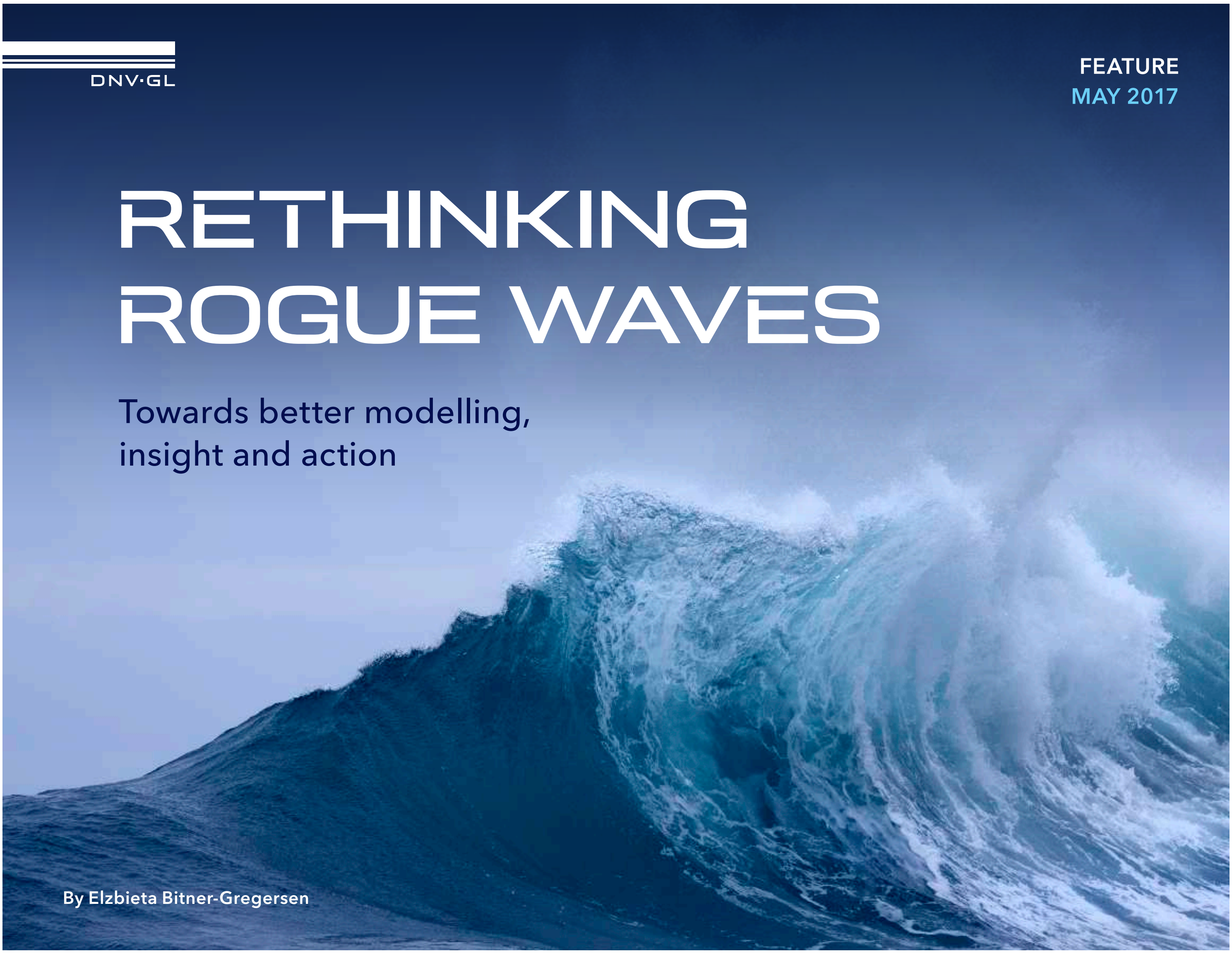

FEATURE
MAY 2017

RETHINKING ROGUE WAVES

Towards better modelling, insight and action

By Elzbieta Bitner-Gregersen

Rogue waves are real, and, surprisingly, not so rare. They present the shipping and offshore industry with important questions: which ocean regions will be most affected by such waves? Should rogue waves be accounted for in design? If so, how best to do so?

