Vår saksbehandler
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Shall NORSOK N-003[1] and NORSOK N-006[2] be updated as a result of findings in LOADS JIP? Conclusions from the evaluation committee.

1 The evaluation committee and their scope of work and conclusion

This evaluation has been performed by a core team of 5 experts where two where prenominated by EG N. The additional 3 senior experts where selected based on their key competence and long track record on offshore structures and standardization. The committee consists of:

- Gunnar Lian (project manager)
- Sverre K Haver
- Torgeir Moan
- Øistein Hagen
- Gerhard Ersdal

The main objective is to review the LOADS JIP and the HSE study and give recommendations regarding possible updates of the NORSOK N-standards. All the LOADS JIP reports were made available to the working group. Moreover, the committee also received a presentation by Chris Swan and Richard Gibson of the findings from the LOADS JIP. Further, the review included the Guidance on Extreme Environmental Loading issued by OCG (OCG-50-04-23E November 2020) as a follow-up project to the LOADS JIP, part of the publicly available HSE reports. A major challenge in this evaluation is to estimate the wave-in-deck loading we also received a presentation of the event matching method by Thomas B. Johannesen of DNV.

The committee has reviewed the main findings of the LOADS JIP (as described briefly in chapter 3) and provided recommendations regarding possible inclusion of these items in the NORSOK standards. An overview of the findings of the LOADS JIP, the committee evaluation (chapter 4) and the possible need for updates of the NORSOK N-standards (chapter 5) are provided in the following table.

OCG requirements based on LOADS JIP	Committee evaluation	Need for NORSOK N updates
1 Long-term analysis		
1.1 Derivation of extremes: Extremes must be derived using best practise statistical methods.	"All sea states approach" as described in N-003 can still be used at NCS. A POT approach is possibly to be preferred with the present amount of	No immediate need for updates but should be

[1] NORSOK N-003:2017 Actions and action effects
[2] NORSOK N-006:2015 Assessment of structural integrity for existing offshore load-bearing structures.

Recommendations: POT, GPD and temporal variation in a storm.	good quality wave hindcast data or wave model data (e.g. NS1200).	considered in later revisions.
1.2 Covariate effects: Covariate effects such as direction and season must be included. Recommendation: Heffernan and Tawn.	At present, the notation "covariate effects" can be confusing. In practise, at NCS, it is sufficient to describe important characteristics conditionally with respect to proper direction sectors and seasons. The omni-directional modelling described in N-003 can easily be generalized to a conditional description with respect to direction and season. The Hefferman and Tawn approach is not sufficiently matured among metocean engineers for being introduced as the default approach.	No immediate need for update, but it may be considered for later revisions. Future change: Estimate omni-directional distribution from the directional distributions.
1.3 Directional criteria: Directional criteria must be estimated using a method that achieves the desired omnidirectional reliability. Recommendation: Modified NORSOK Criteria	We agree in the reliability requirement regarding directional criteria, and this is included in the NORSOK N standards. We see no immediate need for the modified NORSOK approach suggested by OCG (q/N versus 2q/N where N is the number of directional sectors).	No need for update at the moment but may be considered at later revisions.
1.4 Epistemic uncertainty: The epistemic uncertainty in the estimation of extremes must be included.	The design recipe in the NORSOK N standards is based on a semi-probabilistic LRFD approach (called deterministic in LOADS JIP). In the LRFD approach, normal epistemic uncertainties are assumed to be covered by partial safety factors in ULS. However, in regions with less metocean data or other situations with large uncertainties (wave-in-deck) in the ULS evaluation, epistemic uncertainties should be accounted for. The epistemic uncertainty included in the method proposed by the LOADS JIP seems to primarily include statistical extrapolation uncertainty. For an existing jacket structure with insufficient airgap, other uncertainties (e.g. in calculating wave-in-deck loads) are also important. The strategy in NORSOK N standards is to account for epistemic	No immediate need to update NORSOK N standards, but the text in N-003 can be made clearer and should be performed in a future updating of the document. Guidance for how to include epistemic uncertainties in ULS and especially ALS evaluations is needed in a future update.

	uncertainties by conservative choices, as discussed further in this document.	
2 Short-term distributions		
2.1 Crest distributions Crest elevations must be estimated using a distribution that includes nonlinearity beyond second-order and wave breaking	The work performed in LOADS seems very interesting and it looks to behave qualitatively correct. But further work is necessary, in particular, regarding the effects of wave breaking on the resulting non-linear crest height. The NORSOK N-003 requirement of 10 % on top of the Forristall's crest seems reasonable, but for very steep sea states the recommendation may be overly conservative.	No immediate need for updates. The next revision of NORSOK N-003 should consider status on closed form crest height models accounting for non-linearity beyond second order and wave breaking.
2.2 Wave heights Wave heights must be estimated using a distribution that includes the effect of bandwidth and wave breaking.	N-003 is recommending both the empirical Forristall wave height distribution and the Næss wave height distribution. The latter includes explicitly the effect of bandwidth.	N-003 includes the necessary issues.
3 Deterministic analyses		
3.1 Irregularity of event The irregularity of wave events must be considered.	N-003 include both deterministic regular wave analysis and irregular sea analysis. However, design events and focussed waves are not a part of the NORSOK N standards. If the structure can experience a wave in deck event, the N-003 recommend utilizing model test in irregular sea.	No immediate need for updating NORSOK N standards. The next revision of NORSOK N-003 should consider alternative design events.
4 Probabilistic Analysis	NORSOK is a standard based on the partial factor method, and probabilistic analysis (i.e. structural reliability analysis) is not really a part of the guidance given. If a probabilistic analysis is to be performed, aleatory and all epistemic uncertainties need to be included.	No immediate needs for updates. If future updates of the NORSOK N standards should include probabilistic analysis such issues need to be considered.
4.1 Aleatoric randomness of wave loading The aleatoric randomness of wave loading must be considered.		
4.2 Epistemic uncertainty in loads The epistemic uncertainty in the long-term distribution of loading must be included.		
4.3 Epistemic uncertainty in resistance		

