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SCOPE

This Project Standard and Specification specifies general principles and guidelines for assessment of the structural integrity of existing offshore structures. This Project Standard and Specification serves as an alternative for cases where structures are to be operated beyond original design requirements and structural resistance is not easily verified through ordinary design calculations, and where use of additional information gained through the life of the structure can be used to demonstrate structural adequacy.

The general principles of this Project Standard and Specification is applicable to all types of offshore structures used in the petroleum activities, including bottom founded structures as well as floating structures. As the majority of ageing facilities are fixed structures of the jacket type, the detailed recommendations given are most relevant for this type of structure.

The general principles given in this Project Standard and Specification is applicable to different types of materials used including steel, concrete, aluminium, etc. For assessments of structures of other materials than steel the detailed requirements that may be needed should be developed on a case by case basis.

The general principles of this Project Standard and Specification is applicable to the assessment of complete structures including substructures, topside structures, vessel hulls, foundations, marine systems, mooring systems, subsea facilities and mechanical outfitting that contributes to maintain the assumed load conditions of the structure.

REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the Company and the Vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

1. ISO 19900 — Petroleum and natural gas industries – General requirements for offshore structures
2. ISO 19901-7 — Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Station

keeping systems for floating offshore structures and mobile offshore units

3. ISO 19904-1 Petroleum and natural gas industries – Floating offshore structures – Part 1: Monohulls, semi-submersibles and spars
4. ISO 19902 Petroleum and natural gas industries – Fixed steel offshore structures
5. ISO 19903 Petroleum and natural gas industries – Fixed concrete offshore structures
6. BS 7910 Guidance on Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures
7. DNV-RP-C203 Fatigue Design of Offshore Steel Structures
8. DNV-RP-C205 Environmental Conditions and Environmental Loads
9. DNV-RP-C206 Fatigue Methodology of Offshore Ships
10. The Duty of Information Regulations - PSA, SFT and NSHD: Regulations relating to material and information in the petroleum activities.
11. The Facility Regulations - PSA, SFT and NSHD: Regulations relating to design and outfitting of facilities etc. in the petroleum activities.

DEFINITIONS AND TERMINOLOGY

Design service life - assumed period for which a structure is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary.

Extended design service life - assumed period the structure is to be used in addition to its original design service life.

Original design service life - design life premised at the design stage.

Total design service life - sum of the original design service life and the extended design service life.

Unmanning criterion - environmental condition (e.g. sea state, wind speed) at which the facility should temporarily be unmanned.

SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION	DESCRIPTION
ALS	accidental limit states
API	American Petroleum Institute
BS	British Standard
CFD	computational fluid dynamics
DFF	design fatigue factor
DNV	Det Norske Veritas
EC	eddy current
FLS	fatigue limit states
FM	fracture mechanics
ISO	International Organisation for Standardisation
MPI	magnetic particle inspection
NDT	non-destructive testing
POD	probability of detection
RBI	risk based inspection
SCF	stress concentration factor
SLS	servicability limit states
ULS	ultimate limit states
D_{LCF}	accumulated damage from low cycle fatigue during the considered storm period using Palmgren-Miner accumulation rule
D_{HCF}	accumulated damage from high cycle fatigue during service life using Palmgren-Miner accumulation rule
Hs	significant wave height
N	number of cycle
$\bar{a}$	intercept of the design S-N curve
d_f	directional wave factor
M	negative inverse slope of the S-N curve
$p_{f\text{-}target}$	required probability level for an environmental action
$\Delta\sigma$	stress range

ASSESSMENT PROCESS

General

Assessment of existing structures shall be undertaken if any of the initiators specified below are triggered. The purpose of such an assessment is to demonstrate that the structure is capable of carrying out its intended functions in all phases of their life cycle.
The assessment process shall include or be based on:

- design, fabrication and installation resume and as-built drawings,
- documentation of as-is condition,
- planned changes and modifications of the facility,
- updated design basis and specifications,
- calibration of analysis models to measurements of behavior if such measurements exists,
- the history of degradation and incidents,
- prediction of future degradations and incidents,
- the effect of degradation on future performance of the structure,
- a documentation of technical and operational integrity,
- planned mitigations,
- a plan or strategy for the maintenance and inspection.