These and other important questions, not least the impact of climate change on future sea states and rogue waves, are surfacing as research work progresses.

Rogue waves – also called freak, abnormal, or giant waves – are very steep and much larger than the surrounding waves. They may occur in low, intermediate and high sea states. The existence of these exceptionally large waves – much higher, steeper, and more dangerous than those

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expected for a given sea state – has always been a part of maritime folklore. For centuries, sailors have reported giant waves appearing from 'nowhere'.

For a long time such events were believed to be mostly anecdotal, but in recent decades new, more reliable measurements (see Figure 1) and advances in wave modelling have confirmed the existence of rogue waves. These abnormal waves have received considerable attention, both in the media and in the scientific community, and also in the shipping and offshore industries through larger research programmes, meetings, workshops, and conferences all dedicated to the rogue wave phenomenon.

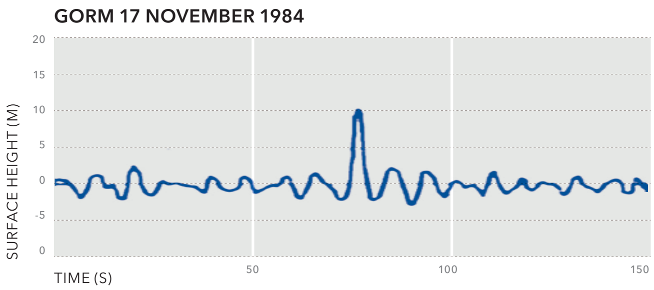
In 1826, French explorer and naval officer, Captain Jules Dumont d'Urville, reported encountering a wave more than 100 feet in height in the Indian Ocean grown as a wall of water.

Definitions and probabilities

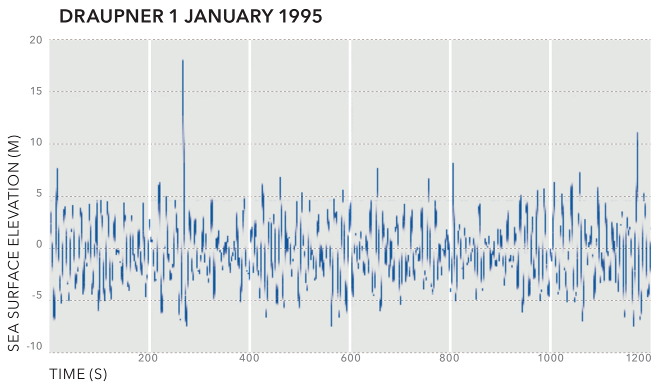
The mechanisms of rogue waves and their detailed dynamic properties are becoming clearer with recent research and through a growing consistency between numerical models and the experimental data documented by many studies. Several different mechanisms may be responsible for generating these waves such as linear focusing of energy, wave-current interactions (e.g. observed in the Agulhas current alongside the southeast coast of South Africa), crossing seas (wind sea and swell or two swell systems), quasi-resonant nonlinear interactions (modulational instability), shallow water effects and wind [5,6,7].

Several rogue wave-related accidents involving ships and offshore structures have been reported, and yet, as of today, rogue waves are not explicitly included in classification society rules and offshore standards. This is understandable, due to a lack of consensus on the precise definition of rogue waves. Without a specific definition, there is also no agreement either on the probability of occurrence of such waves, being still a subject of research.

