

Assessment of structural integrity for existing offshore load-bearing structures

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Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are, as far as possible, intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK standards are normally based on recognised international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001.

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Introduction

The principle standard for offshore structures is NORSOK N-001 which especially refers to ISO 19900 *General requirements for offshore structures*. This NORSOK standard gives additional requirements for assessment of the structural integrity of offshore structures in-service and for life extension. This standard is based on the principles in ISO 2394, *General principles on reliability for structures* and ISO 13822, *Bases for design of structures —Assessment of existing structures*.

The changes since last revision are that clauses in NORSOK N-004 that dealt with existing structures are moved to this standard. Furthermore there are modifications to the text in 6.3, new reference and text for probabilistic inspection planning is introduced and minor corrections and updates.

All revisions compared to edition 1 are marked with vertical lines in the left margin.

Please notice that dots are used as decimal marker in the figures.

1 Scope

This NORSOK standard specifies general principles and guidelines for assessment of the structural integrity of existing offshore structures as a supplement to NORSOK N-001 and should be used in conjunction with NORSOK N-003, NORSOK N-004 and NORSOK N-005. This NORSOK standard serves as an alternative to NORSOK N-001 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 NORSOK standard are applicable to all types of offshore structures used in the petroleum activities. 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 NORSOK standard 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 NORSOK standard 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.

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet the requirements of the referenced standards.

2.1 Normative references

ISO 19900,	<i>Petroleum and natural gas industries – General requirements for offshore structures</i>
ISO 19901-7,	<i>Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Station keeping systems for floating offshore structures and mobile offshore units</i>
ISO 19904-1,	<i>Petroleum and natural gas industries – Floating offshore structures – Part 1: Monohulls, semi-submersibles and spars</i>
ISO 19902,	<i>Petroleum and natural gas industries – Fixed steel offshore structures</i>
ISO 19903,	<i>Petroleum and natural gas industries – Fixed concrete offshore structures</i>
NORSOK N-001,	<i>Integrity of offshore structures</i>
NORSOK N-003,	<i>Actions and action effects</i>
NORSOK N-004,	<i>Design of steel structures</i>
NORSOK N-005,	<i>Condition monitoring of load bearing structures</i>
NMA 878/91	<i>Ballast regulation</i>
NMA 879/91	<i>Stability regulation</i>

2.2 Informative references

BS 7910,	<i>Guidance on methods for assessing the acceptability of flaws in fusion welded structures</i>
DNVGL-RP-0001,	<i>Use of Probabilistic Methods for Planning of Inspection for Fatigue Cracks in Offshore Structures</i>
DNVGL-RP-0005,	<i>Fatigue Design of Offshore Steel Structures</i>
DNV-RP-C205,	<i>Environmental Conditions and Environmental Loads</i>
DNV-RP-C206,	<i>Fatigue Methodology of Offshore Ships</i>
DNV-RP-C208,	<i>Determination of structural capacity by non-linear FE analysis methods</i>

3 Terms, definitions, abbreviations and symbols

For the purposes of this NORSOK standard, the following terms, definitions, abbreviated terms and symbols apply.

3.1 Terms and definitions

3.1.1

can

verbal form used for statements of possibility and capability, whether material, physical or casual

3.1.2

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

3.1.3

extended design service life

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

3.1.4

may

verbal form used to indicate a course of action permissible within the limits of this NORSOK standard

3.1.5

original design service life

design life premised at the design stage

3.1.6

shall

verbal form used to indicate requirements strictly to be followed in order to conform to this NORSOK standard and from which no deviation is permitted, unless accepted by all involved parties

3.1.7

should

verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required

3.1.8

total design service life

sum of the original design service life and the extended design service life

3.1.9

unmanning criterion

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

3.2 Abbreviations

ACFM	alternating current field measurement
ALS	accidental limit states
API	American Petroleum Institute
BS	British Standard
CFD	computational fluid dynamics
DFF	design fatigue factor
DNV	Det Norske Veritas (Name changed to DNV GL in 2014.)
EC	eddy current
FLS	fatigue limit states
FM	fracture mechanics
ISO	International Organisation for Standardisation
MPI	magnetic particle inspection
NDT	non-destructive testing
NMA	Norwegian Maritime Authority
POD	probability of detection

