Using research experiences in marine technology for advancing offshore wind technology

by

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Outline

► Introduction
► Marine structures
  - serviceability
  - safety
  - example concepts
► Marine operations
► Research drivers
► Examples: sea loads & response, safety management, crack control, riser & umbilicals, wave energy converters
► Concluding remarks
Introduction: Marine technology

Safe, sustainable and economical utilisation of the oceans through:

- Transport
- Seafood production
- Oil and gas
- Infrastructure
- Ocean Energy
  - Wind
  - Waves
- Systems
- Operations

Introduction: Shipping vs wind turbines?

From machinery to propellor

From rotor to electricity

Photo of Fram on the polar expedition in March 1894
Introduction

Oil and gas exploitation

➢ The oil and gas industry is crucial to the world economy
➢ At the same time, the society at large is concerned about the industry's potential damage to the environment (and to men) – and its control
➢ Focus on safety for men, environment and property loss - implying “zero release” philosophy

Open sea fish-farming

➢ Sea food production beyond 100 Mtons a year depends on aquaculture
➢ Increased production / quality could be achieved by large farms in open sea
➢ Novel industry with opportunities and challenges

Introduction

Wind power offshore

➢ Developing fast – in shallow water and gradually in deeper water
- as e.g. described in presentations at this seminar

Wave power

➢ Many facilities: concept development, involving model scale testing
Some concepts: at prototype testing level
➢ Wave power occupies ocean space and meets the environmental challenge – by avoiding the coastal zone
Marine Structures

**Design**  
**Fabrication**  
**Operation**

**Life Cycle approach**

- **Ultimate Limit State**
- **Fatigue Limit State**
- **Accidental Collapse Limit State**

**Design criteria**  
ULS, FLS, ALS

**Design check**  
Reference to specified probability level

**Failure probability**  
$P_f = P(R<S)$

**Design approach**

- Explicit Limit State Criteria
  - Serviceability
  - Safety (ULS; FLS, ALS)

- Direct analysis of
  - Loads
  - Resistance

- Probabilistic methods
  - Reliability approach

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**Introduction, continued**

**Design for Servicability (use)**

- Platforms for drilling for and production of oil and gas
- Fishfarms
- Wind turbines

- Provide containment - prevent escape
- Ensure proper fish welfare
- Operational suitability for moving fish in and out, feeding etc
- Access for IMMR

- Provide support of payload
- Limited motions
- Access for IMMR

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Nowitech: Norwegian Research Centre for Offshore Wind Technology
Introduction

Design for Safety

to avoid:
► Fatalities or injury
► Environmental damage
► Property damage

Regulatory regime (depends on economy; accident potential):

<table>
<thead>
<tr>
<th>Offshore oil and gas</th>
<th>Fish farming</th>
<th>Wind energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>- National regulatory bodies;</td>
<td>- National Regulatory body, Norway:</td>
<td>- IEC</td>
</tr>
<tr>
<td>- Industry: API, NORSOK,</td>
<td>- Design code enforced in January 2004.</td>
<td>- national reg. bodies</td>
</tr>
<tr>
<td>- Classification soc.</td>
<td>- Classification societies ??</td>
<td>- classification societies</td>
</tr>
<tr>
<td>- ISO/IMO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Regulatory principles
- Goal-setting viz. prescriptive
- Probabilistic viz. deterministic
- First principles viz. purely experiential

Example concepts for the oil and gas industry

(Stationary) Floating Production Systems

<table>
<thead>
<tr>
<th>SEMI</th>
<th>SPAR Classic</th>
<th>SPAR Truss</th>
<th>SSP buoy</th>
<th>TLP- 4 Leg</th>
<th>TLP- 1 Leg</th>
</tr>
</thead>
</table>

Mobile drilling units
Marine operations
Dynamic positioning and manoeuvring

► Mathematical modelling
► Manual vs automatic control
► Human factors

Crane operations

Transport of heavy objects

Knowledge transfer regarding concepts, methods - from oil & gas, aquaculture

► Differences between offshore wind turbines and other marine systems
  - function;
  - loads/hazards; risk of fatalities, environmental damage,
  - costs
  - size
  - one-of its-kind vs. mass production

► Analysis and design of system
  - sea loads
  - structural engng. & materials technology
  - safety (risk) management

► Installations, operations & maintenance

- Standardization (Best practice)
- Guidance
Introduction

**Research drivers**

Deepwater development of oil & gas

- **market pull** (industry driven)
- **technology push** (researcher driven):
  - Disciplinary research
  - Inter-/cross-disciplinary (CeSOS: integrate hydrodynamics, structural mechanics and automatic control)
  - Inventions or innovations