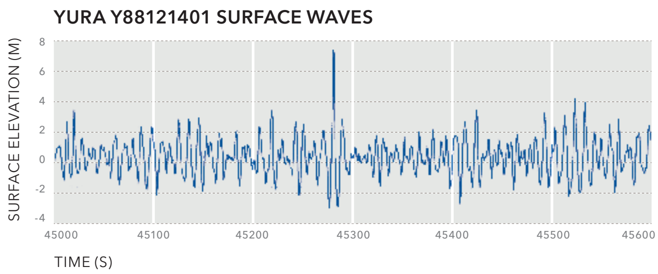
FIGURE 1: Examples of some observations of rogue waves



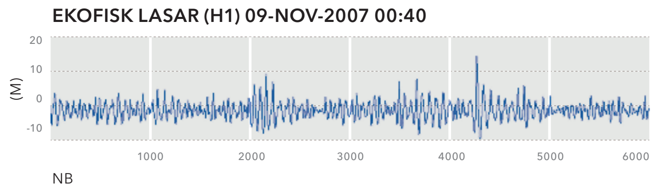
Rogue wave recorded at the Gorm platform in the North Sea, Dysthe et al. (2008)[1].



Rogue wave recorded at the Draupner platform in the North Sea, Haver (2000)[2].



The Yura wave recorded in Sea of Japan, Mori et al. (2002)[3].



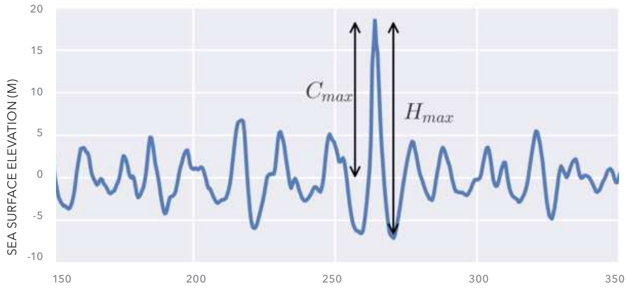
The Andrea wave recorded at the Ekofisk field, Magnusson and Donelan (2013)[4].

While different definitions of rogue waves are proposed in the literature, a common and simple approach is to define a rogue wave as a wave whose wave height or crest height exceeds some thresholds related to the significant wave height Hs (an average of one third of the highest waves in a wave record), such as the criteria proposed by Haver[2],

$$\frac{H_{max}}{H_s} > 2 \quad \text{AND/OR} \quad \frac{C_{max}}{H_s} > 1.25$$

where Hmax denotes the zero-crossing wave height, Cmax is the crest height, and Hs is typically calculated from a 20-minute measurement of the surface elevation (see Figure 2).

FIGURE 2: The New Year wave that was recorded at the Draupner platform on 1st January 1995. The maximum wave height and crest height are indicated.



On the basis of the simple definitions given by the example above, rogue waves are not so rare. The second-order wave model, which in many cases gives a satisfactory description of the probability of rogue wave occurrence, shows that we may expect rogue waves in a specific ocean location to occur about once every 8 days[8]. However, a freak wave is not necessarily critical for a specific design, as this is obviously case-dependent and is, for example, different for the design of offshore platforms and the operation of small fishing vessels. If, in addition to the wave crest and wave height criteria, a requirement of the severity of the sea state is included (e.g., Hs > 8m), then the corresponding probability of occurrence is reduced.

The significance of severe sea state conditions may grow in some ocean regions in the future owing to global warming[9], and this may also suggest more extreme waves[10]. The topic was addressed in the Research Council of Norway project ExWaCli (Extreme Waves and Climate change: Accounting for uncertainties in design of marine structures), https://www.dnvgl.com/technology-innovation/sri/maritime-transport/extreme-waves-project.html

