offshore regimes.

The main means of managing the extreme weather hazard is to design to an appropriate loading criterion, by providing an adequate air gap and by managing marine growth. Reduction in the air gap can occur through subsidence (see geological and geotechnical hazards). Ageing processes can result in structural damage to an installation which can reduce its capacity to resist extreme environmental events. This damage may arise from fatigue cracking, corrosion, accumulated accidental damage which are addressed as separate hazards.

Table 5 shows the structural elements vulnerable to extreme environmental events, risk management measures and possible consequences.

Table 5 - Structural elements vulnerable to extreme environmental events

Element	Risk Management measures	Possible consequences	Issues relating to life extension
Members in steel sub-structure	Design for extreme environmental event, check on air gap, regular inspection to locate damage and repair if required	Members failure due to overloading (e.g. buckling),	Original design criteria, updated assessment using modern codes & standards, monitoring air gap, inspection for damage with the potential to reduce structural performance
Joints in steel sub-structure	Design for extreme environmental event, check on air gap, regular inspection to locate damage and repair if required	Joint failure doe to overloading	Original design criteria, updated assessment using modern codes & standards, monitoring air gap, inspection for damage with the potential to reduce structural performance
Structural supports for risers underwater	Design for extreme environmental event, check on air gap, regular inspection to locate damage and repair if required	Local failure, possibly leading to gas/oil release	Recent inspection data
Topside structural supports	Design for extreme environmental event, regular inspection to locate damage and repair if required	Failure of support systems for plant, cranes, flare tower accommodation from overloading	Original design criteria, Recent inspection data

4.6 Modifications and Change of Use

During operational life many modifications are made to an offshore installation, to allow for example additional topside facilities to be added. Weight management is a tool that monitors these changes and records of topside weight and any changes in this are normally part of the recorded platform data. The topside weight is a factor to be taken into account in life extension, both from the point of view of additional structural loadings and effect on other hazards such as fatigue and corrosion.

4.7 Marine Growth

Fouling of structures in the sea from marine growth occurs and such growth can increase the wave loading on a structure and usually requires to be limited in thickness during periodic inspections, if beyond design limits. Devices fitted to platform legs can minimise marine growth as a result of wave action. This hazard is relatively easy to manage in terms of life extension.

4.8 Gross Errors due to Human and Organisational Factors

Gross errors can occur at the design stage resulting in underdesigned structural elements, at the installation stage resulting in damaged elements, or at the operation stage resulting in poor quality inspections and missed damage. Control of gross errors is difficult but is usually undertaken by careful specification of materials and workmanship requirements, using experienced and competent personnel and by using an effective quality management system during the various stages of platform design, fabrication, installation and operation. However gross errors can accumulate during the life of an installation which could cause problems with structural integrity.

Management of gross errors is recognised as a particular difficult task, both from the point of view of individuals and organisations. Proper management of these is important for life extension.

5 Applicability of UK HSE study on life extension to Norwegian fixed structures

5.1 Background:

A study has been undertaken for the UK Health & Safety Executive on the structural integrity of UK Offshore Installations for Life extension [8]. The objectives of this study were to:

- Review current industry practice for the operation of offshore installations beyond their original design life; and treatment of life extension in other related industry sectors;
- Identify (a) deficiencies in current approaches, and (b) needs for the development of risk-based best practice for safe operation offshore;
- Develop a framework for the management of life extension;
- Propose minimum requirements, including Performance Standards for safety critical elements, to inform regulatory review of installations operating beyond their original design life.

The activities undertaken included:

- Review of approaches in codes and standards;
- Review of current industry practice in the North Sea;
- Treatment of life extension in a selection of UK sector safety cases;
- Review of treatment of life extension in different regulatory regimes (Norwegian sector, Gulf of Mexico) and in other industries Review relevant literature, including workshop reports on life extension, requalification;
- To contact key personnel in selected oil companies for inputs on life extension;
- Identification of gaps in current technology and associated research.

In addition a framework for life extension, proposed requirements and recommended good practice was developed as part of the study. This addressed data collection, assessment of the major hazards affecting life extension as well as inspection & maintenance planning. This part of the report is to review this framework in the context of Norwegian offshore structures.

5.2 Proposed UK requirements for Life Extension

The primary recommendation is for a Long Term Safety Review (LTSR) of the structural safety critical elements at the stage where life extension is being envisaged. It was considered that this would form part of a future safety case submission.

The stages in the LTSR included:

- Defining the end of the anticipated operating life (based on the notional design life or 20 years as a minimum).
- Defining the target extended anticipated operating life (EAOL) (based on field life and other factors)
- Undertake a LTSR to confirm continued integrity of the structural safety critical elements (SCEs) to the end of the EAOL, taking account of relevant hazards and threats to structural integrity. The LTSR should also establish the current configuration, materials properties and physical condition of the structure, through assessment of past records and recent testing and inspection data. A further requirement for the LTSR is to carry out a full structural assessment of the structural SCEs, based on best available data and checking against modern codes and standards. A redundancy analysis is also recommended to demonstrate that in the event of reasonably foreseeable damage to the installation sufficient structural integrity would remain to enable action to be taken to safeguard the health and safety of personnel on board.
- Identify any shortfall in the long term integrity of the structural SCEs.
- Implement any improvements required to maintain the integrity of the installation over the EAOL.
- If improvements are unable to extend the operating life then a revision to the anticipated operating life is required.

5.3 Recommended Assessment Procedure:

Recommendations were also made on the assessment of long term integrity for the identified hazards, based mainly on ISO 19902 [3] which are reviewed below.

5.3.1 Assessment for Fatigue

It is recommended that assessment for fatigue in life extension should be carried out in accordance with ISO 19902, clause 24 combined with Clause 16 subject to some exceptions and amendments. In addition fatigue design factors with values ranging from 2 to 10, according to failure criticality and inspectability should be taken into account (see Annex A to ISO 19902, A16.1.2).

Acceptance criteria are recommended to be based on calculated fatigue lives (including the above design factors) are at least equal to the total service life of the installation to the end of EAOL and that the latest inspections demonstrate no evidence of cracks or the detected cracks have been repaired.

When this criterion cannot be satisfied but inspection of the joint reveals no defects a conservative fracture mechanics analysis using BS 7910 [11] considering a postulated defect size demonstrated adequate remaining life to EAOL. If defects are found then the same procedure is to be adopted using a conservative fracture mechanics analysis based on the size of the defect found.

Where the calculated fatigue life (including the above design factors) is less than the EAOL it is recommended that an enhanced inspection regime should be implemented to assure continued integrity of the SCE to the end of the EAOL.

5.3.2 Assessment for corrosion

Assessment for corrosion should address the integrity of the corrosion protection system (e.g. coatings, CP system) and the effect of any corrosion loss on the load carrying capacity of corroded members. This integrity can be checked through visual inspection of coatings and anodes and monitoring of cathodic potentials. In situations where the corrosion allowance is a critical factor actual corrosion loss should be measured using an appropriate technique. If the allowance has been consumed by corrosion then structural analyses should be undertaken to assess the capacity of the corroded member.