The assessment for life extension shall conclude on a safe life extension period with respect to technical and operational integrity of the facility. The assessment shall further identify the circumstances that will limit the life of the facility without major repairs or modifications, and specify criteria defining safe operation (e.g. permissible cracks lengths, permissible corrosion or remaining thickness, remaining anodes, degrading of paint protection, subsidence, deteriorating compounds (such as H_2S, stagnant water), changed load conditions, deteriorated mechanical outfitting), including appropriate factors of safety.

The assessment process is illustrated in Figure 1. This flow sheet may be followed for assessment of all groups of limit states, i.e. ULS, SLS, ALS and FLS. Data collection is an important part of an assessment process, see 5.2. A further collection of data should be considered, if significant data are missing. The feasibility of data should be considered. An update of the design basis may be part of the assessment of data. If data are missing, one solution to this may be to make assumptions to the safe side.

Structural analyses for assessment should be performed on the basis of reliable data and assumptions to the safe side. Then the safety level of the structure can be assessed and it can be decided if mitigation is required. By analysis is understood an engineering process that can imply assessment based on simple hand calculation or more refined structural analysis.

Mitigation actions as indicated in Figure 1 involves:

- mitigation actions,
- documentation,
- maintenance after mitigation.

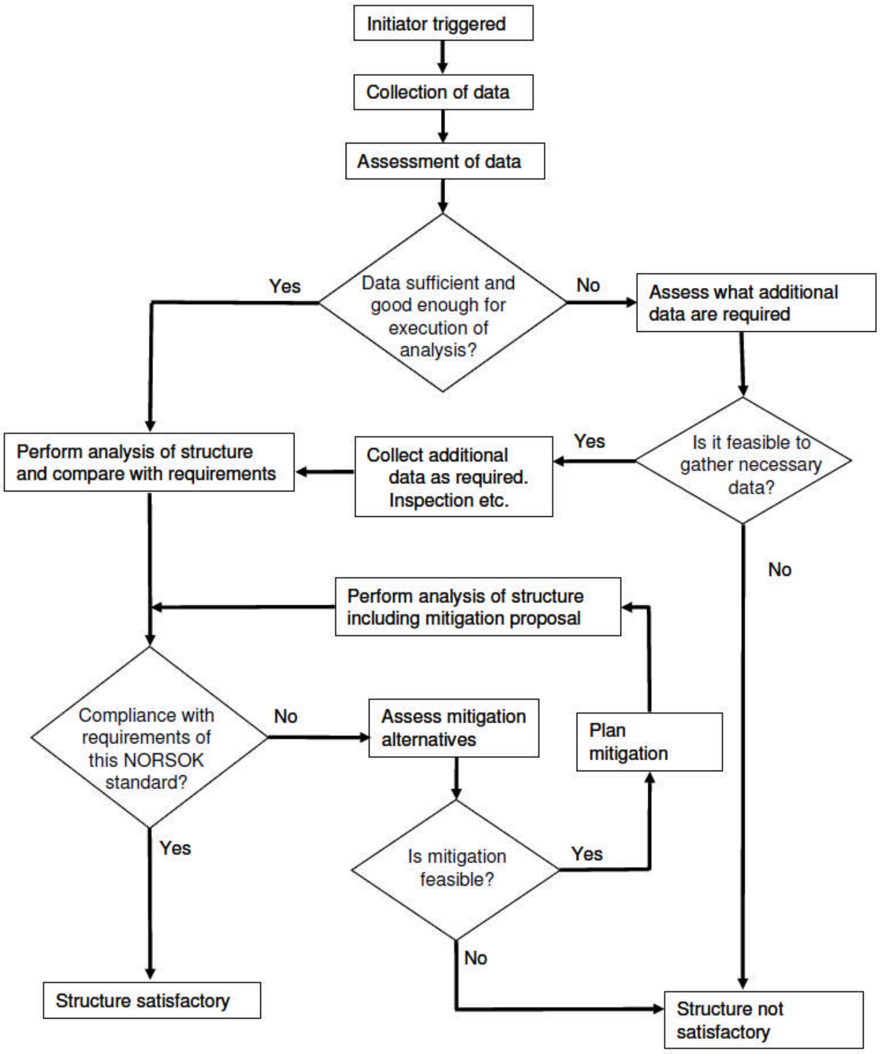

Figure 1 - Flow sheet of the assessment process

Structural Assessment Initiators

An existing structure shall be assessed to demonstrate its fitness-for-purpose if one or more of the following conditions exist:

1. changes from the original design or previous assessment basis, including:
   a. modification to the facilities such that the magnitude or disposition of the permanent, variable or environmental actions on a structure are more onerous,
   b. more onerous environmental conditions and/or criteria,
   c. more onerous component or foundation resistance data and/or criteria,
   d. physical changes to the structure's design basis, e.g. excessive scour or subsidence, or relocation of mobile offshore units to a new location,
   e. inadequate deck height, such that waves associated with previous or new criteria will impact the deck, and provided such action was not previously considered.
2. damage or deterioration of a primary structural component or a mechanical component which contributes to maintain the assumed load conditions of the structure. Minor damage can be assessed by appropriate local analysis without performing a full assessment. However, cumulative effects of multiple damages shall be documented and included in a full assessment, where appropriate;
3. exceedance of design service life, if either
   a. the remaining fatigue life (including design fatigue factors) is less than the required extended service life,