RBI	risk based inspection or probability based inspection
SCF	stress concentration factor
SLS	servicability limit states
ULS	ultimate limit states
UT	Ultrasonic

3.3 Symbols

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
H_s	significant wave height
N	number of cycles
$\bar{a}$	intercept of the design S-N curve with the log N axis
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

4 Assessment process

4.1 General

Assessment of existing structures shall be undertaken if any of the initiators specified in 4.2 are triggered. The purpose of such an assessment is to demonstrate that the structure is capable of carrying out its intended functions and to maintain essential design assumptions in all phases of its 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 behaviour 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.

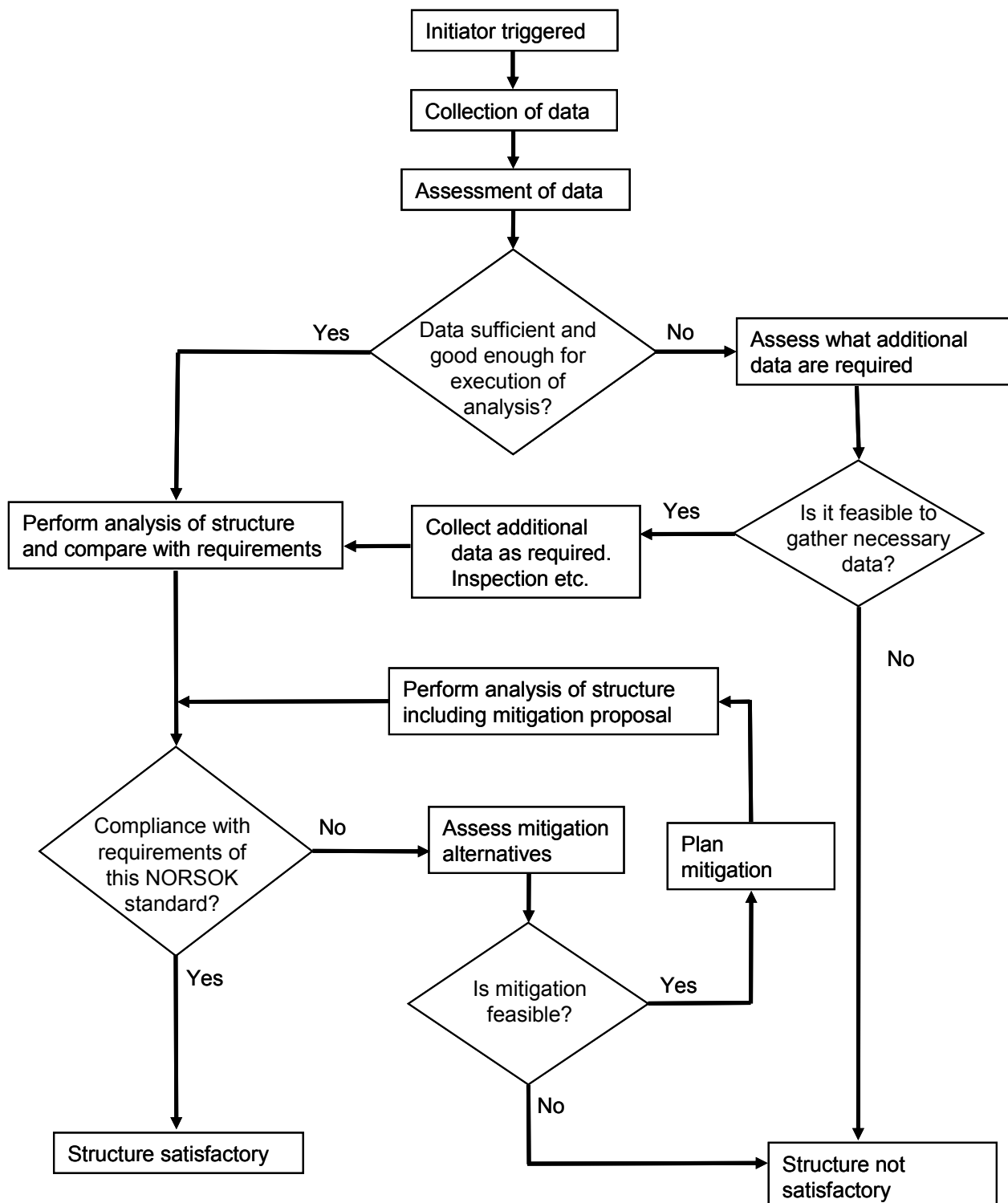


Figure 1 – Flow sheet of the assessment process

4.2 Structural assessment initiators

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

- a) Changes from the original design or previous assessment basis, including
 - 1) modification to the facilities such that the magnitude or disposition of the permanent, variable or environmental actions on a structure are more onerous,
 - 2) more onerous environmental conditions and/or criteria,
 - 3) more onerous component or foundation resistance data and/or criteria,
 - 4) physical changes deviating from the structure's design basis, e.g. excessive scour or subsidence, or relocation of mobile offshore units to a new location,
 - 5) inadequate deck height, such that waves associated with previous or new criteria will impact the deck, and provided such action was not previously considered.
- b) 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.
- c) Exceedance of design service life, if either
 - the remaining fatigue life (including design fatigue factors) is less than the required extended service life,
 - degradation of the structure beyond design allowances, or is likely to occur within the required extended service life.
- d) New knowledge.
- e) Insufficient documentation of structural integrity or other issues that may give doubt with respect to structural integrity.

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, see 4.2 a). 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.

NOTE On the Norwegian Continental Shelf the design life will be limited to the planned design service life stated in the Plan for Development and Operation as defined in The Management Regulation.,

5 Data collection

5.1 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.

Requirements to data management for offshore structures can be found in NORSOK N-001, NORSOK N-005 and ISO 19902.

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.

5.2 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 concrete 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, erosion/abrasion, chloride intrusion, leakages, sulphate attacks, alkali-reactions (concrete) and spalling (concrete);