It is recommended that the corrosion loss on critical structural members should be considered in assessing capacity of these members in resisting extreme environmental loadings.

5.3.3 Assessment for Scour & Subsidence

Assessment for foundation capacity should be carried out by using ISO 19902 [3] clause 24, taking account of any scour or settlement as found from surveys. If any significant scouring has been found the likely extent of this to the end of EAOL should be estimated and accounted for in the foundation capacity. A similar approach is recommended for settlement and tilt.

5.3.4 Assessment for Environmental Overload

It is recommended that this is carried out in accordance with ISO 19902 clause 24, with some exceptions and amendments. A minimum level of inspection of Level III is recommended in place of level II (as currently in ISO 19902, clause 23).

Additional requirements are recommended to be a redundancy analysis to demonstrate that in the event of reasonably foreseeable damage to the installation sufficient structural integrity is retained to enable appropriate action to be taken to safeguard the safety of personnel on the installation. Damage should include bowing and denting of members, as well as member severance as a result of vessel impact and progressive fatigue cracking.

5.3.5 Assessment for Inspection & Maintenance Planning

The generic framework in clause 23 of ISO 19902 [3] is recommended as representing good practice, with some exceptions and amendments. It is noted that the default inspection programme in clause 23 should not be used, as it does not meet the UK DCR regulation 8 requirement for a SIM plan [12]. Some additional requirements are made concerning the use of flooded member detection (FMD). In particular it is recommended that the interval between FMD inspections is sufficient to ensure that failure of any one member does not lead to progressive fatigue failure before the next inspection.

For fatigue sensitive joints consideration of a fatigue utilisation factor (FUI) is recommended, defined as the ratio of “total anticipated operating life of the installation” to the “calculated fatigue life” including appropriate design factors as identified in section 3 above. Inspection requirements for welds should be based on the value of the FUI.

For welds for which FUI ≤ 1 inspection requirements should be in line with those given in ISO 19902 [3], section 23. Welds for which the FUI ≥1 the approach given above should be followed until the FUI=1. Beyond this time the inspection regime and intervals should be reviewed and possibly enhanced.

For inspection for corrosion the recommendation is to include visual inspection of coatings, anodes and monitoring levels of CP, as per ISO 19902. In addition is recommended that steel thickness is monitored in situations where corrosion allowance has been provided for and there is no other means of protection. For structural members which are not protected or where corrosion protection has become ineffective a periodic programme of corrosion loss monitoring should be implemented. For inspection of piles where corrosion is suspected as a problem it is suggested that instrumented PIGS may be required through the inside of the jacket legs to monitor integrity.

It is recommended that the inspection regime for foundations should include scour and seabed instability and that any activity should be assessed against design criteria and action taken if required to mitigate the effects. Settlement and tilt of the platform should also be monitored using specialist equipment where there is a risk of subsidence.

5.4 Relevance to Norwegian Installations

Many of the background sections of the HSE study are clearly relevant to the life extension of Norwegian installations. In addition the review of the treatment of life extension in different industry sectors is of value as the ways in which extension of life is treated in other industry sectors is relevant to both Norway and the UK.

However some aspects of the HSE study are clearly less relevant to the Norwegian situation, These include the role of life extension in HSE Regulations, including safety cases.

In particular it is suggested that the form of the Long Term Safety Review (LTSR) is appropriate for Norwegian installations, (without the UK specific link to the installation's safety case). The recommended assessment procedure for the hazards associated with ageing is also considered to be very relevant, as it is based mainly on ISO 19902, and this standard is an international one and expected to become the accepted procedure for assessment once issued (scheduled for August / September 2007.

6 Development of an underlying philosophy for regulating ageing installations and life extension

There are a number of Norwegian Regulations relating to aspects of ageing and life extension. It is proposed to use a risk based approach to assess the underlying philosophy for regulating life extension and ageing. This assesses the steps from risk identification through management of risk (including acceptance criteria) to mitigation – see Figure 3 and Table 6 below. Against each of these steps the relevant items of Norwegian Regulations are mapped.

The joint NPD/PSA regulations relating to offshore installations are:

- Regulations relating to Material and Information in the Petroleum Activities (The Information Duty Regulations) [13]
- Regulations relating to Design and Outfitting of Facilities etc in the Petroleum Activities (The Facilities Regulations) [14]
- Regulations relating to Management in the Petroleum Activities (The Management Regulations) [15]
- Regulations relating to conduct of Activities in the Petroleum Activities (The Activities Regulations) [17]
- The pressure equipment regulations (Norwegian only)
- The machinery regulations (Norwegian only)

Many of the provisions of the regulations relate mainly or wholly to the design or early life of new installations.

The need for consent for life extension is included in the Information Duty regulations (sections 5,6) [13] and overall safety requirements are listed in the Facilities Regulations (sections 6,7) [14].

