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COMPUTATION OF HIGHER ORDER DIFFRACTION EFFECTS USING A FULLY NONLINEAR SIMULATION METHOD

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INTRODUCTION

A number of studies, experimental or numerical, have been recently undercome in order to gain some understanding of the so-called "ringing" phenomenon. Ringing events observed during model tests or at sea occur in sea states with peak periods equal to 3 to 5 times the structure's resonance period, suggesting that highly nonlinear effects are involved.

If the phenomenon is to be modelized using a perturbation approach, it means that at least a third order expansion is required. Such a methodology has recently been adopted by Malenica & Molin (1995), who implemented a consistent perturbation scheme for the evaluation of third order-triple frequency loads on vertical bottom mounted cylinders submitted to regular Stokes waves. A third order time domain approach based on the code SWAN has also been undercome by Sclavounos & Kim (1995), but up to our knowledge, no third order numerical results have yet been reported. Following a different approach, Faltinsen, Newman & Vinje (1995) developed a long wave theory in which both the radius of the cylinder and the wave amplitude are assumed to be small compared to the wavelength. The comparison of both methods gave rise to some controversy (see for example discussions at the 10th WWWFB in Oxford), as results from Malenica and Molin seemed to restrict the validity of FNV theory to very low ka (under 0.025). However, in their conclusion, Malenica & Molin insisted on the lack of experimental validation of their results, while they suggested that fully nonlinear simulation codes were not mature enough for the accurate capture of such higher order diffraction effects.

The aim of the present paper is to partly answer this need for more validation, by reporting on nonlinear simulations of the diffraction of long waves on a vertical bottom-mounted cylinder, using a modified version of the code ANSWAVE. Full results including nonlinear time depending forces and runup on the cylinder as well as free surface maps in the vicinity of the cylinder are produced. Frequency domain coefficients for the forces and runups are then obtained by moving window Fourier analysis of the time series, and it is shown that with the adopted mesh density, stable results are obtained up to the fourth harmonics. However, the analysis is focused on triple frequency diffraction loads which tend to confirm M&M results in the long wave regime.

PROBLEM FORMULATION - NUMERICAL PROCEDURE

The essential of the solution method as described in the paper presented at the last Workshop in Oxford [4] is unchanged, but the problem is formulated here in terms of the perturbation induced to the incident wave by the body, in a manner comparable to the one exposed by Lalli *et al* (1995), while in [4] the total flow was simulated. A semi-Lagrangian formulation with markers fixed horizontally is adopted, and solved using an isoparametric linear boundary element method, coupled with a 4th order Runge-Kutta scheme for the time stepping. The incident nonlinear wave potential and elevation are given by a stream function model (Rienecker & Fenton 1981).

NUMERICAL RESULTS

A series of simulations have been undercome with parameters corresponding to cases already treated in [1]. The wavelength is set to a constant , $\lambda/H=0.785$, i.e. $kH=8.$, where H is the water depth, while the radius a of the bottom-mounted cylinder is varied so that $0.05 \leq ka \leq 0.30$. The incident wave amplitude is $A/H = 0.0075$, except for the lowest wavenumber, $ka = 0.05$, for which the amplitude has been cut by half, because of stability problems in the simulations. For each different wavenumber (and cylinder radius), an adapted mesh is set up, with the free surface being discretised up to a radius equal to two wavelenths, and with a density of about 100 panels per wavelength in the vicinity of the cylinder, in order to be able to capture diffracted 3ω free waves. The mesh density becomes lower when the distance from the body increases, and the total number of panels on the half-domain is about 4000. Free surface conditions modified by damping terms acting on the perturbation potential and wave elevation are applied for radial distances over one incident wavelength.

