Safety of Marine Operations

Transport of heavy objects

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When do the accidents happen?

Ref. Lotsberg, I., Olufsen, O., Solland, G., Dalane, J. I., Haver, S.

Photo: Kulturminne Ekofisk
Types of heavy transport

Heavy and/or large objects are moved by many methods

Photo: Haugesund avis / Kai-Inge Melkeraaen

Photo: Haugesund avis / Terje Størkersen
Tow of submerged structures

To options shown:
Structure suspended in buoy and towing through moonpool

From Risoe, M. Mork, Johnsgard & Gramnes
“The Pencil Buoy Method—A Subsurface Transportation and Installation Method”
*Offshore Technology Conference, 2007*
Multiwheel trailer transport of topside module
Transport of topside module
Ship transport of topside module
Jacket platforms
Topside installation sequence

The Module Support Frame (MSF) including some modules are installed first. Then additional modules and flare tower are installed. Final choice of method depends on module weights and crane capacity.
Topside installation

Photo: Statoil (F. G. Nielsen, 2003)
Tow of jacket and topside

We limit the scope to transport of heavy objects by sea transport on a barge.
What is a “barge”? (In Norwegian: “Lekter”)

www.boa.no
Different barge types

Flat top barge with transom, raked or Ship shaped bow. Submersible barges have superstructure. No self propulsion.
In case of towline failure, the tow must be reconnected. First priority is to retrieve the bridle and connect it to the spare towline from the tug. Second alternative is to connect to the emergency towing line on the barge.
Barge equipment
Risk Management

Recommendations and guidance from DNV aim at a probability of structural failure equal to, or lower than $10^{-4}$ per operation.

In practical projects, it may be difficult to quantify the risks.

The risk for towline breakage depends on many factors; wave height and wind speed, towing line dynamics and the captain’s decision.

- The capacity of the towline will be reduced if it is worn, increasing the risk for towline failure. Not easy to include such effects in reliability analyses.
Practical way to handle risk

Use of recognized rules and standards.
Practical way to handle risk, continued

Use of Marine Warranty Survey

Long historical traditions for this type of verification. It goes back to the

Marine Insurance Act 1906

The Warranty Surveyor will see to that the work is performed according to approved procedures and according to the rules, and within accepted environmental criteria.
Practical way to handle risk, continued

- Adaptation to risk level:

- The matrix illustrates the combinations of consequence and initial probability of failure which results in “intolerable risk” and “tolerable risk”.

- The border area between intolerable and tolerable risk is denoted “ALARP - As Low As Reasonably Practicable” and therefore requires actions to be taken in order to be tolerable.

- The purpose of insurance warranty is to ensure that no operations are approved to be carried out with “intolerable risk”.

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<table>
<thead>
<tr>
<th>Probability of Hazards</th>
<th>CONSEQUENCES</th>
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<tbody>
<tr>
<td></td>
<td>Minor</td>
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<tr>
<td>Likely</td>
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<td>Reasonably Probable</td>
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<td>Unlikely</td>
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<td>Remote</td>
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<tr>
<td>Extremely Remote</td>
<td></td>
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<tr>
<td>Theoretically Possible</td>
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Typical Marine Operations

Intolerable Risk Area
Border Area (ALARP)
Tolerable Risk Area
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Barge transport, design case

- In case of tow line failure, the barge will float freely and be exposed to beam seas, then roll motion is governing
- Define environmental criteria, calculate barge motions
- Calculate forces in sea fastening, barge and transported object, and compare with structural capacity
Some issues for sea transports

- For transport of large objects on ocean going barges, sea fastening is a major issue. The amount of sea fastening (cost) and the reliability level depends on the input from the motion analyses in relation to real motions.

- Roll motions are governing for many structural systems

- To learn more about roll, we have done…
Experimental Investigation of Barge Roll motion in severe beam seas

- To learn more about the effect of beam seas for typical barge transports, a Standard North Sea barge in scale 1:50 was tested at Marintek’s facilities.

- Rolling of barges is a phenomenon with strong non-linear effects, and there are many challenges related to the motion analyses.

- The damping was estimated from roll testing.

- The uncertainty in the motion analyses is estimated based on the input from the motion analyses in relation to motions from model tests.
Free decay tests
Damping from free decay tests

\[
(I_m + A_{44})\ddot{\theta} + B_1 \dot{\theta} + B_2 |\dot{\theta}| \dot{\theta} + C \theta = 0
\]

\[
(I_m + A_{44})\ddot{\theta} + B_{eq} \dot{\theta} + C \theta = 0
\]

\[
B_{eq} = B_1 + \frac{8}{3\pi} \omega_d \theta_i B_2
\]
Forces in seafastening

The deviation between the calculations and the model tests is defined as the ratio between the response from the test and the numerical result:

\[ X_S = \frac{S_{Test}}{S_{calc}} \]

\( S \) is the response, from model tests and from calculations.

The mean value and standard deviation of \( X_S \) is then estimated based on results from the model tests.
Effect of roll response on reliability

- During structural design, load and material factors are used to get the required capacity:
  \[
  \frac{R_C}{\gamma_M} \geq \gamma_S S_{\text{pred}}
  \]

- The probability of failure can be found by FORM or Monte Carlo simulations.

- Roll response may be overestimated in calculations, hence affecting the reliability level. If motions are overestimated by 50%, the probability of structural failure may change by a factor of 100.

- The forces in the sea fastening is caused by the barge motion, so any uncertainties will affect the structural system and hence the reliability level directly.
Towing line analysis
Towing line failures

Structural capacity
Failure definitions
Calculation of failure probability

Probability for a given environmental condition:

\[ P(ENV_{ij}) = f_{Hs,Tz}(h_{s,i}, t_{z,j}) \Delta h_s \Delta t_z, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \]

The failure probability is a sum of several probabilities based on beam sea (towline failure):

\[
P_f = \sum_{i=1}^{m} \sum_{j=1}^{n} P(BEAM \cap SF \cap ENV_{ij})
\]

\[
= \sum_{i=1}^{m} \sum_{j=1}^{n} P(SF|BEAM \cap ENV_{ij}) P(BEAM|ENV_{ij}) P(ENV_{ij})
\]
Summary

- The load in the sea fastening depends on acceleration and motions of the transport vessel.

- Roll motion is an important contributor to loads in the sea fastening.

- By use of appropriate viscous damping, a linear analysis may calculate the structural loads with reasonable accuracy.

- The reliability will depend highly on the results from motion analyses, for which the sea fastening is designed.
References

1. DNV (www.dnv.com)
2. Haugesund avis (www.h-avis.no)
4. Kulturminne Ekofisk (www.kulturminne-ekofisk.no)
7. Statoil (www.statoil.com)
Safeguarding life, property and the environment

www.dnv.com