Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

Fixed and floating offshore structures used in the exploration and production of oil and gas in the UK sector should be designed such that as far as practicable, they can withstand such forces acting on them as are reasonably foreseeable [1]. In most cases, the application of industry codes and standards, such as the ISO 19900 series of offshore design and assessment documents, ensures that the sub-structure and topside structural components will meet this requirement.

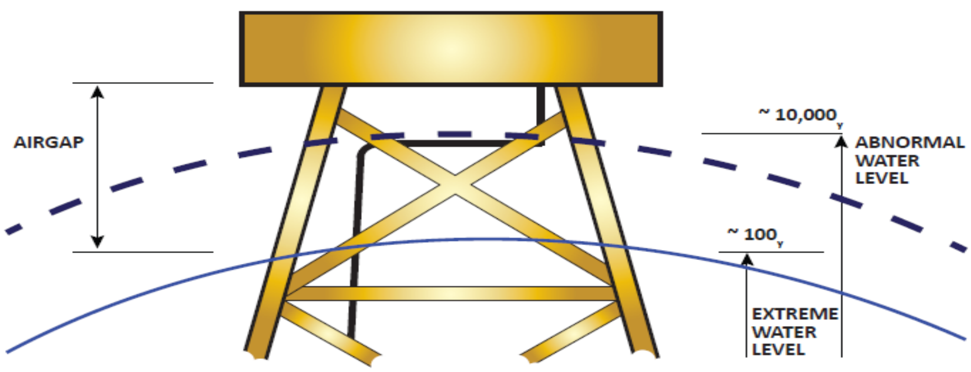
Recent experience within the UK sector suggests that there are two areas where Duty Holders may need to review and focus additional attention:

- Where wave-in-deck loads occur which were not addressed explicitly within the original design or within a subsequent assessment.
- Where there are platform equipment and / or process facilities in the region above the design crest elevation and below the lowest deck level (herein referred to as the airgap). Such elements may include appurtenances, risers, caissons, pipes and pipe supports, ESDV or other platforms.

Where such components are not adequately engineered to account for an appropriate level of hydrodynamic loading, local structural failures can occur or the ability of the sub-structure to meet its performance standard could be impaired. Loss of platform services could lead to operational disruption and, where hydrocarbon containing lines are present; there is a risk of LoPC.

This may be particularly relevant for under deck horizontal pipe runs and ESDV enclosures which could experience high fluid forces and slamming loads.

Figure 1: Key Parameters



Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

Oil & Gas UK
the voice of the offshore industry

Purpose of this Technical Note

This Technical Note reminds Duty Holders of the need to carry out a thorough engineering assessment of the ability of all parts of an offshore structure, its appurtenances, platform services and associated hydrocarbon containing hardware to withstand metocean loads in excess of those normally considered in the original design or latest assessment.

This Technical Note is relevant to the design and assessment of fixed and floating structures, and site specific assessment of mobile offshore units, i.e. fixed steel jacket and bottom founded concrete structures, FPSOs, jack-ups drilling units and both drilling and production semi-submersibles.

Traditional Approach to the Design and Assessment of Offshore Structures

Traditional structural assessment centres around the identification of a design condition from which design loads are calculated and, through the application of codified safety factors, a structure is designed that delivers an adequate level of reliability against environmental overload.

In the latest ISO standards [2], [3], [4] the design environmental condition adopted is typically the 100 year return period loading event. Through the application of pre-determined load and resistance factors, the resulting structural configuration should deliver an adequate level of reliability. For UKCS manned platforms this might be expressed as the ability to survive a 10,000 year return period event sufficiently intact to enable the safe evacuation of personnel.

Note: The following is a quote from 'The Offshore Installation and Wells (Design and Construction Regulations 1996) states that:
5.—(1) the duty holder shall ensure that the designs to which an installation is to be or in the event is constructed are such that, so far as is reasonably practicable—
(a) it can withstand such forces acting on it as are reasonably foreseeable;
(e) in the event of reasonably foreseeable damage to the installation it will retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it.

In order to deliver this level of reliability, it is assumed that the dominant loads are those resulting from wave and current action on the substructure plus wind loads on the topside structure and components. If wave-in-deck inundation occurs within return periods commensurate with the reliability levels the standard attempts to deliver, then for these cases it cannot be assumed that the reliability levels implied in using the standard are being achieved.

Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

For wave dominated structures, the 100 year loading event is normally addressed as a combination of a 100 year wave with associated wind and current. In the case of fixed jacket structures for example, the 100 year wave is progressed through the structure and the utilisation of members, braces and joints within the water column are checked for code compliance. This process does not directly address any structural components or other appurtenances which may be added to the structure within the airgap. It is important that such components are identified and an adequate structural assessment undertaken in combination with the stresses inherent in the element(s) prior to the application of the hydrodynamic load.

Estimating Abnormal Wave Heights

ISO 19901-1 defines waves used in the design and assessment of structures as 'extreme waves'. Such waves have return periods of around 100 years. Waves in excess of these conditions, with typical return periods of 1,000 to 10,000 years, are referred to as abnormal waves [2].

Estimating the Hydrodynamic Loads on Elements in the Airgap

Once the wave height has been determined, models are available which will allow particle kinematics in the wave crest to be estimated [2].

The operator should assess which elements (structural and non-structural) are affected by hydrodynamic loading at the different extreme crest elevation return periods, and ensure that the risk of a significant failure and TR impairment is ALARP.

Where the item being loaded has a circular cross-section, Morison based loading models can be used. For other items, a loading model appropriate to the shape of the item being loaded will need to be identified.

