Wavemaking by a Large Oscillating Body Near Tank Resonance

Marshall P. Tulin & Yitao Yao
Ocean Engineering Laboratory, Univ. of Califonia, Santa Barbara, CA93106

The neighboring walls can have a profound influence upon the waves caused by an oscillating three dimensional body. These effects, including important non-linear elements, are of importance in ship hydrodynamics for several reasons. First, they can be used to advantage to produce short crested waves in a narrow tank for testing purposes. Second, they cause errors in the forces arising on bodies oscillating in tanks. Their careful study is therefore important.

We have carried out both theoretical & experimental studies of three-dimensional wavemaking in narrow tanks; the theory has combined analytical & numerical techniques, & includes unusual & dominating non-linear effects which occur near discrete (cut-off) frequencies. These are eigenfrequencies for purely transverse wave motion in the tank.

Experiments have been carried out in a wave tank of cross-section 3 ft square and length 75 ft. Several three dimensional wavemakers have been used, and notably a half-cone of 38 degrees total angle. These experiments have confirmed the linear aspects of wave-propagation in the tank, which is itself highly interesting. They have also provided data on non-linear processes near the first cut-off frequency. Two separate non-linear phenomenon were observed. The first involved a suppression and even complete elimination of wave radiation at a specific frequency, f_s, less than the cut-off frequency. The second, involves the generation of slowly modulated propagating wave groups as the cut-off frequency is approached. The first of these phenomena has not previously been noted, to the best of our knowledge. The second had been studied, first in connection with an acoustic wave guides by Mei (theory) and later for gravity waves by Shemer & Miloh (theory & exp.). In neither case, however, was systematic data reported. We have obtained systematic data on wave groups, which show that they arise only for sufficiently large wavemaker stroke & that their speed of propagation increases linearly with stroke thereafter.

Appropriate numerical calculations have been carried out. One set of calculations allows the prediction of linear wave pattern, for an arbitrary body oscillating in a narrow tank, in which the boundary conditions on the body are satisfied exactly (Neumann-Kelvin wavemaking theory). This theory is sufficient to explain the suppression of waves at f_s, previously noted, which in the case of the half cone is completely absent when the wavemaker is represented by a source-sink distribution along its axis (slender body wavemaking theory). It is found that the effect depends in a systematic way both upon the size of the body & its protrusion down-tank. For sufficiently large & sufficiently protruding bodies, a frequency f_s is found to exist for which propagating waves are completely eliminated. Increasing body size can result in f_s considerably small than the cut-off frequency, see Figure 1, bottom.

Another set of calculations, necessary to capture wave group phenomena near cut-off, allows the prediction of the wave flow in the field near the wavemaker including non-linear effects both on the body & on the free-surface, & a matching of that near field with an appropriate non-linear evolution equation (a non-linear Schrodinger equation) in the far field. Very good agreement is shown between our measurements of the amplitude, speed & spacing of wave groups and the predictions of this theory, without empirical corrections of any kind, see Figure 2. A noticeable irregular distortion of the wave envelopes was measured with increasing distance downstream. We have been able to simulate the features of these distortions by allowing a 0.5% variation in the tank width with a period of 4.4 tank widths, see Figure 3.

We can finally conclude that observed non-linear wave group generation and propagation near tank resonance can be simulated with very good accuracy by this invicid model.

