Floating bridges and various methods for determining their long-term extreme response due to wave loading

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Introduction

A floating bridge is a bridge where the vertical loads are supported by the buoyancy of partially submerged supports which do not rest on the seabed. Where and why can we need floating bridges? They can permit crossing water bodies too deep and too wide for traditional bridges, for example large fjords. This project aims to summarise the existing ways of calculating the long-term extreme response of a floating bridge and to propose other methods which may be used for this purpose. Different strategies are demonstrated on an example bridge.

Response for a given sea state – short-term response

Modelling the sea

Generalised Pierson-Moskowitz spectrum

\[ S_p(\omega) = \frac{\bar{h}^2}{8\pi^3} \left( \frac{\omega \tau}{20} \right)^{-5} \exp \left( -\frac{1}{\pi} \frac{\omega \tau}{20} \right)^{-4} \]

Cos-2s directional wave distribution

\[ D(\Theta) = C \cdot \cos(\frac{\Theta - \Theta_0}{2}) \]

Modelling the bridge

Bridge radius: 1000 m, pontoon spacing: 100 m.
- Using Bernoulli beams and Rayleigh damping
- Find structural characteristic matrices: \( M_s, K_s, C_s \)
- Find hydrodynamic frequency dependent and independent characteristic matrices: \( M_{h0}, M_h, C_{h0}, C_h \)
- Calculate displacement transformation matrix: \( H(\omega) = \omega^2 (M_s + M_{h0} + M_h) + i\omega (C_s + C_{h0}) + K_s + K_{h0} \)

Long-term extreme response – over 10, 100, 1000 years

Parametrisation

Significant wave height \( H_s \) and wave peak period \( T_p \) are probabilistic variables.
Wave main direction \( \Theta_0 = 0 \) and spreading parameter \( s = 30 \) are deterministic and fixed.
Probabilistic discretised into 100 elements (10'000 variables total sea states) and follow the distributions for Norwegian Sea, according to DNV-RP-C205.

Full integration method

Exact method for long-term extreme response, but too long computation time \( (w = [h_s, T_p]) \).

\[ F_M(T_p, T_s) = \exp \left( -T_s \cdot \int_{\omega} v_s^2(\omega) f_w(\omega) d\omega \right) \]

with:

\[ v_s^2(\omega) = \frac{\bar{h}^2}{24 \cdot \pi} \exp \left( -\frac{1}{2} \left( \frac{\omega}{\omega_s} \right)^2 \right), \sigma_s^2 = \int_{\omega} S_s(\omega) d\omega \]

Surrogate models:

Evaluate the objective function in a minimal number of locations to precisely interpolate the outcome of the whole function.
- Iterative process: 1) Evaluate an additional location, 2) Interpolate all other locations. Continue until outcome does not change anymore.
- Two different interpolation methods

Universal Kriging

Probabilistic method. Deterministic method. Estimate has a mean \( \mu \) select next location based on a random number and variance \( \sigma^2 \). Select next location with bias, gradient of Bayesian Upper Confidence Bound: \( \max(\mu + 3\sigma) \).

Results and conclusion

All five methods return values in the same size range.
The full integration method likely underestimates the actual response due to too gross discretization to make it solvable timeswise. The ISORM and IFORM behave slightly differently from the other methods, but have similar outcomes as the other methods.
The two different surrogate models have near identical outcomes. They also have the same slope over varying return period as the full integration method, further increasing their credibility. For a similar computation time, surrogate models are able to return outcomes for all return periods as IFORM/ISORM for one return period.

Main conclusions

1) Determining the long-term extreme response of a floating bridge is possible and should not act as a barrier in their conception. 2) Surrogate models show large potential for determining these responses and their application should be further investigated.

Modelling the short-term response

- Find the cross-spectral density of the force acting on all pairs of pontoons: \( S_{mp, mp}(\omega) = \int_0^\infty Q_m(\omega, \theta) S_{mp, mp}(\omega, \theta) Q_m(\omega, \theta)^* d\theta \)

- Generalise to all pontoons:

\[ S_p(\omega) = \left( \begin{array}{c} S_{p1, p1}(\omega) \\ \vdots \\ S_{pN, pN}(\omega) \end{array} \right) \]

- Finally, calculate the displacement spectrum of the response of the bridge: \( S_u(\omega) = H(\omega)S_p(\omega)H(\omega)^H \).

Bibliography