   b. degradation of the structure beyond design allowances, or is likely to occur within the required extended service life.

Existing design documentation can be applied as basis for the assessment if inspection of the structure shows that time-dependent degradation (e.g. fatigue and corrosion) has not become significant and that there have been no changes to the design criteria (any changes to the original design basis are assessment initiators). This requires that in-service inspection has been performed to document a proper safety level.

A structure which has been totally decommissioned (e.g. an unmanned facility with inactive flowlines and all wells plugged and abandoned), or a structure in the process of being decommissioned (e.g. wells being plugged and abandoned) generally does not need to be subjected to the assessment process unless its failure has consequences for nearby facilities.

DATA COLLECTION

General

The information needed to perform the assessment shall have sufficient accuracy for its purpose. In case of lack of data or insufficient information, assumption to the safe side may be made.

In the assessment process, information about past performance of the structure and maritime systems shall be collected. This shall also include gathering of experience from similar facilities, if available.

Collection of Data

The following information shall be available for assessment:

- as built drawings of the structure;
- new information on environmental data, if relevant;
- permanent actions and variable actions;
- previous and future planned functional requirements;
- design and fabrication specifications;
- original corrosion management philosophy;
- original design assumptions;
- design, fabrication, transportation and installation reports which should include information about material properties (e.g. material strength, elongation properties and material toughness test values or concret strength development), weld procedure specifications and qualifications, modifications and weld repairs during fabrication, non-destructive testing (extent and criteria used), pile driving records (action effects during pile driving and number of blows);
- weight report that is updated during service life;
- in-service inspection history including information on marine growth, corrosion, cracks, dents and deflections, scour, damages due to frost, impact, dents, erosion/abrasion, chloride intrusion, leakages, sulphate attacks;
- information on in-place behaviour including dynamic response (measurements and observations);
- information and forecast for seabed subsidence;
- information on modifications, repair and strengthening to the structure during service;
- soil conditions, pore pressures and consolidation;
- experience from similar structures.

Requirements to In-Service Inspection to Assess As-Is Condition

1. General

   Special attention should be made to details in the splash zone. It is difficult to analyse the structure in this area as a number of different phenomena add together in terms of fatigue damage, e.g. wave action, variation in buoyancy due to waves and wave slamming. This area may also be exposed from ship impacts.