Impact on loads and responses

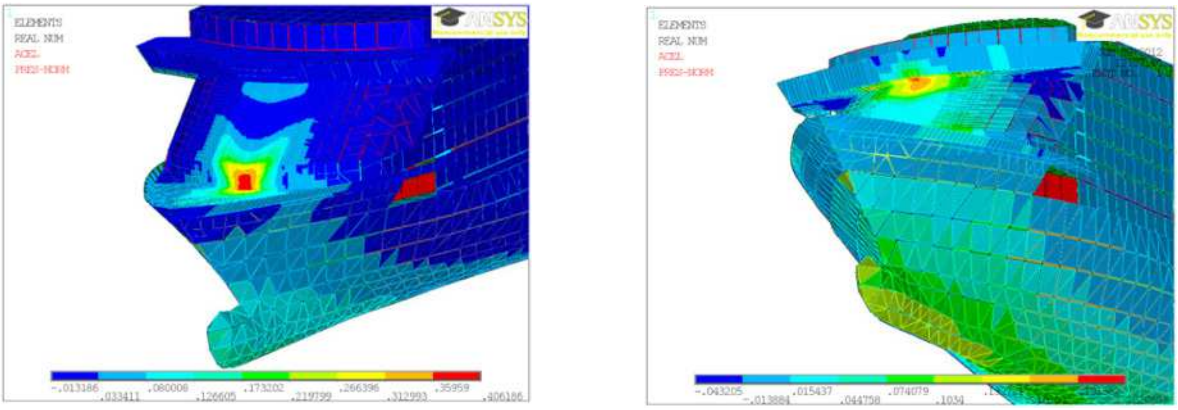
The rules and standards of classification societies are dynamic, and are continually updated to account for state-of-the-art knowledge. Formal recognition of the existence of rogue waves has caused understandable concern about the impact such waves may have on ships and offshore structures. DNV GL intends to remain at the forefront of the research-based development of rules and standards for design and operations of marine structures, and has therefore been an active participant in investigations on rogue waves. Our Research unit has initiated and managed research projects funded by the European Commission, and broader joint industry projects funded by the marine industry in which our operating units have been directly involved[7]. A good example of the kind of broad participation this topic has attracted is the EC EXTREME SEAS (Design for Ship Safety in Extreme Seas) project coordinated by DNV GL's Research unit.

Studies so far have demonstrated that rogue waves may have a significant impact on loads and responses of ships and offshore structures. These waves may affect both global and local loads of ships and offshore structures, and, consequently, their design. High rogue waves are the most dangerous regarding structural integrity, but low and intermediate rogue-prone sea states are also expected to impact on the operation of ships and offshore structures, and may also affect weather-restricted design, as well as design of local loads.

> **THE MECHANISMS OF ROGUE WAVES AND THEIR DETAILED DYNAMIC PROPERTIES ARE BECOMING CLEARER WITH RECENT RESEARCH.**

Although, a systematic revision of classification society rules and offshore standards has not taken place, some of the DNV GL rules for design of superstructures of

FIGURE 3: The cruise ship analysed in EXTREME SEAS by the ship yard Meyer Werft.

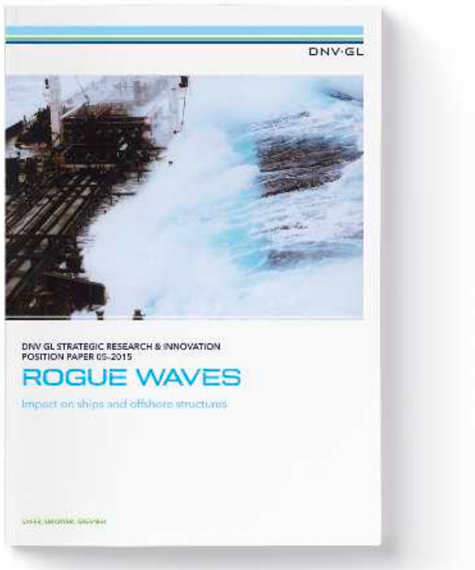


passenger ships have been revised to account for rogue waves as a result of the aforementioned EC EXTREME SEAS project (see Figure 3).

Furthermore, following the lead set by Statoil a simple requirement that accounts for rogue waves, when designing the height of a platform deck, was introduced recently in the revised version of the Norwegian Standard NORSOK[11].

The DNV GL position paper on Rogue Waves provides a summary of the state-of-the-art knowledge on rogue waves and their impacts on marine structures in general, and ships in particular, https://www.dnvgl.com/technology-innovation/rogue-waves/

Knowledge about extreme and rogue waves gathered through our participation in research on this topic has encouraged us to initiate implementation of these waves in our wave-structure interaction codes. Such upgraded tools are needed for assessment of loads and responses in situations with rogue waves. They will allow us to reach research-based decisions regarding possible revisions of our rules and standards. A short technical summary of this development is given below.



