Ringing and impulsive exication of offshore wind turbines. Results from the Wave Loads project

Bredmose, Henrik; Schlütter, Flemming ; Paulsen, Bo Terp; Schløer, Signe

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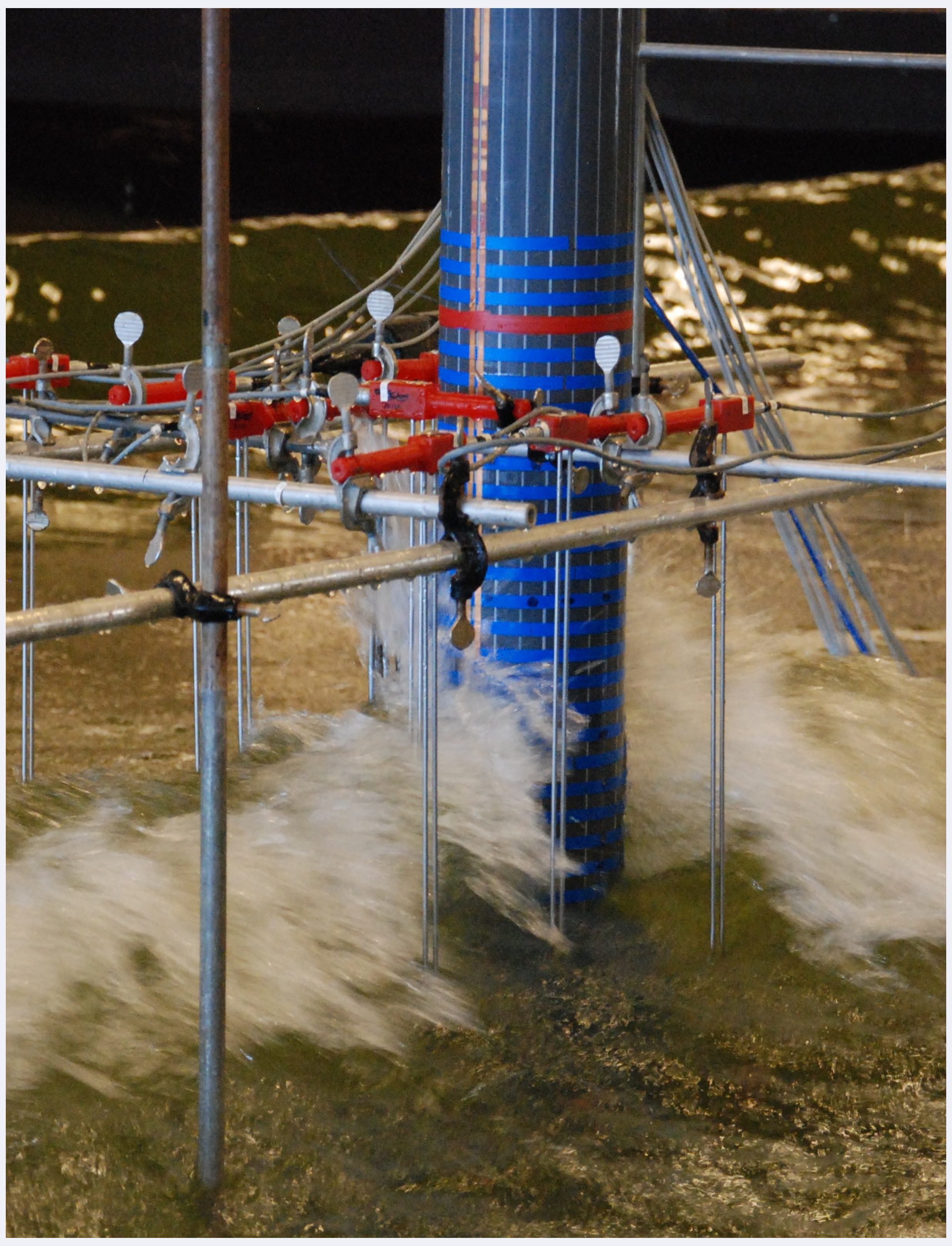
Ringing and impulsive exication of offshore wind turbines
Results from the Wave Loads project

Henrik Bredmose Flemming Schlütter Bo Terp Paulsen Signe Schløer
DTU Wind Energy · DHI · DTU Mechanical Engineering