2. Corrosion protection

   Ordinary inspection procedures will reveal when original corrosion management programme does not longer serve its intended function.
   Mitigation shall be implemented if cathodic protection no longer gives satisfactory protection or is included as a measure in the corrosion management plan. Mitigations can be made in the form of:
   - addition of anodes that are clamped or otherwise attached to the structure and electrically connected,
   - installation of a separate structure with anodes that is placed in the vicinity of the facility and that is electrically connected to the structure,
   - installation of system for impressed current.

   Coated surfaces can be protected against corrosion by proper maintenance. If corroded structural parts are detected, the capacity of the structural members may be assessed.

3. Steel structures

   Requirements to in-service inspection planning and structural integrity management of jacket structures in general may be found in ISO 19902, Clause 23.
   For steel structures it is important to control degradation mechanisms related to corrosion and fatigue.

4. Concrete structures

   Requirements to inspection and condition monitoring are given in ISO 19903, Chapter 14. In addition the inspection should include, among others, the following:
   - epoxy coatings and repairs;
   - cement reactions, e.g. sulfur attack, water leaching;
   - aggregate reactions e.g. alkali-silica, alkali-carbonate, sulfur reactions;
   - through cracking and water-tightness;
   - erosion, abrasion;
   - fatigue effects;

- reinforcement cover;
- reinforcement state of corrosion (cathodic potential measurements);
- concrete strength (drilled cores or rebound hammer);
- tendons, anchors, grouting;
- settlements, inclination;
- scouring protection.

5. Floating structures

   Requirements to in-service inspection, monitoring and maintenance are given in ISO 19904-1, Chapter 18.
   Requirements to station keeping systems are given in ISO 19901-7, Chapter 12 and Chapter 14.

ASSESSMENT PRINCIPLES FOR EXISTING STRUCTURES

General

Existing facilities where the primary structure does not meet the criteria for ULS or ALS related to environmental actions that can be forecast like wave and wind actions, may continue to be used if the following four requirements are fulfilled:

- shut-down and unmanning procedures are implemented. The procedure for shut down and unmanning should meet criteria given below,
- the environmental actions will not jeopardize any other main safety function (other than structural integrity) relevant for the facility during the storm,
- the risk of significant pollution is found acceptable.

With primary structures, in this context, is understood structural parts where a failure in case of a storm situation, may lead to loss of life, significant pollution or loss of main safety functions needed for safe operation of the facility throughout the storm.
Existing facilities where structural details do not satisfy the criteria for FLS may continue to be used if requirements in this Project Standard and Specification are fulfilled.
Requirements to assessment of existing concrete structures are presented in ISO 19903, Clause 15. Assessment of fatigue and corrosion is specially mentioned to be considered.
Floating structures shall in addition be checked in the as is condition for water tight and weather tight integrity.

Assessment of Maritime Systems

The inspection and maintenance program shall be updated to reflect the as is condition with planned modifications, and if relevant, the planned life extension period. Inspection and maintenance program shall include:

- leak detection or equivalent system,
- watertight and weatherproof closing appliances,
- ballasting and stability, included seawater intake,
- mooring and positioning systems,
- related safety systems which depend on emergency power or hydraulics.

Shut-Down and Unmanning Criteria Related to Structural Integrity

A shut-down and unmanning procedure shall be implemented for facilities not satisfying ULS or ALS requirements to manned facilities with respect to environmental conditions and hence need to be shut-down and unmanned during storms.

The shut-down and unmanning procedure shall be implemented in order to ensure that there is less than $5x10^{-4}$ annual probability of the facility being exposed to environmental actions exceeding the structural capacity determined according to the principle of ALS, with personnel onboard.

