An experimental investigation of higher harmonic forces on a vertical cylinder in long waves

by

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In recent time considerable efforts have been made to analyze wave loads which lead to sudden high frequency responses of floating or stationary offshore platforms. On the theoretical side various models have been developed to analyze this problem. Perturbation methods have been developed under the assumption of incoming Stokes waves, to capture the wave loads up to the third harmonic component (Faltinsen, Newman & Vinje [1], Malenica & Molin [2]). Fully nonlinear methods have also been developed to analyze this problem (Cai & Mehlum [3], Ferrant [4]). Several model tests and small scale experiments have been undertaken, primarily in focused waves or irregular waves. A thorough understanding of this problem is still lacking, however. With regard to the perturbation methods, it is uncertain what are their domain of validity. The available fully nonlinear methods assume potential theory, and break down when local wave breaking occurs in vicinity of the body. An important question is then if the main trends of the wave forces are continuous when (local) wave breaking takes place.

This has motivated us to set up small scale experiments on higher harmonic wave loads on a slender vertical circular cylinder in a wave tank. We have chosen to work with incoming Stokes waves in deep water. This corresponds to the assumptions in the perturbation methods. Moreover, the velocity field of the incoming waves has only one frequency, up to a relatively large wave slope. The higher harmonic wave forces are then caused by the presence of the cylinder in the waves. The purpose is a direct comparison between the experiments and the theoretical methods for a relatively large range of wave amplitude to cylinder diameter ratio, at several non dimensional wave numbers. While the experiments are carried out in a relatively narrow wave tank, with a ratio of about 8 between the tank width and the cylinder diameter, the theories assume no vertical boundaries. We find, however, that the effect of a limited width of the wave tank is not very important to the investigation. Somewhat surprisingly, the distance from the wave maker to the cylinder must be very large to avoid unwanted nonlinear wave effects.

The experiment and results

The measurements are carried out in a wave tank which is 24.6m long, 0.5m wide and filled with water to a depth of 0.6m. In one end there is a wave maker which is a vertical plate controlled and monitored by a computer. At the other end there is an absorbing beach. The recordings are performed before any (small) reflected wave has reached the cylinder. The waves are generated by periodic motions of the wave maker. After a leading transient part the wave train becomes periodic, to a good approximation. Recordings of the incoming waves confirm a shape corresponding to Stokes waves for wave slopes less than 0.19, which is the largest wave slope in the experiment.

The cylinder is R = 3cm of radius and is extending throughout the entire water depth. The non dimensional wavenumber in the presented results is $kR = 0.245$. The wave amplitude, A, is varying so that Ak is ranging from $Ak = 0.06$ to $Ak = 0.19$, and the ratio of the wave amplitude and the radius of the cylinder is ranging from $\frac{A}{R} = 0.24$ to $\frac{A}{R} = 0.78$. The distance from the wave maker to the cylinder is ranging from 6.33m to 15.45m. The total force $F(t)$ in the horizontal direction is recorded by two force transducers. The first four harmonic components of F are obtained by Fourier transform over 10 wave periods, i.e.

$$F(t) = Re(F_1 e^{i\omega t} + F_2 e^{i2\omega t} + F_3 e^{i3\omega t} + F_4 e^{i4\omega t} + ...) \quad (1)$$

For the first harmonic force we find an excellent agreement between the measurements and linear theory for all wave amplitudes. We have taken into account the effect of the laminar boundary layer at the cylinder.

In figure 1 we compare our measurements on $|F_2|$ with second order theory (Newman [5], figure 5 and Molin [6]). The experiments are in good agreement with the theory for small Ak. For moderate wave slope the measured $|F_2|$ becomes smaller than the theoretical value. We find, on the other hand, good agreement between theory and experiment for the phase of the second harmonic force for all A (results not shown).

In figure 2 we compare our results with the third order theories of Malenica & Molin [2] (figures 6 and 8) and FNV [1]. We see that both theories are in good agreement with our measurements of the amplitude $|F_3|$. For the phase of the third harmonic, the results of Malenica & Molin are in excellent agreement with the measurements. The theory of FNV predicts a value of the phase that are roughly speaking 180 degrees out of phase with our measurements. We notice that the third harmonic force seems to be well predicted by third order theory up to wave slopes as large as $Ak = 0.19$.

For the fourth harmonic component we give data for Ak exceeding 0.1, since this force is too small to be measured at smaller wave slopes. We find that $|F_4|R/\rho g A^4$ is approximately 3.3. The phase of F_4 is about 2.5.