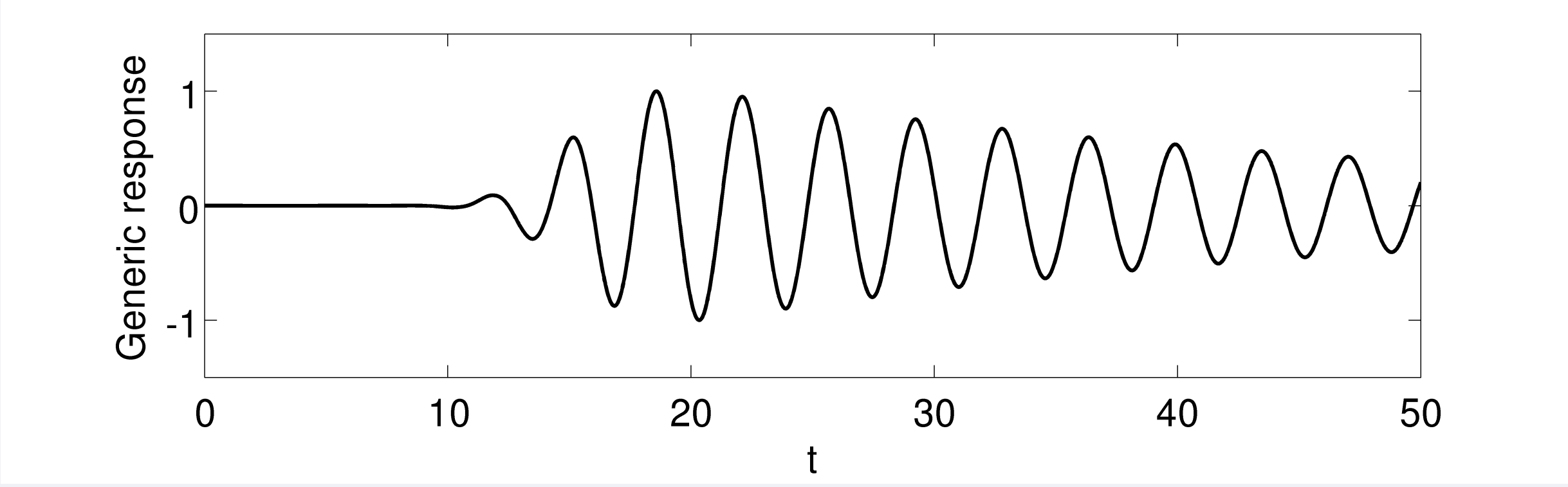
Intermediate depth: Increased nonlinearity



In 2012 the average installation depth for offshore wind turbines was 22m. At such intermediate depths, the waves are not deep-water waves and the nonlinearity becomes stronger. This affects the load which for the steepest waves can generate ringing and impulsive excitation.