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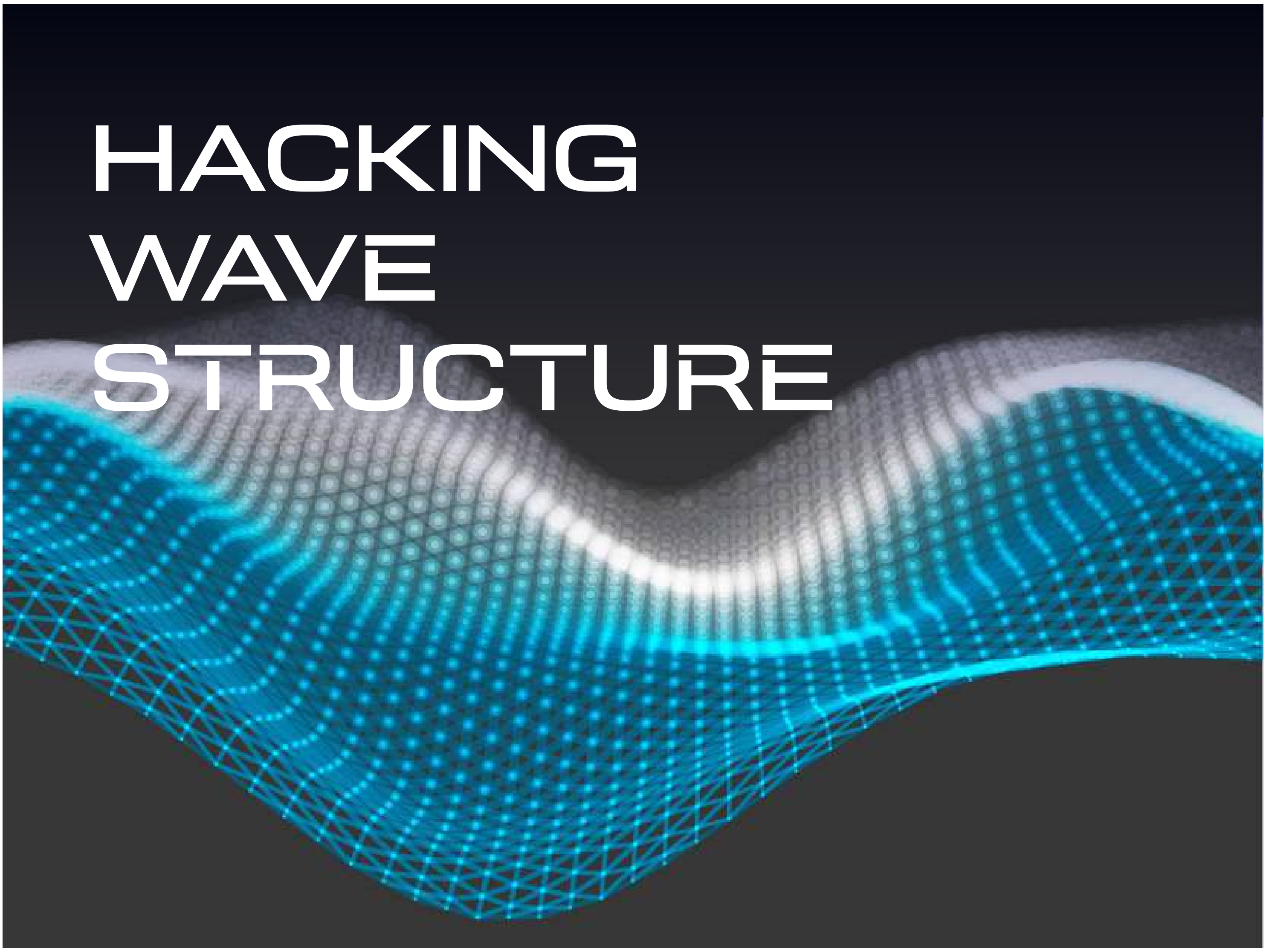
HACKING WAVE STRUCTURE