- 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;
- slope instability, erosion at pile foundations, differential settlement,
- experience from similar structures.

5.3 Requirements to in-service inspection to assess as-is condition

5.3.1 General

General requirements to in-service inspection are given in NORSOK N-005. Requirements for various types of facilities are given in 5.3.3 to 5.3.5.

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 to ship impacts.

5.3.2 Corrosion protection

Ordinary inspection procedures according to NORSOK N-005 will reveal when original corrosion management programme does not longer serve its intended function.

Mitigation shall be implemented if corrosion protection system 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;
- maintenance or recoating of coated surfaces.

If corroded structural parts are detected, the capacity of the structural members may be assessed according to recommendations given in NORSOK N-004.

5.3.3 Steel structures

Requirements to in-service inspection planning and structural integrity management of jacket structures in general may be found in NORSOK N-005 and ISO 19902, Clause 23.

For steel structures it is important to control degradation mechanisms related to corrosion and fatigue. Reference is also made to Clause 7 for assessment of the fatigue limit state.

5.3.4 Concrete structures

Requirements to inspection and condition monitoring are given in NORSOK N-005 and ISO 19903, Clause 14. In addition the inspection should include, among others, the following:

- epoxy coatings and repairs;
- cement reactions, e.g. sulfur attack, water leaking;
- 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.

5.3.5 Floating structures

Requirements to in-service inspection, monitoring and maintenance are given in NORSOK N-005 and ISO 19904-1, Clause 18. Requirements to station keeping systems are given in NORSOK N-005 and ISO 19901-7, Clause 12 and Clause 14.

6 Assessment principles for existing structures

6.1 General

Existing structures shall meet the requirements of NORSOK N-001. Existing facilities where the primary structure does not meet the criteria for ULS or ALS related to environmental actions that can be forecasted like wave and wind actions, may continue to be used if the following five requirements are fulfilled:

- shut-down and unmanning procedures are implemented. The procedure for shut down and unmanning should meet criteria given in 6.3;
- requirements to unmanned facilities according to NORSOK N-001 are satisfied;
- the environmental actions will not jeopardize any other main safety function (other than structural integrity) relevant for the facility during the storm. Requirements are given in 6.4;
- the risk of significant pollution is found acceptable. Procedure to check this is given in 6.5;
- failures do not have consequence for nearby facilities, see requirements in 6.3.

