Experimental study on wave breaking and evolution of wave groups with high steepness

K. Zheng, B.B. Zhao*, W.Y. Duan

College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China
* zhaobinbin@hrbeu.edu.cn

HIGHLIGHTS:

- . Laboratory experiments are conducted in deep-water wave tank to study characteristics of breaking waves arising from the evolved wave train.
- . The peaks of the evolved wave envelop have different performance between the mild breaking and severe breaking wave conditions with respect to the elevation and the numbers.

1 INTRODUCTION

The evolution of wave groups is often investigated to study the nonlinear effect of deep-water waves. Su [1] performs typical experiments on the wave train evolution with limited number of waves per packet. The regular wave train evolves into a number of envelope solitons. Despite a varying degree of wave breaking are observed in the evolved wave train, they only summarize some qualitative phenomenon on the breaking waves. The similar work following Su [1], concentrates on the evolution of non-breaking wave train with moderate steepness [2]. The experimental investigation on the breaking waves arisen from the evolution of strongly nonlinear wave trains is not sufficient in Su [1] and rarely to be reported after his work. The main motivation of our research is to study the wave breaking characteristic in regular wave trains by the physical experiments.

The details on experimental set-ups are introduced in Section 2. The measurements are presented in Section 3. In Section 4, some calculations are presented based on the High Level Irrotational Green-Naghdi (HLIGN) equations implemented with wave breaking model and compared with the laboratory measurement. Summaries and conclusions of this study are provided in Section 5.

2 EXPERIMENTAL FACILITY AND SET-UP

The experiments are conducted in the Fluid Mechanics laboratory of Harbin Engineering University. A sketch of the wave flume is shown in Fig. 1. The wave flume is 25.0m long, 2.0m wide and the water depth is fixed at 1.0m.

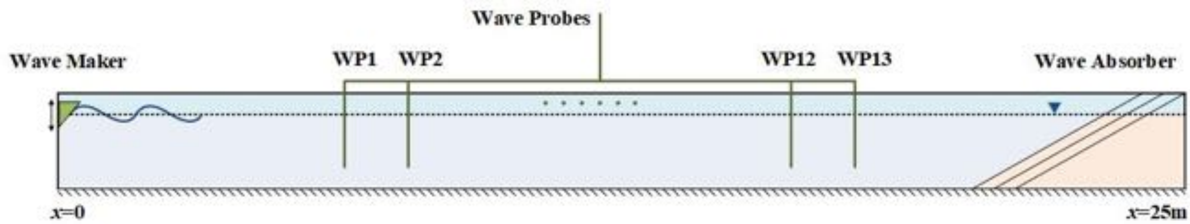

Fig. 1 Sketch of the physical wave tank.

Two experimental wave conditions are considered here, and these are list in Tab.1. The initial wave steepness is the ratio of initial wave height H and the wave length λ. The linear dispersion relation is used to calculate wave length from the wave period T. A settling time of approximately 10 minutes between two successive measurements is sufficient for the water in the tank to become calm.

Tab. 1 Physical test cases

Case	*T* (s)	*H* (m)	*H/λ*	Breaking condition
SR1012	1.0	0.12	0.08	Mild breaking
SR1016		0.16	0.10	Severe breaking

Plunger type wave generator move in the vertical direction to generate regular waves at one end of the tank. The total operating time of the wave maker is T_{stop}=10.0s for each case. The ramping time, which is the time that the wave maker oscillates from still to the maximum position, is T_{ramp}=3.0s. On the other end of the tank, there is a multi-layer sponger-type wave absorber. This absorber is found effective in damping the incoming waves. Thirteen capacitance type wave probes are placed in a line along the wave tank. All probes record the time history of surface elevation simultaneously. The sampling frequency is 50Hz. The location of each wave probe from the wave maker is list in Tab. 2.

Tab. 2 Location of wave probes, measured from the wave-maker end of the tank

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
x (m)	4.5	5.5	7.0	8.5	10.0	11.5	13.0	14.5	16.0	17.5	18.6	19.0	20.5

As shown in Tab.1, wave groups with different wave steepness are considered. The wave breaking observed in the wave tank are remarked as ‘Mild breaking’ and ‘Severe breaking’ although this is a qualitative and relative indication of the wave breaking conditions. As an example, two moments of the breaking surface elevation for cases SR1012 and SR1016 corresponding to the `Mild breaking' and `Severe breaking', respectively, are given in the following Fig. 2.

(a) case SR1012, Mild breaking (b) case SR1016, Severe breaking

Fig. 2 Photos of breaking moments of (a) mild breaking and (b) severe breaking.

