Part II

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Directional Metocean Extremes and Failure Modes

- Turbulence:
  - Oceanic turbulence
  - Atmospheric turbulence

For fully developed turbulence, the velocity fluctuates over a large range of coupled spatial and temporal scales.

\[ u(t) = \bar{u} + u'(t) \]

- Stream velocity
- Mean velocity
- Turbulent fluctuation
Directional Metocean Extremes and Failure Modes

- Between 2001 and 2011, there were 21 mooring failures—an average of more than two per year (Kai-Tung Ma, OTC.13, paper OTC-24025-MS). Nine were multiple-line failures.

- 23 permanent mooring failures since 2000, and four of those were categorized as catastrophic, with riser failure and extended field shutdown. (Granherne, OTC.13, OTC-24181).

- 20 floating production systems (FPS) had integrity issues requiring intervention and 150 mooring lines were repaired or replaced across 33 FPS (Sai Majh, of Granherne).

### North Sea: multiple mooring line failures incidences

<table>
<thead>
<tr>
<th>Year</th>
<th>Name</th>
<th>Type</th>
<th>Cause</th>
<th>No. Lines Broken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>North Sea Pioneer</td>
<td>Semi-sub (FPF)</td>
<td>Large waves and strong winds</td>
<td>ALL</td>
</tr>
<tr>
<td>1994</td>
<td>Petrojarl 1</td>
<td>FPSO</td>
<td>Large waves and strong winds</td>
<td>4 of 8</td>
</tr>
<tr>
<td>2004</td>
<td>Ocean Vanguarg</td>
<td>Semi-sub (drilling)</td>
<td>Large waves and strong winds</td>
<td>2 of 8</td>
</tr>
<tr>
<td>2011</td>
<td>Gryphon</td>
<td>FPSO</td>
<td>Heading control power loss</td>
<td>4 of 10</td>
</tr>
</tbody>
</table>

Ref.: Implications of Potential Mooring Regulation Change on UKCS Installations Carolyne Claxton, 22/11/2013

…..cost an estimated US$1.8billion to reinstate

It’s important therefore to ensure that design methodology assumptions are correct, reflecting worse-case scenarios.
Directional Metocean Extremes and Failure Modes

Wave:
- Swell: Persistent long-period swells from the SSW with uncorrelated low-intensity wind and current;
- Sea: Generated by SW locally monsoon wind
- Current: High-surface current

Wind:
- Moonsoon wind
- Squalls that are short duration (typically one hour) with very high wind speeds (5sec gust greater than 30 m/s);
- Squalls typically originate over land and propagate over the ocean, but locally can be incident from almost any direction
- Squalls are difficult to forecast accurately and varies in intensity and direction
Directional Metocean Extremes and Failure Modes

- A current design methodology
  - Constant wind speed approach
  - Does not give a good level of confidence in the conservatism achieved
  - Factor of safety is unclear

- Conservatism of constant wind case is not clear:
  - Over-estimation of responses?
  - Under-estimation of responses?

Figure 2.7: Spread-moored FPSO response to Squall versus constant wind (Legerstee, et al. 2006)
Directional Metocean Extremes and Failure Modes:

Wind
Bonga fpso
Metocean engineering

Real-time Data

Long-term Field Data

Operational MetOcean
- operational support
- operational planning
- ocean / weather forecasting
- workability statistics
- risk assessment

MetOcean Design & Analyses
- design criteria: platforms, riser, pipelines, floating structures
- tow / transportation criteria
- site-specific conditions
- oil spill modeling
- fatigue analysis

beneficial to operations and engineering improvement
reduce downtime and risks
significant impact on safety, efficiency, and cost
Metocean requirements for each development phase

**PHASE**

- **Rig Selection and Riser Design**
  - Overview of key metocean processes and hazards for the location.
  - Extreme wind, wave and current (1, 10, 100-year return).
  - Monthly, seasonal and all-year operational wind, wave and current statistics.
  - Current profile characterisation.

- **Operational Planning**
  - Overview of key metocean processes and hazards for the location.
  - Monthly, seasonal and all-year operational wind, wave and current statistics.
  - Monthly persistence statistics for wind, wave and current.
  - Principal current direction.

- **Offshore Drilling and Operations**
  - Overview of key metocean processes and hazards for the location.
  - Monthly, seasonal and all-year operational wind, wave and current statistics.
  - Monthly persistence statistics for wind, wave and current.
  - Monthly, seasonal and all-year maximum current profile.
  - Monthly, seasonal and all-year maximum water temperature statistics.
  - Description of wave spectra.