The epistemic uncertainty in the resistance must be included.		
5 Modelling		
5.1 Wave breaking The effects of wave breaking must be included.	According to NORSOK N-003, local wave slamming from breaking waves should be estimated based on model tests. Wave-in-deck loads from wave breaking is in N-003 also recommended to be estimated using model tests.	No immediate needs for updates. As new research is validated the need for very extensive model test may be reduced.
5.2 Area effect The area effect must be considered.	The area effect and possible higher than second order effects are included in NORSOK N-003, given as a combined value of 10 % add-on to the Forristall crest. The 10 % add-on may be slightly on the low side in certain cases if one shall account for both non-linearity and area effect.	No immediate need for updating N-003. Future updates should consider separating the area effect and the higher order effect.
5.3 Validation of wave-in-deck load model Wave-in-deck load models must be fully validated for the conditions being analysed.	Wave in deck load is included in NORSOK N-003, and the recommendation is to use model tests or DNV-RP-C205 (CFD). Correlation between jacket loads and wave-in-deck loads differ significantly between the LOADS JIP moment flux model and the DNV Event matching approach. More work is required in this area prior to updating of the NORSOK N standards. It seems to be a significant uncertainty in the load calculation from these models, possibly due to the kinematic model, the load model and the correlation between the jacket loads and the wave-in-deck loads. Hence, more work is required prior to standardisation.	No immediate need for updating N-003. N-003 recommend using model test to validate the wave in deck model. This recommendation should be kept, but it should explicitly open for using already existing model tests for calibrating of computational tools if the tests are of good quality.
5.4 Consider multiple failure modes The possibility of multiple failure modes must be considered.	Several failure modes being implicitly verified in the design recipe. This is primarily a problem in RSR evaluation based on a 10^{-2} wave crest. The NORSOK N recipe requires the relevant 10^{-4} wave crest to be checked.	No immediate needs for updates
6 Mitigation		

6.1 Limit by forecast events De-manning limits should be based on the probability of failure once the storm event has been forecast.	The committee disagree in the 10^{-4} requirement in a forecasted storm. However, we agree that a de-manning requirement once the storm has been forecasted should be imposed, but as a supplement to the annual criterion. Today in NORSOK an annual probability target is an a priori requirement. Additionally, there is a requirement in the event that a severe storm is forecasted. An annual probability of exceedance of $1 \cdot 10^{-4} - 5 \cdot 10^{-4}$ is prescribed in NORSOK N-006, but no target is quantified for the additional criterion for a given forecasted storm. Common practice in Norway is to use the 0,95 fractile peak criterion in a 3 hour-storm (equivalent to the DNV approach of 0,9 fractile peak criterion in a 6-hour storm).	No immediate needs for updates, but the in-storm probability and method should be updated at the next revision.
6.2 Forecast uncertainty Forecast uncertainty must be considered	N-006 gives tabulated values based on different time intervals of 3, 2 and 1 days forecast. Ensemble forecast may also be used.	No immediate needs for updates. The method given in NORSOK is at present acceptable.

It should be noted that 3 members of this committee participated in the development of the NORSOK N-003 standard. and 2 members participated in the development of the NORSOK N-006 standard.

2. A brief review of design principles for permanent offshore structures in Norwegian Waters

In the over 50 years of offshore oil and gas activities in the North Sea, there has been an evolution of design practice initiated by new knowledge, e.g., relating to operational experiences and research. The regulatory approach has partly been influenced by civil engineering practice for fixed structures and maritime practice for floaters. A general picture has been that mobile units (with temporary or permanent floating mode) have shown to be most risk prone. Jacket platforms have been the most common permanent (production) platform since the beginning. Operational experiences with jackets in the North Sea and the rest of the world, show that it is process related fire and explosion accidents, and wave in deck events in the GOM, that have dominated accidents. In the North Sea the Kielland accident led to increased focus on fatigue and inspection relating to cracks on existing jackets. Cracks were also observed, without causing any severe damage or failure, in jackets. The subsidence of platforms in the Ekofisk area, discovered in the fall of 1984, resulted in operational efforts by jacking-up the deck of platforms, and a “continuous” injection of water to reduce the subsidence. The associated structural integrity assessments involved a significant focus on the safety of jackets with possible wave in deck loading.

Regulatory bodies for North Sea activities adopted limit state criteria (initially developed in civil engineering) to ensure safety of life and the environment. While regulatory bodies initially focused on ULS criteria, FLS and inspection planning (of limited concern in the GOM) came more into focus after the Kielland accident. But, perhaps more importantly, the Kielland accident made it possible to get a sufficient momentum to introduce a long due Progressive Limit State (PLS) requirement – which was later termed Accidental Collapse Limit State (ALS). Such requirements were established to prevent small damages due to accidental loads or deficient strength, to escalate into catastrophic events. Initially this criterion (for production platforms) was referred to an initial damage condition corresponding to an annual exceedance probability of 10^{-4} and survival of the damaged structure to a 10^{-2} storm event, with safety factors equal to 1,0. Later, the environmental condition has been made conditional upon its correlation with the event causing damage. The initial intention was, based on a simplified analysis, to limit the likelihood of "total loss" associated with each hazard to an annual frequency of 10^{-5}. As mentioned below, the ALS was also extended to consider 10^{-4} wave loads with safety factors of 1,0.