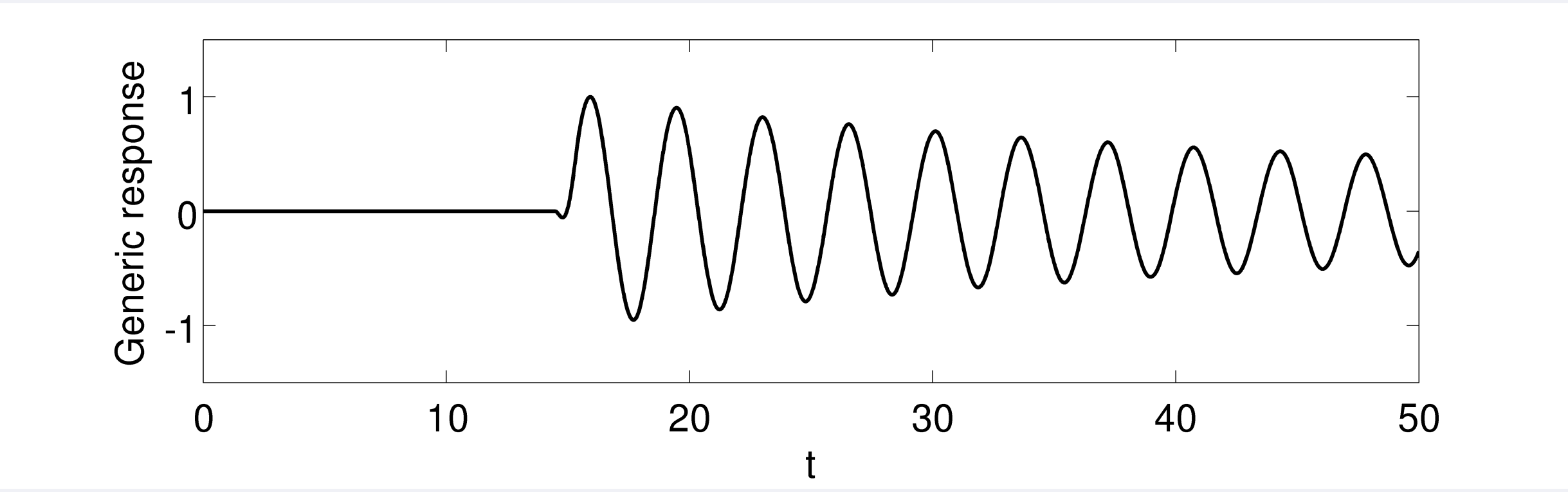
Ringing

Ringing is known from deep water where structures can be excited resonantly by single large waves. The excitation builds up over approximately a wave period and decays with oscillatory motion after the excitation.



Impulsive excitation

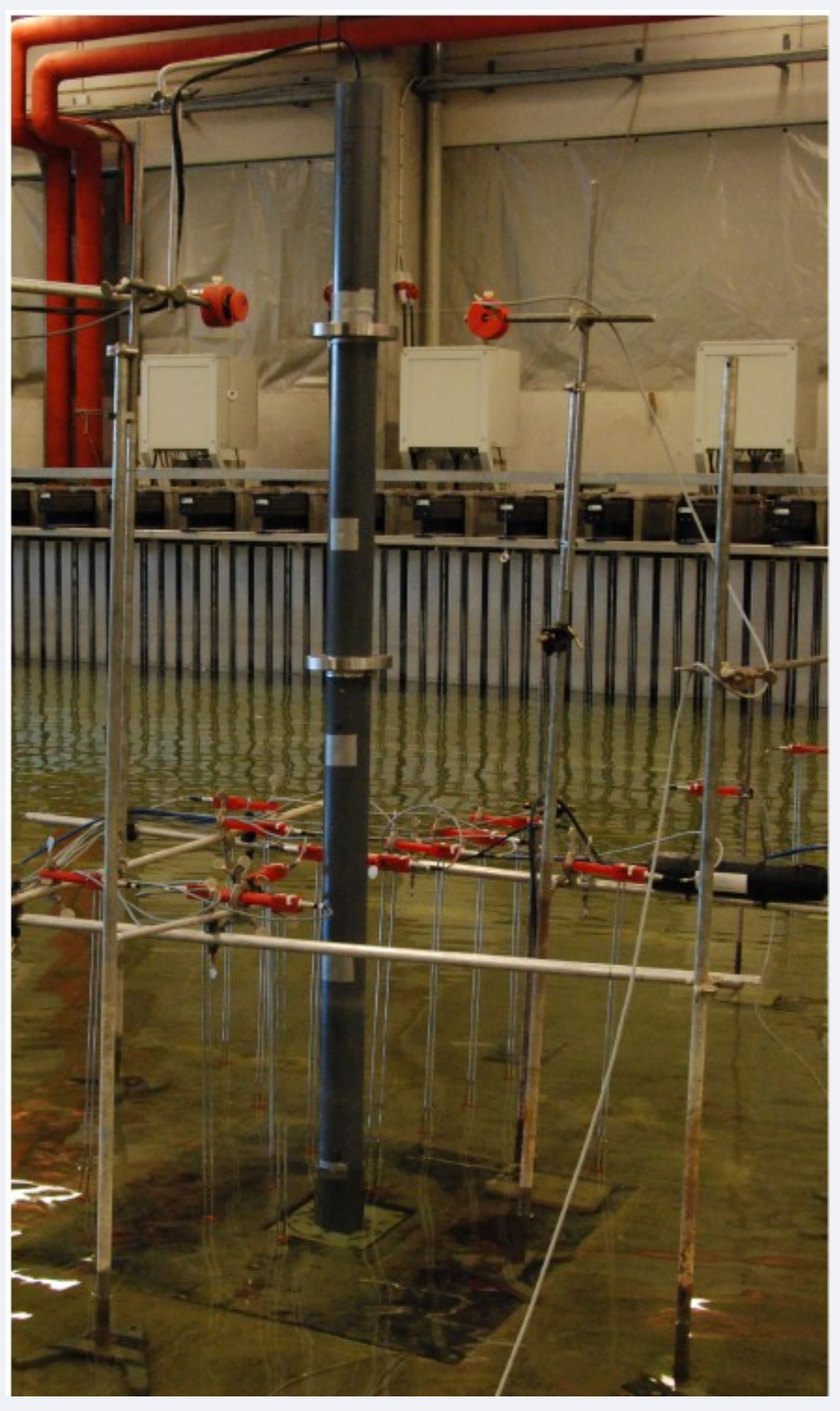
At intermediate and shallow water the wave nonlinearity is stronger. The steepest and near-breaking waves can excite the structure impulsively. The structure responds as had it been hit by a hammer: The maximum amplitude is reached immediately and is next followed by damped oscillations.