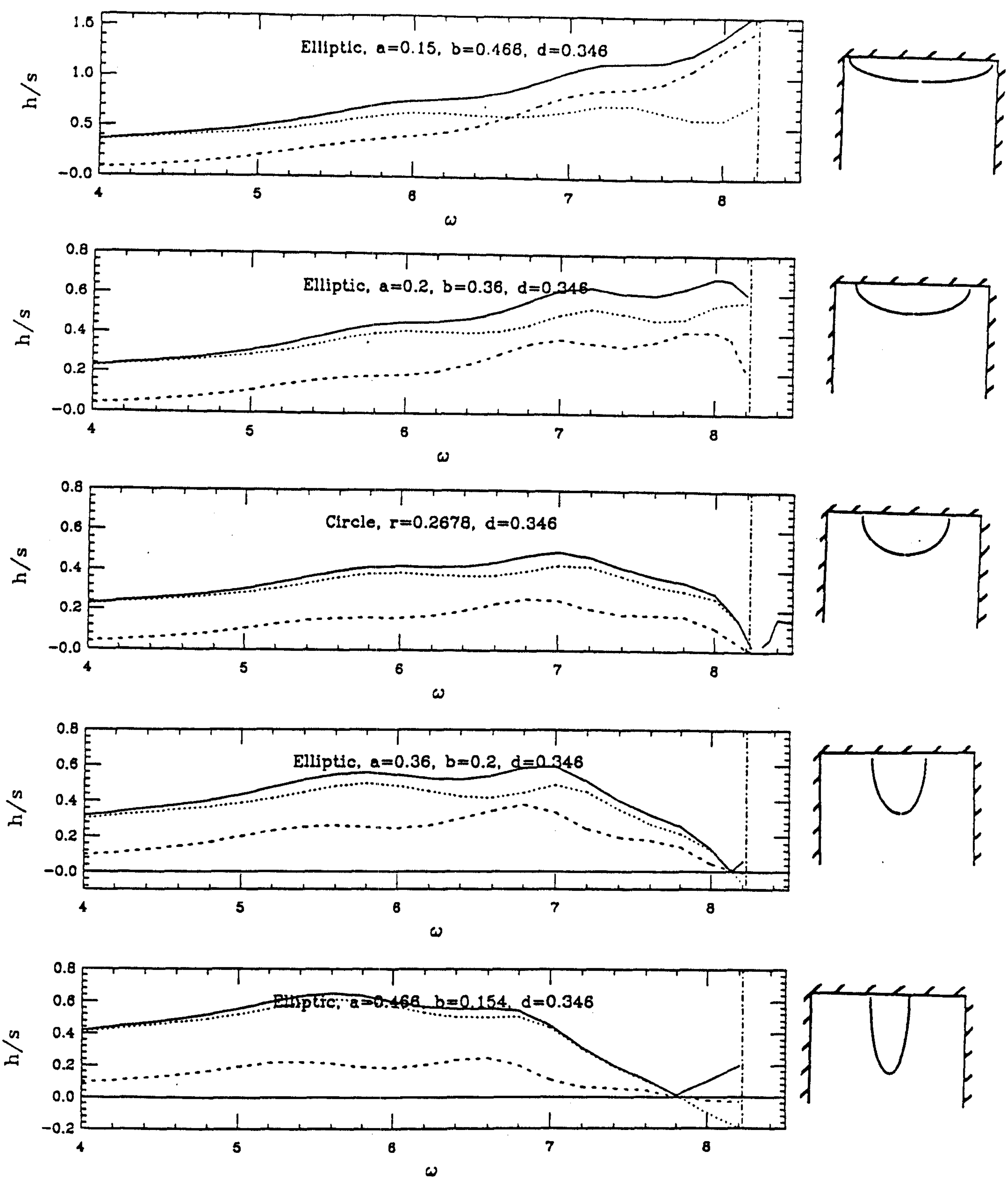
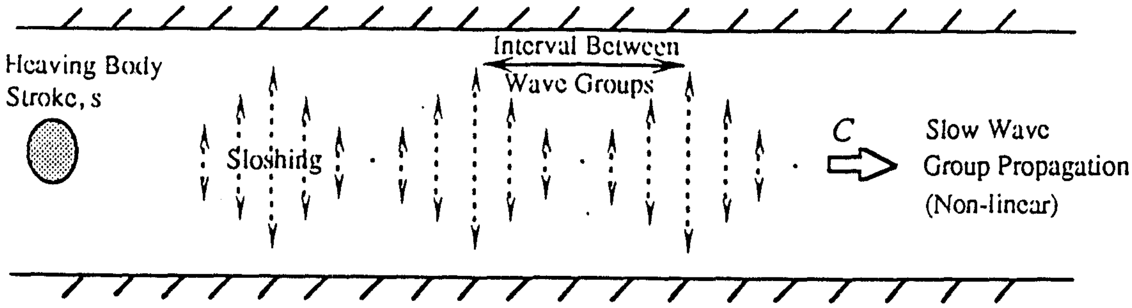


