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ON HIGHER HARMONIC WAVE LOADS ON VERTICAL CYLINDERS AND RINGING OF OFFSHORE STRUCTURES

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The phenomenon of ringing has motivated several theoretical and experimental studies. The experimental studies have been carried out in wave tanks with incoming focussing wave groups and steep random waves (Grue, Bjørshol and Strand 1994, Stansberg et al. 1995, Chaplin, Rainey and Yemm 1997, Scolan et al. 1997) and with incoming periodic waves (Huseby and Grue 2000). The primary focus of the theoretical studies have been to capture the components of the wave force up to the third harmonic wave frequency (Faltinsen, Newman and Vinje 1995, Malenica and Molin 1995). A fully nonlinear model has also been developed by Ferrant (1998). Ringing occurs in relatively large wave events. What we still are after is a fundamental understanding of the higher harmonic force(s) that may generate resonant high frequent motions, and when they occur in terms of the wave parameters.

We here report som recent experiments on the phenomenon. We also include results from investigations at other institutions.

Secondary load cycle. Cylinders of small scale

A large set of experiments has been carried out with periodic incoming waves measuring the horizontal force on a vertical cylinder (see Huseby and Grue 2000). The periodic waves were always preceeded by an unsteady leading wave train. The unsteady waves gave rise to a relatively pronounced higher harmonic force on the cylinder, similar to the observations in focussing incoming waves (figure 2). A secondary load cycle is also observed in large wave events of an irregular sea. A secondary load cycle, although generally less pronounced, is also observed in the periodic part of the wave train when the waves are sufficiently steep.

In experiments with small cylinders (in small wave tanks) a secondary load cycle occurs as marked in the $(kR, k\zeta_m)$-plane, k the wavenumber, R cylinder radius, ζ_m maximal elevation, see figure 1a. The domain is $0.1 < kR < 0.33$, $0.3 < k\zeta_m$. The observations by Grue et al. (1994) and Chaplin et al. (1997) are added to the present experiments, which basically are performed with $R = 3$cm. Some experiments were also made with $R = 6$cm. In Grue et al. (1993) the cylinder radius was $R = 5.95$ cm, while in Chaplin et al. (1997) the cylinder radii were 6.35, 5 and 3.5 cm. There is a good fit between the present observations and the previous ones. The peak to peak force we denote by F_{pp}, and the height of the secondary force oscillation by F_{II}. The largest value of $F_{\mathrm{II}}/F_{\mathrm{pp}}$ is 0.155. Otherwise $F_{\mathrm{II}}/F_{\mathrm{pp}}$ exceeds a level of about 0.08–0.1 in most of the domain $0.1 < kR < 0.3$ and $0.3 < k\zeta_m$.

Our results on this point conform with Chaplin et al. (1997). They concluded that a secondary load cycle occurred when the wave slope exceeded a certain value. In their terminology the waveslope was estimated by $kH/2$, H the wave height. Their treshold value was 0.2. In our description the waveslope is estimated by $k\zeta_m$ and the secondary load cycle occurs when $k\zeta_m$ exceeds 0.3.

Secondary load cycle. Cylinders of moderate scale

A secondary load cycle is also observed in the force on a cylinder with radius 16.35 cm in the leading part of a wave train and in an irregular sea (Saga-report, 1995). The irregular sea recordings showed occurrence of a secondary load cycle in the force 15 times during 1215 wave periods, i.e. about 1.2 % of the time, in the average. The value of $F_{\mathrm{II}}/F_{\mathrm{pp}}$ was slightly less than 0.1 at maximum. In nine of the events F_{II} is in the interval 5–10% of F_{pp}. In three other events F_{II} is in the interval 2.5–5% of F_{pp}. In the remaining three events F_{II} is in the interval 0.4–2.5% of F_{pp}, see figure 1b. The estimated local nondimensional wavenumber in the events is in the range $0.106 < kR < 0.216$. The corresponding range of the waveslope is $0.201 < k\zeta_m < 0.3306$.

The observations with the larger cylinder are not seen for the small cylinder of radius 3 cm, for corresponding nondimensional parameters. The role of viscosity may explain the differences between small and moderate scale.

Observations of ringing and interpretation

The report from the 'Ringing Joint Industry Project 1993' contains recordings of resonant induced motions of models in scale 1:55 of the Draugen Gravity Based Platform (GBS) (radius 8.2 m) and the Heidrun Tension Leg Platform (TLP) (column radius 15 m). The incoming waves were irregular waves. We include all ringing events from these series in figure 1c. Experimental observations of ringing motions of a model of a Gravity Based Platform (GBS) of radius 23 cm (Scolan et al. 1997) are also included in the figure.