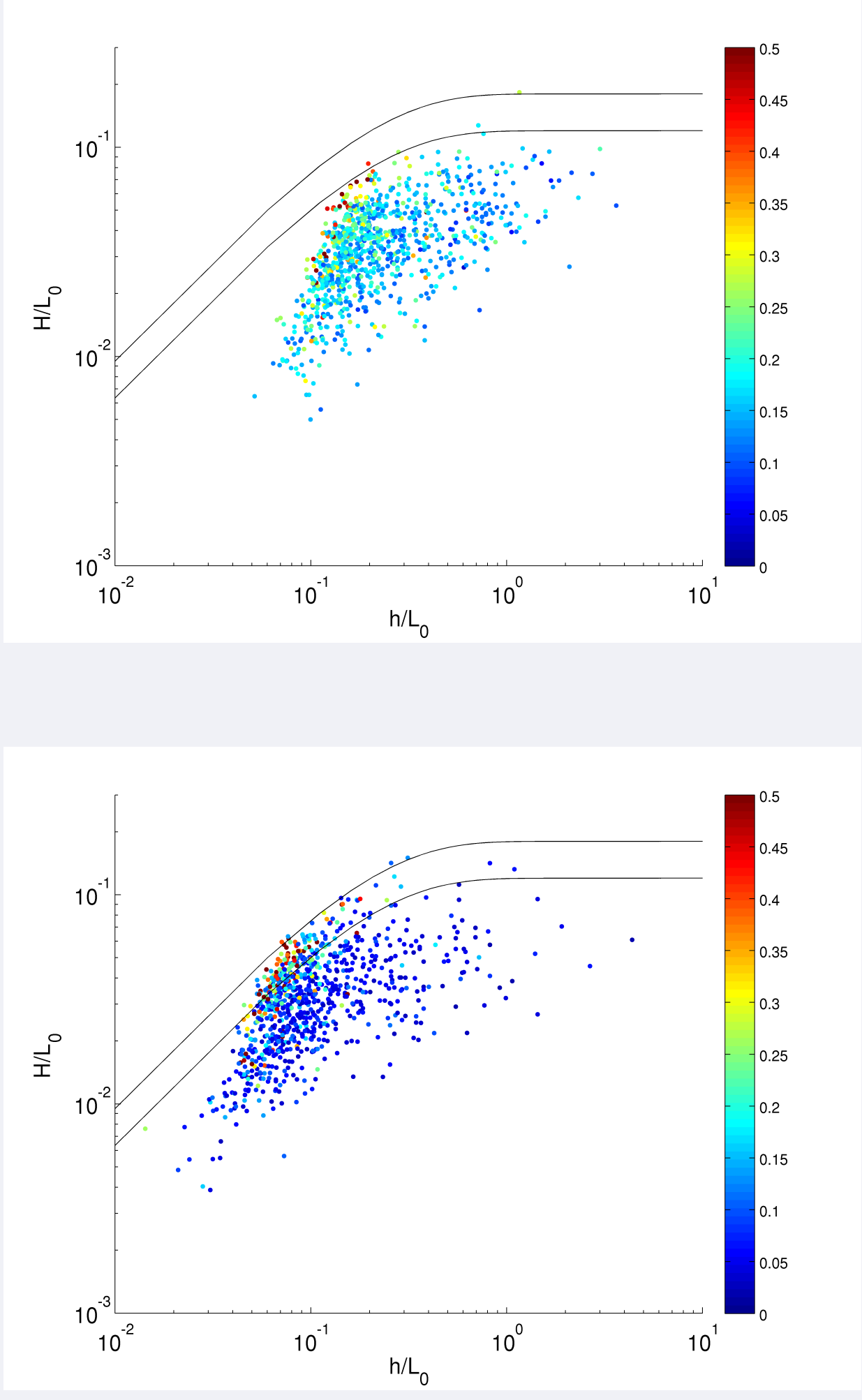


Experiments with a flexible monopile

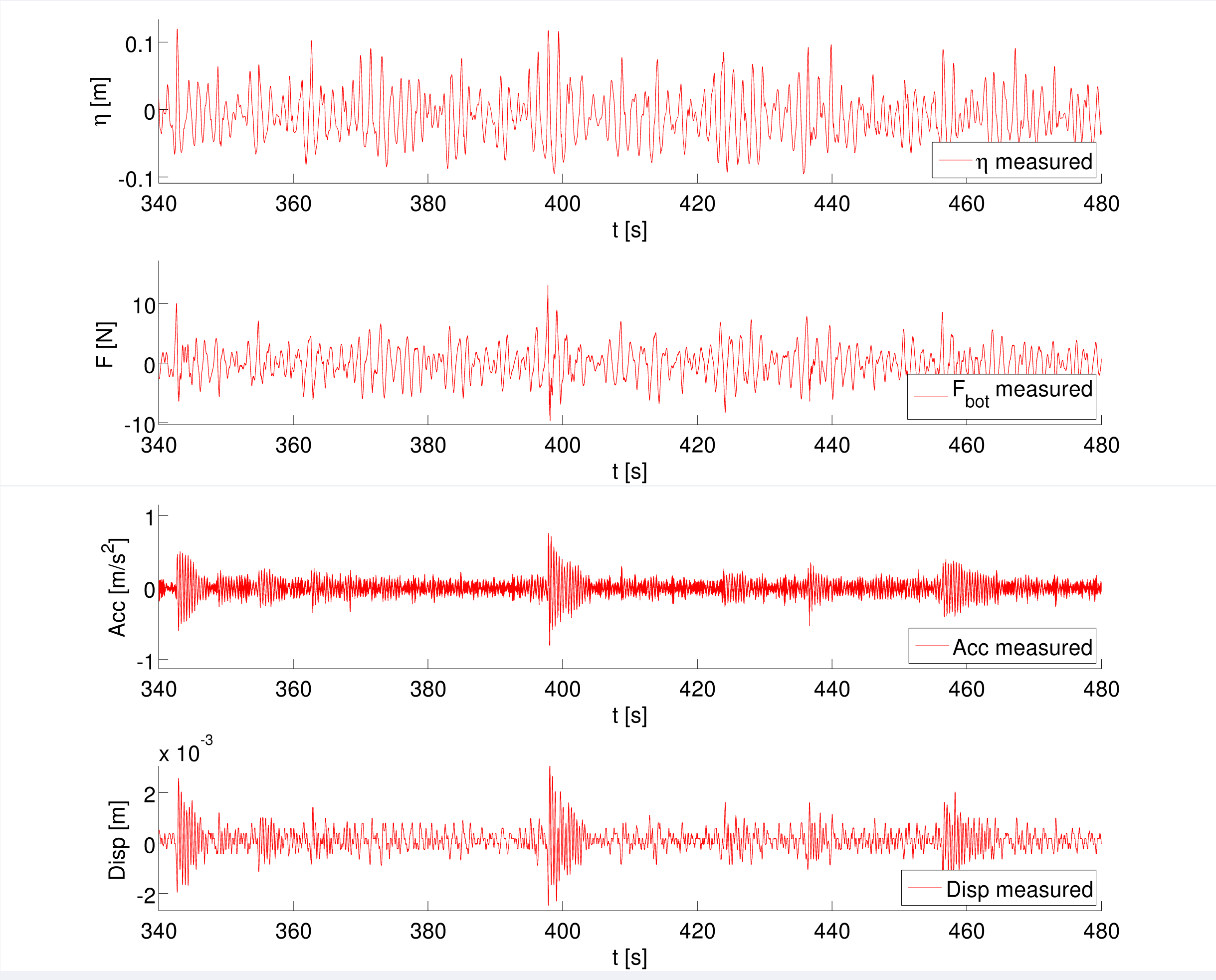
Tests with a flexible cylinder in 2D and 3D waves have been conducted in scale 1:80 to study the dynamic excitation from steep waves. The test structure was made of a PVC pipe with two point masses mounted to match the scaled natural frequencies of the NREL 5MW monopile reference wind turbine of (0.28, 1.9)Hz. The structure was equipped with accelerometers, displacement meters and a bottom force transducer.

Scatter diagrams for the wave steepness (H/L_0)and depth h/L_0 are shown below, resulting from a zero crossing analysis. Two tests of uni-directional waves with H_s=11m and T_p=14s (full scale values) are considered at the two depths of 40m and 20m. The maximum acceleration within the duration of each wave is marked by color. Further, the two black curves represent the breaking criterion of Goda (2010). At 40m (upper plot), most of the waves are non-breaking while at 20m (lower plot), many breaking waves are seen. The breaking waves are clearly associated with the largest accelerations. Generally, the waves at 40m give rise to the largest average accelerations due to the increased moment arm and depth. The extreme accelerations however, are largest at 20m depth due to the stronger nonlinearity and occurrence of breaking.



