Free Surface Elevation near Round and Square Cylinders in Moderate Non-linear Deep Water Waves

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1 Introduction

The assessment of the behaviour of Floating Production and Storage units Offshore (FPSO's) in survival wave conditions could benefit considerably from the application of fully non-linear potential theory calculations.
To get a first idea of the computational difficulties involved, two simple cases are considered: a circular cylinder and a square cylinder with rounded edges. Both are truncated and are kept in a fixed position. For these, measurements are available from an ISSC comparative study (F.G.Nielsen [7]). The focus of this paper is whether we can resolve the resulting wavefield and whether the numerical set-up can reproduce the experimental data.

2 Set-up of computations

The test case considered consists of a monochromatic wave incident on a truncated, fixed cylinder (circular or square) on deep water. The cylinders have a draft of 24 m. The circular one has a diameter of 16 m. The square one has a width of 16 m and an edge radius of 4 m. The waves have a period of 9.0 s, a wave length of 128 m and two different heights: one of 4.22 m and one of 7.90 m.
The calculations are done with our fully non-linear potential theory code based on a higher order panel method as described in e.g. Broeze [1] or de Haas et al. [3]. A circular domain is used. On the outer boundary we prescribe a Rienecker & Fenton [8] type of solution for a monochromatic non-linear wave. A Sommerfeld radiation condition is used on the difference of the total solution with the prescribed incoming wave:

$$\phi_t = \phi_{t,RF} - c((\phi_n - \phi_{n,RF}) + (\phi - \phi_{RF})/2r) \ ,$$

where the subscripts t and n denote partial differentiation and RF denotes the prescribed incoming wave. The calculations are started with the Rienecker & Fenton type of solution prescribed on the entire surface, including the cylinder. In one or two periods the cylinder then changes smoothly to an impermeable one, see Ferrant [4].
Different from his work we do solve the entire solution explicitly instead of only the diffraction field (using the known Rienecker & Fenton solution) and we don't use frozen coefficients in our RK4 time stepping. The grid points are free to move in the vertical direction only. For the entire computations no smoothing techniques were employed.
The calculations used 80 panels in the circular direction and 9000 panels in total. A calculation of 8 periods at 100 steps a period takes 14 hours on 64 processors of a SGI Origin 3800. Calculations with 40 panels in the circular direction and 3000 panels in total run much faster. But although the results are qualitively the same for the circular cylinder with the 4.22 m wave, the diffracted waves were no longer well resolved after 5 periods, perhaps because of aliasing.

3 Results

In the measurements of the ISSC study the wave probes were placed in four rows radiating outward from the cylinders at 90, 45, 22.5 (only circular one) and 0 degrees. The last row was at the front of the cylinders. The radial distances were: 8.05 m, 9.47 m, 12.27 m and 16.00 m, except for the square cylinder at 45 degrees where they were: 9.71 m, 11.13 m, 14.41 m, 17.66 m. The results are given as the maximum wave height divided by half of the incoming wave height plotted against the radial distance divided by the cylinder radius. For reference we added the linear result for an infinitely long circular cylinder (MacCamy and Fuchs [6]) and the results of anonymous participant F from the ISSC study: the only one using fully non-linear potential theory too. For extra experimental data the results of Contento et al. [2] for a bottom mounted circular cylinder in deep water

are also included.
In figure 1 the results are plotted for the circular cylinder with the 7.90 m wave. In addition to the ISSC wave probe positions we also included the mirrored positions of them at the back of the cylinder. At the back we follow the Contento measurements quite good. Note especially the high peak at 180°. At the front our results near the cylinder are lower than the experimental results.
Figure 2 shows the results for the square cylinder. Our results are a bit closer to the experimental data then those of participant F.
In the time series of the run-up round the cylinder (figure 3) two distinctive bumps can be observed, moving to the back and colliding there into a peak. Similar bumps and the resulting peak can also be seen in Ferrant [5], although the situation there is somewhat different.
As can be seen in figure 3, especially in frame 5, the circular cylinder with the 7.90 m wave needs more panels in the circumference than the current 80 panels. The same holds for the square cylinder with the 4.22 m wave. The circular cylinder case with the 4.22 m wave on the other hand, is well resolved by 80 panels in the circumference.