Fig 1. The nondimensional amplitude of the planar wave versus frequency. where the cut-off frequency is $\omega = 8.223$.

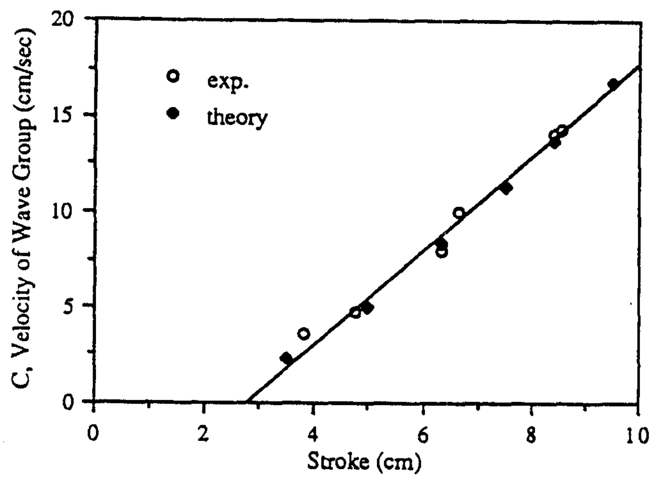
.... - A, ---------------- B, ———————— $(A^2 + B^2)^{1/2}$

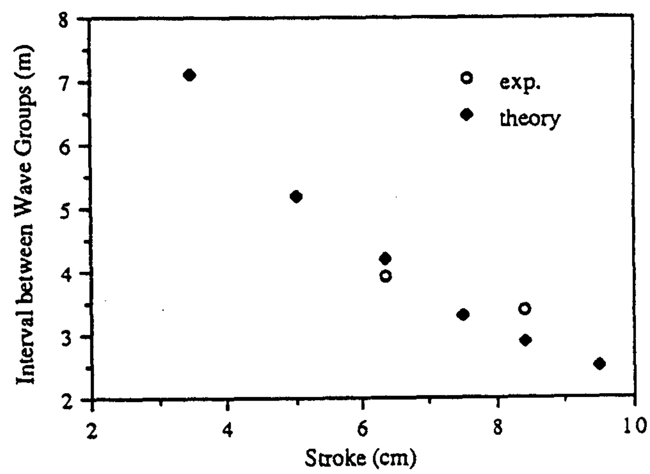
Figure 2. <u>Non-Linear Wave Generation and Propagation</u>