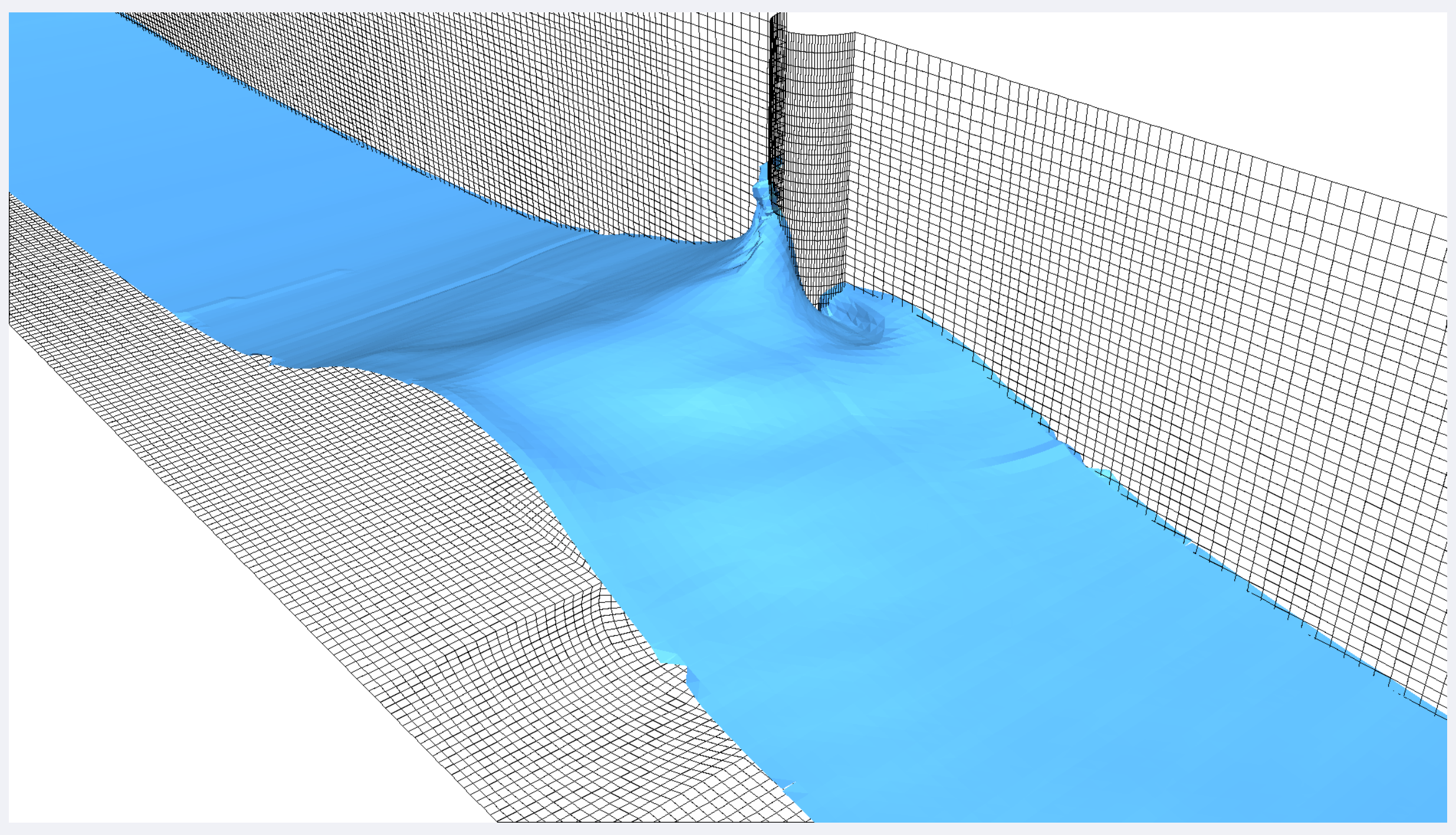


An example of the measured data for a depth of 40m (full scale) is given below in terms of free surface elevation, the bottom connection force, the displacement and the acceleration both measured close to the upper point mass. Ringing can be observed several places in the time series, while a clear example of impulsive excitation is seen at t=440s.