The conventional ULS criteria refer to components. Significant efforts have been devoted to estimate the notional failure probability by structural reliability analysis, considering the normal uncertainties in loads and resistances, i.e., neglecting gross errors made in the life cycle of the structure. While the normal uncertainties partly are due to natural variation, some important ones are due to modelling uncertainties. It is the latter uncertainties that make estimates of failure probabilities notional, and not actuarial. The theoretical annual probability of defined failure of offshore structures designed to meet recognized codes is generally on the order of 10^{-4} to 10^{-5}, somewhat lower for concrete structures than for steel structures. Similar results were obtained in later studies, with modified measures of uncertainties. It is noted that (surprisingly) the environmental load factor is 1,3-1,35 world-wide and for all types of platforms. However, there has been no calibration of ULS requirements considering wave in deck loads.

System failure (collapse) of jackets could follow the first element failure or after redistribution of forces that could take in multi-leg/brace structures. However, in connection with extreme wave-current loads on jackets the overload of several components could take place in the initial event due to the high correlation of forces in these components. Attempts to establish a ULS component check that reflect the system features of the jacket has not been successful.

A main reason for the lower reliability (higher failure probability of jackets compared to gravity based concrete structures (neglecting particular load phenomena like ringing), is the nonlinear load due to drag forces on jackets. This feature can be illustrated by approximating the global loads on a jacket in a wave with height H, by $Q = c \times H^a$, where a can be larger than 2,5 for drag dominated structures. The design value of the wave load: $Q_d = g_Q \times Q_c$ - where g_Q is the load factor and Q_c the characteristic load. If the 10^{-4} wave height is assumed to be 1,3 times the 10^{-2} wave height and the corresponding load factors are 1,0 and 1,3, respectively, the design loads at 10^{-4} and 10^{-2} are the same for a gravity based concrete structure assuming α=1,0, while for the jacket structure the ratio of the design loads at 10-4 and 10^{-2} is 1,3-1,5 for an α equal to 2,0 and 2,5. This difference in design loads, implies an order of magnitude difference in the implied failure probability when assuming a positive airgap. Another argument for such a design situation was that it could be seen as an ALS check – in one step. In reality, there are then two different ALS checks; a two-step approach relating to the progressive development of accidental damage and one relating to making a global ULS check relating to abnormal environmental loads.

The subsidence of platforms in the North Sea and the wave in deck experiences in Hurricanes in the GoM further emphasized the need to consider design checks considering more rare events than the 10^{-2} event to reach the desired safety level. In the early stages of offshore oil and gas activities an airgap of 1,5 m on the (50) 100 year crest was typically required. The NPD Regulations relating to load-bearing structures (1994) refers indirectly to an airgap by requiring that the 10^{-4} wave events should not cause a major damage. In NORSOK N-003, a positive airgap is required for a 10^{-2} crest, but it is recommended (for new structures) to avoid wave in deck by providing a positive air gap for the 10^{-4} wave crest. If not satisfied, the penalty is to satisfy the ALS criterion for the structure with the corresponding wave load. Due to the nonlinear drag load on the jacket, the phasing between the wave-in-deck and the jacket loads is important.

Another issue is the ultimate strength analysis. In the conventional ULS design check the load effects are normally determined by a linear global structural model (but normally a nonlinear pile-structure model), but with component strength determined by laboratory tests/nonlinear structural analysis. However, nonlinear global analysis models were introduced in connection with the ALS check – certainly to determine e. g. accidental impact damage, but also in the second step of the ALS check, analysing the survival of the damaged structure.

If applied to the ALS check with abnormal environmental loads it could be calibrated to correspond to correspond to an acceptable target level. The main challenge then is to assess the load uncertainties associated with estimating the wave condition at an annual exceedance probability of 10^{-4}, far beyond the range of observed data and the model uncertainty of the wave in deck load. It is noted that when the ALS type approaches were introduced, little concern about these uncertainties were made, in a way reflected by the fact that the safety factors were taken to be 1,0. The remaining way to account for the uncertainties then, is to follow the conventional statement of making conservative assumptions regarding data and analysis method. But this means that the safety level is not necessarily consistent for different cases.

It is common practice on the NCS is to design jacket structures with positive airgap, but depletion of the oil reservoir may lead to subsidence of the seabed and thereby reduced air gap. New knowledge about the metocean conditions and different methodologies for predicting extreme actions can also lead to reduced airgap. If an exciting facility does not meet the ULS/ALS criteria due to extreme metocean actions, a shut-down and unmanning procedure shall be implemented to ensure that the structural reliability of the facility with personnel on-board are not less than for a permanently manned installation.

Safety acceptance criteria depend on the failure consequences. The main issue regarding manned vs unmanned platform, i.e., for the North Sea is whether platforms will be evacuated in severe seas or not. Potential environmental damage depends upon potential damage to the risers/conductors (in view of the definition of the global failure limit state) and the safety systems (DHSV's etc.) available.

3. OCG LOAD JIP - Main findings and recommendations

The LOADS JIP has highlighted several issues that the industry needs to consider. A major change is the methods used to estimate the minimum required deck elevation to achieve a safe air gap for a fixed jacket structure due to higher order effects in the short-term distribution of wave crests, area effects and the inclusion of epistemic uncertainties. In addition, the suggested wave-in-deck load recipe proposed by the LOADS JIP differ significantly from the presently available recipes. LOADS JIP also highlights the importance of breaking waves on local loading and wave-in-deck loading on jackets with low airgap.

Committee note: The LOADS JIP is utilizing structural reliability analysis to an extent that is not fully compatible with the NORSOK N-standards. However, the NORSOK N-standards do allow for the use of structural reliability analysis and the guidance of the LOADS JIP may be relevant in such cases. However, the NORSOK N-standards do not at present give detailed guidance on reliability modelling and analysis and the focus of the expert group have been to evaluate the relevance of the LOADS JIP on the current format of the NORSOK N-standards.

The LOADS JIP gives the following recommendations:

Epistemic uncertainties: In all the elements mentioned below, the LOADS JIP recommends that epistemic uncertainties should be (shall?) included in estimation of metocean design load values, determined by Bootstrapping or Bayesian methods.