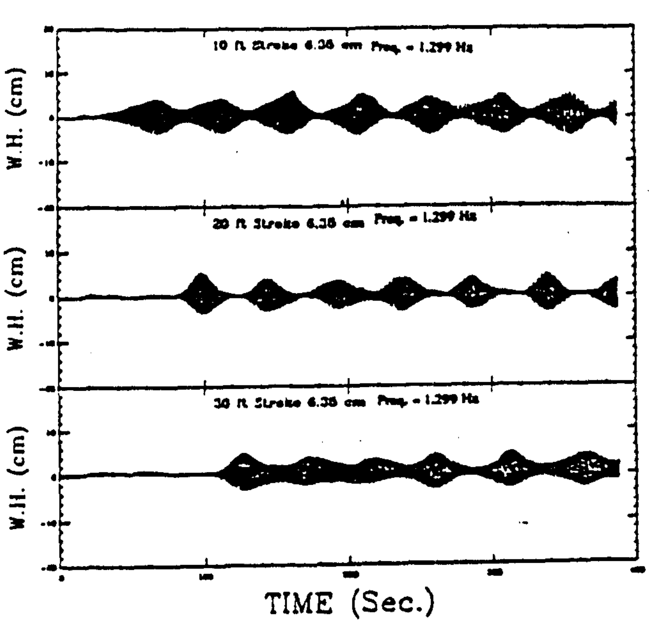


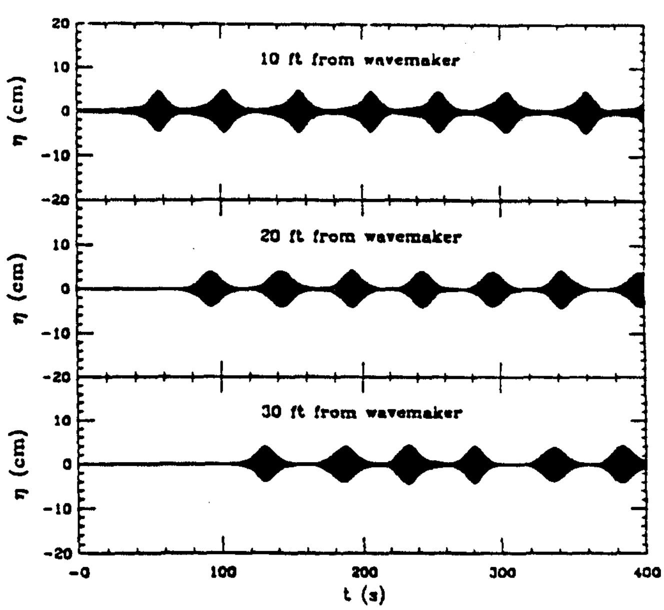
The Situation Near Tank Resonance

Non-linear theory & computations give excellent agreement with experiment









(a) (b)

Sloshing wave height as a function of time at various locations along the channel with a Wavemaker stroke of 6.35 *cm* at frequency 1.299 *Hz*. (a) - exp.; (b) - theoretical.