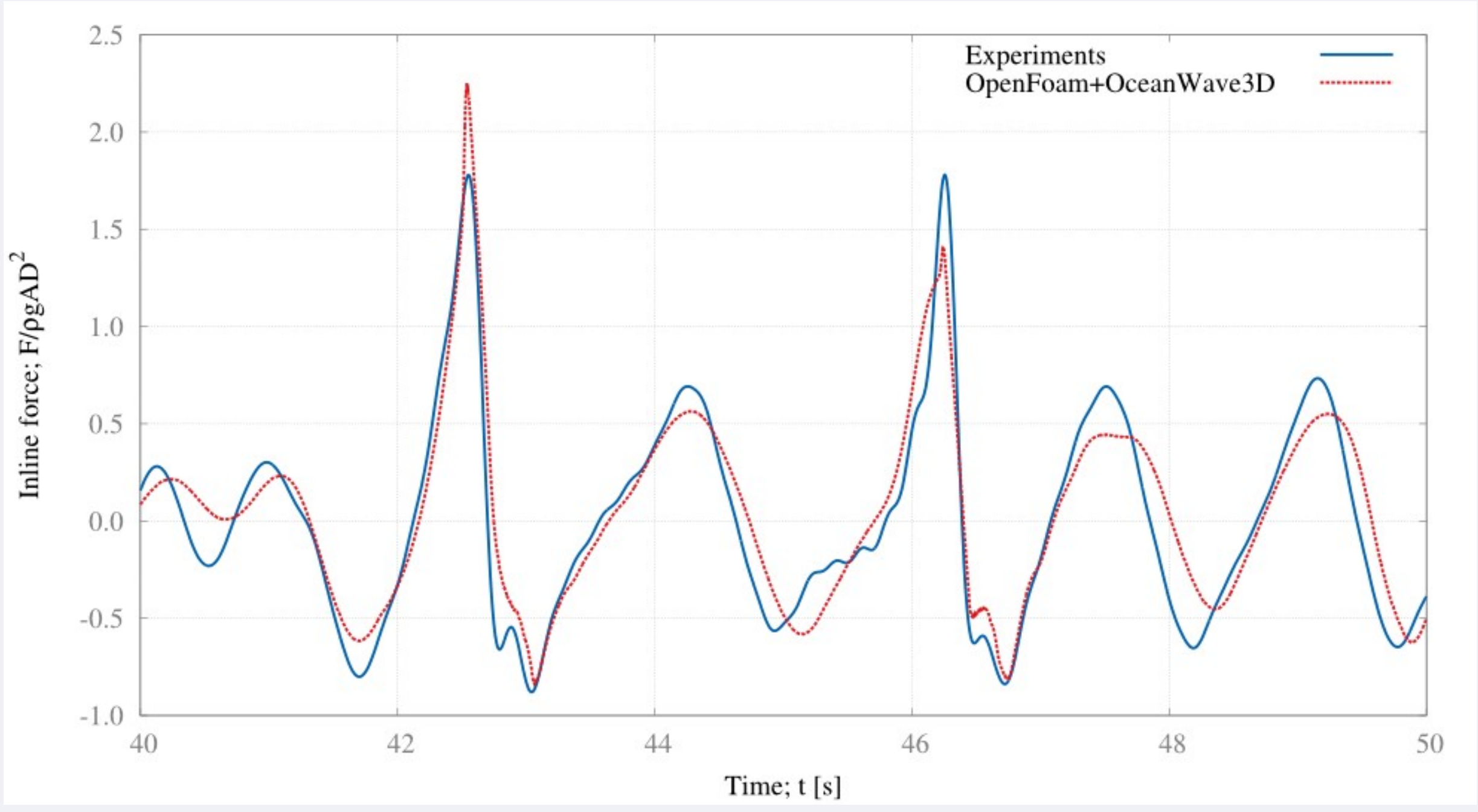
CFD for detailed wave-structure interaction

