Master Thesis in Marine Technology - 2013

Analysis of ice-induced vibrations and comparison with full-scale experimental data

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PROBLEM

Ice-induced vibrations are a problem for structures in ice-infested waters. Structures can suffer from both impact damage and fatigue. Even the working conditions may be disturbed, e.g. force an oil platform to stop the production.

Often resonant-like vibrations have been observed. It would be of great value to develop a model which could give an estimate of the total vibration damage for a given winter. The model shall be based on international standards for arctic engineering (ISO 19906, 2010).

The Norströmsgrund lighthouse has frequently been used to measure ice forces acting on structures and the structural response. This thesis utilizes data measured during a campaign from 1999-2003

Figure 2. Norströmsgrund lighthouse

MODELLING

A model which can calculate the total number of steady-state vibrations during a winter season. Given the total nr. of cycles, the fatigue damage can be estimated. Following groups of inputs are then needed:

- Environmental conditions to calculate ice properties
- Onset criteria for frequency locked-in crushing
- Duration of a typical event with frequency lock-in
- Structural properties of the lighthouse in order to perform a SDOF analysis

For a structure interacting with drifting ice, there are mainly three different response regimes based on the *ice crushing regimes,* as shown in Fig. 1. Drift properties of the ice is estimated using the observations by Nansen (1902). Ice thickness, h_i, is calculated by an empirical relation by Zubov (1943). FDD is freezing-degree days, a measurements of how cold it has been for how long.

$$h_i^2 - 50h_i = FDD \qquad\qquad FDD = \int_0^t (T_m - T_{air})\,\mathrm{d}t$$

The steady-state response is of interest, and a method to find when steady-sate conditions are probable, is developed. The methods used are involving ice thickness, structural diameter, ice velocity, ice temperature and the natural frequencies of the structure.

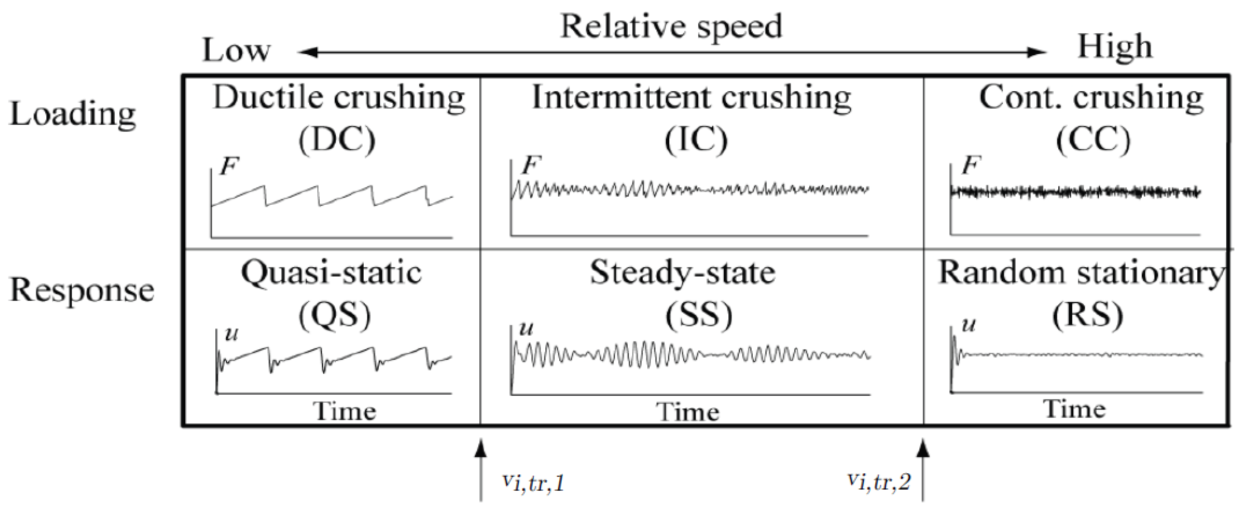

Figure 1. Different crushing regimes and corresponding structural response. Figure taken from Bjerkås (2013).

Using the load and cycle history, the fatigue damage is found using the Miner-sum:

$$D = \sum_{i=1}^{k} \frac{n_i}{N_i} = \delta$$

In addition, the response of a SDOF model representing the waterline response is developed.

RESULTS

Having used different methods to estimate nr. of cycles for a season, the fatigue life of the structure was found as presented in Tab. 1. The response of the SDOF was calculated and compared to the in-situ measured response as shown in Fig. 3.