When we place the cylinder too close to the wave maker, an oscillation as function of the wave amplitude appears in the higher harmonic forces. An example is displayed for $|F_2|$ in figure 1. This effect disappears when the distance to the wave maker is increased.

At the workshop more results for various wave numbers will be presented.

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References

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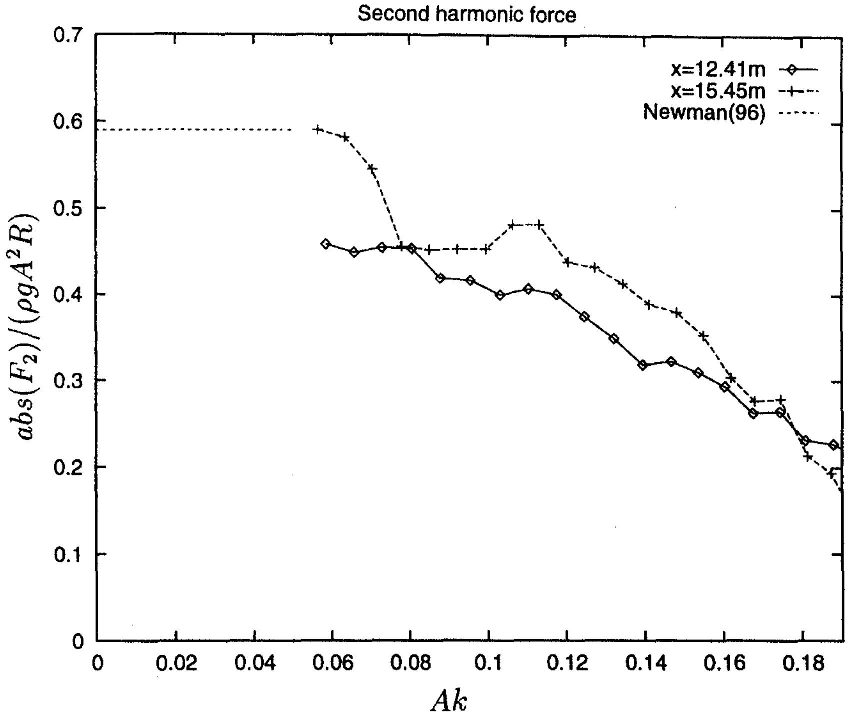


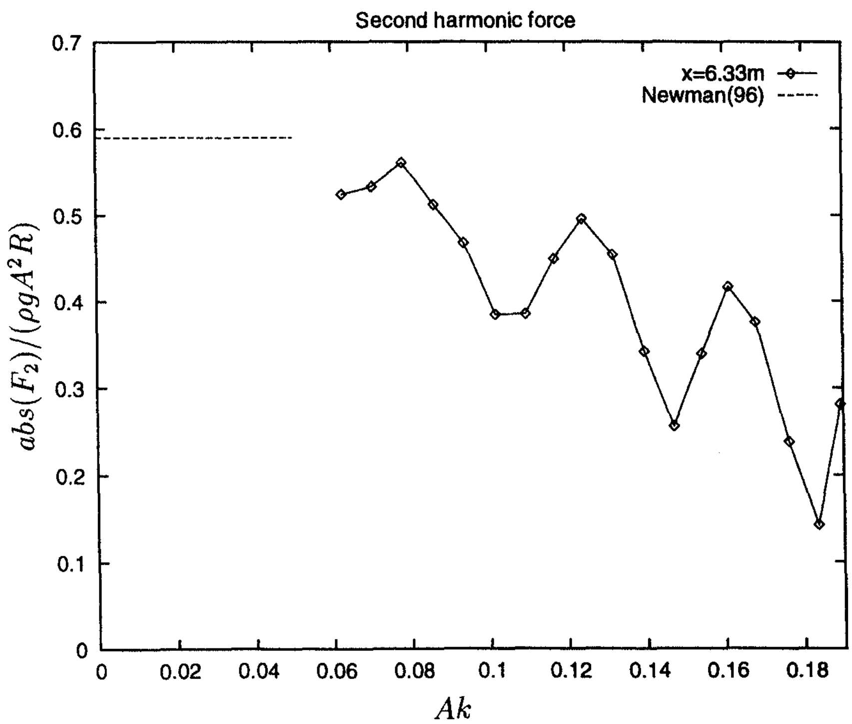
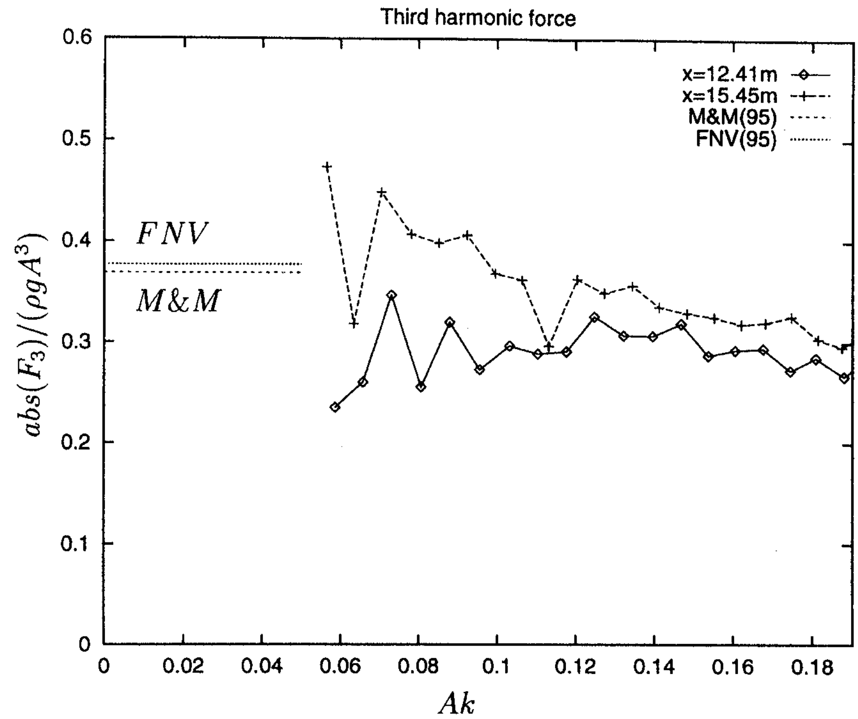