Starting with initial conditions corresponding to the undisturbed incident wave in the domain, the Neumann condition on the body is progressively introduced during the first wave period. Full time-depending nonlinear quantities such as wave patterns, runups and forces are available. Examples of time series are given here, for ka=0.20 (cylinder radius $a/H = 0.025$). Figure 1 is a plot of the horizontal force Fx on the cylinder. Figures 2 and 3 represent runups upwave and downwave, respectively. On each of these plots, the total wave elevation as well as the difference between the the total wave and the undisturbed wave, i.e. the perturbation, are given. For each of these signals, a periodic behaviour is reached within less than two periods. Nonlinearities are mostly apparent in the runups, especially at the upwave position. For comparison with frequency domain results, moving window Fourier analyses of these signals are then undercome. A window width equal to one wave period is applied. The resulting nondimensional force harmonics obtained for ka = 0.20 are given by figure 4, with results for the drift force F0 up to the fourth harmonic F4. A zoomed graph excluding F1 is given by figure 5. F0, F1 and F2 are very stable, some perturbations appearing for F3 and more sensibly for F4, but without any drift, which is quite satisfying. F0 and F2 are scaled by $\rho g A^2 a$, F1 by $\rho g A a^2$, F3 by $\rho g A^3$ and F4 by $\rho g A^4/a$, where A is the wave amplitude and a is the cylinder radius. The same analysis has been applied to runups upwave and downwave, see figures 6 and 7 respectively. Significant perturbations appear for the third harmonic in place of the fourth for the force. One can notice the stronger harmonic content of the runup upwave, which was already apparent on the time series.

These analyses have been repeated for values of ka ranging from 0.05 to 0.30, that is in the range for which ringing is observed. Figures 8 and 9 compare the real and imaginary parts of the triple frequency force F3 obtained with ANSWAVE, with results from the frequency domain third order analysis of Malenica and Molin. The agreement is believed to be quite satisfactory, especially when one considers the very low absolute level of the 3ω force which is extracted from the force time series. For example, for ka = 0.20 and $2*A/H = 0.015$, there is a scale of about 1 to 200 between F1 and F3 ! However, these are the first simulations using the code in such a configuration, and we believe that our results are still subject to improvement.

CONCLUSION

A fully nonlinear simulation method has been applied to the analysis of long wave diffraction by a vertical bottom-mounted cylinder. A quite satisfactory agreement has been found with previously published frequency domain results of Malenica & Molin on the triple frequency horizontal force. With the levels of time and space discretization adopted, nonlinear simulations using ANSWAVE produce stable results up to the fourth harmonics for the forces and to the third harmonics for the runups. Further simulations with increasing amplitudes are planned, in order to illustrate the anticipated divergence between fully nonlinear modelization

