二次元数値造波水槽に発生させたフリーク波

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1. Intorduction

On October 2004, an enormous typhoon No.23 hit Japan and the observation site off Muroto recorded 15m in significant wave height with 26m in maximum wave height. The study of extreme wave becomes more important to prevent people from marine disaster. The wave, which is one of the quite curious wave phenomenons, is known as Freak Wave. Freak waves appear suddenly as an isolated majestic wave, the height of which exceeds twice as large as its surrounding companies. It was recognized in an earlier paper by Klinting (Klinting and Sand, 1987) from the wave record taken at an observation site off Denmark in the North Sea 1981. After that many events like that features were found in several sea area worldwide including the North Pacific Ocean and the Sea of Japan. Those results were reported in the Rogue Wave 2000 Symposium (see Proceedings of Rogue Waves 2000, 2000) held in Brest 2000. Note; the concept of Rogue Wave is almost same as that of Freak Wave. In the symposium, many papers were presented for the mechanism of Freak wave generation such as caused by currents, wind change and non-linear wave interactions. The second round of this symposium was held at the same spot in 2004. Many sort of numerical techniques to investigate such phenomena were presented and the practical problems such as the prediction of Freak wave were proposed in this symposium. However any general consensus has not been made up to present. See Proceedings of the Rogue2004.

This work is attempt to understand some possible reasons and mechanisms of extremely steep transient waves creation in Numerical Wave Tank.

2. Numerical simulation

A Numerical Wave Tank (NWT) based on the Boundary Integral Equation Method is constructed to study mechanisms of creation and annihilation of extremely steep transient waves. The NWT is applied to 2-dimensional wave flume with either plunger or piston or paddle type wave-maker on one side. Free surface boundary conditions are satisfied exactly according to the Euler-Lagrangian formulation to the particles.

First, to check the validity of the NWT several numerical and physical experiments have been carried out:

- regular waves;
- highly non-linear waves and their comparisons with third-order Stocks waves;
- amplitude response functions for plunger, piston and paddle type wave-makers. For the last two cases, the results for waves of small steepness have been compared with their analytical solutions (e.g. Ursell et al., 1960).

Comparison between the numerical and experimental results gives fairly good agreement.

Second, we propose the following possible mechanism of freak wave generation:

- focusing waves;
- Benjamin-Feir instability;
- soliton envelope;
- breather solution.

The success of transient wave generation of defined shape directly depends upon the wave-maker motion (input signal). The signal depends mainly on wave frequency. Simply, to obtain regular wave with given height (steepness) and phase shift, the amplitude and phase response functions have to be applied. However, for high steep waves, the amplitude response function depends upon their steepness. Moreover, in physical experiments for steep and high frequency (>2Hz) waves, non-linear effects (friction, viscousity etc.) should be taken into account.

The dispersion of surface water waves plays an important role to gather the energy of frequency modulation wave train into one prescribed point. In the case of infinitely deep water, frequency modulation is governed with the relation

$$\frac{d\omega}{dt} = -\frac{g}{2x}$$

where x is the location of the focused point from the wave-maker. However, in the finite depth case such type of equation is written in some complicated manner and must be solved numerically.

Benjamin-Feir instability is well known as the disintegration of Stokes wave (Benjamin and Feir, 1967). In their theory the criterion of the occurrence of the disintegration was given with respect to the wave steepness. However in the developed stage nothing was predicted in their paper. Many experiments were conducted (see, for example, Yuen and Lake (1975)) it is difficult to examine a long time evolution of a wave train precisely because breaking and/or higher order instability modify the feature of waves. One of the present authors (Tomita et al, 1997) performed the systematic experiment for this later stage and found the diagram of the qualitative behavior of wave train to the parameters (ak, kx) where the former is the steepness of the wave and the latter is the non-dimensional fetch of it. Several phenomena associated with the Benjamin-Feir instability such as

- 2-dimensional weak modulation;
- 2-dimensional strong modulation with crest pairing;
- 2-dimensional breaking;
- 3-dimensional modulation;
- 3-dimensional breaking with radiation of crescent wave

were classified with respect to above two parameters. Famous FPU recurrence phenomenon (Fermi, Pasta and Uram (1955)) did not take place within the fetch of wave flume.

As a possible model of Freak wave, we choose the second case here.

Because of the high steepness of the wave train the numerical computation failed due to wave breaking on initial stage (if steepness is modest, it will take so long fetch and exceeds to the limit of the physical experiment). Very long fetched computations are to be done in near future.