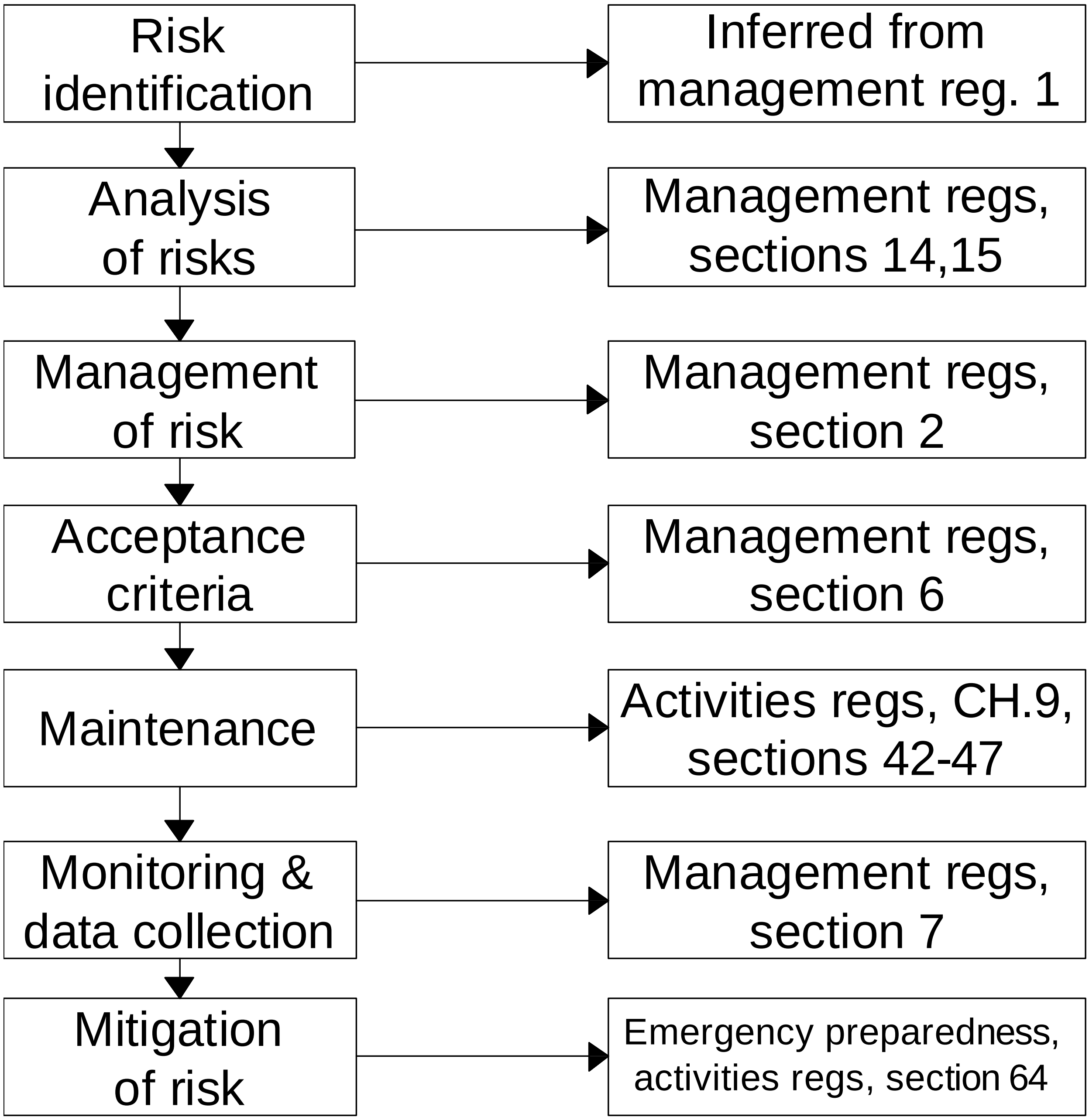

Figure 4 - relevant parts of the Norwegian offshore Regulations mapped against risk management steps

The linkage the Regulations to the risk management steps are shown in Table 6, with details of the specific parts of the regulations in 11.2.

Table 6 - Norwegian Offshore Regulations linked to risk management steps

Topic	Regulation.	Section
Risk identification	Management regulations [15]	Section 1
Risk analysis & reduction	Management regulations [15]	Section 9 - Risk reduction
Analysis of major accident risks	Management regulations [15]	Section14 - Analysis of major accident risk
		Section 15 - Quantitative risk analyses and emergency preparedness analyses
Management of risks	Management regulations [15]	Section 2 - Barriers
Acceptance criteria	Management regulations [15]	Section 6 - Acceptance criteria for major accident risk and environmental risk
	Guidelines to Information Duty regulations [17]	
Maintenance	Activities regulations[17]	Ch. 9, Sections 42-47
Monitoring	Management regulations [15]	Section 7 - Monitoring parameters and indicators
Measuring & Data collection	Management regulations [15]	Section 18 - Collection, processing and use of data
Emergency preparedness	Activities regulations [17]	Section 64 - Establishing emergency preparedness

The mapping of regulations against the risk management steps is variable, with some steps being well covered whilst others (particularly risk identification), having a low profile. This gap is considered to be important as new risks are associated with ageing and life extension. Management of risk is primarily associated with 'barriers'. It is noted in the Guidelines that barriers may be physical or non-physical or a combination of both. It is also stated that the barrier function should operate for the lifetime of the facility. In connection with ageing and life extension new or modified barriers can be needed to manage the new risks arising. Overall it is considered that the regulations are too 'design' oriented, not fully recognising that issues associated with operations and particularly life extension are now important.

7 Discussion of decision making for life extension based on uncertain data

7.1 Introduction & Background:

Assessment of existing offshore structures is needed to demonstrate that they are fit for purpose, particularly when life extension is being considered. The assessment procedure has only recently been developed, initially as part of API RP2A [4] and latterly as part of ISO 19902 [3]. In Section 24 of ISO 19902 "Assessment of Existing Structures" there are a number of stages involving different levels of complexity. The main steps in the assessment process for life extension, following the ISO standard, are:

1. Collection of data to establish platform condition (see 2. below).

2. Review of loadings on the structure, including establishing relevant metocean data. The deck elevation should be determined and allowing for subsequent subsidence over the period of life extension. The deck height needs to be checked for potential inundation, as this can have a major effect on overall structural reliability.

3. Assessment of platform resistance: The simplest level in this part is a design level check, following the same requirements as for a new design (but using up-to-date codes and standards e.g. ISO 19902). The structure needs to be assessed based on its current condition or future condition (allowing for the period of life extension). This includes allowing for the actual stiffness of damaged or corroded members and joints. A procedure for undertaking this is given in NORSOK N-004 [9].

4. Acceptance criteria: If the design level check shows that all components have utilisations less than or equal to unity it is considered that the structure is fit-for-purpose. If this is not the case then ISO 19902 recommends using refined actions and resistances to undertake a design level check. Such 'refined' data depends on having sufficient information to justify this approach.

7.2 Consideration of Uncertainties

Uncertainties exist due to the natural variation, the physical uncertainty or the randomness in the basic variables (aleatoric or Type I uncertainties), and those due to the factors that are a function of lack of complete understanding or knowledge (epistemic or Type II uncertainties). It can be seen that the uncertainties in life extension include both Type I and Type II uncertainties.

As an installation ages it may be that there is improved knowledge of the environment (reducing Type II uncertainties) and there may also be improved knowledge of the loading from the environment (also reducing Type II uncertainties) particularly if some form of correlation between, for example, wave height and stresses in primary elements is available.

Experience can provide more confidence in data, as extreme events are useful in demonstrating resistance to such events (assuming no significant damage had occurred).

Uncertainties in platform resistance can be due to limited knowledge of the condition of the structure. The ability to analyse damaged members has improved but there is often insufficient data to support the analyses. In general the two main uncertainties in the condition of the structure relate to fatigue and corrosion, the two main ageing processes.

Clause 24.3 in ISO 19902 [3] outlines the structural data required for assessment, which is:

1. Original design analyses

2. Specifications and fabrication records including material certificates and inspection

3. Records of transportation, installation (including piling) and in-service inspections

4. Engineering evaluations

5. Modifications and repairs

6. Incidents

Items a), b) and most of c) form part of the DFI résumé for Norwegian installations. The requirement to maintain and update the DFI résumé is established in NORSOK N-005 [19]. In this it is stated that the information included in the résumé should be the design basis, condition monitoring concept, areas of vital importance to the structural integrity and functional performance, deviations and the other as-built data significant to developing a condition monitoring programme.