**Enabling technologies**

- Information and comm. technologies, e.g. (FEM, CFD)
- Materials technology
- Measurement technologies

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**Analysis for design**

- **Functional loads**
  - dead loads
  - pay loads
- **Sea loads**
- **Accidental loads**

**Load effects**

- Extreme moment (M) and axial force (N)
- Local stress range history

**Design criteria**

- **ULS:** Collapse resistance
- **ALS:** Ultimate global resistance
- **FLS:** SN-curve/fracture mechanics

**Defined probability level**

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**Ocean environment**

**Industrial and Operational Conditions**

Piper Alpha
Methods for generating new knowledge about seaoards

Field measurements is the only way to estimate the probability of wave, wind conditions.

Computational Fluid Mechanics

Potential Flow Methods

Basic Assumptions

Domain Decomposition

Navier-Stokes Methods

Forms of the Governing Eqs

Lagrangian

Boundary-Fitted Grids

Moving particles (SPH, MPS)

Fixed Nodes (RKPM)

Eulerian

Gridless Methods

FDM solver

Interface capturing (VOF, LS, MAC, CIP)

Body

body modeled numerically

Grid methods: inside body problem, body capturing

Gridless methods: body force/particles, ghost particles

Body 'naturally' tracked

Air-Water Interface

Eulerian

Lagrangian

Interface tracking
Challenging hydrodynamics phenomena

- Impulsive loading should always be treated by dynamic analysis
  - wave slamming
  - ringing loading due to steep, high waves

- Harmonic or irregular loading at natural frequencies (dynamic response)
  - wave frequency or sum or difference frequency loading due to drag term in the loading, nonlinearity associated with finite wave elevation and motions of the body

Ringing loads and response

**Features**
- Ringing occurs in:
  - high, steep waves
  - platforms with large volume and natural periods below 8s

- Load calculation is reasonably accurate for single columns
In general: loads need to be determined by lab. tests

- Dynamic analysis is straightforward

- Ringing was discovered in the early 1990’ies
High frequency wave load effects - tether tension

- Steady state
  - nonlinear features of hydrodynamic loading for a wave with frequency $\omega$ imply load components with frequencies $2\omega$, $3\omega$, $2\omega$ or $3\omega$ coincides with a natural frequency

- Transient
  - amplified effect of load with short duration
  - maximum transient response coincides with a maximum in the steady-state response

Stochastic analysis of wave load effects

Extreme values and fatigue loads

- long term analysis
  (different sea states)
- short term
  - 3 hour irregular wave sequence
    (by contour line method)
  - wave episode
  - regular (design) wave

Reduction of computational and experimental efforts
Lessons learnt from accidents

Causes

Technical/physical
- Capsizing/overturning
- Structural failure

Human-organizational (management) factors

a) Alexander L. Kielland – fatigue failure, progressive failure and capsizing, North Sea, 1980

b) Ocean Ranger, flooding and capsizing, New Foundland, 1982 (Model during survival testing)

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Safety management

Risk Control with respect to
- overall structural failure
- overall loss of stability

Risk control of accidental events

Reduce probability
Reduce consequences

“known events”
“unknown events”

Event Control of accidental events
Direct ALS design
- Abnormal resistance
- Accidental loads

Indirect design
- robustness
- redundancy
- ductility

Risk Analysis, or, Prescriptive code requirements

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Design for robustness (ALS criterion)

• **Background**
  - ships and floating platforms have been required to have damage stability for a long time

• **General criterion**
  - consequences of "any" small damage should not be disproportionally large

(Petroleum Safety Authority, Norway)

![Diagram showing capsizing/sinking due to flooding](image1)

**a) Capsizing/sinking** due to (progressive) flooding

![Diagram showing explosion damage](image2)

**b) Structural failure** e.g. due to impact damage,....

![Diagram showing failure of mooring system](image3)

**c) Failure of mooring system**

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**Accidental (Abnormal) Loads and their Effects**

**Ship impacts?**

1. **Explosion loads** (pressure, duration - impulse)
   - scenarios
   - explosion mechanics
   - probabilistic issues
   ⇒ characteristic loads for design

2. **Fire loads** (thermal action, duration, size)

3. **Ship impact loads** (impact energy, -geometry)

4. **Dropped objects**

5. **Accidental ballast**

6. **Unintended pressure**

7. **Abnormal Environmental loads**

8. **Environmental loads on platform in abnormal floating position**
In-service experiences with cracks in North Sea platforms