4 Conclusion

Our results are close to the experimental data, but there is enough deviation to justify further study. It would be a great help if there was more detailed experimental data to compare with the computational results as shown in figure 3.
For these moderate to high non-linear waves a lot of resolution is needed in the circumference of the diffracting object. The rounded square cylinder requires more resolution than the circular cylinder: the same amount of panels per circle part. These resolutions are not yet feasible for larger objects, e.g. stretching the square to get a more barge-like shape.

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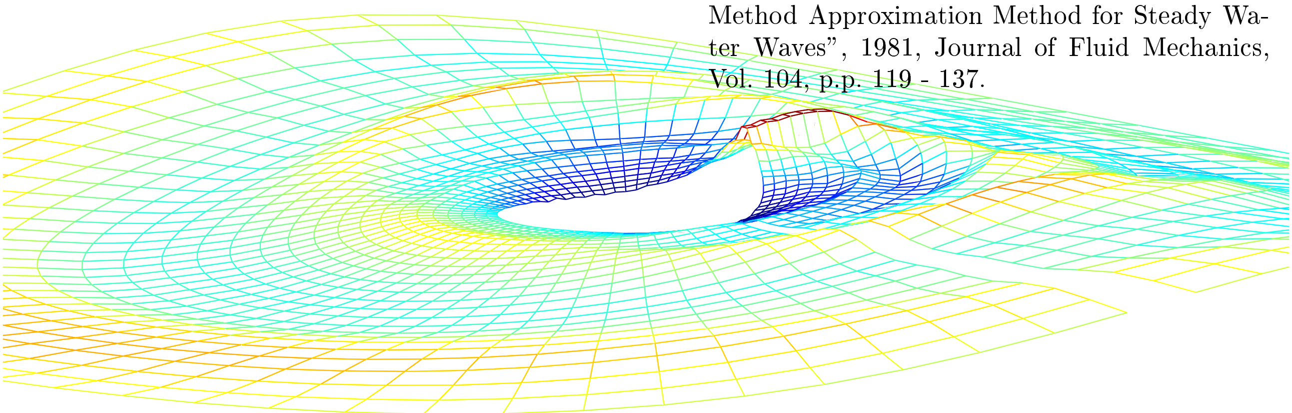