**METEOCEAN CRITERIA**

- **Production**
  - Fixed structures and jack-ups
    - Extremes (typically for 1, 5, 10, 50, 100 and 1,000-year return)
      - Directional wind speeds.
      - Directional Hs and associated parameters (Tp, Tz, Hc, Hmax, THmax).
      - Directional current speeds and current profile.
      - Surge (positive and negative).
      - Maximum and minimum total water level (tide + surge + wave crest).
    - Tidal water levels (HAT, LAT, MSL etc).
    - Wave scatter diagrams (joint occurrence of Hs and Tp).
    - Individual wave number of occurrences (H and T) for deterministic fatigue analysis.
    - Characterisation of directional wave spectra.
    - Air and sea temperature.
    - Ice, iceberg and snow, if any.

- **Production**
  - Floating structures
    - Extremes (typically for 1, 10 and 100-year return)
      - Directional wind speeds.
      - Directional Hs and associated parameters (Tp, Tz, Hc, Hmax, THmax).
      - Directional current speeds and current profile.
      - Maximum and minimum total water level (tide + surge + wave crest).
    - Tidal water levels (HAT, LAT, MSL etc).
    - Wave scatter diagrams (joint occurrence of Hs and Tp).
    - Individual wave number of occurrences (H and T) for deterministic fatigue analysis.
    - Characterisation of directional wave spectra.
    - Contour plots giving combinations of significant wave height and peak periods for a 100-year return period.
    - Wind/wave/current angular separation data.
    - Air and sea temperature.
    - Ice, iceberg and snow, if any.
Metocean requirements: Jack-ups

- Extremes (typically for 1, 5, 10, 50, 100 and 10,000-year return)
  - Directional wind speeds.
  - Directional Hs and associated parameters (Tp, Tz, Hc, Hmax, THmax).
  - Directional current speeds and current profile.
  - Surge (positive and negative).
  - Maximum and minimum total water level (tide + surge + wave crest).
- Tidal water levels (HAT, LAT, MSL etc).
- Wave scatter diagrams (joint occurrence of Hs and Tp) by direction.
- Individual wave number of occurrences (H and T) for deterministic fatigue analysis.
- Characterisation of directional wave spectra.
- Air and sea temperature.
Metocean Data for Offshore Structures Design

Design of Fixed Platform Structure
- Structural Concept – Elevations, Framing, Member
- Minimum Airgap – Above 10,00 year Storm
- Dynamic Sensitivity – Modal Response, Fatigue

Jack Up Rig Site Specific Assessment
- Feasibility of Jack up Drilling Concept – Location Specific

Design for Construction
- Weather Window Installation (Lift, Launch etc.)
- Modular or Integrated Platform Concepts
- Pile Connection Point
- Transport Analysis (Topside and Jacket)

Design for Operations
Video Bonga Tandem
Plot of variate (Hs) against direction (upper panel) and seasons of the year
Comparison of observed and fitted data split by direction. Observed data - red lines, model data - black lines. Solid lines represent the median, dashed lines represent the bootstrap 95% confidence range.
Directional Metocean Extremes and Failure Modes

Ultimately, we are more interested in the probability of structural failure than in the probability of exceedance of various metocean conditions. In the hypothetical case of a structure, such as that depicted in Figure 5.1, which is infinitely strong in the East-West plane, the waves coming from East and West are effectively irrelevant and only the other 6 directions need be considered.
## Directional Extremes

### Omnidirectional Extreme Wave Heights

<table>
<thead>
<tr>
<th>Wave Height</th>
<th>RETURN PERIOD (YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Hs</td>
<td>2.9</td>
</tr>
<tr>
<td>Hmax</td>
<td>5.9</td>
</tr>
<tr>
<td>Crest</td>
<td>3.3</td>
</tr>
</tbody>
</table>

### Independent & Composite directional Extreme Wave

<table>
<thead>
<tr>
<th>Wave Height</th>
<th>RETURN PERIOD (YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>S</td>
<td>2.9</td>
</tr>
<tr>
<td>SW</td>
<td>2.9</td>
</tr>
<tr>
<td>Omni</td>
<td>3.0</td>
</tr>
<tr>
<td>Hmax</td>
<td>5.7</td>
</tr>
<tr>
<td>S</td>
<td>5.7</td>
</tr>
<tr>
<td>SW</td>
<td>5.7</td>
</tr>
<tr>
<td>Omni</td>
<td>5.9</td>
</tr>
<tr>
<td>Hc</td>
<td>3.2</td>
</tr>
<tr>
<td>S</td>
<td>3.2</td>
</tr>
<tr>
<td>SW</td>
<td>3.3</td>
</tr>
<tr>
<td>TEWL</td>
<td>3.5</td>
</tr>
<tr>
<td>S</td>
<td>3.5</td>
</tr>
<tr>
<td>SW</td>
<td>3.5</td>
</tr>
<tr>
<td>Omni</td>
<td>3.7</td>
</tr>
</tbody>
</table>
WindSea & Swell