Data: Underlying metocean database can be a long period of offshore measurements, a wave hindcast forced using reanalysis wind fields (for example, NEXTRA or NORA10) or a simulation forced using climate model winds (for example, NS1200). Hindcast or simulated datasets should have been validated against offshore measurements – taking due consideration of the bias and limitations in both measured and modelled data.

Long term analysis: "Extremes must be derived using statistical methods that follow best practice as defined in the statistical literature. Covariate effects such as direction and season must be included." LOADS JIP further recommends the use of:

— Peaks-over-threshold approach including modelling and threshold uncertainties (bootstrap or Markov Chain MCS).

— Generalised Pareto distribution to fit the extremes including suitable covariates, such as direction and season.

— Joint distributions modelled using Heffernan and Tawn (2004) including suitable covariates.

— Temporal variation in metocean parameters over the course of a storm.

— Model parameters that are estimated using likelihood-based methods.

— Bootstrapping or Bayesian methods to evaluate the uncertainty in extremes.

Associated Conditions (waves, wind, current and water level): LOADS JIP recommends that associated conditions are derived using a single long-term model for the metocean environment to ensure that different extremes are mutually consistent. Associated conditions should be determined using a using a simple structural load model, applying a full joint model for the environment in which the temporal profile of waves, surge and tide through a storm event is captured.

Short-term distributions: The LOADS JIP indicate that the second-order model of Forristall (2000) for crest heights may be non-conservative and recommends the use of short-term distributions of crests from ShortCrest JIP for deep water, LOADS JIP for intermediate to deep water and LOWISH Phase 3 for intermediate to shallow water. Further, the LOADS JIP recommends that the short-term distribution of wave heights to be according to Boccotti (1983) for intermediate to deep water and the model from LOWISH Phase 3 for intermediate to shallow water.

Directional metocean criteria: The LOADS JIP recommends that directional metocean criteria should be derived using a modification of the NORSOK N006 (2015) approach (calculate the NxR return period value for each sector and limit the values such that none is larger than the omnidirectional result, where N is the number of directional sectors and R the return period). The use of the omnidirectional value all directions is suggested as a simple and conservative approach.

Area effect: LOADS JIP recommends that the maximum crest over the plan area of the topside is described by the method given in Forristall (2006), calculated through numerical or laboratory simulations of random irregular nonlinear directionally spread wave fields.

Deterministic evaluation: A deterministic evaluation is suggested as a simple, conservative approach by the LOADS JIP, with due consideration of the variabilities in the metocean modelling. The suggested method for including such variabilities is to model:

— Three regular waves all with a $1 \cdot 10^{-4}$ wave crest and a low, medium and high associated wave period.

— Three irregular focussed wave events all with a $1 \cdot 10^{-4}$ wave crest and a low, medium and high associated wave period. The waves should be focussed at numerous positions around the structure in order to ensure that a full range of failure modes are considered, at least including the centre, the edges and the corners.

— An irregular focussed wave event with a $1 \cdot 10^{-4}$ wave crest that is a plunging breaker.

— For structures with a negative air-gap it is also recommended to include an irregular wave event with a $1 \cdot 10^{-4}$ wave crest including area statistic with a median spectral peak period.

Probabilistic evaluation: The LOADS JIP recommends the use of structural reliability analysis as a method to avoid conservativism in the evaluations. The structural reliability analysis should be based on a probabilistic description of the long-term environment, the short-term loading and structural response. The short-term loading should include irregularity, directionality and nonlinearity of wave events, wave breaking, area effects and phasing between wave-in-jacket and wave-in-deck loading. The structural response should include structural dynamics and the fact that more than one failure mode may contribute to the probability of failure. The analysis should include all relevant uncertainties and take into account any correlation between failure modes.

Modelling - structure: The guidance document from the LOADS JIP provides some recommendations for how to include dynamic effects for structures with Te>2s and further recommends that dynamic analysis is always included when evaluating wave-in-deck events. In addition, the possible torsional moment effect of a wave-in-deck event should be considered.

Modelling – wave profile and kinematics: The LOADS JIP indicates that the surface profiles and kinematics associated with breaking waves can be derived using one of the following:

— laboratory testing;

— numerical simulations that can accurately model wave breaking (for example, fully validated computational fluid dynamics (CFD); or

— empirical methods derived on the basis of extensive laboratory observations (for example, LOADS JIP).

For non-breaking waves the LOADS JIP indicates that regular methods for the surface profiles and kinematics associated with regular wave events can be used, but indicate that wave kinematics factor for directionality should not be less than 0,95 and that no kinematics factor for 'irregularity' should be applied. The surface profile and kinematics associated with non-breaking irregular wave events can be calculated using second-order theory, provided that the crest elevation is matched to an estimate that includes nonlinearities beyond second-order.

Modelling – wave loading: The LOADS JIP indicates that many of the present wave-in-deck load models (Graff, silhouette and Kaplan methods) do not provide an adequate description of the applied loads. As a result, the LOADS JIP recommends that wave-in-deck loading are calculated as follows:

- through laboratory testing;
- a fully validated and calibrated load model; or
- the application of fully validated CFD modelling.

A fully validated and calibrated load model includes, according to the LOADS JIP, the new momentum flux model (Ma and Swan, 2019) which incorporates the porosity of the topside structure, is said to avoid entirely the need for empirical calibration and has been extensively validated in respect of both regular and random waves.

No new recommendations are provided for wave-in-jacket loading.

Mitigation by un-manning: The LOADS JIP indicates that if the assessment shows that the structure does not meet the required performance standard, mitigations should be implemented to reduce risk. Mitigations to reduce the likelihood of exceedance like reducing topside loads, removing marine growth, removal of under deck equipment, platforms, decks and stairways, raising the deck and various strengthening methods are suggested. In addition, consequence reducing mitigations by permanently or temporary de-manning of the platform is mentioned, primarily de-manning of a platform when a severe storm is forecasted.