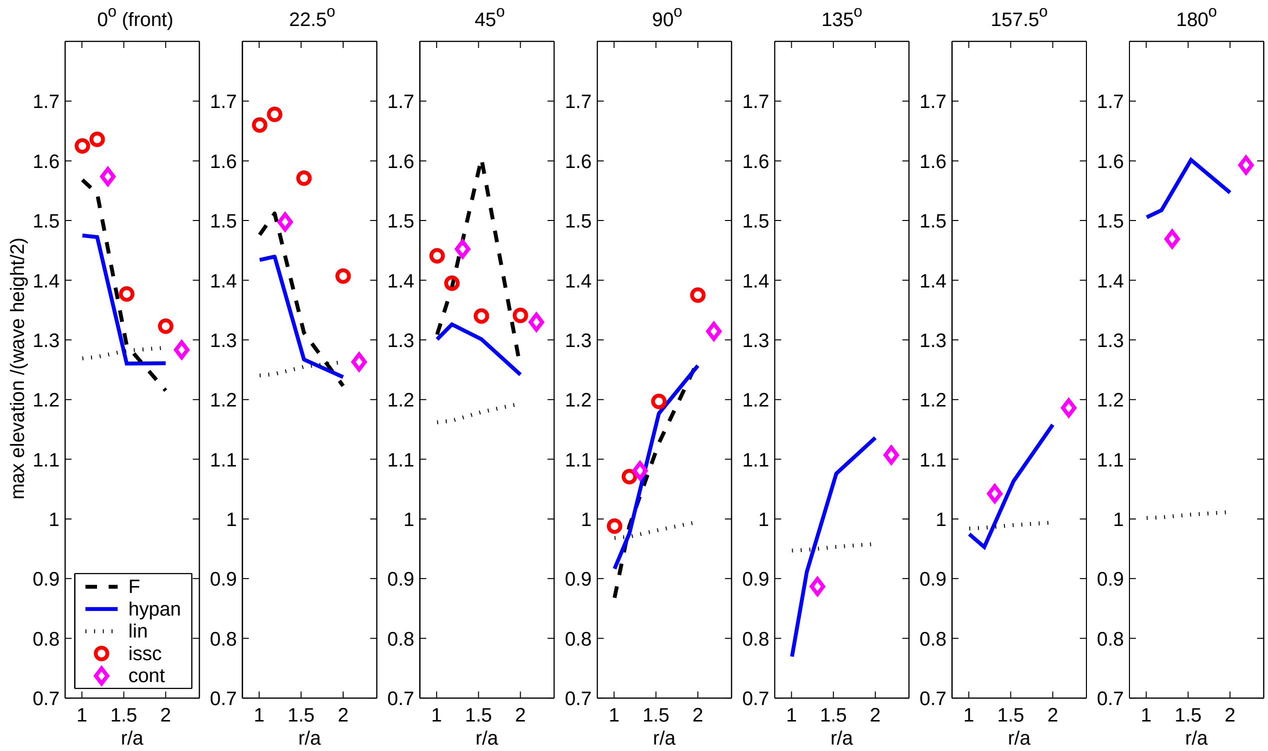

Figure 1: Maximum relative surface elevation near the circular cylinder in the 7.90 m wave. $H/\lambda = 1/16$, $H/D = 1/2$, $D/\lambda = 1/8$.

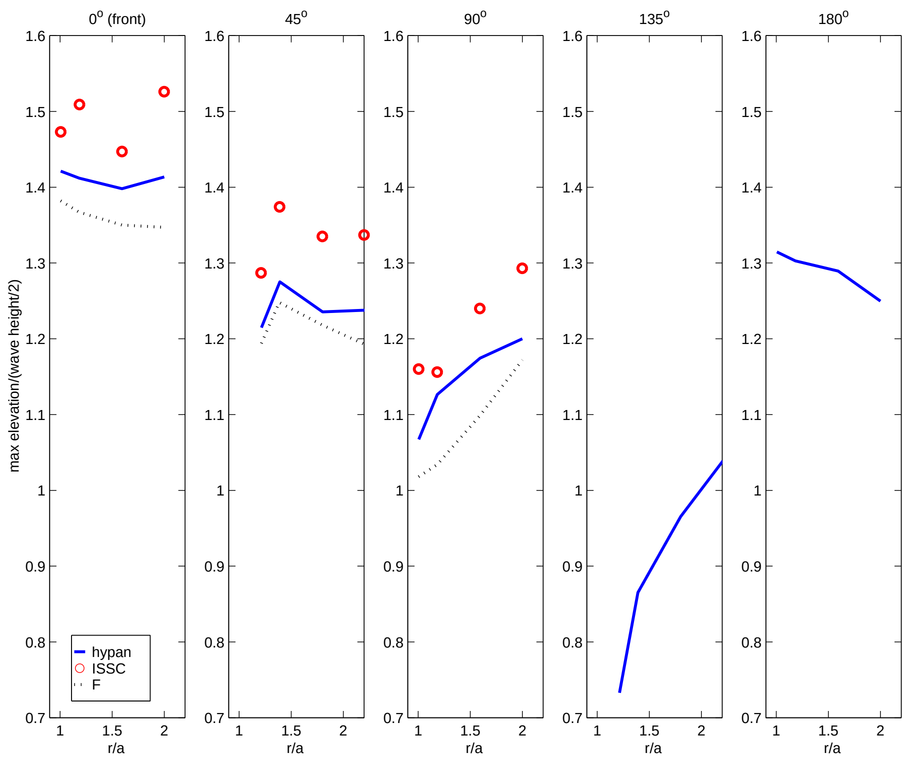

Figure 2: Maximum relative surface elevation near the square cylinder in the 4.22 m wave. $H/\lambda = 1/30$, $H/D = 1/4$, $D/\lambda = 1/8$.

