Dynamic analysis and verification of the Universal Buoyancy system

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1. Introduction

Liquefied natural gas (LNG) is becoming an increasingly popular alternative to traditional marine fuels. A large contributor to the increasing popularity is the new ECA (emission control areas) regulations, which reduces the sulphur emission limit from 1% to 0.1% of total mass. To follow up the increased demand for LNG infrastructure, Connect LNG has developed a **new concept for LNG offloading** , the Universal Buoyancy System, intended for the small-scale market. This thesis investigates the **dynamic behaviour** of the UBS by using **computer simulations** in MARINTEK's simulation programme SIMA, as well as **model tests** in the Marine Cybernetics laboratory.

2. Methods

Model test

A simple model of the system was constructed, using plywood and Divinycell. The following tests were carried out:

- Decay tests, to find added mass and damping
- Regular wave tests, to find validate transfer functions for input in SIMA
- Irregular wave tests, to find extreme values

The model had a scale ratio of 1:15, and Froude scaling was applied.

Computer simulations

Analytical calculations were carried out in SIMA, a computer programme based on the **finite element method**. For each time step, the **equilibrium equation** is solved for all nodes [1]:

$$\boldsymbol{M}\ddot{x} + \boldsymbol{C}\dot{x} + \boldsymbol{D_1}\dot{x} + \boldsymbol{D_2}\boldsymbol{f}(\dot{x}) + \boldsymbol{K}(x)x = \boldsymbol{q}(t, x, \dot{x})$$

The equation includes mass (M), frequency-dependent, linear and quadratic damping (C, D_1, D_2), stiffness (K) and excitation forces (q).

Sea states

The irregular sea state tested in simulations and model test had a duration of three hours and is described by the JONSWAP spectrum with parameters H_s=1.2 m, T_p= 5s and γ=1.65. Three different wave headings were investigated; head, quartering and beam sea.

Post-processing

The output from both model tests and computer simulations is time series. This needs to be processed to obtain relevant information. Most of this was done in MATLAB. The results are **filtered** to remove noise, before wave- and response spectra are calculated from the time series. Now, transfer functions may be found by [2]:

$$|H(\omega)|^2 = \frac{S_{yy}(\omega)}{S_{xx}(\omega)}$$

To estimate the expected value of the largest maximum during a sea state with a duration of three hours, it is assumed that the individual wave heights are Rayleigh-distributed. The **expected value of the largest maximum** is now given by [3]:

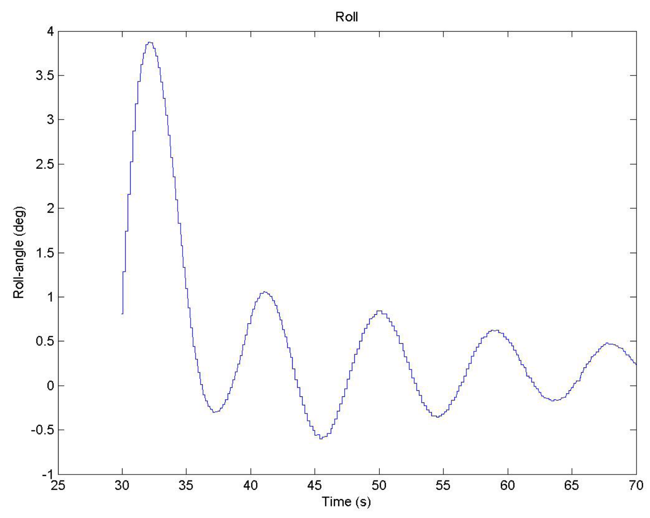
$$E[X_{LM}] = \int_0^\infty x f(x) dx = \sigma \left\{ \sqrt{2 \ln N_w} + \frac{0.5772}{\sqrt{2 \ln N_w}} \right\}$$

Where f(x) is the probability density function with standard deviation σ and N_w is the expected number of waves during that three hour sea state.