7.3 Importance of Performance Data

Where the quality of available structural data is limited, it has been proposed that a conservative approach to assessment would be required [20]. This provides a strong motive to maintain an efficient structural integrity management system and database. The margin of conservatism 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 maintaining overall integrity, particularly if codes and standards have become more onerous since the platform was built. This is illustrated in Table 7 (based on Reference 17).

Table 7 - Input data requirements linked to safety margins

Quality of structural data	Original design, fabrication and installation records	Engineering evaluations	Modifications & repairs	Incidents	Effect on safety margins
High	Well documented, good set of data available	Current environmental data established, wave history fully documented, including incidences of deck loading, joint and member assessments known against current codes	IRM data fully documented and assessed,	All incidents reported and platform condition assessed subsequently	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, lack of design analysis of joints & members against current codes	Gaps in IRM data,		Some additional safety margin required over current design levels
Low	Poorly documented, major gaps in DFI resume	Limited knowledge of current environmental data, poor records of wave history, (e.g. encounters with deck)	IRM data poorly established or assessed	Poor records of incidents, lack of information on any assessments following incidents	Considerably higher safety margins required than in original design. Increased IRM required. May require urgent inspection to establish relevant data before assessment process

It can be seen from Table 7 that there are considerable penalties for poor data management prior to life extension assessment. However it is recognised that the route to establishing quantitative safety margins is more difficult.

8 Potential show stoppers and possible mitigation measures

8.1 General

Following discussion with PSA it is considered that there are a number of potential “show stoppers” regarding life extension.

A "show stopper" is a circumstance in which the life extension could not be allowed to proceed, in practice there are means of overcoming any potential show stopper (mitigation measures), but in many cases the implementation of the mitigation measures would be difficult and probably uneconomic. In such circumstances PSA could come under pressure from both the operator and from the Norwegian fiscal authorities to allow a relaxation of the requirements to enable continued field production. If this is to be considered the risk and benefits should be rigorously calculated to ensure that the benefits to Norway justify the implicit increased risks.

8.2 High fatigue utilization factor

Fatigue Utilisation Index (FUI) > 1 for non-inspectable joints.

Examples of structural items which are usually considered non-inspectable are:

- Members in the splash zone: {Mitigation: can be inspected with difficulty (using for example rope access)].
- Ring stiffened joints: inspectability is limited but some research has established that cracks can be detected in the ring inner edge and in the weld between the chord and the ring. [21], although this is not normal practice. [Mitigation – could add clamp to offer alternative load path].
- Piling: Normally regarded as uninspectable but may be possible to inspect from inside a pile. [Mitigation - secondary piling could be added to increase load capacity].
- Grouted connections: Usually regarded as uninspectable, particularly for the bond between the grout and the inner and outer steel. [Mitigation: provide additional strengthening or secondary piling]
- Shear plates for pile sleeve connectors: usually regarded as uninspectable, but possible ROV inspection, particularly in deep waters. [Mitigation: provide additional strengthening or secondary piling]
- Structural parts located in water depths >150m. In NORSOK N-004 [9] it is recommended that such parts be considered non-inspectable. [Mitigation: possible ROV inspection and repair]

8.3 Excessive storm utilization

Installation not able to withstand 100 year wave without utilizations exceeding 1.0 or not able to withstand 10 000 year storm with partial safety factors set to 1,0. [Mitigation: increase the air gap (lift deck), or strengthen structure]

A related issue is wave in deck, as the increased wave loading can be severe [Mitigation: increase air gap, reinforce structure, demanning when severe weather forecast]

8.4 Insufficient knowledge

Having insufficient knowledge of the installation or its environment to demonstrate extended life is safe is difficult to handle in practice due to the definition of “insufficient knowledge”. [Mitigation: obtain better data, check available records, create data by measurement].

8.5 High fatigue utilization and limited inspectability

Fatigue utilisation index >1 and not able to inspect at sufficient intervals to maintain integrity. This is most likely to be appropriate for very short fatigue life components. [Mitigation: strengthen area of low fatigue life, provide alternative load paths]

8.6 Cumulative effect of damage excessive (including accidental damage)

This can arise from a build up of dents on legs, due for example from minor ship collisions or damage to bracing members from for example dropped objects. Analysis methods for damaged members/joints are available, for example in NORSOK N-004 (design of steel structures) [9] or in ISO 19902 [3]. It is important to note that there is no analysis procedure for effect of hydrostatic pressure on damaged members in codes and standards at present. [Mitigation: Visual checks from an ROV, for example when undertaking flooded member detection for fatigue cracks]. A published paper [10] has identified bows/dents as significant in terms of reducing member strength and possibly not detectable via visual inspection.

8.7 Widespread fatigue damage

This is an accepted problem in ageing aircraft [22]. It is most likely to occur when there are several similarly loaded joints with low fatigue lives. This is more likely in semi-submersible type structures or in jack-ups rather than in fixed steel structures. Nevertheless relying on flooded member type detection may not detect widespread fatigue type damage until a number of cracks are through thickness, with little remaining life.

8.8 Damage tolerance requirements

For manned installations a normal code requirement is that the platform shall remain intact following an accidental event for a sufficient period for all personnel to be evacuated, and for all process plant to remain safe (e.g. ISO 19902, section 10.1.6.1)[3]. Accidental or extreme events can include:

- Storm event: Norwegian regulations require design such that damage tolerance is met for a 10^{-4} storm event.
- Seismic event: 10^{-4} seismic event is much more difficult to manage, as it is not possible to de-man in advance. Some localised areas of the North Sea may be at risk from such an event.
- Ship collision, passing vessel. Installations normally designed to withstand boat impact from two situations, which are:
  - low energy level, representing the frequent condition, based on the type of vessel which would routinely approach alongside the platform (e.g. a supply boat) with a velocity representing normal manoeuvring of the vessel approaching, leaving, or standing alongside the platform;
  - high energy level, representing a rare condition, based on the type of vessel that would operate in the platform vicinity, drifting out of control in the worst sea state in which it is allowed to operate

close to the platform. This case represents an ultimate limit state in which the structure is damaged but progressive collapse should not occur.

The second case is the more demanding and being able to demonstrate that progressive collapse should not occur depends on the mass and velocity of the selected vessel.

8.9 Not meeting acceptance criteria

ISO 19902 Section 25.9.2 [3] provides acceptance criteria for the fatigue limit state. If these cannot be met this would provide a "show stopper". [Mitigation: minimise fatigue loading on structure by for example removing conductors from completed wells, taking out launch bracing, reducing levels of marine fouling]

9 Recommendations & conclusions

9.1 Industrial workshop

A workshop was held and was well attended by the companies operating in Norway, Attendees showed keenness and that they were becoming aware of life extension issues. A second workshop would enable some of the key issues identified at the first workshop to be explored further, but would need to focus on specific topics.

9.2 Elements of ageing

A number of hazards have been reviewed; fatigue, corrosion, subsidence and settlement are recognised as the main hazards.