Case	N_{cycles}	$\Sigma\, n_i/N_i$	$t_{fatigue}$
$\delta_{extreme}$	40950144	0.1525	7
$\delta_{onset\ 1}$	1950172	0.0143	70
$\delta_{onset\ 2}$	541008	0.0041	239
$\delta_{onset\ 3}$	2546437	0.0188	54
$\delta_{onset\ 4}$	2446790	0.0165	61
$\delta_{onset\ 5}$	4707232	0.0331	31
$\delta_{observed}$	5090	0.0002	4911

Table 1. Fatigue life of the different cases.

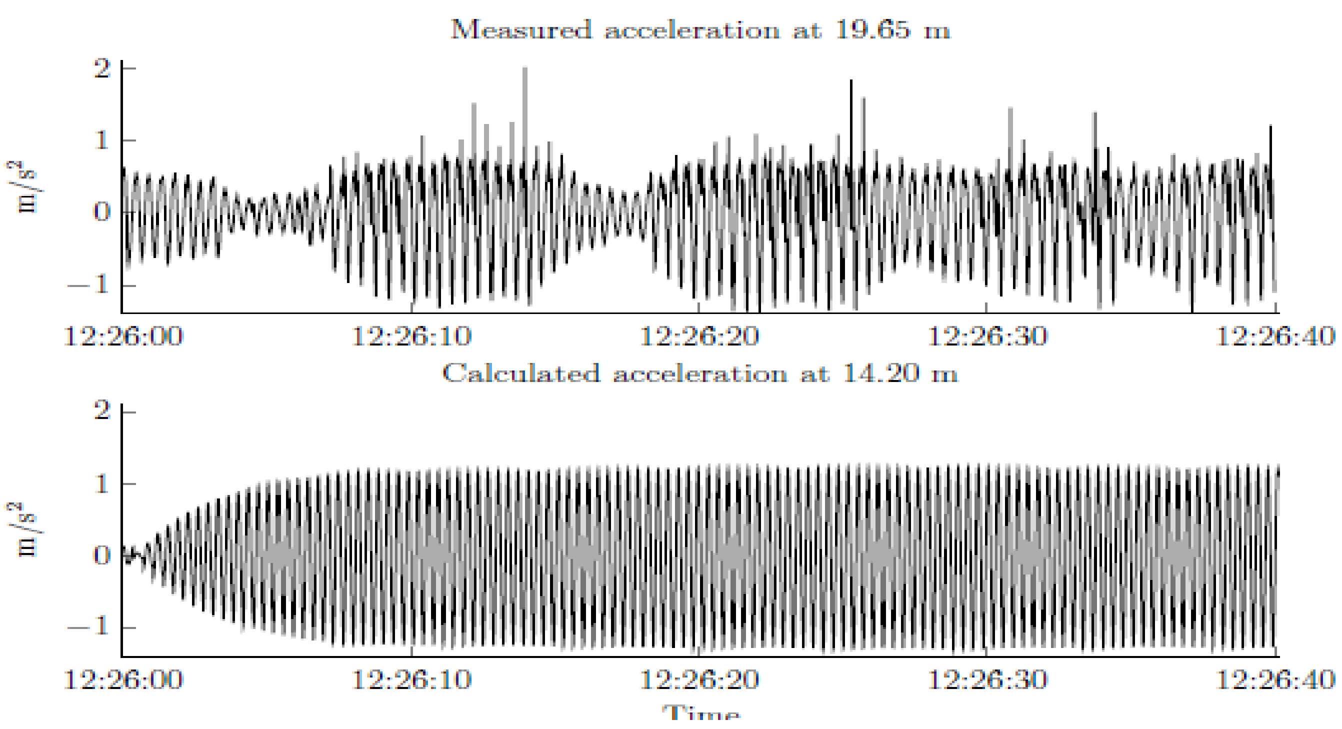

Figure 3. In-situ measured acceleration and acceleration calculated by SDOF model.

CONCLUSION

The following key conclusions were made after investigating fatigue and dynamic response of Norströmsgrund lighthouse:

- A straightforward model has been developed to predict onset conditions for FLC and steady-state vibrations. Estimated number of cycles ranged from 541008 to 40950144, depending on the approach used. The model over-estimated the number of cycles compared to the observed number, which was 5090.
- The model in the present work estimated the fatigue life of the lighthouse to be ranging from 7 to 4911 years, depending on the method applied. A fatigue life of 7 years is very unlikely, while the other (30 to 70 years) are more reasonable.
- The response of the SDOF model used in the model gave results close to which was observed in-situ. Simple SDOF models can be utilized when performing a first evaluation of the structural response.

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