Next generation wave-structure interaction codes

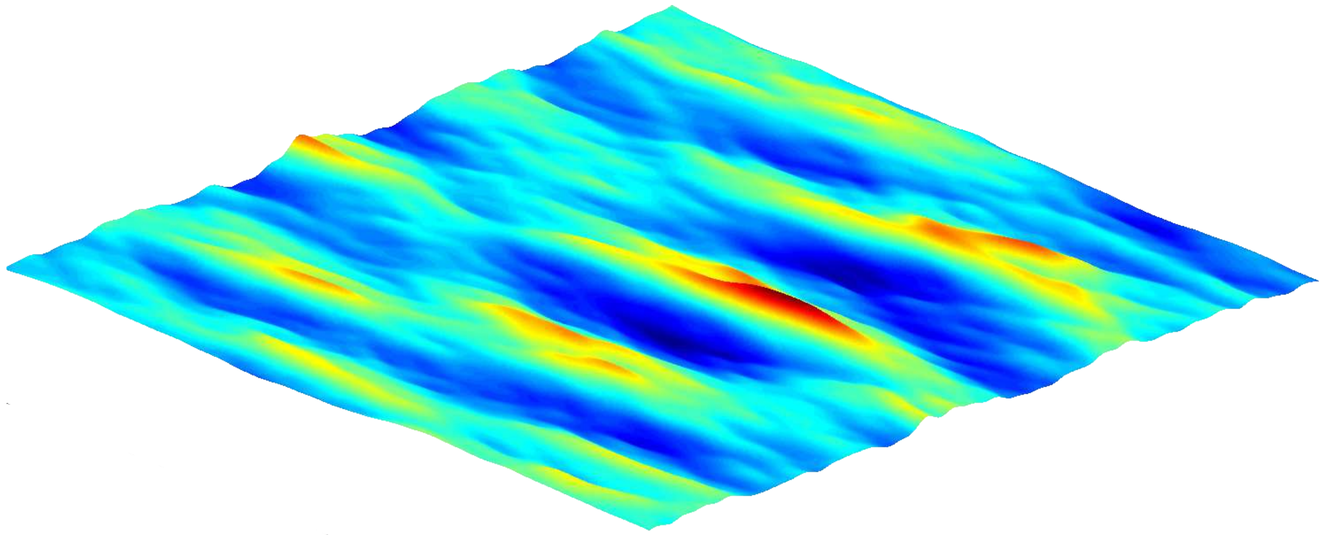
Traditionally, the shipping industry has used linear irregular waves as input to numerical codes for calculations of structural loads and responses, while nonlinear second order irregular waves are applied currently by the offshore industry when assessing loads and responses of offshore structures. Neither linear nor second order wave models are able to realistically describe very steep waves and both models fail to correctly predict abnormal events such as rogue waves. The introduction of nonlinear waves beyond the second order as input to the wave-structure interaction codes is necessary in this case.

Further, the increasing use of Computational Fluid Dynamics (CFD) in ship and offshore structure analysis requires proper descriptions of very steep waves that can be obtained from nonlinear wave models. Very steep nonlinear waves will have a significant impact on water particle kinematics, for which proper descriptions are very important for design and marine operations. Breaking waves, traditionally not accounted for in design, are also receiving growing attention in the marine industry owing to their effect on loads and responses. Combining input from nonlinear wave models with CFD analysis in these respects is essential and will provide support to model tests.

In DNV GL, implementation of nonlinear waves in wave-structure interaction codes has already been initiated via a cross-functional research and business operations team. A nonlinear wave code based on the Higher Order Spectral Method (HOSM)[12] is used in this process.