9.2.1 Fatigue design factors

Inclusion of fatigue design factors in fatigue analysis as part of an assessment can be very demanding, particularly when they were not included in the original design. This approach which is part of current offshore standards can lead to significant problems with life extension. For fatigue there are issues associated with crack detection in service as this is an requirement to enable cracks to be detected and repaired before causing loss of structural integrity. The possibility of widespread fatigue damage needs to be addressed, particularly in the life extension stage of life.

9.2.2 Corrosion

For North Sea fixed structures corrosion underwater is not likely to be a problem provided the CP system is maintained. For splash zone usage of corrosion allowance could be an issue and could need checking as part of the assessment for life extension. Any significant corrosion loss on critical structural members should be considered in assessing capacity of these members in resisting extreme environmental loadings.

9.2.3 Subsidence and settlement

Subsidence can be a result of reducing the pressures in the hydrocarbon reservoir and leads to a lowering of the seabed over a large area, Settlement is a more localized and shallower effect due to the weight of the structure on the foundations. In both cases the result is an increase in the water depth leading to a reduction of the air-gap and in increase in the environmental loading on the structure. Both should be assessed and, if possible, measured, before determining the acceptability of life extension.

9.2.4 Foundation failure

Failure of the foundations (e.g. piling) is potentially a serious hazard, enhanced by the very considerable difficulty of inspection in service. Special inspection tools may need to be devised if pile failure is seen as a key life extension issue.

9.3 UK experience

The scope and results from the UK HSE study to assess life extension and ageing issues have been reviewed in the light of their relevance to Norwegian installations. It is considered that many of the concepts and recommendations are transferable but some are related to meet UK Regulatory requirements. A long term safety review at the stage of life extension is the main recommendation, with acceptance criteria based mainly on ISO 19902 [3], which is considered to be relevant to Norwegian installations

9.4 Existing Norwegian regulations

These have been reviewed against a risk management framework. It is considered that these do not need major revision to include ageing and life extension. A significant gap is the topic of risk identification which is inferred only from the Management Regulations. New risks may be associated with ageing and their identification is important. The establishment and barriers and their management in service is seen as the main method for risk reduction. In connection with ageing and life extension new or modified barriers may be needed to manage the new risks arising. It is understood that some revisions to the Norwegian Regulations are in hand (but in Norwegian and not immediately available to the authors).

9.5 Decision Making for Life Extension based on Uncertain Data

The uncertainties in ageing and life extension have been reviewed. In section 24 of ISO 19902 [3] the structural data required for assessment is listed. Much of this forms part of the DFI résumé. The requirement to maintain and update the DFI résumé is established in NORSOK N-005 [19] but for some installations this has not always been the case. Where the quality of available structural data is limited, it has been proposed that a conservative approach to assessment would be required with conservative safety factors being required depending on the paucity of the data.

9.6 Potential Show Stoppers and Mitigation Measures

Eight potential "show stoppers" have been identified which could make the case for life extension difficult to accept. These include problems with fatigue for non-inspectable structural components, inability to meet the 100 year wave requirement, insufficient knowledge to demonstrate extended life is safe, cumulative effect of damage (including accidental damage) being excessive and not being able to meet the requirements for damage tolerance after accidental damage. In some of these the criteria are reasonably well established (e.g. fatigue) but in others it may be difficult to decide what is acceptable. Mitigation measures are presented but in many cases these are likely to be difficult and costly and may limit life extension.

9.7 Gross errors

It is recognised that these occur in practice but are very difficult to manage but could have major consequences in life extension.

9.8 Human & organisational factors

It has been recognised in related work for PSA that some platform personnel are unaware of the structural limitations of an installation, particularly those resulting from the initial design. This can provide unwarranted confidence in ageing structures. As part of the DFI résumé NORSOK N-005 [19] states that the information in this should include “areas of vital importance to the structural integrity and functional performance”. Awareness of these at management levels could reduce the lack of apparent knowledge as stated above.

9.9 Life extension issues

It is considered that the more significant issues relate to topside plant rather than to the underwater structure. However ageing structural problems on the sub-structure can be more difficult to mitigate and costly.

9.10 Corrosion of topside structure

Several examples of heavily corroded items on topsides equipment and secondary structure due to lack of maintenance have been presented at a recent conference [24]. These could have significant consequences for operational plant.

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11 Attachments

11.1 Report from industry workshop

11.1.1 Life Extension & Ageing Presentation (supporting text to section 4.2)

In the presentation by Professor Sharp the main hazards for life extension were seen as:

- Extreme weather
- Fatigue (welded connections, piles, supports)
- Corrosion (steel substructure, piles, topside structural supports etc)
- Geological & geotechnical (subsidence, scour, pile failure)
- Accidental damage (ship impact, dropped objects – cumulative effects)
- Marine growth
- Modifications & change of use
- Gross errors due to human and organisational factors. An example of a typical "bath tub" curve was shown with three phases i) early life failures, ii) constant failure rate, iii) wear-out phase. It was noted that the point at which the "wear-out" phase starts is not known and may require additional NDE to locate.

A review of current national regulations concerning life extension was made. Norway requires consent for life extension; in ISO 19900 [2] assessments are required at the end of the original design life; in section 25 in the draft ISO 19902 (fixed structures) [3] the end of design life is a trigger for a detailed assessment of structural integrity. Section 17 in API RP2A [4] does not include life extension as a requirement for a special analysis, The UK HSE had issued a special safety notice concerned with ageing semi-submersibles [but the safety case for fixed installations did not require taking special account of life extension.

Structural integrity management (SIM) plans had been reviewed from five different sources. A wide variability in style and content had been found. A suggested set of information to be included in a SIM plan had been proposed.

Interviews with 8 operators and 2 verifiers had been undertaken, relating to life extension. A questionnaire had been used as a basis for the interview, covering 11 topics. The main results from these questionnaires were presented. Few operators recognized "design life" as such, except for fatigue analyses. Design life was not recognized as an issue for safety case preparation. API RP2A was the preferred code to be used for reassessment. Uninspectable items (e.g. piles) were dealt with in several different ways. Treatment of damage accumulation was addressed by recording all damage as it occurred and some operators took account of accumulation. The need for a "long tern safety review" at the end of the original design life was not considered necessary by most operators but felt to be required by the two verifiers. The management of gross errors was handled by having proper procedures in place and using competent staff.

Details of the life extension requirements in ISO 19900 and ISO 19902 were explained.

Life extension in other industry sectors had been reviewed, which were:

- Nuclear: there were requirements for a long term safety review to the UK Nuclear Installations Inspectorate. This was the basis for extending life. Generic issues had been identified and periodic safety reviews were also introduced
- Civil Aviation: This area is well developed with requirements for ageing aircraft. An ageing aircraft Task Group has been set up. Supplemental structural inspection programmes have been implemented. There is concern about Widespread Fatigue Damage
- Power & Process Plant: there is a written scheme of examination for each pressure system, there is also best practice in the management of ageing pressure systems and related plant not widespread across industry.
- Ships: There is no formal procedures for life extension of ships other than part of the regular survey procedures, based on Classification Society rules.
- Bridges: Reassessment regime are being developed and formalised.