3. Results

Decay tests

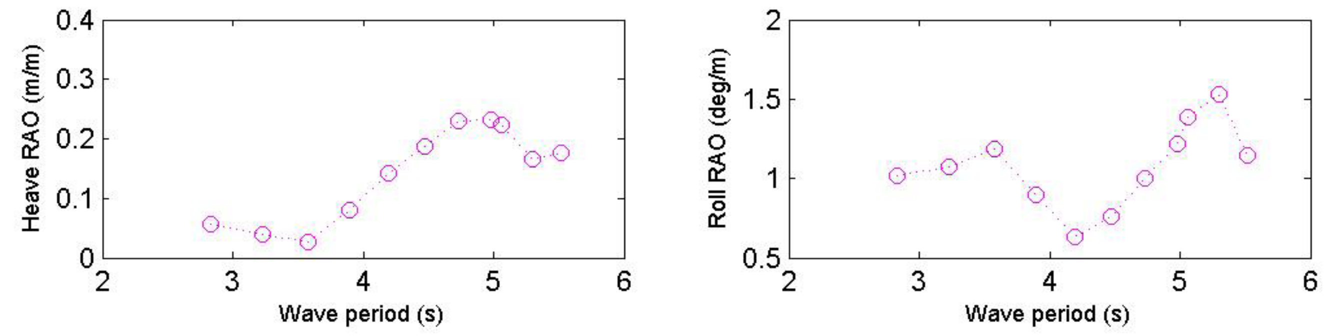
The decay tests showed that the degree of freedom with the largest added mass and damping was roll, with an added mass of 1773.8 tonnes and an equivalent damping of 627.2 kNm/s. The corresponding damped Eigen period was 9 seconds.



Decay test in roll

Regular model test

Motion and force transfer functions for the three different wave headings were calculated on the basis of the model test results. Neither visual inspection of the model test nor the calculated transfer functions revealed any indications of resonant motions in the wave frequency range that was tested.

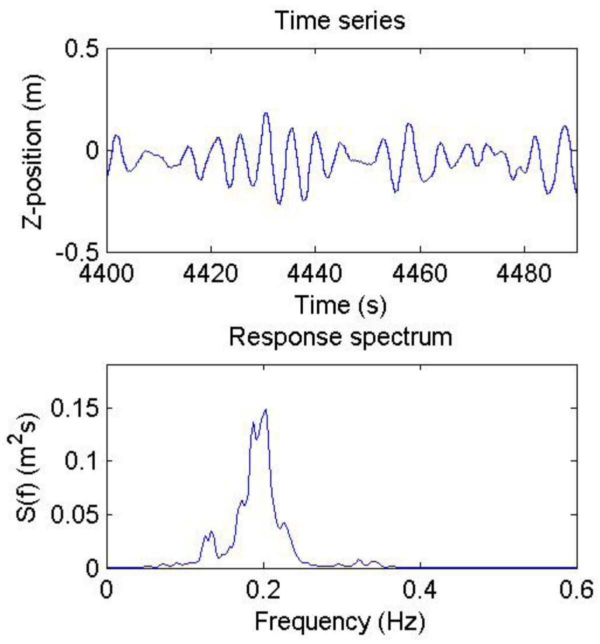


Transfer functions in heave and roll, wave heading 0 degrees

The results from the regular tests did, to some extent, validate the transfer functions used as input in SIMA calculations. The generals trends were mostly the same, but the accuracy was not good enough to fully confirm the input parameters.

Irregular model tests

For the irregular model tests, spectral analysis was performed on all degrees of freedom in each of the different wave headings. In general, the responses were not very large. The most exposed configuration was a wave heading of 45 degrees. Heave was the largest of the translations with a maximum of 0.27 m. The largest rotation was pitch, with a maximum of 3.12 degrees.



Time series and response spectrum for heave, model test, waves at 45 degrees

Computer simulations

The results from the computer simulation were slightly different from the model tests. However, the order of magnitude of response was about the same. The finite element calculations agreed that 45 degrees is the most vulnerable configuration, and that the largest translation is in heave. The maximum heave value recorded in SIMA was 0.41 m. The maximum rotation is SIMA was roll, peaking at 3.78 degrees.

4. Conclusion

The results from the model test and computer simulations show that:

- The largest damping and added mass occurs in roll
- The transfer functions used for input in SIMA are to some extent validated by the model test results
- The irregular tests in SIMA and laboratory confirm that the **worst case scenario is a wave heading of 45 degrees**

References

[1] MARINTEK. *SIMO Theory manual.* V4.0 Rev 1. Trondheim, 2012.
[2] Steen, Sverre. *Experimental methods in Marine Hydrodynamics*. Trondheim, 2012.
[3] Myrhaug, Dag. *Statistics of Narrow band Processes and Equivalent Linearization*. Trondheim, 2005.

Acknowledgements

- Professors B. Leira and S. Steen at NTNU
- T. Wahl and P. Levold at MARINTEK
- S. Magnusson and D. Knutsen at Connect LNG

NTNU
Department of Marine Technology
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