The HOSM code developed by the University of Turin and first caught DNV GL's attention during participation in the EC Marie-Curie Network SEAMOCS workshop (Applied Stochastic Models for Ocean Engineering, Climate, and Safe Transportation), http://www.maths.lth.se/seamocs/info/Seamocs. It was brought to DNV GL Research and modified to study ocean waves. The code was used in SEAMOCS and the EC EXTREME SEAS project to investigate physical and statistical properties of waves beyond the second order, and was shown to be a very successful tool for this purpose. The numerical predictions coincided well with experimental and field data. Recently, DNV GL Research has developed its own HOSM code which allows prediction of wave properties not only on the water surface (see Figure 4) but also in the water column, providing essential information for calculations of structural loads and responses. The code accounts also in a simple way for wave breaking.

Figure 4: Sea surface simulated by the DNV GL HOSM code.



In 2015, as part of an internal project titled 'HOSM in Sea-keeping', we established an interface between HOSM and the DNV GL 3D Panel code, WASIM. This enabled the sea-keeping code to be run with more realistic nonlinear waves as input. A subsequent project "Nonlinear Wave Model and CFD Interfacing" extended this work and developed an interface between HOSM and the CFD code Star-CCM+, providing nonlinear wave kinematics in the CFD domain covering the structure (Figure 5).

DNV GL HOSM

HOSM (Higher Order Spectral Method) is a numerical method for solving the nonlinear equations for waves on the water surface. The method was first developed independently by West et al.[12] and Dommermuth et al.[13]. One of the main advantages of HOSM is that it provides a very efficient way to describe nonlinear waves, which makes it suitable for applications where a large amount of wave data is required.

DNV GL Research has developed its own HOSM code, that in addition to describing the wave surface, also calculates the wave kinematics below the waves (that is, for example, water velocities and accelerations, water pressure, and so on). Knowledge of the wave kinematics is essential for e.g. calculation of wave loads on structures. In recent projects the DNV GL HOSM code has been successfully coupled with other tools such as the seakeeping code WASIM and CFD code, providing realistic nonlinear wave input to these tools.

DNV GL RESEARCH HAS DEVELOPED ITS OWN HOSM CODE, THAT IN ADDITION TO DESCRIBING THE WAVE SURFACE, ALSO CALCULATES THE WAVE KINEMATICS BELOW THE WAVES.

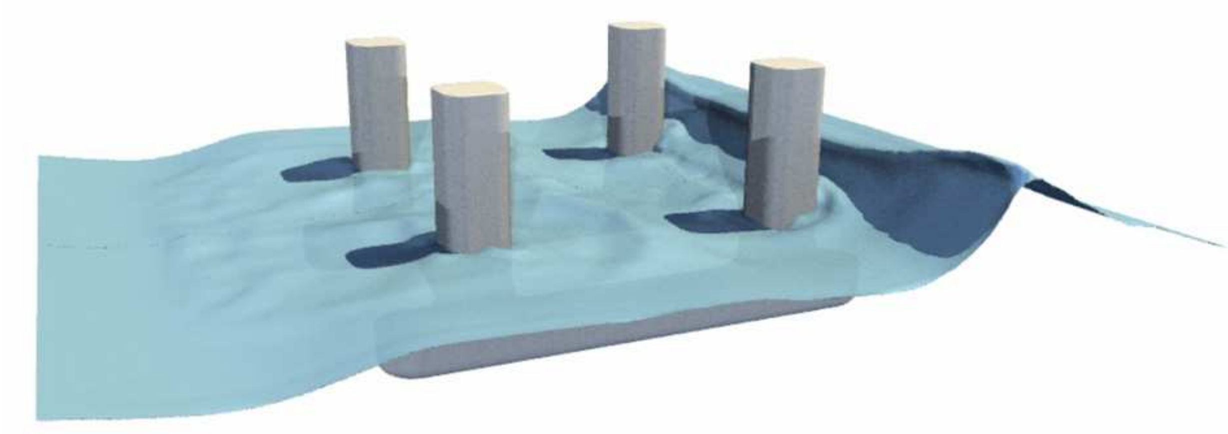
The interface was validated through a case study of a semi-submersible and the effects of using linear and nonlinear waves as input for predictions of loads and responses were investigated. As expected, significant differences were identified. It was shown that when using more realistic nonlinear wave input, a smaller CFD domain may be used, due to a reduction of the wave's evolution time, saving precious and expensive computational time.