Shut-Down and Unmanning Criteria Related to Main Safety Functions

The threshold for environmental conditions above relate to structural capacity of the facility and presumes that topside equipment is properly protected or secured against waves or wind actions and that necessary operational safety procedures are in place. This is to ensure that main safety functions other than structural integrity that are relevant for the facility during the storm are not jeopardized. If topside equipment is not properly protected or secured against waves or wind actions, the facility shall be shut-down and unmanned based on a threshold which gives an annual probability of $1x10^{-4}$ of the main safety functions being impaired.

Structural Requirements Due To Pollution Risk

For well-head facilities and facilities with large oil storage tanks, requirements to unmanned structures may not be sufficient to satisfy required safety levels for major pollution events, e.g. blowout. In such cases it should be shown that the combined probability of a structural failure and leakage that could lead to significant pollution is less than $1x10^{-4}$ per year.

Determination of Directional Wave Criteria

When directional wave criteria are used, it may be necessary to use modified probability levels for the characteristic actions in each direction compared to omnidirectional criteria. It should be ensured that the sum of probability of failure for all directions for structures assessed by use of directional criteria is not larger than what would be obtained by using omnidirectional design values for a structure with the same resistance characteristics regardless of directions. The values of the characteristic waves to be used will be a function of the directionality of the waves and the properties of the structure for the various directions. There is consequently, no general answer to this and it can be necessary to develop criteria in each case. If specific criteria are not derived, the method described below for determining directional criteria can be used.
Characteristic directional waves are calculated as waves with a probability of being exceeded equal to $p_{f\text{-}target}$ / d_f, where d_f is a wave directional factor and $p_{f\text{-}target}$ is the exceedance probability level for the characteristic wave in question. Proposed value of d_f is given in Table 1. The directional wave criterion for a sector is defined as the minimum of the characteristic directional wave for the sector and the omnidirectional wave.
Directional wave criteria may be used for the following groups of limit states SLS, ULS and ALS as found appropriate.

Table 1 - Values for the directional factor

Number of directions	d_f
4	2
8	4
12	6

CHECK OF FATIGUE LIMIT STATES (FLS)

General

The fatigue life is considered to be acceptable and within normal design criteria if the calculated fatigue life is longer than the total design service life times the DFF. Otherwise a more detailed assessment including results from performed measurements of action effects and/or inspections throughout the prior service life as shown in Figure 2 is required.
Well documented in-service records of joints with the shortest calculated fatigue lives can be used to document the fatigue reliability.
A fatigue assessment should take into account all available information, which includes the following:

a. in-service history of the structure. This shall include changes and modifications to the facility (weight and weight distribution, ballasting etc), and assessment of any reported damages (including fatigue damages). This shall also include measurements from structural monitoring, if available;
b. planned future changes to the facility;
c. consider the structural analysis models required to obtain a reliable assessment. Different structural models can be required for different phases, subsidence stages or modifications. When different analysis models are used, the total fatigue damage should be calculated by adding together the damages from the different models representing a defined time period;
d. a detailed and consistent fatigue analysis of the structure based on best practise for such analysis and use of S-N data;
e. for structures where sufficient fatigue lives cannot be documented based on analyses and when it is considered difficult to document sufficient structural reliability by inspection only, it is recommended to perform measurements of action effects of the global force flow in the structure, e.g. axial forces in brace elements. These can then be used to calibrate the calculated forces and/or the analysis model to arrive at more precise fatigue lives;
f. the calculated fatigue lives should be compared with results from in-service inspections with respect to fatigue cracks. If fatigue cracks are found in primary details in the structure, it should be checked that this can be expected based on calculated lives.
   If calculated lives are not in agreement with observed fatigue cracking, it is recommended to look into the remaining uncertainties related to calculation of hot spot stress and fatigue capacity. This means assessment of relevance of stress concentration factors used in case of complex connections and S-N data for the actual fabrication.
   Then a further calibration of data may be performed based on a total assessment of the most significant parameters contributing to uncertainty in calculated fatigue life.
   Finally a revised fatigue assessment shall be performed as basis for planning further in-service inspection for fatigue cracks that fulfils target safety level.
g. for planning of in-service inspection for fatigue cracks it is recommended to develop crack growth characteristics, i. e. calculated crack length/depth as function of time/number of cycles (this depends on type of joint, type of loading, and possibility for redistribution of stress during crack growth);
h. the crack growth analysis based on FM should be calibrated to that of the S-N data in such a manner that the crack growth characteristics will not be non-conservative when it is used for assessment of inspection intervals;
i. the acceptance criterion for crack growth shall be linked to redundancy or consequence of failure as is implicit in the requirement to DFFs.