It is tempting to plot all occurrences of a secondary load cycle together with the occurrences of pronounced ringing motion. We observe a relatively good correspondence between the occurrence of the high frequency load and the observed ringing (figure 1d). We also indicate two lines, namely the lines $Fr = 0.38$ and $Fr = 0.43$. The Froude number is given by $Fr = \omega\zeta_m/\sqrt{gD}$ where $\omega\zeta_m$ is an estimate of the maximal fluid velocity in the wave, ω the wave frequency. An appropriate scaling of the fluid velocity in free surface flows is $\sqrt{gD}$, g the acceleration of gravity, D the diameter of the cylinder. We observe that all the events are to the right of these lines, practically speaking, although the transision zone is not entirey sharp.

The value of $\omega\zeta_m$ indicates the magnitude of the local quasi-steady current due to the wave. A Froude number of 0.4 corresponds to a free wave with length equal to the cylinder diameter, on the local quasi-steady current at the cylinder. A Froude number of 0.5 corresponds to a wavelength which equals half of the cylinder circumference. Occurrence of the secondary force cycle due to a particular resonance between the cylinder and the induced local flow at the cylinder should not be overlooked.

Resonant build-up of motions

It is tempting to indicate the role of a secondary load cycle to ringing events. We employ a simplified model of a resonator for this purpose, i.e. $\ddot{y} + \sigma^2 y = F(t)$, $y(t=0) = \dot{y}(t=0) = 0$, giving $y(t) = \frac{1}{\sigma}\int_0^t \sin[\sigma(t-s)]F(s)ds$ where F denotes the recorded force. The simulated motion, here with $\sigma = 4\omega$, illustrate the resonant build-up of the motion during a wave period. The large motions occur after the passage of the wave crest.

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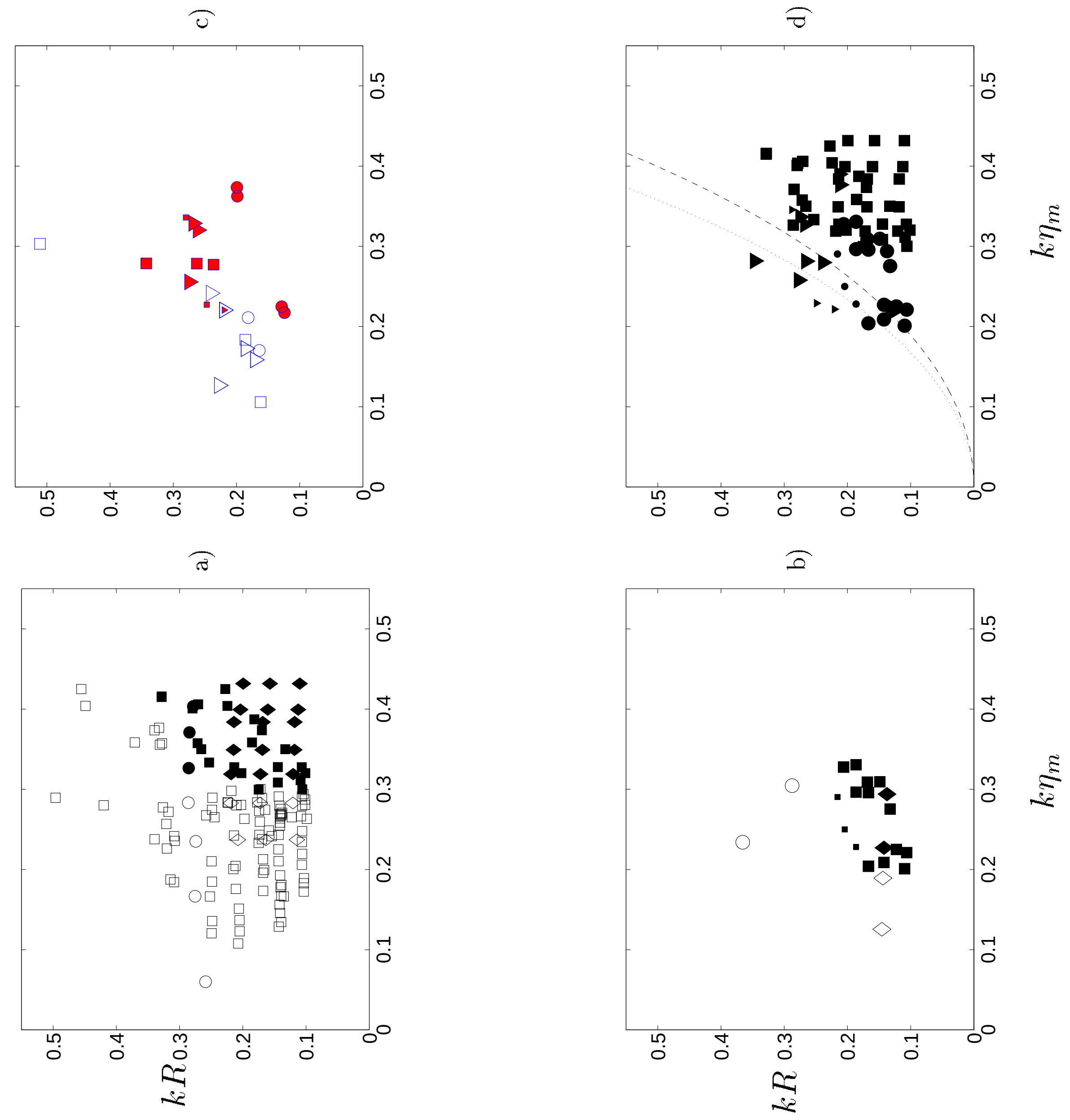

Figure 1: a) Occurrence of a secondary load cycle in small scale experiments. Presence (filled symbols). Absense (open symbols). b) Same for experiments in moderate scale. The small symbols mean weak interaction. c) Occurrence of ringing. Presence (filled symbols). Absense (open symbols). The small symbols mean weak ringing. d) Occurrence of a secondary load cycle and ringing. $Fr = 0.38$ (dotted line). $Fr = 0.43$ (dashed line).