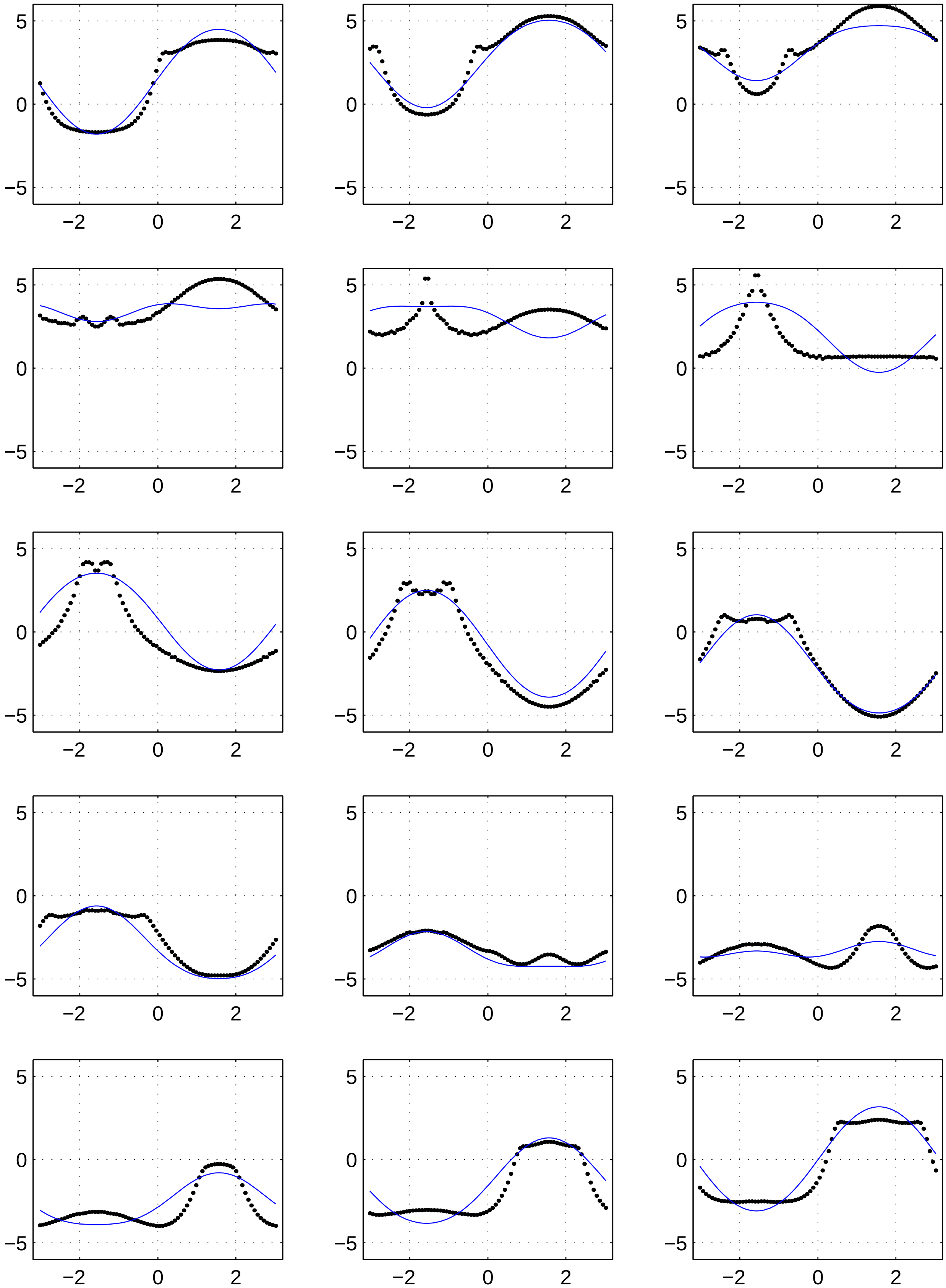

Figure 3:
Surface elevation on the cylinder in the 7.90 m wave in 15 frames from one period. Elevation in meters versus angle in radians. Front at $+\pi/2$, back at $-\pi/2$. The dots are the collocation points nearest to the cylinder, at 1.04 times the radius. The thin blue line is the linear solution. $H/\lambda = 1/16$, $H/D = 1/2$, $D/\lambda = 1/8$.