The study had identified a number of gaps and limitations; the main points being:

- Lack of a clearly defined and specified design life for the structural safety critical elements (SCEs) of offshore installations
- Lack of full recognition of the significance of ageing processes in connection with life extension beyond original design life
- Extension of operating life beyond original design life is not a criterion for a revised UK safety case
- Lack of a long term safety review of the structural SCEs for life extension Limited application of modern codes and standards for reassessing design fatigue life and utilisation, taking account of appropriate design fatigue factors
- Lack of awareness of the potential for widespread fatigue cracking. Limited procedures for the management of structural components with long fatigue lives which are very difficult to inspect in service
- Lack of additional measures for the management of potential fatigue cracking and corrosion when the original utilisation had been taken up
- Limited monitoring, recording and taking full account of accumulated accidental damage
- Limited optimisation of the design to ensure life extension is feasible
- Limited recognition of the benefits that preventive maintenance and other reasonably practicable measures can have in expediting life extension

A framework for life extension, proposed requirements and recommended good practice had been developed as part of the study. This addressed data collection, assessment for fatigue, corrosion, scour & subsidence, environmental overload, inspection & maintenance planning

ISO 19902 (section 24) has been identified as representing good practice for the assessment of fixed installations in the life extension phase, with several amendments and additions which were outlined.

Overall the main conclusions were:

- Life extension is an ongoing requirement;
- Procedures to manage life extension are required, via a long term safety review;
- For fixed structures ISO 19902 is a good basis, with additions and amendments.

11.1.2 Breakout groups 1 and 3:

How should life extension procedure look like and what standards could be used; Quality of DFI and the inclusion of repair work and modifications

The main points from this breakout group were:

- Companies like the goal setting approach better. Setting up for a choice of "methods". To do this a set of criteria needs first to be defined;
- The reason of the regulation is to make the operators gain more control so that there are no "surprises" when one reaches the end of the "bath-tub" curve;
- Method discussed: Capacity > Load. Keep track of load as well as capacity of your structure;
- "As is analysis" can be made. But where is the limit?
- What do we know about deterioration? We need information about deterioration to calculate the form of the "bath-tub" curve;
- The weakness of today's regulation is that there are no guidelines of how to proceed from now (with old installations);
- Data gathered today must be made available to the "next generation". Keeping the DFI up to date is one important point;
- How often should databases be updated? (Metocean etc.);
- o Trigger points:
- o Guidance of how to proceed.
- o System for shutdown should be addressed. (Shutdown in storm, evacuation to other platforms.)
- o How do deviations from design affect lifetimes?
- Remember to address drifting criteria.
- "It might be easy to accept lower criteria for older platforms."
- Regulations should require an established management system
- Standards should describe the management system
- Document hazard tolerance / assessment (?)
- How to capture and document effects of ageing?

See also Figure 5 from this breakout group

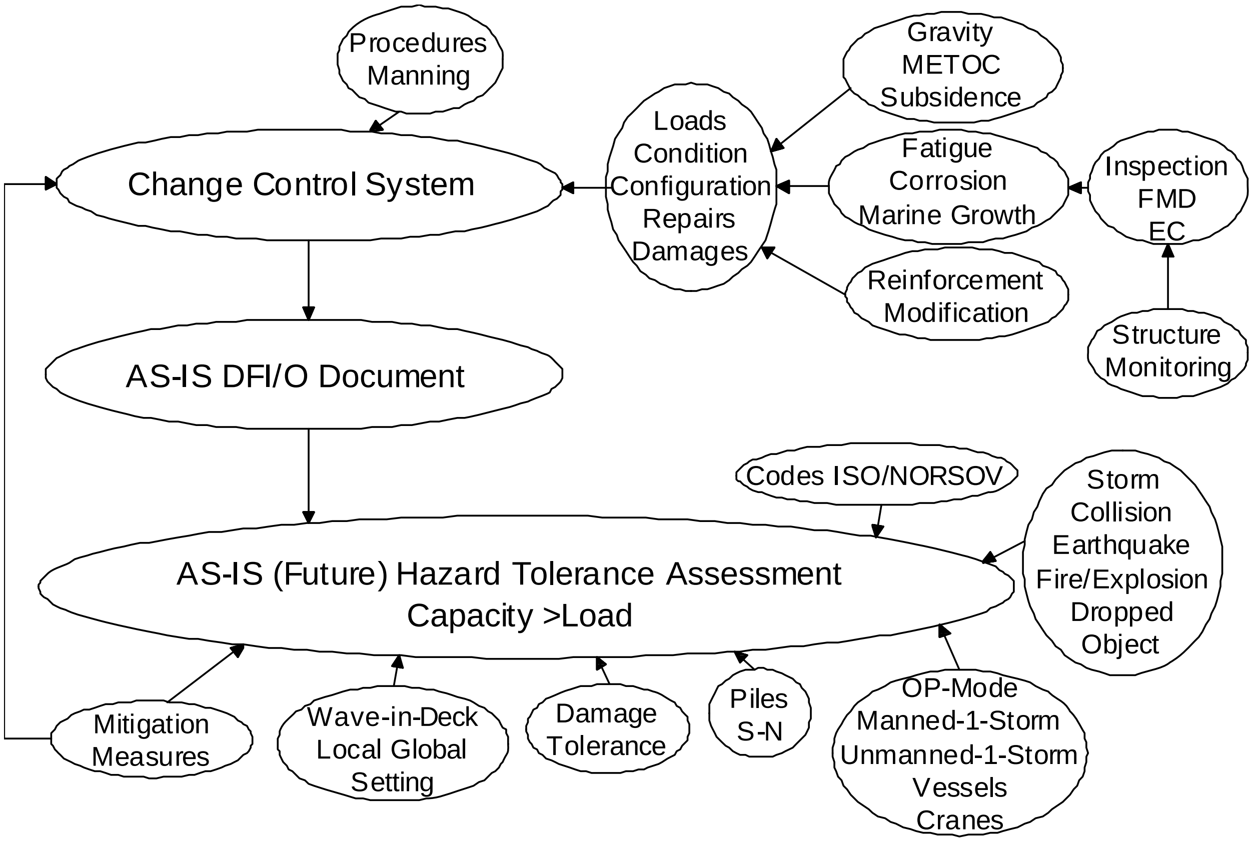

Figure 5 – Worksheet from breakout group 1/3

11.1.3 Breakout group 2: Main outstanding issues regarding life extension

The main points from this workshop were:

- Fatigue capacity: inspection is a means for verifying. Fatigue capacity is usually better than documented. Need guidelines for risk based inspections. However optimization in design leads to less margin and less potential for fatigue extension. Piles are not inspectable.
- ALS Loads: New knowledge may have led to increased loads. Blast loads have increased and the 10000 year wave has increased. May be show stoppers.
- Push over analysis. Can these be used for evaluating structures that do not meet the code? Use of “Ultiguide”?
- Some practices have been established for installations that do not meet the requirements but further work is required
- Anodes and coating; Some challenges, difficult to replace - welding introduces errors.
- Performance of bolted connections; condition status needs maintaining.
- Accumulation of damage: Sum of damages from several individual damages together with corrosion and cracks may contribute to reduced capacity.
- Marine growth may increase due to extensions but this is not a showstopper.
- Difficult to remove the ageing concrete structures as the piping system is corroding. The removal phase has to be evaluated in life extension.