j. assessment of maximum allowable crack size (corresponding to some defined maximum action effect that gives satisfactory reliability) should be made. This can be based on BS 7910. If BS 7910 is used for the assessment, characteristic environmental actions with 100 year return period and load and resistance factors equal to unity can be used;
k. the inspection interval should be made dependent on the reliability of the inspection method that is being used;
l. elapsed time from earlier inspections should be accounted for in this assessment.

In-service inspection is an integral part of structural integrity management, which is an ongoing process for ensuring the fitness-for-purpose of an offshore structure or of a group of structures.

For steel structures it is recommended to use electromagnetic NDT methods, i.e. EC or MPI for the detection of surface cracks (e.g. at weld toe hot spots) in high consequence welded connections. In addition, it is recommended to periodically verify the condition of low consequence members by means of flooded member detection.

For floating structures the condition may be controlled by leak detection systems. In order to rely on such systems "leak before failure" shall be documented.

If an EC/MPI surface crack detection program based on RBI analysis is performed without findings, the time to next inspection may be reassessed based on this information. However, if significant fatigue cracks are found, it is necessary to review the inspection intervals for similar important joints which have not required previous EC/MPI inspection.

For structures where several primary connections show short calculated fatigue lives and/or the inspection history of these connections indicates that significant fatigue damage may have been accumulated, it is recommended to consider that more than one connection can fail due to fatigue in combination with a severe storm loading. This can be performed by an assessment of consequence of failure of the relevant connections. Such an assessment may lead to a reclassification of the considered structural component from being "Without substantial consequence" to that of "Substantial consequences".

This also implies that the target safety level for in-service inspection will be enhanced. For example when planning in-service inspection based on RBI methods the target safety level is normally linked to the DFF required for the considered connection.

