Intrinsic variability in wave parameters and effect on wave statistics

Elzbieta M. Bitner-Gregersen and Anne Karin Magnusson
Banff, 28 October 2013

Elzbieta Bitner-Gregersen
28 October 2013
EXTREME SEAS
Design for Ship Safety in Extreme Seas

- **Work Programme:**
  
  2008, *Cooperation Theme 7, Transport*,
  7.2 Sustainable Surface Transport (SST),
  FP7- SST – 2007- RTD-1

- **Activity:** 7.2.4 Improving Safety and Security

- **11 Partners from six European countries.**

- **Starting Date:**
  
  1st Sept. 2009 – 30 April 2013

- **Coordinated by DNV; with the overall objectives:**

  - To develop technology and methodology that need to be a part of design for ship safety in extreme seas.
  - To develop *warning criteria for extreme sea states* for marine structures.
  - To help shipping industry *to adapt to climate change.*

- **Budget: 4.1 million Euro**
The sea floor at the Ekofisk field is subsiding due to the oil extraction, and constructions are therefore more and more exposed to wave forces.

«EXWW» are special procedures developed between Phillips Petroleum - now ConocoPhillips - and MET-Norway to ensure safe activity offshore.

In this, monitoring of environmental parameters in real time is of primary importance.
ExWaCli
Extreme waves and climate change: Accounting for uncertainties in design of marine structures

- The Research Council of Norway (RCN) project
- Funded: 40% by RCN, 60% by the Partners
- Partners
  - DNV
  - The Norwegian Meteorological Institute
  - The University of Oslo
  - Expected external participants
- Starting Date:
  1st January 2013 – 30 December 2015

- Managing by DNV; with the overall objectives:
  - To understand how climate change will impact wave conditions in the northern areas the 21st century and specifying uncertainties associated with the predicted changes;
  - To suggest an integrated approach that handles the uncertainties associated in climate change projections and to take this into account in current design and operation of marine structures.
  - Recommendations for design and operations of marine structures.
- Budget: ca. 1.3 million Euro
Background for the study
Uncertainties

- **The oceanographic community** has always been concerned with providing environmental models and data which approximate the physics of the ocean in the most accurate way.

- **The marine industry**, on the other hand, needs accurate data and models for design purposes.

- Although **uncertainties** of data and models were discussed **before the 1980’s**, they were not systematically quantified.

- Further development of the **Structural Reliability Analysis (SRA) methodology** (Madsen et al., 1986) and their implementation by some parts of the industry in the 1980’s has brought **much focus onto the uncertainties associated with environmental description**. SRA allows quantification, in a probabilistic way, of the uncertainties in the different parameters that govern structural integrity.
Background for the study
Uncertainties

Uncertainties

- Aleatory (physical) uncertainty
- Epistemic (knowledge) uncertainty

Bitner-Gregersen and Hagen (1990, J. Marine Safety) proposed classification of met-ocean uncertainties. The proposed definitions were later generalised and included in DNV Rules (DNV, 1992).

- Data uncertainty
- Statistical uncertainty (sampling variability, fitting procedure)
- Model uncertainty (physical model, adopted distributions to fit the data).
- Climatic uncertainty (different time periods which the data sources cover as well as different locations they represent).

- The true value $\tau$ of a quantity considered is an ideal number which can be known only if all sources of error are eliminated (bias and precision).

- Sampling variability – uncertainty due to limited numbers of observations.
  - Usually measurements 17.5-30 min.

- Random sea.
- Statistics of sea surface will be influenced by this uncertainty.
Intrisic variability in wave parameters and effect on wave statistics

Sampling variability of Hs and Tz

- **Significant wave height Hs** is defined as an average of one third of the largest waves in a wave time series and is commonly evaluated using 17.5 or 30 minutes long recordings. It can also be calculated from a wave spectrum Hm0.

- **Zero-crossing wave period Tz** (or Tm02)

- **Donelan and Pierson (1983)** investigated both laboratory and field data and obtained 8% variability for Hs.

- Sampling variability of Hm0 and Tm02 - the formulae are given in **Bitner-Gregersen and Hagen (1990)**. Uncertainties of data for the offshore environment. *Structural Safety*, Vol. 7.

\[
\text{var}(H\hat{M}0) = \frac{4}{\hat{M}_0} \text{var}(\hat{M}_0)
\]

\[
\text{var}(T\hat{M}02) = \pi^2 \left( \frac{\text{var}(\hat{M}_0)}{\hat{M}_0 \hat{M}_2} - 2 \frac{\text{cov}(\hat{M}_0, \hat{M}_2)}{\hat{M}_2^2} + \hat{M}_0 \frac{\text{var}(\hat{M}_2)}{\hat{M}_2^3} \right)
\]

\[
\text{cov}(H\hat{M}0, T\hat{M}02) = 2 \pi \left( \frac{\text{var}(\hat{M}_0)}{\hat{M}_0 \sqrt{\hat{M}_2}} - \frac{\text{cov}(\hat{M}_0, \hat{M}_2)}{\hat{M}_2^{3/2}} \right)
\]
Sampling variability of Hs and Tz

- The sampling variability standard deviation (in %) of for the JONSWAP spectrum; Bitner-Gregersen and Hagen (1990)

<table>
<thead>
<tr>
<th>Hs (m)</th>
<th>Tm01 (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-4</td>
<td>3.3</td>
</tr>
<tr>
<td>5-6</td>
<td>3.8</td>
</tr>
<tr>
<td>7-8</td>
<td>4.4</td>
</tr>
<tr>
<td>9-10</td>
<td>5.1</td>
</tr>
<tr>
<td>11-12</td>
<td>6.7</td>
</tr>
<tr>
<td>13-14</td>
<td>8.0</td>
</tr>
<tr>
<td>15-16</td>
<td>9.1</td>
</tr>
</tbody>
</table>