Figure 1: The second harmonic force calculated taking the Fourier transform over 10 wave periods. Upper figure: The distance from the cylinder to the wave maker is 12.41m and 15.45m from. Bottom figure: The distance from the cylinder to the wave maker is 6.33m.



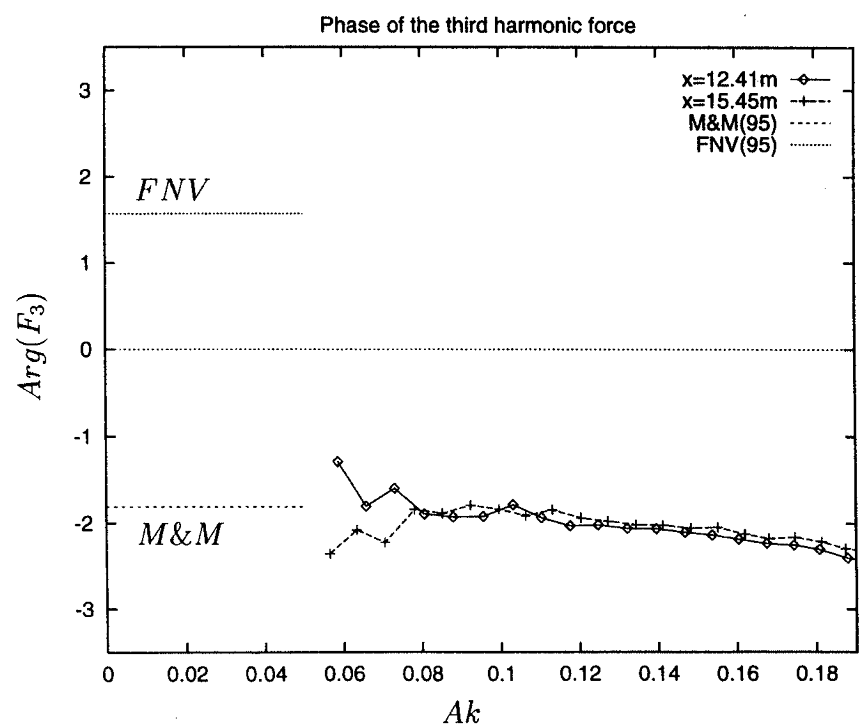


Figure 2: The third harmonic force calculated taking the Fourier transform over 10 wave periods. The distance from the cylinder to the wave maker is 12.41m and 15.45m. Upper figure: The amplitude of the third harmonic force. Bottom figure: The phase of the third harmonic force.