From the theoretical point of view, the 2-dimensional weak modulation is described by the Non-Linear Schroedinger (NLS) equation as follow

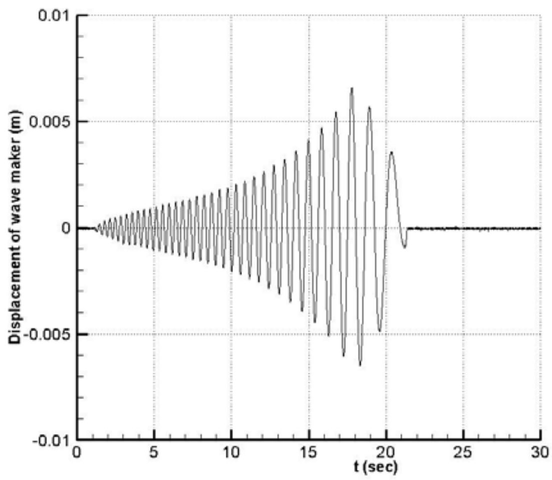
$$iq_T + q_{XX} \pm 2|q|^2\ q = 0$$

see, for example Peregrine (1983). For the case of positive sign in the last term, it is called self-focusing NLS equation or simply NLS+. Otherwise, the equation is called de-focusing NLS or NLS-.

Water waves are described by NLS+ equation, which has several exact solutions, for example steady progressive soliton envelope wave group (Zakharov, 1968; Kawahara, 1975; Tomita, 1986) and breather solution (Dysthe and Trulsen, 1999). In the first case, the wave group survives through long time evolution without any change of form by dispersion commonly appears for ordinary wave groups. The second case is characterized by a sudden creation and instant annihilation of an isolated high crest in otherwise regular wave train surrounding.

3. Experiment

Above mentioned results are examined in the highly controlled physical experiments. Experiments were conducted in the 2-dimensional wave channel of the National Maritime Research Institute of 20mL, 0.5mW, and 0.5mD. The plunger type wave-maker is controlled from the signal stored in PC. Arbitrary motion is possible within the limit of 3 Hz in frequency and 30 cm in stroke. A capacitance remote sensing wave gauge are newly developed and equipped in the distance x from the wave-maker. Since wave-making efficiency is very important to have designed wave system, the response function of the wave-maker not only for amplitude but also for phase lag was measured for regular waves in the beginning.



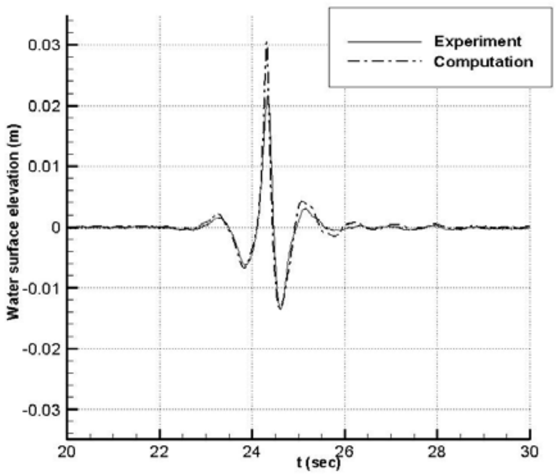


Fig. 1: Signal for self-focusing waves with amplitude response function applied (upper), and coalescence of focusing wave (lower). Solid line is experimental results, dashed dot line is computation.

In Fig.1 it is shown the signal designed for self-focusing waves (upper), and coalescent wave (lower) due to the given signal. It should be noted that maximum amplitude of wave group is about 0.6cm nevertheless the peak of single crest is up to 2.2cm (more than 3.5 times larger). Experimental results are compared with computed ones.

Experiment for breather solution realizing in a wave tank needs very precise setup so that we must leave it as a future task.

4. Conclusions

A numerical wave tank was constructed to examine various types of transient wave system including isolated high wave creation and instant annihilation. In this sort of research, the knowledge of response function of the wave-maker is indispensable in contrast to regular and/or irregular stationary wave test. Several cases of design wave computation were conducted such as self-focusing wave, Benjamin-Feir instability, envelope soliton wave group and breather wave train. Quasi-nonlinear wave making technique was also applied, which improved concentration of focusing wave to great extent.

The results were compared with corresponding physical experiment in a wave flume. Fairly good agreements were found within several limitations. In order to accomplish the useful numerical wave tank of full-nonlinear computation applicable to make up arbitrary designed wave, many effects such as the response function (both frequency and phase), water depth of the tank, amplitude dispersion of the wave train for making up the pertinent modification of target signals. The most difficult point is to take the effect of amplitude response of the given type of wave-maker into consideration. It is so laborious task that we do not attempt it in this paper and remain to the future. The inevitable effect of wave breaking phenomenon is also the most difficult problem in particular for the case of large amplitude waves. It deforms the computed results and even prevents its normal accomplishment. However the numerical tank experiment is very excellent mean for the investigation into non-linear transient wave creation and annihilation.

We surmise that these sorts of phenomena cast the light to the possible cause of actual Freak wave observed in ocean and the numerical tank developed in this work will be great help to the future study in this field.

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