# ENAC / PROJET DE MASTER 2019-2020
# SECTION DE GÉNIE CIVIL

## 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. Additionally, they provide additional alternatives for crossings where the best solution is not obvious. For example, they could be an alternative for «La traversée de la Rade» in Geneva, Switzerland.
This project aims to summerise 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 [1]

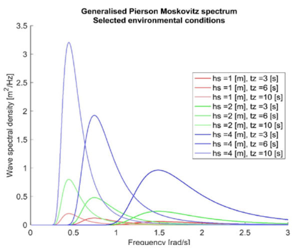
### Modelling the sea

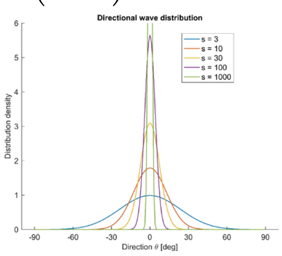
Generalised Pierson-Moskowitz spectrum

$$S_\eta(\omega) = \frac{h_s^2 t_z}{8\pi^2}\left(\frac{\omega t_z}{2\pi}\right)^{-5} \exp\left(-\frac{1}{\pi}\left(\frac{\omega t_z}{2\pi}\right)^{-4}\right)$$

Cos-2s directional wave distribution

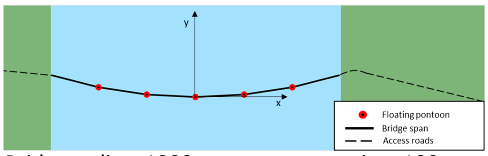
$$D(\theta) = C \cdot \cos^{2s}\left(\frac{\theta - \theta_0}{2}\right)$$




$$S_\eta(\omega, \theta) = S_\eta(\omega) \cdot D(\theta)$$

### 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: $M_{h0}, M_h(\omega), K_{h0}, C_h(\omega)$.
- Calculate displacement transformation matrix: $H(\omega) = \omega^2\left(M_s + M_{h0} + M_h(\omega)\right) + i\omega\left(C_s + C_h(\omega)\right) + K_s + K_{h0}$.

### Modelling the short-term response

- Find the cross-spectral density of the force acting on all pairs of pontoons: $S_{pr,ps}(\omega) = \int_\theta Q_r(\omega,\theta) S_{\eta r,\eta s}(\omega,\theta) Q_s(\omega,\theta)^H d\theta$, where $Q_r(\omega,\theta)$ is a transfer function from wave height to excitation force for a given pontoon shape. *This integral requires large computational effort – it takes a long time to calculate.*
- Generalise to all pontoons:

$$S_p(\omega) = \begin{pmatrix} S_{p1,p1}(\omega) & \cdots & S_{p1,pN}(\omega) \\ \vdots & \ddots & \vdots \\ S_{pN,p1}(\omega) & \cdots & S_{pN,pN}(\omega) \end{pmatrix}$$

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

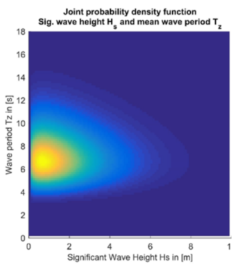
Note: It is possible to solve the calculations in modal coordinates of the main mode shapes, to save computation time, with little effect on the outcome.

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

### Parametrisation

Significant wave height $H_s$ and wave peak period $T_z$ are probabilistic variables.

Wave main direction $\theta_0 = 0$ and spreading parameter $s = 30$ are deterministic and fixed.
Probabilistic discretised into 100 elements each (10'000 variables total sea states) and follow the distributions for Norwegian Sea, according to DNV-RP-C205.




### Full integration method [2]

Exact method for long-term extreme response, but too long computation time ($\boldsymbol{w} = [h_s, t_z]$).

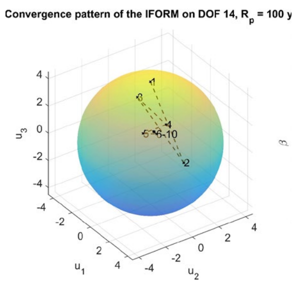
$F_{M(T_{LT})}(a) = \exp\left(-T_{LT}\int_W v_x^+(a|\boldsymbol{w}) f_W(\boldsymbol{w}) d\boldsymbol{w}\right)$ with:

$v_x^+(a) = \frac{1}{2\pi}\frac{\sigma_{\dot{x}}}{\sigma_x}\exp\left(-\frac{1}{2}\left(\frac{a}{\sigma_x}\right)^2\right)$, $\sigma_x^2 = \int_{-\infty}^{\infty} S_u(\omega) d\omega$, and $\sigma_{\dot{x}}^2 = \int_{-\infty}^{\infty}\omega^2 S_u(\omega)\, d\omega$

### IFORM/ISORM [3]

Inverse first/second order reliability method.
Gradient based optimisation method to find the response for a given movement and return period.

The optimisation process happens in a standard normal domain.
*First order:* linear approximation of response function at critical point.
*Second order:* curvature estimate of response function at critical point.



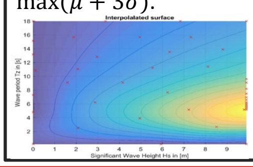

However, gradient based models are not ideal when working with time-consuming functions without explicit derivative forms, due to the large number of function evaluations necessary to simply estimate the gradient.

### 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**

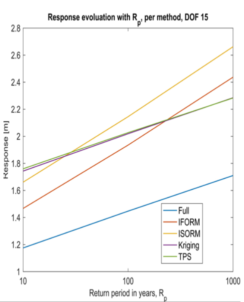
*Universal Kriging* [4]
Probabilistic method. Estimate has a mean $\mu$ and variance $\sigma^2$. Select next location with Bayesian Upper Confidence Bound: $\max(\mu + 3\sigma)$.




*Thin Plate Splines*
Deterministic method. Select next location based on a random bias, gradient of current interpolation, distance from previous locations and prominence. This methods is called SummitSearch, and developed in this project.

## 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 timewise.
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.

## Bibliography (selection)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**3)** F. I. G. Giske, B. J. Leira, and O. Øiseth, "Full long-term extreme response analysis of marine structures using inverse FORM," Probabilistic Eng. Mech., vol. 50, no. April, pp. 1–8, 2017

**4)** G. Matheron, "Le Krigeage Universel." Ecole Nationale Supérieure des Mines de Paris, Paris, p. 84, 1969.