With primary structures, in this context, is understood as 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 Clause 7 and Clause 9 are fulfilled.

Requirements to assessment of existing concrete structures are presented in ISO 19903, Clause 15. Consideration of fatigue and corrosion is specially required.

Floating structures shall in addition be checked in the as is condition, with data as described in 5.2, for water tight and weather tight integrity.

6.2 Assessment of maritime systems

Assessment shall be performed of the:

- intact and damaged stability;
- changes in displacement and operational weights.

NOTE: For the Norwegian Continental Shelf intact and damaged stability and ballast systems shall be in accordance with NMA Ballast regulation 878/91 and NMA Stability regulation 879/91

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:

- The updated inspection and maintenance program shall include an evaluation of the need for inspection and maintenance of:
- leak detection or equivalent system;
 - watertight and weathertight closing appliances;

- ballast system and seawater system, including seawater intake, overboard valves and other openings directly exposed to sea;
- mooring and positioning systems;
- related safety systems which depend on emergency power or hydraulics.

6.3 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 determined in a way that ensures that the structural reliability of the facility with personnel on-board is not less than for ordinary manned platforms.

NOTE See Annex A, A.3, for an example of how an unmanning criterion for waves expressed as sea state thresholds ($H_{s,thr}$) can be determined.

The possibility that surrounding infrastructure may threaten the facility, including potential loss of lives, environmental spill and material loss, shall be evaluated and included when determining the unmanning criterion.

6.4 Shut-down and unmanning criteria related to main safety functions

The threshold for environmental conditions in 6.3 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 1×10^{-4} of the main safety functions being impaired.

NOTE See Annex A, A.4, for an example of how a criterion for waves expressed as sea state thresholds ($H_{s,thr}$) can be determined.

For requirements to main safety functions, see The Facility Regulations, Section 7.

6.5 Structural requirements due to pollution risk

For well-head facilities and facilities with large oil storage tanks, requirements to unmanned structures in NORSOK N-001 may not be sufficient to satisfy required safety levels for major pollution events, e.g. blow-out. In such cases it should be documented that the combined probability of a structural failure and leakage that could lead to significant pollution is less than 1×10^{-4} per year.

6.6 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 wave climate 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 $p_{f-target} / d_f$, where $p_{f-target}$ is the exceedance probability level for the characteristic wave in question and d_f is a wave directional factor. Proposed values for d_f are given in Table 1. The characteristic directional wave 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

7 Check of fatigue limit states

7.1 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:

- In-service history of the structure. This shall include changes and modifications to the facility (weight and weight distribution, ballasting, operation, location etc.), and assessment of any reported damages (including fatigue damages). This shall also include measurements from structural monitoring, if available.
- Planned future changes to the facility.
- 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.
- A detailed and consistent fatigue analysis of the structure based on best practice for such analysis and use of S-N data.
NOTE Guidance can be found in DNVGL-RP-0001.
- 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 determine more precise fatigue lives.
- 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 or the intended safety level in NORSOK N-001.
- 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).
NOTE Reference is also made to Annex A.
- 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.
NOTE Reference is made to DNVGL-RP-0001.
- The acceptance criterion for crack growth shall be linked to redundancy or consequence of failure as is implicit in the requirement to DFFs presented in NORSOK N-001, reference can also be made to DNVGL-RP-0001.
- 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 according to NORSOK N-004 should be used.

NOTE Reference is also made to Annex A, A.11, Comm.7.5.

- 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 a 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. Other NDT methods, such as UT, should be considered for high consequence welded connections related to potential plane embedded defects. 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. In a "leak before failure" assessment, the damage tolerance shall be checked to ensure that:

- the remaining capacity of the structure is still able to withstand the loads according to the ALS post damage criterion in NORSOK N-001, and;
- the calculated time for crack growth should be based on the necessary time for preparation and repairs, and waiting for necessary weather window, or;
- necessary time for controlled demobilization, controlled disconnection and tow.