The procedure proposed by the LOADS JIP for mitigation by unmanning is to implement limiting conditions such that at different forecast horizons various steps within the de-manning procedure are implemented. Practically this may be that at relatively long horizons (three to five days) non-essential personnel are de-manned and then at shorter horizons (one to two days) essential personnel are de-manned – in a controlled manner. The limiting conditions can be defined in terms of forecasted significant wave height, crest elevation or load, depending on the sophistication of the forecast model. It is essential that uncertainty in the forecast is considered and that this is included when determining the limiting conditions. Although, not explicitly stated in the reports, our understanding after the presentation by OCG is that they would recommend an in-storm constraint of $1 \cdot 10^{-4}$.

4. Reviewing LOADS JIP findings recommendations in view of existing versions of N-003 and N-006

4.1 Methods for estimating characteristic load effects for design

The committee interprets the LOADS recommendation on this issue as recommending a peak over threshold approach for estimating characteristics in order to ensure close to independence between short term metocean events (storms). The committee agrees in that this a good method for calculating extremes and the peak-over-threshold approach is also recommended in N-003. NORSOK N-003, however, recommends the all-sea-state approach as an equally valid design approach. In spite of the large correlation among neighbouring 3-hour metocean characteristics, we have good experience with the all-sea-state-approach. Provided that there are no severe outliers (high or low) in the metocean data base, estimated extremes are rather similar with the all-sea states approach being slightly conservative due to the assumption independence for the correlated 3-hour events. In a later revision of N-003, one should possibly present a peak-over-threshold as the preferred approach, but still include all-sea-states approach as a valid alternatively.

LOADS JIP recommends a generalized Pareto distribution for estimation of extremes. This may well be the best asymptotic model. But in most cases, regarding excess of threshold both GPD and the 2-parameter Weibull distribution are equally well fitted to the observed excesses. The difference is mainly taking place at the upper tail where there are no observations to validate the fitted model. In N-003 we recommend a 2-parameter Weibull model for the excess of threshold, but GPD is mentioned as an alternative model. We explicitly warn against GPD if the fitted model introduces a too low upper bound for extreme value under consideration. An upper bound should be explained by the physics at the site not as the results of fitting a distribution to a limited amount of data.

LOADS JIP states that parameters of distributions shall be fitted using likelihood-based methods. We agree that the Maximum Likelihood Estimators are the best possible estimators if we know the correct model and we have an infinite amount data. We are not convinced that these two conditions are fulfilled in practise. We will often prefer moment estimators since they are more sensitive to the tail indicated by the data.

For joint modelling of metocean conditions, possibly being conditional with respect to season and/or direction, LOADS JIP states that one shall use Heffernan and Tawn technique. There is hardly any practical experience with this method among Norwegian Engineers. Until a thorough evaluation of this approach is performed, involving practising metocean and design engineers, N-003 should continue to recommend preparing joint distribution using a conditional distribution approach, possibly conditional on direction and/or season. This approach is very transparent regarding what is done.

Conclusion: At present there is not sufficient validated practical experience for revising NORSOK N-003 regarding topics dealt with under this chapter.

4.2 Crest height models accounting for non-linearities beyond 2nd order and wave breaking

LOADS JIP has presented an approach where one can estimate percentiles of the non-linear crest height accounting for second order effects, non-linearities above second order and effects of wave breaking as a function of the percentiles of Rayleigh distribution (the theoretical distribution function of crest height of zero crossing waves of a stationary and Gaussian surface process not being too broad banded).

How important is it to include non-linearities beyond 2nd order and the crest reduction effect of wave breaking on the Norwegian Continental Shelf?

According to DNV RP-C205, the maximum peak sea state steepness, s_p, is 1/15 (0,067) for spectral peak period less or equal to 8 s and for peak periods larger than 15 s the maximum steepness is 1/25 (0,04). Between 8 s and 15 s, the steepness limit can be approximated by linear interpolation. For the low period range the governing limiting effect is wave breaking. For the long period range, the mechanisms underlying the empirical limit suggested by DNV is possibly a combination of peak mean wind speed of storms on the NCS, duration of high wind speed and underlying available fetch. The maximum significant wave height of 10000-year contours at NCS correspond to a sea state steepness between of 0,03 and 0,04. In this range a second order analysis of crest height is slightly on the low side. The degree of underestimation is in the order 5 % or less. We agree that we should account for this as a robust short- term crest height model becomes available. In this range one may experience wave breaking. However, plunging breakers of the largest waves are not expected. For steepness less than 0,04, the LOADS JIP model for including non-linearities beyond second order should be valid. As we go to steeper sea states the effect of non-linearities beyond second order increases rapidly to unrealistic values. That means that the breaking effect also must be included in the crest height distribution if effects beyond second order are introduced.

The LOADS JIP model (or minor variations of it) may well be a possible choice for crest height distribution in the next planned revision of NORSOK N-003 if the modelling of the crest reduction effect of wave breaking is further matured.

At present we will maintain the existing recommendation of N-003, namely, increasing the extreme second order crest heights predicted using the Forristall crest height distribution by 10 %. But in very steep sea states Forristall may be well on the safe side.

In present version of N-003, this correction is said to account for both non-linearity beyond second order and area effect. In next revision of N-003, one should use 10 % or somewhat less for non-linearities and consider area effect separately.

Conclusion: No immediate need for updating N-003. In the next revision it should be considered if a matured closed form distribution for non-linear crest height accounting for non-linearity and the reduction of extreme crest heights due to wave breaking.