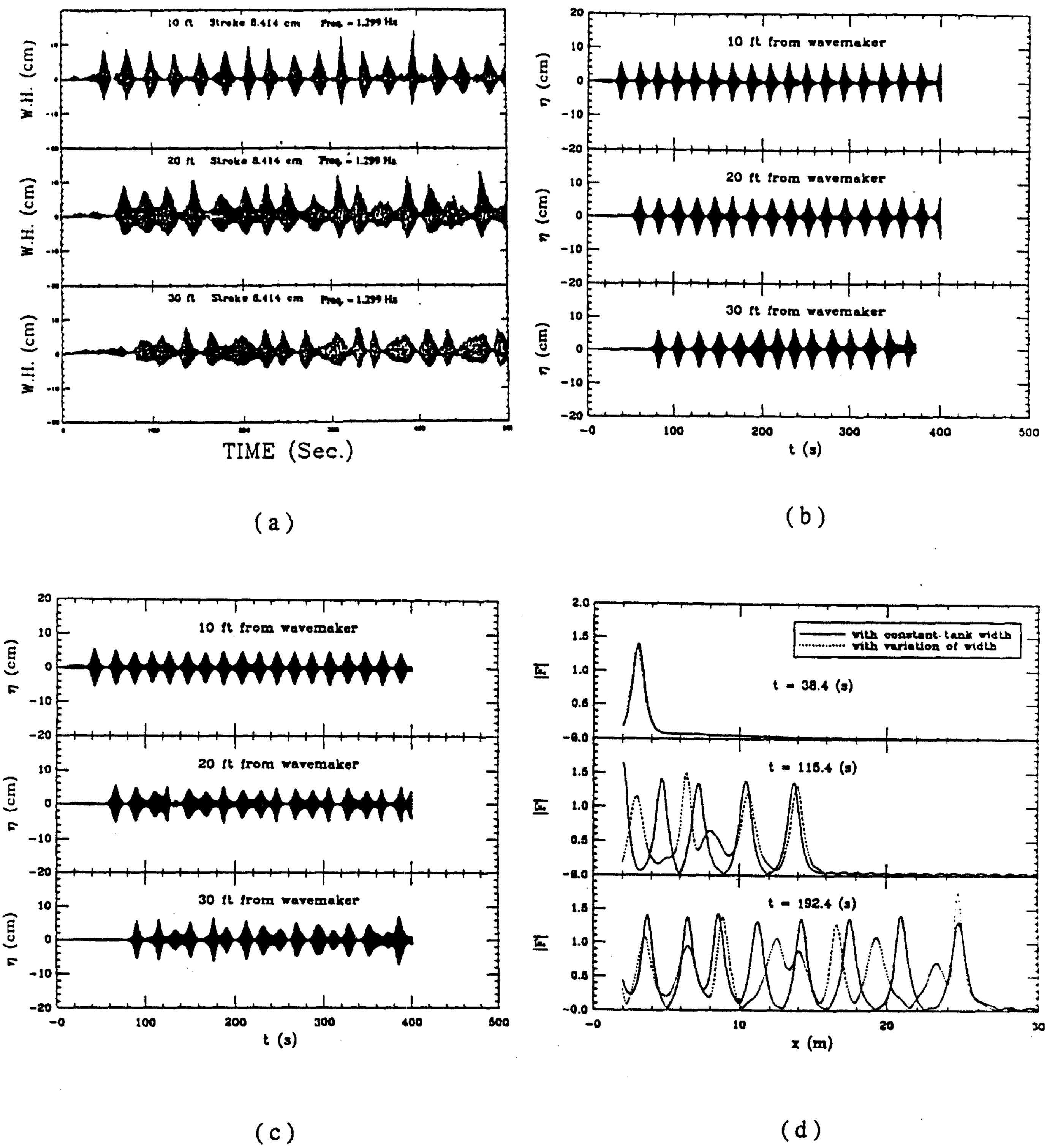


Figure 3. Sloshing wave heights as a function of time at various locations along the channel with a wavemaker stroke of *8.41 cm* at frequency *1.299 Hz*. (a) - experiment ; (b) - theory (constant width); (c) - varied width

(d) - Numerical solution for space-time evolution of $|F|$.

DISCUSSION

MARTIN: What are the effects of the far end of the tank? Presumably, at least in your linear model, you could include a better representation than propagating modes, so as to account for any reflection.

TULIN & YAO: We have a good beach, so we carried out the linear theory assuming no reflections of the propagating mode, but I imagine reflections could be taken into account if required. The non-linear wave groups are calculated as an initial value problem and during the length of the runs considered, the groups do not reach the end of the tank.

EVANS:

1) Have you tried oscillating the wave maker sideways to produce an antisymmetric motion?

2) Presumably the absence of radiated waves at a particular frequency implies the exciting force on the fixed wave maker due to an incident plane wave at that frequency is also zero by the Haskind relations.

TULIN & YAO:

1) No. We have only studied heaving, but there would seem no reason why the methods used could not be adapted for more general motions.

2) Thank you for pointing out this interesting fact. Perhaps the experiment should be tried.

OHKUSU: I observed almost the same phenomenon in my tank as you showed in the first picture. Surprisingly the water jumped out of the tank. In that case, wave maker has a uniform cross section from one tankwall to another and flow field generally must be two-dimensional. Therefore the cross waves are the start of this phenomenon. Is your theory applicable to this situation?

TULIN & YAO: Cross waves, so called, are the result of a parametric instability of the planar wave. They have been analyzed using multiple scale techniques, Jones (1984). The waves we have observed and studied theoretically are produced directly by the shaped wavemaker and are not the result of an instability.