- Human and organizational factors: Inspection is the guarantee for the safety of the structures. Taking account of H&O errors in inspection is important.
- Gross errors from design, fabrication and installation are already being discovered.
- Comments from the audience: Drifting acceptance criteria for older installations. Worse conditions are accepted for older installations. Perception is an issue.
- Moving into areas where the tools we have today do not handle life extension.

11.1.4 Breakout group 4: How to decide what is safe enough?

The main points from this workshop were:

- What is safe enough? Dynamic with time, depends on perspective (human safety, environment, installations etc)
- Measure against the regulation best practice, best available technology
- Perception. What is safe enough for the owner is not necessarily safe enough for the worker. Who is taking the benefit and who is taking the risk?
- ALARP (without acceptance criteria) will lead to continuous risk reduction.
- Cost vs. benefit -> NOT always applicable, benefit will vary from the point of view
- Costs are "real" -> "benefits" hopefully invisible

11.1.5 Breakout group 5: Maintenance philosophy - how and why?

The main points from this breakout group were: Need to reassess Safety Critical Systems and equipment

- Structural integrity
- Marine systems
- Major accident hazards
- Maintenance reviews should be reviewed based on updated data and previous experience (continuous process)
- Continuous/conditional monitoring of critical equipment or elements if needed. (Compensational actions)
- Uninspectable items - piles of jackets - reanalysis and reassess the soil data, research and development, achieve longer calculated life Conclusion:
- Continue to do as we do today (but perhaps in a different way).
- Extending life periods is a milestone for reassessment

11.2 Extracts from Relevant Existing Documents concerning Life Extension

11.2.1 Norwegian Information Duty Regulation [12]

Section 5 of this Regulation states that there is a requirement for an operator to obtain consent prior to use of a facility exceeding its life span and the assumptions on which approval of the plan for development and operation of petroleum deposits and the plan to install and to operate facilities for transport and utilisation of petroleum is based.

The Guidelines to the Information Duty Regulations identify a number of requirements for the application, including an assessment of how long one now thinks the facility can be used, or of the length of the life span in terms of safe operation of the facility. Identification of the circumstances that will limit the life span and specification of the criteria for safe operation to the extent it is possible to do so (e.g. permissible lengths of cracks, maximum permissible corrosion or remaining thickness, remaining anodes, degrading of paint protection).

11.2.2 Other Norwegian Regulations

11.2.2.1 Risk identification

Management regulations [14] Section 1

No specific mention of risk identification in the Regulations. Inferred from Section 1 of Management Regulations.

11.2.2.2 Risk analysis & reduction

Management regulations [14] Section 1 - Risk reduction

In risk reduction as mentioned in the Framework Regulations Section 9 on principles relating to risk reduction, the party responsible shall choose technical, operational and organisational solutions which reduce the probability that failures and situations of hazard and accident will occur.

In addition barriers shall be established which

a. reduce the probability that any such failures and situations of hazard and accident will develop further,
b. limit possible harm and nuisance.
c. Where more than one barrier is required, there shall be sufficient independence between the barriers.
d. The solutions and the barriers that have the greatest risk reducing effect shall be chosen based on an individual as well as an overall evaluation. Collective protective measures shall be preferred over protective measures aimed at individuals.

11.2.2.3 Analysis of major accident risks

Management regulations [14] Section14 - Analysis of major accident risk

Quantitative risk analyses and other necessary analyses shall be carried out to identify contributors to major accident risk, including showing

a. the risk connected with planned drilling and well activities, and show which effect these activities have on the total risk on the facility,
b. the effect of modifications and the carrying out of modifications on the total risk,
c. the risk connected with transportation of personnel between the continental shelf and shore and between facilities.
d. The analyses shall in addition be used to set conditions for operation and to classify areas, systems and equipment with respect to risk.

Management regulations [14] Section 15 - Quantitative risk analyses and emergency preparedness analyses

Quantitative risk analyses which provide a balanced and as comprehensive picture as possible of the risk shall be carried out. The risk analyses shall

a. identify situations of hazard and accident, select initiating incidents and map the causes of the incidents, carry out modelling of accident sequences and consequences so that, among other things, possible dependencies between physical barriers can be revealed, and so that the requirements that must be set in respect of the performance of the barriers, can be calculated,

classify important safety systems,

show that the main safety functions are adequately provided for,

identify dimensioning accidental loads,

provide the basis for selecting the defined situations of hazard and accident.

Necessary sensitivity calculations and evaluations of uncertainties shall be carried out.

Emergency preparedness analyses shall be carried out which shall

b. define situations of hazard and accident,
c. set performance requirements to the emergency preparedness,
d. select and dimension emergency preparedness measures.

11.2.2.4 Management of risks

Management regulations [14] Section 2 - Barriers

The operator or the one responsible for the operation of a facility, shall stipulate the strategies and principles on which the design, use and maintenance of barriers shall be based, so that the barrier function is ensured throughout the life time of the facility.

11.2.2.5 Acceptance criteria

Management regulations [14] Section 6 - Acceptance criteria for major accident risk and environmental risk

The operator shall set acceptance criteria for major accident risk and environmental risk.

Acceptance criteria shall be set for

the personnel on the facility as a whole, and for groups of personnel which are particularly risk exposed,

the loss of main safety functions as mentioned in the Facilities Regulations Section 6 on main safety functions,

pollution from the facility,

damage done to third party.

The acceptance criteria shall be used in assessing results from the quantitative risk analyses, cf. Section 14 on analysis of major accident risk, Section 15 on quantitative risk analyses and emergency preparedness analyses and Section 16 on environmentally oriented risk and emergency preparedness analyses. Cf. also the Framework Regulations Section 9 on principles relating to risk reduction.

Guidelines to Information Duty regulations [17] - section 6

The Guidelines to the Information Duty Regulations identifies a number of requirements for the consent application for life extension, including an assessment of how long one now thinks the facility can be used, or of the length of the life span in terms of safe operation of the facility. Identification of the circumstances that will limit the life span and specification of the criteria for safe operation to the extent it is possible to do so (e.g. permissible lengths of cracks, maximum permissible corrosion or remaining thickness, remaining anodes, degrading of paint protection).