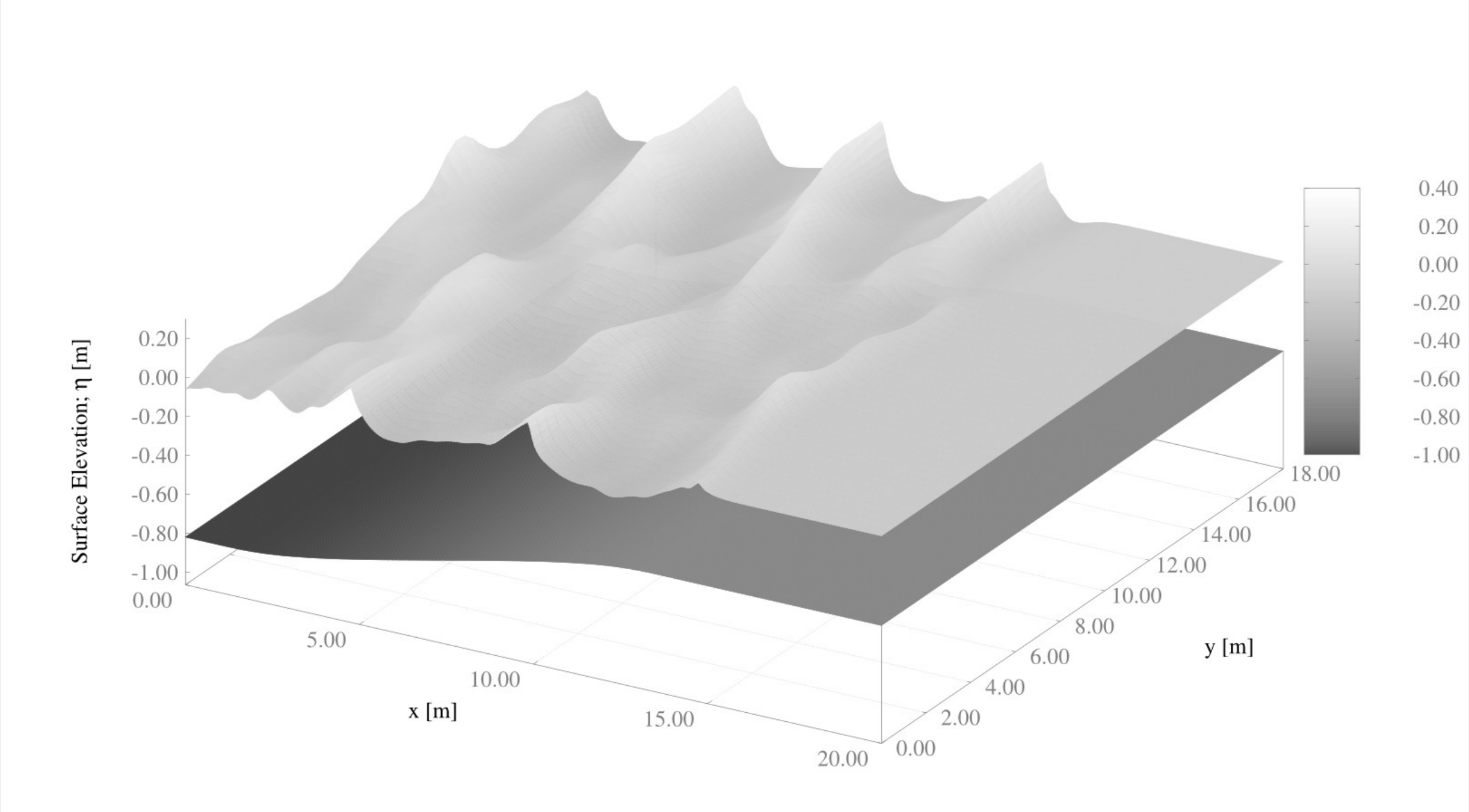
Systematic OpenFOAM CFD computations for steep regular wave impacts have been made. This includes comparison to existing ringing theories for the third-harmonic force and detailed analysis of the secondary load cycle [1]. The free surface was treated with the VOF method.



Coupled solver

A coupled solver has been developed where an inner CFD domain is driven by a fully nonlinear potential flow wave model [2]. This allows for efficient computation of large domains and long irregular time series. Below is shown a reproduction of steep wave impacts in the lab on a cylinder (1:36; rigid pile). A good match is seen. Further, an example of computation of multi-directional waves is shown. More details can be found in [1].





Conclusions

The Wave Loads project has provided insight into forces from steep and breaking waves on monopiles at shallow and intermediate depth. The work includes experiments, CFD and aero-elastic calculations. For the aero-elastic results, see the poster of Schløer et al. The work has been reported in 2 PhD theses [1,3] and 14 conference papers. Several journal papers are submitted and in preparation.

Contact: Henrik Bredmose hbre@dtu.dk

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[2] Engsig-Karup, A., Bingham, H. and Lindberg, O. (2009). An efficient flexible-order model for 3D non-linear water waves. J. Comp. Phys. 228(6), 2100–2118.
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