- Data basis
  - 3411 inspections on 30 North Sea jackets
  - 690 observations of cracks
- The predicted frequency of crack occurrence was found to be 3 times larger than the observed frequency

- Cracks which are not predicted, do occur (13% of observed fatigue cracks occurred in joints with characteristic fatigue life exceeding 800 years; due to abnormal fabrication defects or

<table>
<thead>
<tr>
<th>Name</th>
<th>Built Year</th>
<th>Depl. %</th>
<th>Thr.</th>
<th>No of Cracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAYYOD DOPHIN</td>
<td>1976</td>
<td>23.3%</td>
<td>0.80</td>
<td>115</td>
</tr>
<tr>
<td>DEEPSEA EMM</td>
<td>1976</td>
<td>22.5%</td>
<td>0.98</td>
<td>34</td>
</tr>
<tr>
<td>TRANSOCEAN MILD</td>
<td>1977</td>
<td>24.8%</td>
<td>1.20</td>
<td>50</td>
</tr>
</tbody>
</table>

- Cracks have occurred, due to
  - lack of fatigue design check,
  - inadequate design check
  - abnormal fabrication defects
  - inadequate inspection

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Crack control measures

<table>
<thead>
<tr>
<th>Struct. type</th>
<th>Type of joint</th>
<th>Fatigue Design Factor</th>
<th>Residual fatigue life</th>
<th>Ultimate reserve strength</th>
<th>Inspection (and repair) Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jacket</td>
<td>Tubular joint</td>
<td>2-10</td>
<td>Some - Significant</td>
<td>Normally</td>
<td>NDE^2) Underwater</td>
</tr>
<tr>
<td>Semi-Subm.</td>
<td>Plated brace</td>
<td>1-3</td>
<td>Some</td>
<td>By ALS^4) Limited</td>
<td>LBB^3) NDE</td>
</tr>
<tr>
<td></td>
<td>Plated col.-p.</td>
<td>1-3</td>
<td>Some</td>
<td>By ALS Limited</td>
<td>IM^5) LBB NDE</td>
</tr>
<tr>
<td>TLP</td>
<td>Tether Plated</td>
<td>10</td>
<td>Small</td>
<td>By ALS Limited</td>
<td>IM^5) LBB NDE</td>
</tr>
<tr>
<td>Ship</td>
<td>Plated longt.</td>
<td>1-3</td>
<td>Significant</td>
<td>None</td>
<td>Close Visual</td>
</tr>
</tbody>
</table>

1) Fatigue Design Factor – by which the service life is to be multiplied with to achieve the design fatigue life
2) NDE - Non Destructive Examination Method
3) LBB - Leak before break monitoring
4) ALS - Accidental Collapse Limit State
5) IM - Instrumental monitoring (by “an intelligent rat”)

Reliability - based design

Design code calibration

\[
R_C/\gamma_R > \gamma_D D_C + \gamma_L L_C + \gamma_E E_C
\]

Goal: The Implied

\[
P_f = P(R > D + L + E) \cong P_{ft}
\]

\(R\) — resistance
\(D, L, E\) — load effects due to
  • permanent
  • live
  • environmental

\(P_f\) depends upon the systematic and random uncertainties in \(R; D, L, and E\)

Reliability-based inspection planning:
Safety of Marine Operations
- Considering automatic control and human factors

Research topics:
- hydrodynamic modelling of motions
- automatic control
- reliability and safety (human factors)

Anchor handling and other subsea operations (the "Bourbon Dolphin" case)

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Station keeping system
Catenary mooring system
Taut mooring

Challenges
Conventional Mooring –
- Long-term failure rates remain uncertain
  (One FPSO line failure every 6 yrs)
- Particular problems at connectors & interfaces
  (Noble Denton JIP)

Synthetic moorings
- Damage during handling
- Long term integrity
- Particular problems at terminations

Tension-leg system
- High strength - low weight
  carbon fibre tether instead of steel tether

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Riser tensioner, slip joint and heave compensator

Umbilicals on floating platforms

Wave energy converters

Fred Olsen Ltd FO³
Synergy of renewable offshore (wind & wave energy) & conflicts of interest

- Transfer of knowledge regarding design & operation
- Share infrastructure;
- Power to shore or to other facilities

- with offshore oil and gas, - with aquaculture,

Concluding remarks

- Concepts and operational procedures as well as assessment methods established in the oil & gas and other marine industries may be adapted in offshore wind activities by proper adjustment in view of the differences in the relevant industries

- bottom fixed and floating wind turbines
- hydrodynamic analysis
- safety management in general and in crack control in particular