The crack growth calculations should account for variation in the metocean data and should reflect the consequence of failure.

If an EC/MPI surface crack detection program based on RBI analysis is performed without findings, the time to next inspection may be reassessed. 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". See NORSOK N-001 for definitions. This means that requirements to DFFs will be enhanced following NORSOK N-001 when going from "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. Reference is also made to Clause 9.

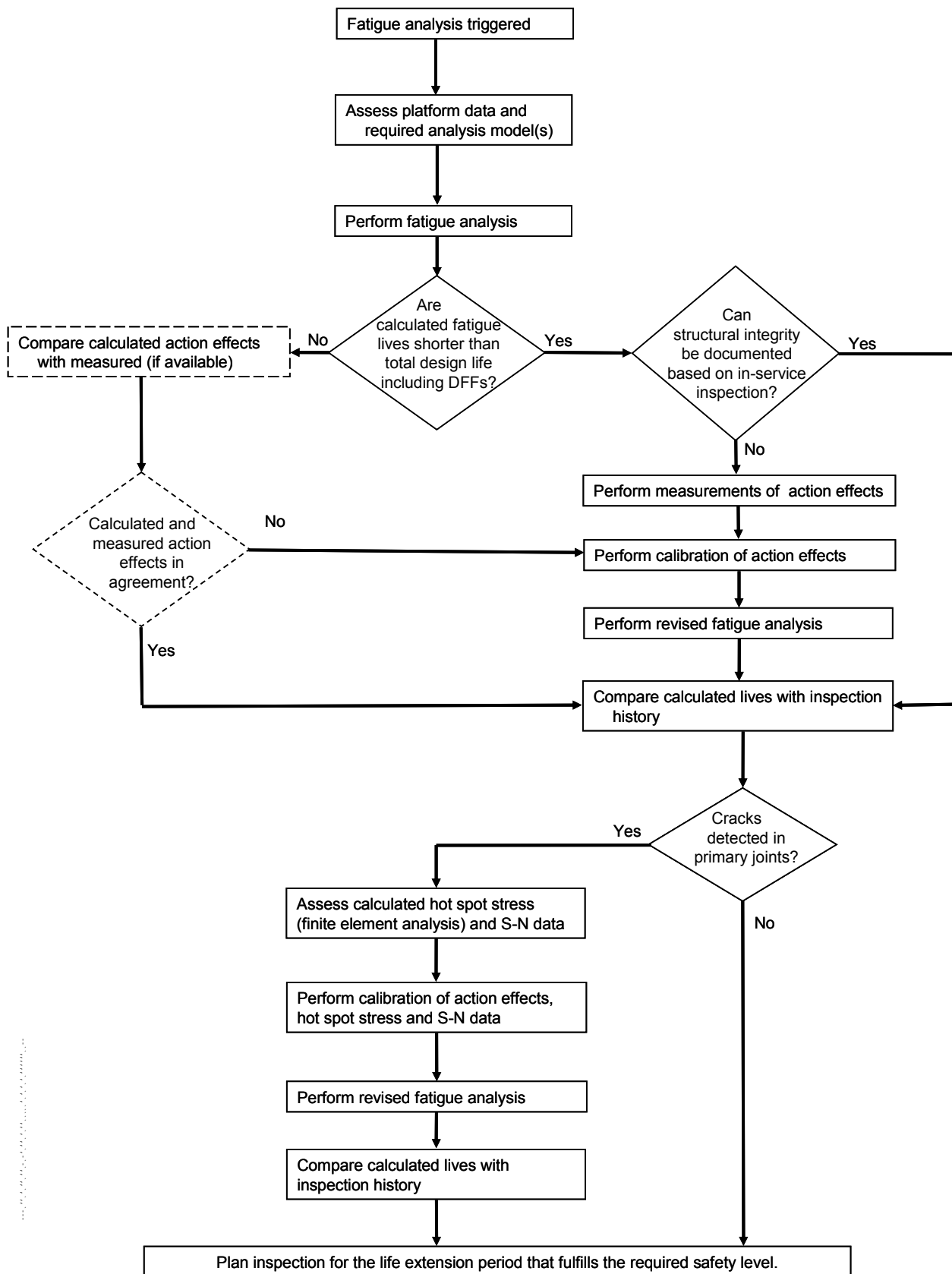


Figure 2 – Assessment with respect to fatigue. Requirements in boxes with dotted frames are optional.