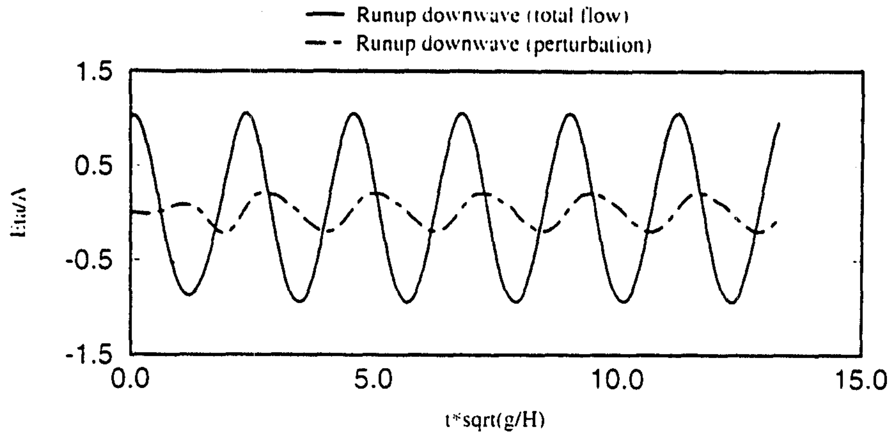
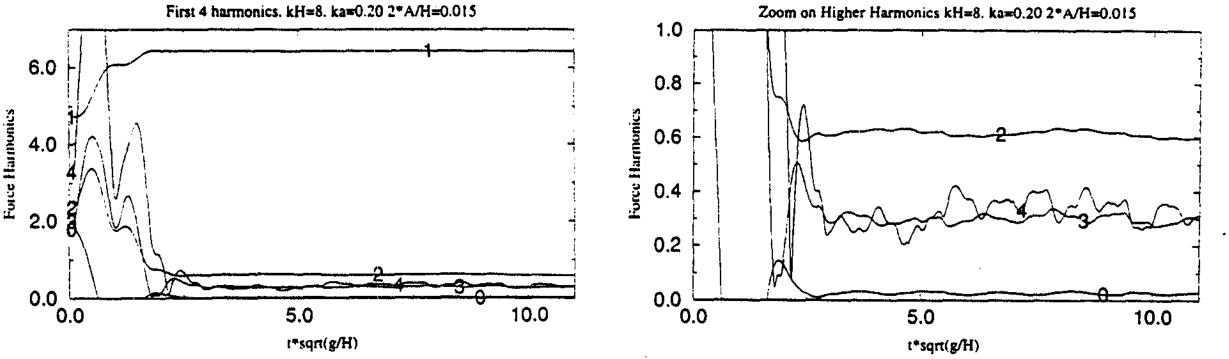
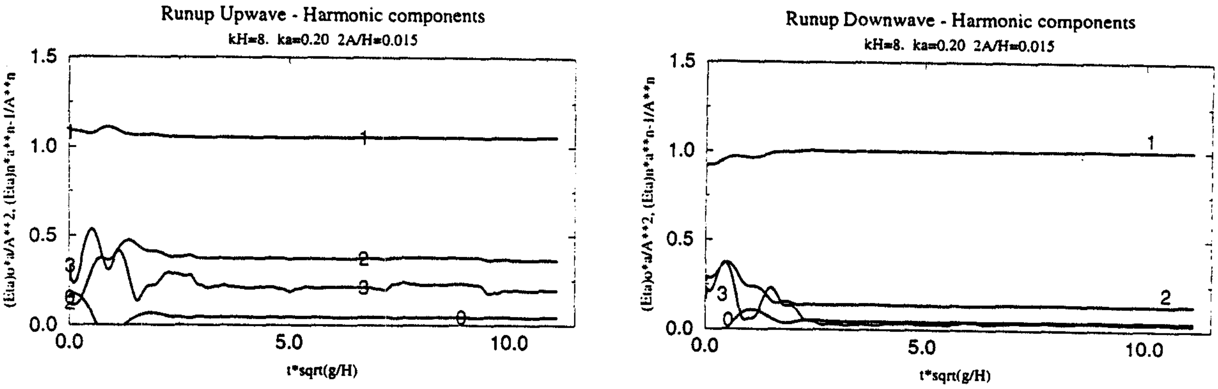


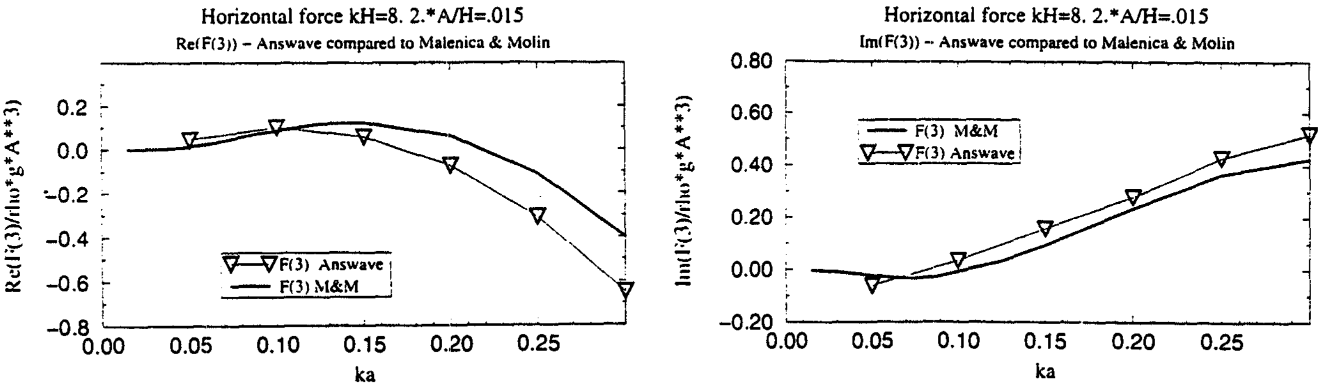
Figure 3: Runup downwave. ka=0.20 kH=8. 2A/H=0.015