4.3 Joint modelling of met-ocean characteristics

In the LOADS JIP the joint distributions of several dependencies are estimated, i.e., sea-state steepness, wind speed and storm duration, each is separately estimated conditional on the peak significant wave height. According to the JIP this should be done by applying the Heffernan and Tawn method and include suitable covariates, e.g., wave direction.

The Hefferman and Tawn approach is not sufficiently understood and matured among metocean and design engineers for being introduced as the default approach. It may well be that this approach will be recommended in future editions of N-003. But it is the committee's view that proper design of offshore structures can be done without introducing this method.

For the *all-sea-states approach*, N-003 recommends establishing a joint distribution of metocean characteristics by a standard conditional modelling, e.g. for joint modelling of H_s and $Tp;$ $f_{Hs}(h) \cdot f_{Tp|Hs}(t|h)$. The NORSOK N-003:2017 present an omni-directional joint modelling. In the text, however, a similar approach is advocated for various direction sectors. This can also be conditional for season if found convenient.

For the *all-storms-over-threshold* N-003 is recommending the so-called response-based approach proposed by Tromans and Vanderschuren. A joint model is normally not needed for the most important metocean characteristics. The long-term information is carried by the long-term distribution of the most probable largest storm response, i.e., the long term variability of storm peak significant wave height, associated spectral peak period and duration of most severe part of storm and their effect on the response under considerations. This assumes that the response problem does not experience a bad-behaviour nature, i.e., the probability of a wave-in-deck-event is assumed to be well below 10^{-4} per year.

If a joint model of metocean characteristics is needed for the all-storms-approach, it may well be that a Heffernan and Tawn approach is a better approach than the conditional modelling due to few very severe observations, in particular if analysis shall be done sector wise. However, method should be more matured among users.

Conclusion: No immediate need for updating of N-003. But it is important that case studies utilizing the methods recommended by LOADS are initiated so that engineers become familiar with the approaches before next updating of NORSOK N-003.

4.4 Estimation of directional extremes

From the LOADS JIP we noted two recommendations:

1. The LOADS study recommends using directional distributions continuously vary in the long-term analysis instead of the traditional sector wise approach.

2. If the directional extremes are estimated for N sectors, the sector return period should be scaled by N, but limited to the omnidirectional return period value.

The first recommendation is not considered to be of importance when performing a long-term analysis to estimate the directional extremes. The NORSOK-N standards are describing sector wise approach. We will continue recommending this for the all-sea-state approach. For storms-over-threshold approach fewer events are included and we are open for including a continuously varying directional distribution. However, further experience with the LOADS JIP recommendations is needed prior to introducing this to NORSOK-N standards. We would presently recommend a sector wise assessment, but the width of the sectors should vary and capture the changes of storm severity as an effort to have more data in the dominant sectors.

The second recommendation is supporting the simplified approach adopted by N-006 for directional extremes of individual wave heights, but LOADS JIP recommends scaling the return period requirement with the number of sectors and not half the number of sectors as is recommended by NORSOK N-006. We do not see the need for the suggested increased return period scaling as a general recommendation.

Conclusions: We see no need for immediate updating of NORSOK N-003. A full directional long-term analysis can be done with information presently available in N-003. Recommended distribution functions for – say- significant wave height and spectral peak period should be critically assessed when modelling the sector-wise joint distributions. Fetch and possible extreme wind speeds may affect the choice of distribution function for the various sectors.

4.5 Estimated characteristics for design and epistemic uncertainties

A fundamental proposal of the LOADS JIP is to include epistemic uncertainties in an LRFD design framework, i.e. characteristic values for design are obtained incorporating epistemic uncertainties in the analysis. However, the epistemic uncertainties that are included in the LOADS JIP is basically statistical uncertainties due a final number of observations that are included. Other epistemic uncertainties as for example model uncertainties are not considered. An example of such uncertainties is model uncertainties by adopting the GPD for a set of POT data.

Based on statistical theory, the Generalized Pareto is the asymptotically correct model. However, can we, by default, be sure that the distribution for an excess variable has reached the asymptotic shape?

A generalized Pareto distribution and a 2-parameter Weibull distribution for the excess of a threshold level are often more or less coinciding within the range of observations, but beyond observations they could deviate significantly.

In a full probabilistic design check using structural reliability methods, one should of course – in addition to aleatory variability - include all types of uncertainties (statistical uncertainties, uncertainties in choice of probabilistic model, uncertainties in structural dimensions, geotechnical uncertainties and load formula uncertainties) - quantitatively or qualitatively. Structural reliability analysis may well represent a preferred approach for special cases, but for routine design LRFD framework is more convenient also for jackets – in particular if bottom of steel is sufficiently high to avoid wave-in-deck.

The committee supports the NORSOK N-003 approach regarding ULS assessments. The committee is more concerned regarding ALS assessments. In most cases the partial safety factor for ALS is 1,0. The latest revision of N-003 is recommending that there should not be significant wave-in-deck impacts for the 10^{-4} – annual probability crest height level when storm surge and subsidence are properly accounted for. Since the loading on the structure will increase very fast with increasing submergence of bottom of steel (BOS), the committee is somewhat concerned regarding the ALS recommendations in N-003, as the method in ALS does not quantify a safety margin to account for epistemic uncertainties. However, NORSOK N-003 indicate that conservative choices should be made to include this uncertainty. In order to obtain a more rigorous implementation of such uncertainty, it is recommended that this should be further looked into in next revision of NORSOK N-003.

The committee agree with the LOADS JIP that uncertainties must be accounted for. However, the introduction of epistemic uncertainties in the determination of the characteristic values would require a thorough evaluation of the safety format in the ULS and ALS acceptance criteria and experience from the present practice. Hence, the committee is reluctant, at present, to change the established practise in the NORSOK standards. The committee recommends at present that the NORSOK strategy to:

— account for epistemic uncertainties in predicting wave conditions and possible hydrodynamic wave in deck loads by the partial safety factors in ULS and,

— by conservative choices in ALS

are maintained until a thorough evaluation is done possibly in connection with future updates of NORSOK N-standards.