7.2 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 direction dependency, short or long crestedness),
- 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.

7.3 Assessment of details that cannot be inspected

7.3.1 General

Items that cannot be inspected for fatigue cracks and corrosion can be critical issues in an assessment of offshore steel structures.

Details that cannot 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. Reference is made to NORSOK N-001 for definition of “without substantial consequences”.

- 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 the status of the corrosion protection system, assess the likely condition of areas that cannot be inspected.
- b) Perform a consistent fatigue analysis of “as-is structure” and actions based on design standards of today. See also Annex A for explanation of consistent fatigue analysis. This may also imply use of refined finite element models of the actual hot spot stress areas.

NOTE 1 Guidance on consistent fatigue analysis can be found in Annexes to DNVGL-RP-0001

NOTE 2 For determination of hot spot stresses with finite element methods general guidance can be found in DNVGL-RP-0005.

- c) Check if calculated accumulated fatigue damage during service life is in accordance with NORSOK N-001. If not, perform measurements of stresses that are strongly correlated with the nominal stress ranges at the actual hot spot.
- d) Perform a calibration of the analysis procedure.
- e) Perform a consistent fatigue analysis based on calibrated action effect data.
- f) The reliability of the considered detail can alternatively be controlled by in-service inspection of areas with strongly correlated loading close to the considered hot spot. The calculated fatigue life of the considered non-inspected detail should be at least three times longer than the calculated fatigue life at the hot spot that is inspected.

NOTE Reference is made to /1/

Provided that fatigue cracks are not detected at the region with a short calculated life, it is also likely that the considered hot spot has sufficient fatigue capacity (due to correlation in stresses). It should be noted that the use of this methodology requires that analyses are performed accurately and that these analyses include the same degree of bias in assumptions and analysis basis (such as different conservatism in calculated SCFs for the different hot spots) or that “consistent” has been performed as described in DNV GL-RP-0001. Assumptions and performed analysis should be documented.

If it is not possible to document sufficient safety by these measures, mitigation is required. Reference is made to Clause 9.

7.3.2 Design fatigue factors for piles

The piles in jacket structures are an example where a reliable in-service inspection of welds is hardly realistic.

Assessments of pile fatigue should be based on the actual number of blows and the energy used during the piling operation. For fatigue evaluation of already installed piles a minimum DFF = 3 shall be used for assessment of accumulated fatigue damage due to pile driving provided that the calculated fatigue damage is derived based on driving records that are properly documented in terms of

- data for the hammer used,
- number of blows (number of hammer blows per unit length of permanent set) of a pile as function of penetration depth,
- the energy transferred to the pile, if monitored, alternatively relevant performance data such as hammer stroke.

In lack of properly documented driving records, a minimum DFF = 5 shall be used for assessment of accumulated fatigue damage due to pile driving if damage consequence is classified as "substantial consequences", for fatigue evaluation of already installed piles. See also /2/.

In lack of properly documented driving records, a minimum DFF = 3 shall be used for assessment of accumulated fatigue damage due to pile driving if damage consequence is classified as "without substantial consequences", for fatigue evaluation of already installed piles.

For the service phase, the DFF shall be taken according to Table 3 in NORSOK N-001.

For back calculation analyses of driveability used to determine stress ranges it is conservative to assume a high energy transfer. Thus, a realistically high estimate of energy transfer or hammer efficiency should be applied for back calculation analyses.

The total accumulated fatigue damage from in-service life should be added to that from pile driving for calculation of accumulated damage. The acceptance criterion is that the total accumulated calculated damage is less than 1,0 when appropriate DFFs are included for the pile driving phase and the in-service phase.