Figures 4 and 5: Moving window Fourier analysis of the force. ka=0.20 kH=8. 2A/H=0.015



Figures 6 and 7: Moving window Fourier analysis of the runups. ka=0.20 kH=8. 2A/H=0.015



Figures 8 and 9: Components of the triple frequency force compared to M&M results.

and perturbation analysis, and will be presented at the Workshop. Cross comparison between existing three dimensional fully nonlinear simulation programs is also very desirable for quantities for which no reference results are available, such as higher order runups and 4ω forces (and over). The extension of the model to irregular waves and the inclusion of wave-induced body motions are also considered.

Acknowledgments

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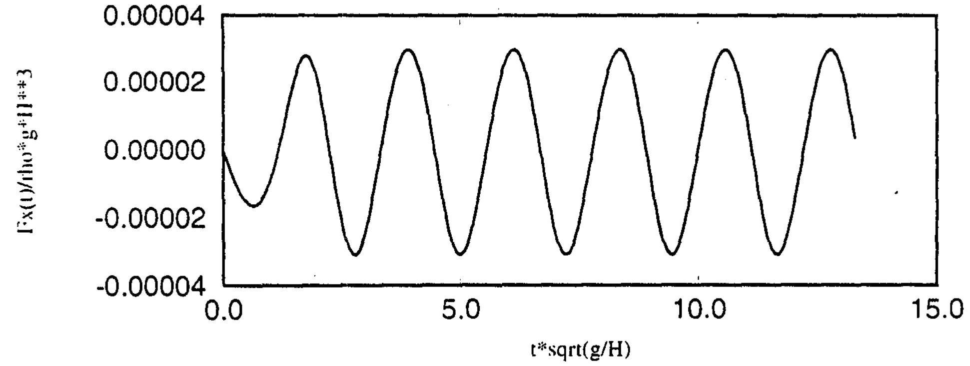

Figure 1 : Time series of the inline force Fx, ka = 0.20. kH = 8.

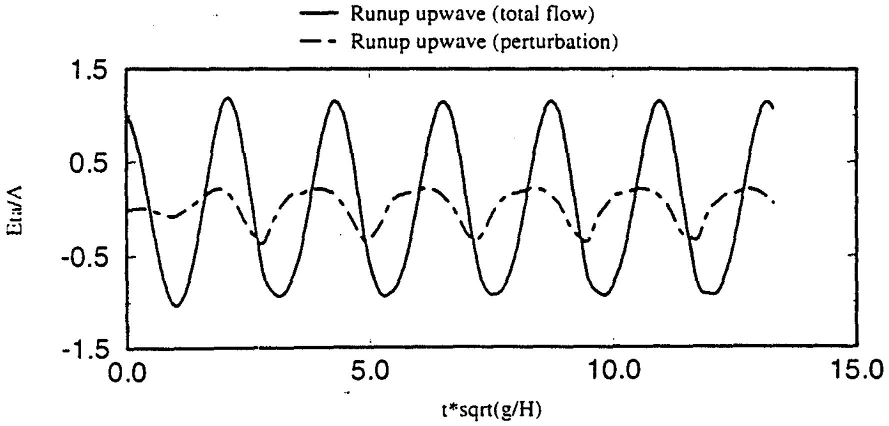

Figure 2: Runup upwave. ka=0.20 kH = 8. 2A/H=0.015