Hence, it is tacitly assumed that the resulting effect of "normal uncertainties" are with good margin compensated for by the rule defined partial safety factors. It is, however, pointed out several places in NORSOK N-003 that uncertainties must be considered. In case a source of epistemic uncertainty has an effect comparable to the aleatory variability, action should be taken, but it is not suggested which action should be taken. Typically, the likely action would be to select a conservative approach.

For the all-sea states approach there is normally minor or no statistical uncertainty due to the high number of sea states. However, there are modelling uncertainties that should be accounted for, such as correlation effects.

A possible general strategy to account for modelling uncertainty is to consider several analysis approaches and select a slightly conservative value.

Conclusion: There is no immediate need for updating of N-003. But the committee for the next revision of NORSOK N-003 should consider if there is a need to strengthen the ALS recommendation regarding minimum airgap between wave crest and BOS and the possible inclusion of epistemic uncertainties. This is not merely of interest for jackets. Jack-ups, concrete gravity platforms and TLPs should also be kept in mind. This will also apply for semi-submersibles operating as floating production units. However, mobile offshore units are not required to comply with the NORSOK N standards.

4.6 Load calculations including non-linearities beyond 2. order and wave breaking with focus on wave-in-deck load.

LOADS JIP points out that is important to account for non-linearity beyond 2. order and effects of wave breaking. We do not disagree in that these effects shall be accounted for, but the importance of these effects for design of new jackets at the Norwegian continental shelf (NCS) can be discussed:

— Effect of non-linearities beyond second order:
  For the sea states expected to be governing regarding target actions and action effects for ULS and ALS design, the present practise of increasing second order results by 10 % is conservative. A new jacket should not be designed such that the probability of a significant wave-in-deck impact is larger than 10^{-4} per year.

— Effect of wave breaking:
  Breaking waves will be very important if they can hit topside structure as they break. For a new structure NORSOK N-003 aim to avoid this by ensuring a sufficient airgap. It is possible that a larger margin should be introduced in later revisions of N-003. If a breaking wave hit the jacket substructure will this be an important load case? At NCS a plunging breaking wave crest is likely to be significantly smaller that the than the 10^{-4} – annual probability crest height. N-003 requires that the slamming load of breaking waves shall be considered for both ULS and ALS. According to LOADS JIP, wave breaking will affect upper tail of the crest height distribution for the parameter, $\mu > 0{,}065$. Along the DNV steepness limit, this value of μ corresponds to a sea states steepness of 0,042 and a significant wave height of 14 m. A large effect, say 10 % reduction of the non-linear crest height percentiles or more, require a steepness beyond 0,052, corresponding to a significant wave height of 11 m. For a long term analysis of 10000-year crest height, the important sea state domain will be close to the top of the contour and wave breaking will most probably not affect the estimation of the 10000-year crest height.

We do not think that any designer plan to design a new jacket with wave-in-deck loading. LOADS JIP is when it comes to actions and action effects focusing on actions coming from wave-in-deck impacts, that means that LOADS JIP is especially relevant for existing structures and their problems.

Although methods advocated in N-003 can be used for existing structures, N-003 does not explicitly deal with steps to be taken for ensuring safety of existing structures. In case of existing structures, NORSOK N-006 (or internationally ISO 19901-9) should be consulted. Regarding wave in deck loading NORSOK N-003 recommends that, since wave in deck analyses are subjected to large uncertainties, analysis methods should be validated by high quality model tests. In model testing the higher order kinematics, wave breaking and area effects are implicitly taken into account.

Conclusions: No immediate need for updating NORSOK N-003. The LOADS JIP recommendations load calculations need further validation and digesting among Norwegian experts before it can be implemented to NORSOK N-003 at a later revision.

4.7 Existing structures and possible mitigations (de-manning)

The LOADS JIP follows an assessment process similar to that given in NORSOK N-006, including the possibility for both assessment by deterministic and probabilistic methods. The LOADS JIP suggests two ways to mitigate risk, more or less identical to those listed in NORSOK N-006:

1. Reduce the likelihood for having severe events by reducing load or increasing capacity, as also described in NORSOK N-006, clause 8.9.

2. Reduce the consequences of severe metocean events by preparing for de-manning of structure in very severe storm events, as also described in NORSOK N-006, Clause 6.

A difference between the NORSOK N-006 and the LOADS JIP recommendations is the de-manning criteria:

- NORSOK N-006 - For installations that does not comply with the ULS and ALS criteria related to metocean actions, N-006 describes how the unmanning criteria can be established. 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.
    - The guideline gives an annual probability exceedance requirement, providing a similar safety to that of manned structures.
    - In addition to the annual probability requirement, it is recommended that a constraint is imposed that limits the maximum exceedance probability during a forecasted storm. This ensures that the platform is unmanned in case an exceptionally severe storm is forecasted.
- LOADS JIP - an in-storm constraint, possibly at a $1 \cdot 10^{-4}$ level.

An example of the NOSOK N-006 and LOADS JIP criteria is illustrated in Figure 1.