- Validation by Ekofisk data

- Continuous measurements of wave profile at 2Hz sampling rate are gathered in 60 minutes time series.
- 22 consecutive windows of 17.5 minutes length, with increment of 2 min over each 60 minutes records, are used to evaluate sampling variability of Hs and Tz.
One day of Ekofisk data
Comparing Hs and Tz over different sampling periods

- Significant wave height Hs

- Zero-crossing wave period Tz

---

Intrinsic variability in wave parameters and effect on wave statistics
28 October 2013
© Det Norske Veritas AS. All rights reserved.
Standard deviation in % of the 17.5 minute values of wave height or period as function of the 60 minutes values

- Significant wave height $H_s$
  - $\text{SIG}(H_s|17.5\text{min})[\%]$
  - $0$ to $12$
  - $H_s(60\text{min})[m]$ from $0$ to $12$
  - (5.5-5.6%)

- Zero-crossing wave period $T_z$
  - $\text{SIG}(T_z|17.5\text{min})[\%]$
  - $0$ to $12$
  - $T_z(60\text{min})[m]$ from $0$ to $12$
  - (2.5-2.6%)

The standard deviations are seen to be very variable. The spread is though higher for $H_s$ than for $T_z$ (TM02), showing similarity with numbers given in the tables from Bitner-Gregersen and Hagen, 1990.

(ongoing work)
Intrisic variability in wave parameters and effect on wave statistics

28 October 2013

Hs comparison (sensors and time averaging)

**Hourly averages have higher correlations**

**Hs\_LASAR = 0.99 \cdot Hs\_WR + 0.28**  
Corr=0.95 (1-hourly)

**Hs\_MRF = 0.86 \cdot Hs\_WR + 0.5**  
Corr = 0.93 (1-hourly)

Hs = 5 m: 5% lower  
Hs = 10 m: 10% lower
Sampling variability in wave parameters and effect on wave statistics

- Higher order moments will be more affected
- Simulated skewness; realizations per seastate and average value as function of number of simulations; Torsthaugen spectrum $H_s=12\text{m}, T_p=19.6\text{s}$
  - 2D - 350 simulations of a 1024s timeseries at 4Hz
  - 3D - 250 repetitions of a 1024s timeseries at 4Hz

Sampling variability will affect short-term and long-term description of sea surface

- Short-term description
- Numerical simulations
  - Laboratory tests
  - Distributions of sea surface and wave parameters, e.g. crest distribution, see Hagen (2007).
  - Spectral description

- Long-term description
- Long-term distributions
  - Validation of wave spectral models
  - Design and operational met-ocean criteria impact on design of marine structures.

Skewness vs simulation length; Torsethaugen, $H_S=12\text{m}, T_p=19.6\text{s}$

Bitner-Gregersen and Hagen (2003)
Sampling variability in wave parameters and effect on short-term wave statistics

- Extreme waves, 2\textsuperscript{nd} order wave model

  - Extreme waves, 2\textsuperscript{nd} order wave model
  - Simulated exceedance probability for crest/$h_s=1.1$ and 1.2 for a random crest. Results both for nominal $H_s$ and random $H_s$. 2\textsuperscript{nd} order wave model, long crested sea (2D), JONSWAP spectrum, Bitner-Gregersen and Hagen (2004)

- 2\textsuperscript{nd} order wave model, $C_{\text{max}}/H_{4\text{std}}$

  - Wave crest factor for nominal and simulated significant wave height, long crested sea (2D), PM spectrum, Bitner-Gregersen and Magnusson (2004)
Intrinsic variability in wave parameters and effect on long-term wave statistics

- The Torsethaugen spectrum

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total sea</th>
<th>Wind sea</th>
<th>Swell</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$ (m)</td>
<td>16.91</td>
<td>3.08</td>
<td>16.63</td>
</tr>
<tr>
<td>$T_p$ (s)</td>
<td>17.44</td>
<td>7.42</td>
<td>17.44</td>
</tr>
</tbody>
</table>

- Total $H_s$ increased by 1m ($\approx 1\sigma$)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total sea</th>
<th>Wind sea</th>
<th>Swell</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$ (m)</td>
<td>17.91</td>
<td>1.19</td>
<td>17.87</td>
</tr>
<tr>
<td>$T_p$ (s)</td>
<td>17.44</td>
<td>4.73</td>
<td>17.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total sea</th>
<th>Wind sea</th>
<th>Swell</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$ (m)</td>
<td>15.55</td>
<td>15.55</td>
<td>0.32</td>
</tr>
<tr>
<td>$T_p$ (s)</td>
<td>16.36</td>
<td>16.36</td>
<td>18.47</td>
</tr>
</tbody>
</table>

- Sampling variability will impact long-term distributions

Bitner-Gregersen and Toffoli (2009)
Conclusions

- **Sampling variability** represent an important uncertainty in description of ocean waves; it needs to be accounted for.

- Sampling variability of Hm0 and Tm02 derived from the theoretical formulas due to Bitner-Gregersen and Hagen (1990) compared well with field data from Ekofisk.

- It has significant impact on short-term and long-term wave statistics.

- It needs to be considered in model tests, numerical simulations.

- Important for validation of wave spectral models.

- It has impact on met-ocean design and operational criteria.

- The present study is preliminary and ongoing.
Intrisic variability in wave parameters and effect on wave statistics

THANK YOU FOR YOUR ATTENTION
Safeguarding life, property and the environment

www.dnv.com