11.2.2.6 Maintenance

Activities regulations [15] - Section. 9, paragraphs 42-47

The party responsible shall ensure that facilities or parts thereof are maintained, so that they are capable of carrying out their intended functions in all phases of their lifetime. The systems and equipment of facilities shall be classified with regard to the health, environment and safety related consequences of potential functional failures. With regard to functional failures that may entail serious consequences, the party responsible shall identify the different fault modes with associated failure causes and failure mechanisms, and estimate the failure probability in respect of the individual fault mode. The classification shall constitute the basis for the choice of maintenance activities and maintenance frequency, and for the priority of different maintenance activities

Fault modes which constitute a risk to health, environment or safety, cf. Section 43 on classification, shall be systematically prevented by means of a maintenance programme. The programme shall comprise activities for monitoring of performance and technical condition, which will ensure that fault modes that are developing or have occurred, are identified and corrected. The programme shall also contain activities for monitoring and control of failure mechanisms that may lead to such fault modes.

An overall plan shall be prepared for conduct of the maintenance programme and corrective maintenance activities, cf. the Management Regulations Section 9 on planning. There shall exist criteria for giving priority with associated time-limits for the conduct of the individual maintenance activities. The criteria shall take into account the classification as mentioned in Section 43 on classification.

The effectiveness of the maintenance shall be evaluated systematically on the basis of recorded data for performance and technical condition in respect of facilities or parts thereof. The evaluation shall be used for a continual improvement of the maintenance programme, cf. the Management Regulations Section 22 on improvement.

Condition monitoring shall be carried out in respect of new structures during their first year of service. With regard to loadbearing structures of a new type, data shall be collected from two winter seasons in order to compare them with the design calculations, cf. the Facilities Regulations Section 16 on instrumentation for monitoring and recording. With regard to pipeline systems where fault modes may constitute an environment or safety risk, cf. Section 43 on classification, inspections shall be carried out to map possible corrosion of the pipe wall. Parts of the pipeline system where the lay condition or other factors may cause high loads, shall also be checked. The first inspection shall be carried out in accordance with the maintenance programme as mentioned in Section 44 on maintenance programme, however at the latest two years after the system has been put into operation

11.2.2.7 Monitoring

Management regulations [14] Section 7 - Monitoring parameters and indicators

The party responsible shall establish monitoring parameters within his areas of activity in order to monitor matters of significance to health, environment and safety, including the degree of achieving objectives, cf. Section 4 on objectives and strategies and Section 5 on internal requirements.

The operator or the one responsible for the operation of a facility, shall establish indicators to monitor changes and trends in major accident risk.

11.2.2.8 Measuring & Data collection

Management regulations [14] Section 18 - Collection, processing and use of data

The party responsible shall ensure that data are collected, processed and used to

monitor and control technical, operational and organisational aspects,

produce monitoring parameters, indicators and statistics,

carry out and follow up analyses during various phases of the activities,

generate generic data bases,

take corrective and preventive actions, including improvement of systems and equipment.

Requirements shall be set with regard to the quality and the validity of the data, based on the relevant user needs.

11.2.2.9 Emergency preparedness

Activities regulations [16] - Section 64 - Establishing emergency preparedness

The operator or the one responsible for the operation of a facility shall prepare a strategy for emergency preparedness against situations of hazard and accident, cf. also Section 7 on the duties of the health service, (item c). The emergency preparedness shall be established on the basis of results from risk and preparedness analyses as mentioned in the Management Regulations Section 15 on quantitative risk analyses and emergency preparedness analyses and Section 16 on environmentally oriented risk and emergency preparedness analyses, the defined situations of hazard and accident and the performance criteria applicable to the barriers, cf. the Management Regulations Section 2 on barriers.

11.3 International standards

11.3.1 ISO 19900 [2]

This standard addresses the assessment of existing structures. It is stated that the need for assessment shall be considered when an existing structure has exceeded its intended design life. The assessment shall determine fitness-for-purpose for the aspects of the design that have been identified as no longer complying with the original design criteria. This may involve justifying a deviation from the basis of design or conducting modifications to the structure or its operation to achieve compliance with the intent of this international standard. When operational experience shows that the acceptability of aspects of design is uncertain, fitness for purpose shall be determined by specific assessment and appropriate measures taken to maintain acceptable standards of performance. The general principles for assessment are outlined, emphasising the need for an up to date knowledge of the structural condition. The standard also addresses assessment when damage is present.

11.3.2 ISO 19902: Section 24 – Assessment [2]

Section 24.4 addresses structural assessment initiators. It is stated that an existing structure shall be assessed to demonstrate its fitness-for-purpose if one or more of the following

conditions a) to c) exist.

a) Changes from the original design or previous assessment basis,

b) Damage or deterioration of a primary structural component

c) Exceedance of design service life, if either:

- the fatigue life (including safety factors) is less than the required extended service life; or
- degradation of the structure due to corrosion is present, or is likely to occur, within the required extended service life.

An extension of the design service life may be accepted without a full assessment if inspection of the structure shows that time-dependent degradation (i.e. fatigue and corrosion) have not become significant and there have been no changes to the design criteria (any changes to the original design basis are assessment initiators, see a) above).

11.3.3 ISO 13822 - Assessment of existing structures [22]

ISO 13822 [22] is aimed at the assessment of all types of existing structures, recognising that extending the life of structures is increasingly being required. The standard provides a general framework for assessment, based on performance levels, such as the safety performance level, continued performance level (i.e. continued function for certain types of buildings in the event of an earthquake, impact etc) and special performance requirements relating to property protection or serviceability. The framework recommended in this standard is similar to that adopted in ISO 19902.

The recommended procedure for assessment is based on several steps, listed below. These are:

- Specification of the assessment objectives
- Scenarios relating to changes in structural condition
- Preliminary assessment (based on a preliminary inspection and checks)
- Detailed assessment (including detailed inspection and material testing, structural analysis and verification)
- Results of assessment (reporting, conceptual design of construction interventions, control of risk)
- Repeat the above sequence if necessary.

Additional sections of the standard provide information on acquiring data for assessment, material properties, properties of the structure, structural analysis, model uncertainties, deterioration models and verification. This last stage includes a recommendation that it should be based on limit states (ultimate and serviceability), using appropriate partial safety factors.

Recommended target reliability levels to be used for verification are those in proven and accepted design codes. In addition account should be taken of the reference period and possible failure consequences. In cases where the assessment concludes that the reliability of the structure is insufficient the standard recommends possible interventions to be proposed, including both constructional (i.e., repair, upgrading) or operational (i.e. monitoring, change of use). It is noted that in all cases an inspection and maintenance plan during the remaining working life should be specified depending on the results of the assessments.