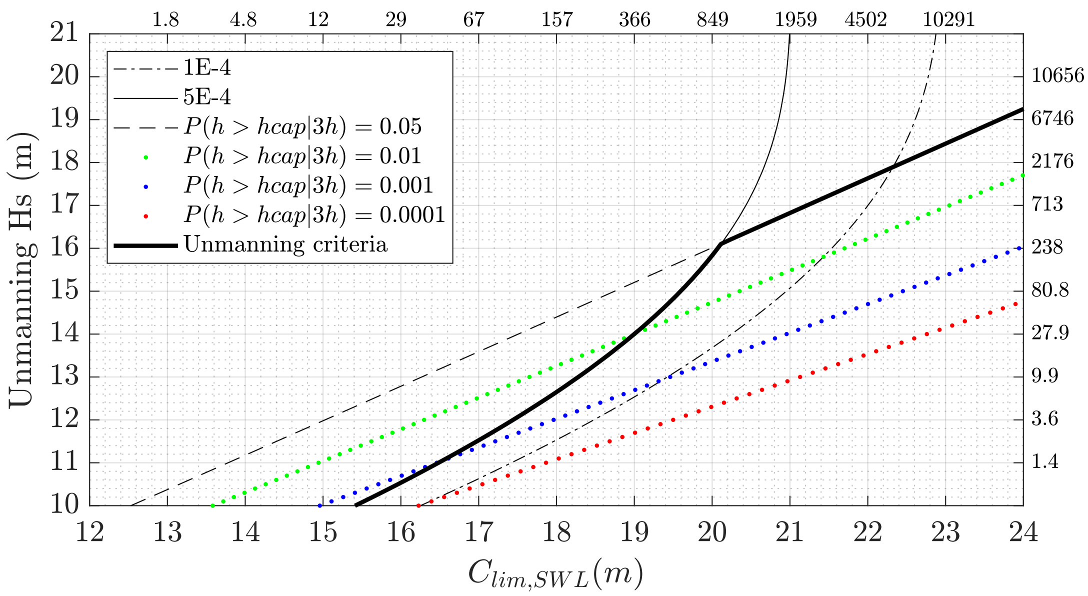

Figure 1: The solid black line indicates an example of the NORSOK N-006 criterion and the dotted red line indicates an example of the committee's understanding of the LOADS JIP criterion.

In NORSOK N-006 it is assumed that the same safety level related to structural integrity is achieved by unmanning for a characteristic metocean action of $5 \cdot 10^{-4}$ exceedance probability per year compared to a permanently manned installation that can withstand metocean actions with an annual probability of exceedance of $1 \cdot 10^{-4}$.

This assumption is based on the reasoning provided in NORSOK N-006, including:

— unmanning of the platform will mean that the probability of personnel being exposed to accidents caused by failure due to gross errors will be lower for platforms that are operated as unmanned during storms compared to manned platforms

— modification of tail behaviour of the long-term load distribution when platform is manned, because the unmanning threshold gives upper limits for sea states that are experienced when platform is manned.

In addition to the annual probability of exceedance criteria, NORSOK recommends establishing a criterion in the event that a severe storm is forecasted. However, no probability target is quantified in NORSOK N-006 for the in-storm criterion. The committee therefore recommended to include in N-006 a clear in-storm constraint to be used in combination with the annual probability of exceedance. Common practice in Norway is to use the 0,95 fractile peak criterion in a 3 hour-storm (equivalent to the DNV approach of 0,9 fractile peak criterion in a 6-hour storm).

NORSOK N-006 specifies that uncertainty and/or bias in weather forecasts should be accounted for, e.g., by reducing the threshold $h_{s,thr}$, by proposed safety margins that are tabulated in the standard.

The committee recommends that the quality of ensembles forecasts is assessed, and experience gained before ensembles are used operationally. The committee for the next revision of N-006 should consider if guidance on use of ensemble forecast shall be included in the next update of N-006. The uncertainty in the actual forecasted storm will then be better assessed.

The current NORSOK N-006 procedure has been used for over 15 years with acceptable results. The experience indicates that no wave in deck events on a non-demanned platforms have occurred where the procedure has been properly implemented.

It should be noted that NORSOK N-006 recommends that the characteristic strength of the structure should be used in the assessment, while the LOADS JIP use the mean value of the strength. The characteristic strength is typically 5-10 % lower than the mean strength.

Conclusions:

— There is no immediate need for updating the NORSOK N-006 standard. However, the next revision of NORSOK N-006 should consider including more detailed requirements regarding: The inclusion of forecast uncertainty.

— The constraint for a forecasted storm to be used in combination with the annual criterion.

In addition, the next revision could use learnings from the LOADS JIP and other experience more generally to update the procedures for assessing existing structures.

5. Concluding remarks regarding updating of NORSOK standards

The committee have not identified issues that would require an immediate update of the NORSOK N standards and considers the current versions of the NORSOK standards to give sufficient guidance to achieve the target safety level defined by the PSA.

The main challenge addressed in the LOADS JIP is related to wave-in-deck loading on a fixed jacket structure with insufficient airgap. For a new jacket structure designed according to the recommendations given in the current version of N-003 the annual probability of wave-in-deck should be less than 10^{-4} and, hence, there should be no need for wave-in-deck considerations.

For existing jacket structures with insufficient airgap, the safety for personnel and the environment is commonly mitigated by shutting down and unmanning. The challenge is then to estimate the limiting sea state for initiating shut-down and unmanning. N-006 provides a procedure to estimate the limiting sea state based on the annual probability of exceedance. In the next revision of N-006 it is recommended to explicitly also provide a maximum allowable probability of exceedance for the actual forecasted storm.

The LOADS JIP have developed some interesting methods and tools that should be thoroughly evaluated and considered implemented in later revisions, if they are further matured and validated by a wider group. Metocean engineers and design engineers involved in practical design of offshore structures should be involved in the evaluation.

The LOADS JIP have led to several ongoing activities (HSE, Energy Institute, IOGP, API, ISO), and it is recommended to consider the outcome of these prior to the next revision. Furthermore, we recommend verifying the consensus between the methods developed by the LOADS JIP and the AWARE project.

The estimation of wave-in-deck loading is an extremely difficult task that involves large uncertainties. This is further confirmed by the large difference between the estimated wave-in-deck loads by OCG (using the LOADS JIP procedure) and DNV (using CFD and event matching).

The committee foresees a new revision of NORSOK N-003 around 2025 and expect that there will be a wider understanding and validation of the methods proposed by the LOADS JIP by then.