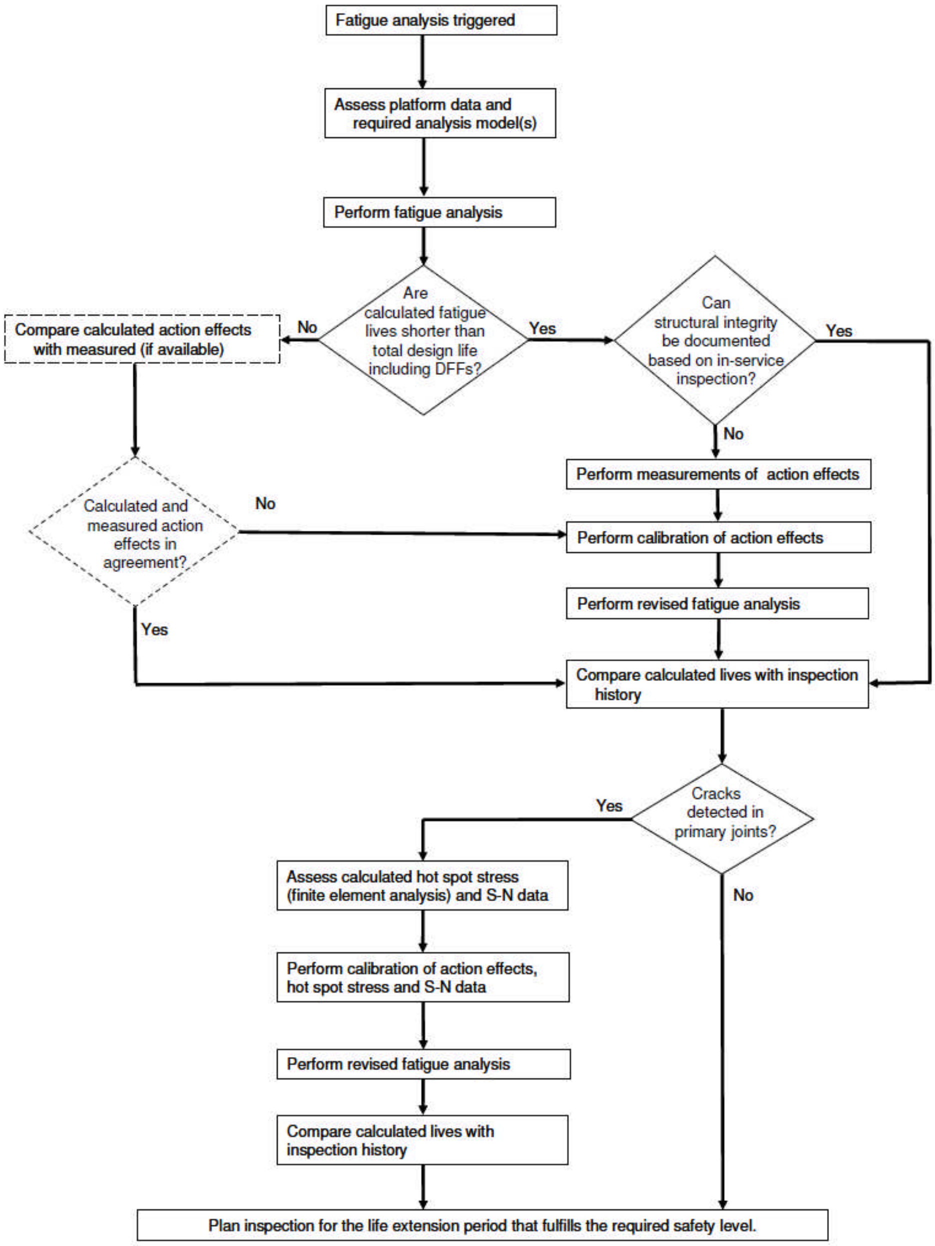

Figure 2 - Assessment with respect to fatigue. Requirements in boxes with dotted frames are optional

Fatigue Analysis Procedure

The determination of fatigue life is of great importance in an assessment situation. A fatigue analysis procedure implies selection of a number of different parameters, where each of these parameters may have significant influence on calculated fatigue life of the considered structure. Typical important parameters include:

- environmental data (wave heights and associated wave periods and directionality),
- wave theory,
- marine growth,
- hydrodynamic coefficients,
- joint flexibility and structural modelling of members,
- stress concentration factors as function of geometry and loading,
- combination of stresses into a hot spot stress taking into account direction of loading and multiplanar joints,
- S-N curves,
- corrosion protection,
- Palmgren-Miner damage.

The largest uncertainties for fatigue analysis of offshore structures are associated with the parameters leading from environmental data to a hot spot stress, especially for joints in the splash zone area of jackets.

Assessment of Details That Can Not Be Inspected

1. General

   Items that can not be inspected for fatigue cracks and corrosion can be critical issues in an assessment of offshore steel structures.
   Details that can not be inspected and that do not fulfil the original requirements to calculated accumulated fatigue damage including DFFs should be subjected to further assessments. Assessment for this is shown as flow sheet in Figure 3. Fatigue assessment for details defined to be without substantial consequences can be performed as described below:

   a. Perform an assessment of the in-service history of the structure to check control of corrosion protection systems like potential readings including check of consumed anodes and condition of coating in and above the splash zone area. Based on status of this, assess likely condition of corrosion protection in areas that can not be inspected.
   b. Perform a consistent fatigue analysis of ”as-is structure” and actions based on design standards of today. This may also imply use of refined finite element models of the actual hot spot stress areas.