Plot of variate (Hs) against direction (upper panel) and seasons of the year: windsea

Plot of variate (Hs) against direction (upper panel) and seasons of the year: swell
## Directional Extremes

<table>
<thead>
<tr>
<th>WindSea</th>
<th>Independent</th>
<th>100-year Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000</td>
<td>100</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>2.8</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>SW</strong></td>
<td>2.7</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>2.1</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>NW</strong></td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Omni</strong></td>
<td>2.9</td>
<td>3.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Swell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>S</strong></td>
</tr>
<tr>
<td><strong>SW</strong></td>
</tr>
<tr>
<td><strong>W</strong></td>
</tr>
<tr>
<td><strong>NW</strong></td>
</tr>
<tr>
<td><strong>Omni</strong></td>
</tr>
</tbody>
</table>
Independent and Joint Design Criteria

Part III

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Squall event no 29: 18-05-2013 18:37:00

Wind Direction [degrees]

Wind Velocity (blue) [m/s], Temperature (green) [deg]

Time [minutes]
Independent and Joint Design Criteria
Joint Design Conditions

Correlations between wind, wave and current
Independent Design Criteria: Offshore West Africa

Wind

Current

Wave

Roseplot at 0.5 m below MSL
Correlations between wind, wave and current – Offshore West Africa

Swell at the site is created by storms far away in the southern ocean. Most of the current appears to be related to the large scale equatorial circulation. It is therefore very likely that the swell height and current speed are statistically uncorrelated with the local wind and waves. The duration of squalls is too short for them to have much effect on waves or currents. A design based on combining the independently derived extreme values of all of these parameters will thus be very conservative.
Independent Design Criteria: Sea & Swell

\[ H_{sea} = 0.629 + 0.376 H_{swell} \]
Independent Design Criteria: Current, Wind & Swell

A regression of current speed against wind speed gives
\[ CS = 0.3604 - 0.0108WS \]

Figure 1: Hourly average current speed at a depth of 2.5 m against hourly average wind speed at 3 m elevation measured by the Wavescan buoy. The correlation coefficient is 0.1465.

A regression of current speed against wave height gives
\[ CS = 0.2244 + 0.1094H_{swell} \]
Independent Design Criteria

Figure 6.2.3: Graphical representation summarising dominant directions of metocean parameters (Note directional conventions used)
Independent Design Criteria: Sea & Swell

A linear regression of swell on sea gives

$$H_{\text{sea}} = 0.7835 + 0.0721H_{\text{swell}}$$

Figure 1: Significant heights of the sea and swell partition of the wave spectrum measured by the Waverider buoy. The correlation coefficient is 0.6638.

A regression of sea on swell gives

$$H_{\text{swell}} = 1.0178 + 0.0655H_{\text{sea}}$$

Figure 1: Measured swell (partition of spectrum with periods greater than 10 seconds) from the Wavescan buoy against wind speed measured on the same buoy at a height of 3 m.
Independent Design Criteria

The squall apparently has no effect at all on the wave height.

Figure 1: Hourly values of 3 second wind speed and wave height (sea partition) during the squall of January 23, 2002.
Joint Design Criteria

If wind, wave and current conditions are nearly uncorrelated, it would be unduly conservative to design for their extremes to occur simultaneously.

For preliminary design and concept selection, this method is used to develop several design cases in which one feature of the environment is extreme and the other features have the most probable values associated with this extreme. The calculations make use of the regression equations developed previously to find the associated.

If two parameters are statistically independent, then the most probable value of the second parameter associated with the extreme value of the first parameter is its mean value.
Joint Design Criteria

If two parameters are statistically independent, then the most probable value of the second parameter associated with the extreme value of the first parameter is its mean value.

\[ H_{sea} = \overline{H}_{sea} + s(H_{swell}^{100} - \overline{H}_{swell}) \]
Joint Design Criteria

For the swell dominated design case, the extreme values of swell are taken from the independent analysis (previous slides). To compute the most probable locally generated seas associated with these extreme values of swell, we use the slope of the regression line in equation 8.1. The associated sea height is then its mean value increased by the slope times the difference between the 100 year wave height and its mean value, or

\[
A_{100} = \bar{A} + s(B^{100} - \bar{B})
\]

\[
H_{sw} = \bar{H}_{sw} + s(H_{sw}^{100} - \bar{H}_{sw}) = 0.86 + 0.0721(3.17 - 1.27) = 1.00
\]