If simple models are not readily available, CFD based models or wave tank modelling may be used to provide an estimate of the anticipated loads.

In the event that the steepness of the wave is such that instability and wave breaking is possible, more sophisticated models and/or model tests may be required to determine the resulting kinematics and associated loads.

Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

Wave-in-Deck Loads

In order to determine whether wave-in-deck loads need to be considered in the design or assessment of a structure, a simple check can be carried out to establish whether the abnormal wave crest elevation with a return period of approximately 10,000 years results in deck inundation.

Where abnormal wave crests are predicted to impinge on decks, an impulsive step change in loading occurs.

Advanced analysis techniques are available to estimate loads from deck inundation.

Structure Type Specific Issues

Fixed Steel Jacket Structures

Fixed steel jacket structures are relatively transparent to the oncoming wave and current field. The traditional approach to the design of fixed steel jacket structures centres around the use of a design condition which, on the UKCS is related to independent 50 year wind, wave and current criteria or more recently to 100 year joint metocean criteria [3].

Mobile Jack-Up Units

The requirements for jack-ups in set down configuration are similar to those for fixed jacket structures. Provided the hull of the jack-up does not attract wave-in-deck loads, it is only those components placed in the airgap which will need to be assessed for abnormal wave loads.

Semi-submersibles

Determining what is an abnormal crest elevation for a semi-submersible is complicated due to the response of the structure in differing wave conditions. This will be a function of the response characteristic of the installation and its mooring and riser system, its loading condition and whether it is has been de-ballasted to survival drafts and the type of sea state to which it is exposed.

Appropriate analysis should be undertaken accordingly to demonstrate that these risks do not impair the integrity of the installation.

Structures with Large Diameter Members

Fixed or floating structures with large diameter structural members, typically in excess of 1/5th the length of the incoming wave, may be subject to additional wave loading effects not experienced on more transparent truss structures. These are the result of interactions between reflected waves and the incoming wave field which can result in a substantial, but very local increase in crest height. Local structural damage has occurred on at least one UK based installations as a result of these types of effect.

Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

Oil & Gas UK
the voice of the offshore industry

The nature of the loading which results from wave-structure interaction effects may differ from those experienced in a more traditional (drag dominated) wave loading regime. Standard wave kinematic models, which are related to wave height and period parameters, may poorly represent the kinematics in a complex and interacting wave field. Diffraction models which combine near and far field effects provide an insight to the form of loading that might be experienced. Additionally, physical model testing can be used for calibration and sensitivity studies

Summary

Structural and non-structural elements located above the design crest elevation and which may be subjected to rare wave loading should be assessed for conditions up to the abnormal metocean conditions which are typically taken to be in the order of the 10,000 year return period condition.

The estimation of abnormal metocean conditions, in particular crest heights, requires access to long term datasets and expert metocean knowledge.

In the event that wave-in-deck loads occur at return periods commensurate with the reliability levels implied in the structural standards, then a full assessment will need to be undertaken in order to demonstrate that the structure meets its intended performance requirements.
Such an assessment will require the use of competent personnel with proven expertise in such assessment and the use of industry recognised wave-in-deck loading models and/or the result of a model testing programme.

Sensitivity studies should be undertaken to validate the underlying assumptions and quantify the uncertainties in the estimation of abnormal values, and the associated loading and strength checks.

Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

Oil & Gas UK
the voice of the offshore industry

Definitions

abnormal value
Design value of a parameter of abnormal severity used in accidental limit state checks in which a structure is intended not to suffer complete loss of integrity

Note to entry: Abnormal events have probabilities of the order of 10^{-3} to 10^{-4} per annum. In the limit state checks, some or all of the partial factors are set to 1,0.

design crest elevation
Extreme crest elevation measured relative to still water level

NOTE to entry: The design crest elevation is used in combination with information on astronomical tide, storm surge, platform settlement, reservoir subsidence and water depth uncertainty and is derived from an extreme value analysis. Where simplified models are used to estimate the kinematics of the design wave, the design crest elevation can be different from (usually somewhat greater than) the crest elevation of the design wave used to calculate actions on the structure. In reality, the wave with the greatest trough-to-crest height and the wave with the highest crest will be different waves.

design wave
Deterministic wave used for the design of an offshore structure

Note 1 to entry: The design wave is an engineering abstraction. Most often it is a periodic wave with suitable characteristics (e.g. height *H*, period *T*, steepness, crest elevation). The choice of a design wave depends on:

- the design purpose(s) considered;
- the wave environment;
- the geometry of the structure;
- the type of action(s) or action effect(s) pursued.

Note 2 to entry: Normally, a design wave is only compatible with design situations in which the action effect(s) are quasi-statically related to the associated wave actions on the structure.

extreme value
Design value of a parameter used in ultimate limit state checks

Note to entry: Extreme events have probabilities of the order of 10^{-2} per annum.

Technical Note

(HSTN002)

Subject: Hydrodynamic Loading of Elements located above the Design Crest Elevation that may be impacted by an abnormal wave

Oil & Gas UK
the voice of the offshore industry

References

1. The Offshore Installations and Wells (Design and Construction, etc) Regulations 1996.
2. ISO 19901-1: 2005 Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating considerations.
3. ISO 19902: 2007 Petroleum and natural gas industries – Fixed steel offshore structures.
4. ISO 19904-1: 2006 Petroleum and natural gas industries – Floating offshore structures - Part 1: Monohulls, semi-submersibles and spars

In preparation and publishing this technical note, Oil and Gas UK gratefully acknowledge the contribution of the following members:

Don Smith	**Eni UK**
Terry Rhodes	**Shell UK**
Philip Smedley	**BP**