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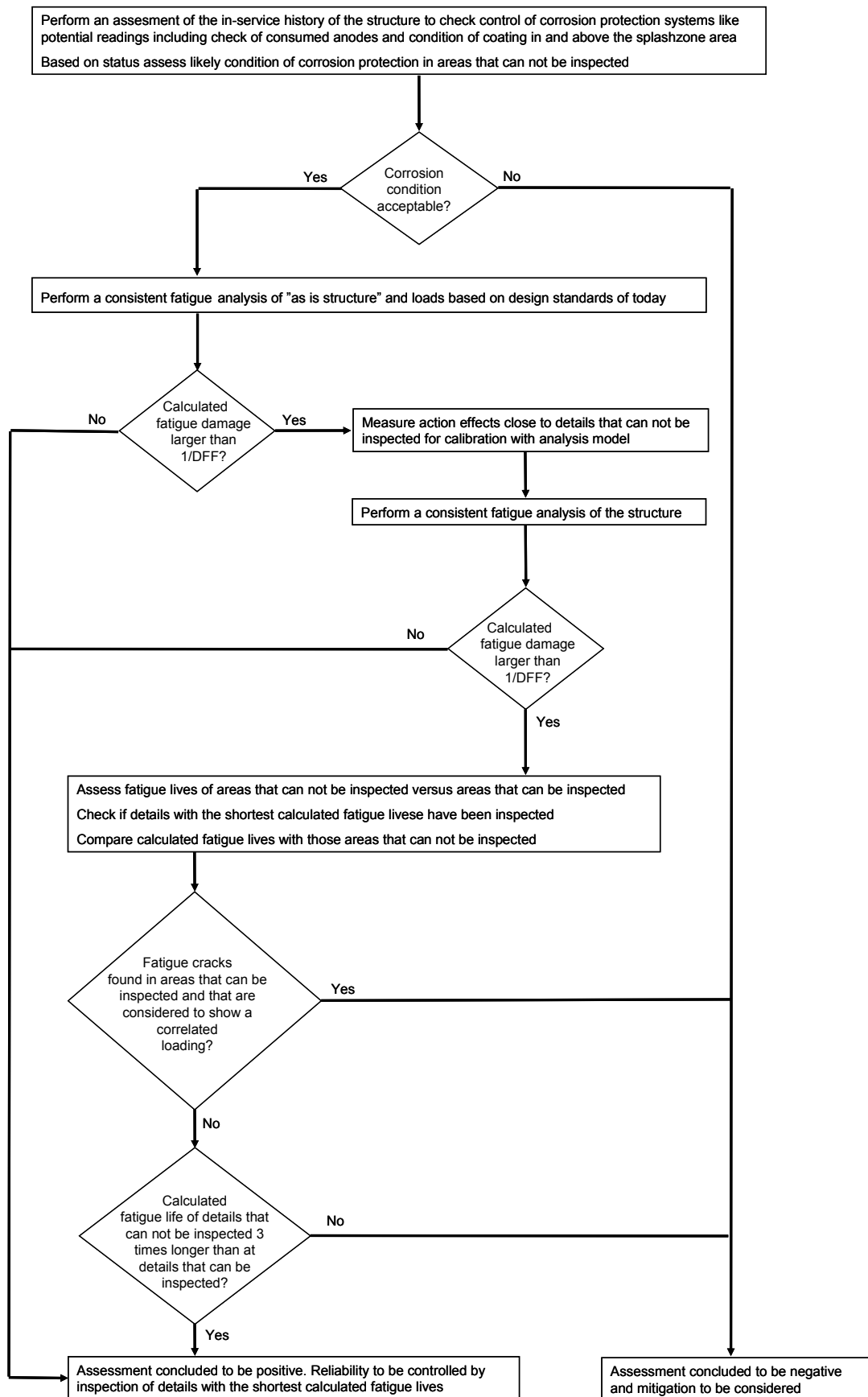


Figure 3 – Assessment of details that cannot be inspected for fatigue cracks