This work needs to continue to be able to evaluate the existing margins in the classification rules and offshore standards which need to be known before firm decisions are reached regarding inclusion of nonlinear and rogue waves in rules and standards. Retaining the current safety level in rules and standards during this process is crucial.

Warning criteria

In addition to be able to describe rogue waves properly through the use of nonlinear wave models, another important topic is whether we are able to develop warning criteria for in what types of sea states such waves are more likely to occur. Existing warning criteria for rogue waves are not fully developed and nor are they sufficiently reliable.

FIGURE 5: Semi-submersible; interface between HOSM and Star-CCM+.



The animation shows computational fluid dynamics (CFD) simulation of a very steep breaking wave hitting a semi-submersible. As input to the CFD, simulation nonlinear waves from the DNV GL HOSM code were used.

Such criteria may increase safety at sea and affect the planning and execution of operation of ships and offshore structures. The development of warning criteria remains a high priority topic within the scientific community, and for the ship and offshore industries. This topic is addressed by the ongoing research project ExWaMar (EXtreme wave WArning criteria for MARine structures), funded partly by the Research Council of Norway and coordinated by DNV GL https://www.dnvgl.com/technology-innovation/sri/maritime-transport/exwamar.html. The project will be completed in 2019. The Norwegian Meteorological Institute and the University of Oslo participate in the project.

ENDNOTES

1 Dysthe, K., Krogstad, H.E. and Müller, P., 2008. Oceanic rogue waves. Ann. Rev. Fluid Mec., 40, 287-310.

2 Haver, S., 2000. Evidences of the existence of freak waves. Proc. Rogue Waves, 2000. Ifremer, 129-140.

3 Mori, N., Liu, P., Yasuda, T., 2002. Analysis of freak wave measurements in the Sea of Japan. Ocean Eng. 29 (11), 1399–1414.

4 Magnusson, A.K. and Donelan, M.A., 2013. The Andrea wave. Characteristics of a measured North Sea rogue wave. JOMAE 135, 1-10.

5 Kharif C, Pelinovsky E, Slunyaev, A., 2009. Rogue waves in the ocean. In: Advances in geophysical and environmental mechanics and mathematics. Springer, Berlin.

6 Onorato M, Residori S, Bortolozzo U, Montina A, Arecchi FT, 2013. Rogue waves and their generating mechanisms in different physical contexts. Phys Rep 528:47–89.

7 Bitner-Gregersen, E.M. and Gramstad, O. (2016). Rogue waves. Impact on ship and offshore structures. DNV GL R&I Position Paper, 05-2015, issued March 2016. https://www.dnvgl.com/technology-innovation/latest-publications.html

8 Bitner-Gregersen, E.M. and Hagen, Ø., 2004. Freak Wave Events within the 2nd Order Wave Model. Proc. OMAE-2004, June 20-25 2004 Vancouver, Canada.

9 IPCC, 2013. Climate Change 2013: The Physical Science. Contribution of Working group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

10 Bitner-Gregersen, E.M. and Toffoli, A. (2015). Wave steepness and rogue waves in the changing climate in the North Atlantic. Proc. OMAE 2015, May 31 - June 5, 2015, St. John's, Newfoundland, Canada

11 Norwegian Standard NORSOK (2017), Edition 3 of NORSOK N-003 Actions and action effects (N-003:2017)

12 West, B.J., Brueckner, K.A., Jand, R.S.,Milder, D.M., Milton, R.L., 1987. A new method for surface hydrodynamics. J Geophys Res. 92:11803–11824

13 Dommermuth, D.G., Yue, D.K., (1987). A high-order spectral method for the study of nonlinear gravity waves. J. Fluid Mechanics 184, 267–288.