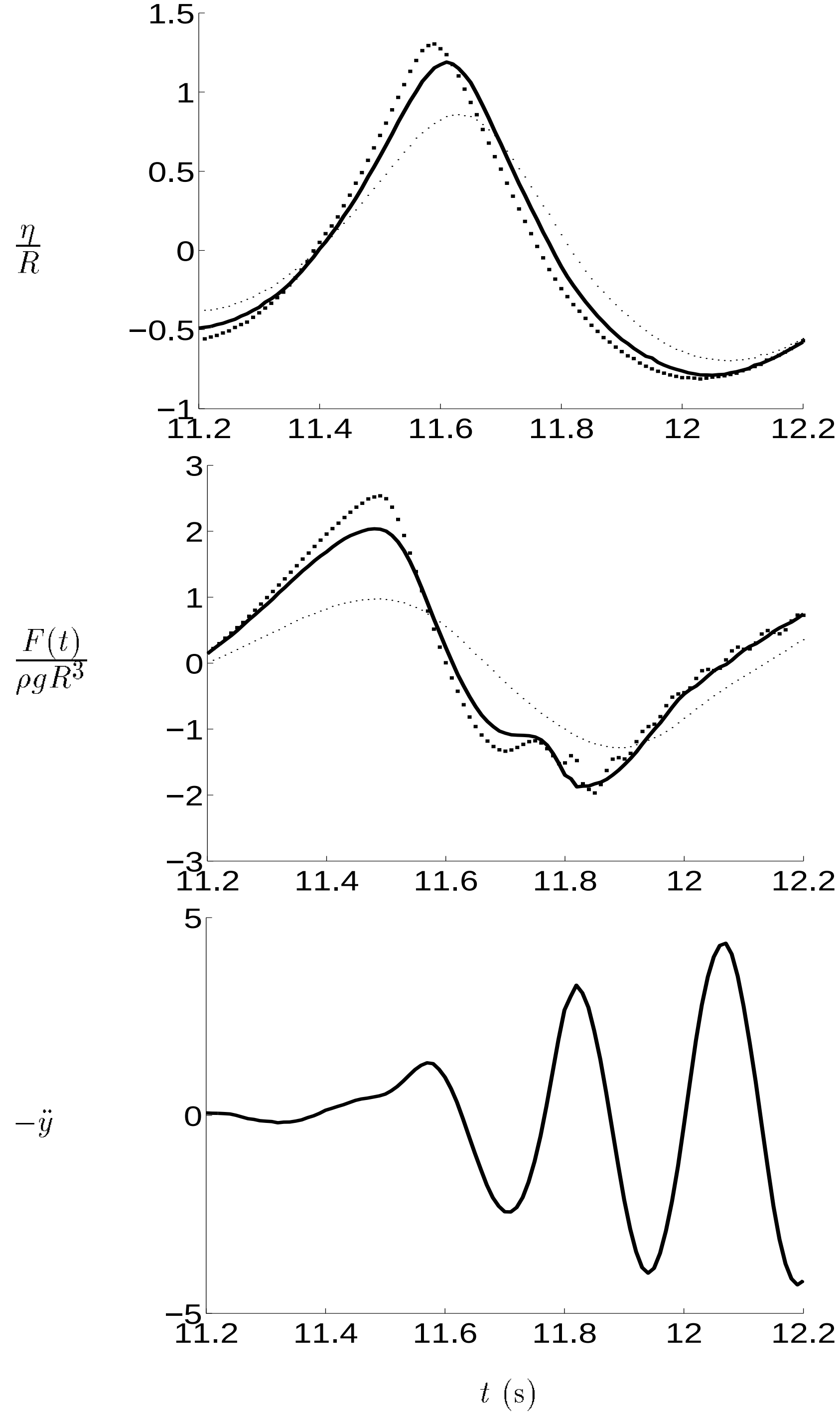

Figure 2: Horizontal wave force on a vertical cylinder in focussed waves. Upper: Elevation at the cylinder position, with $k\eta_m$=0.22 (thin dots), 0.31 (solid line), 0.34 (thick dots). Middle: Corresponding non-dimensional force on the upper force transducer (corresponding to the moment with respect to the bottom of the cylinder). Lower: simulated aceleration. Wave period 1.05 s. kR=0.27. $R = 6cm$.