3 EXPERIMENTAL MEASUREMENTS

In this section, time series of surface elevation recorded by the 13 wave gauges are presented in the following figures for cases SR1012 and SR1016.

3.1 Case SR1012

The experimental measurements of the mild breaking case, SR1012, is presented in Fig. 3. The black lines show the wave gauges' data of surface elevation, and the red lines indicate the upper envelop. The upper envelop is obtained by a data analyzing software based on the percentile filter algorithm.

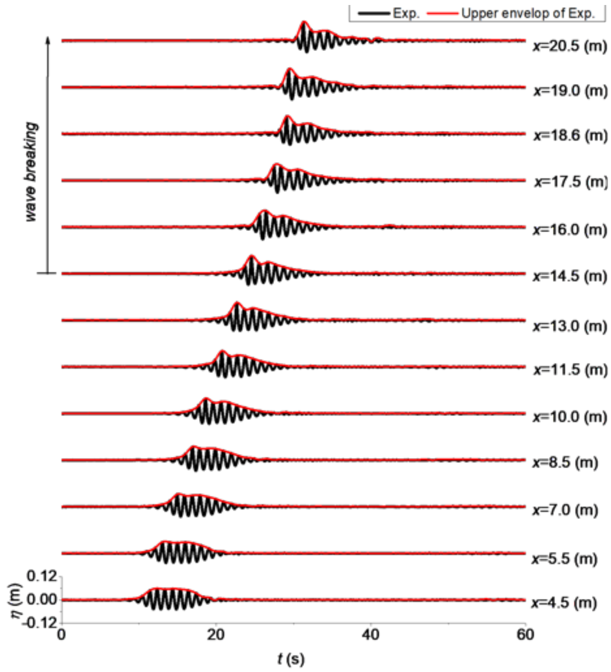

Fig. 3 Evolution of wave surface elevation measured by the wave gauges in the wave flume for case SR1012

As indicated in Fig. 3, wave breaking occurs at $x \geq 14.5$m. The uniform wave train gradually evolves and becomes non-uniform from $x = 4.5$m to $x = 20.5$m. The envelop peak at the leading side, which is in the left side of the wave train seen in Fig.3, is getting higher during the evolution.

3.2 Case SR1016

The experimental measurements of the severe breaking case, SR1016, is presented in Fig. 4.

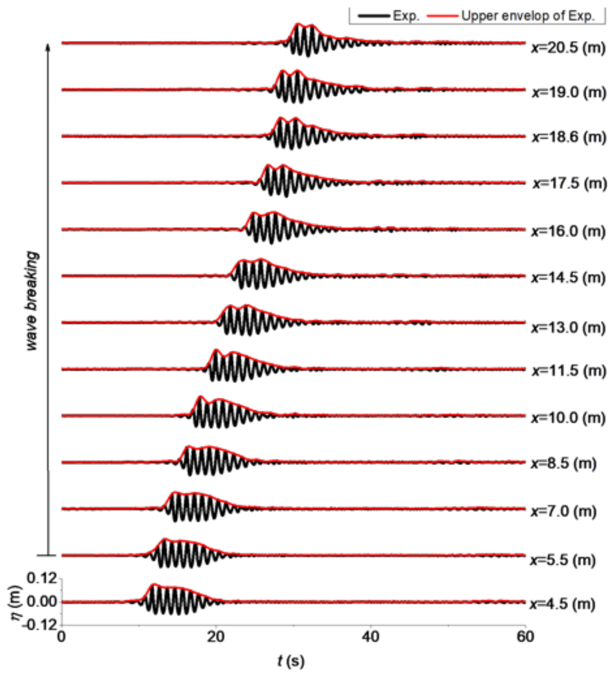

Fig. 4 Evolution of wave surface elevation measured by the wave gauges in the wave flume for case SR1016

Different with that observed in Fig. 3, wave breaking occurs at $x \geq 5.5$m for case SR1016. It means that the wave breaking occurs earlier as the increasing of initial wave steepness. The performance on the envelop is also different between these two wave trains seen in Figs. 3 and 4 at the same location. For the SR1016, two envelop peaks with similar elevation are observed. More quantitative results will be presented on the workshop to show the relation between the profile of wave train and the wave breaking.

4 NUMERICAL SIMULATION WITH HLIGN EQUATIONS

The numerical simulations are also performed by use of HLIGN equations with the eddy viscosity wave breaking model proposed by Tian [3] for the same cases as the laboratory experiments. The comparison between the converged HLIGN results (red line) and the experimental data (black dot) for three wave probes, $x = 4.5$m, $x = 11.5$m, $x = 18.6$m, is presented in the following Fig. 5 for severe breaking case SR1016.

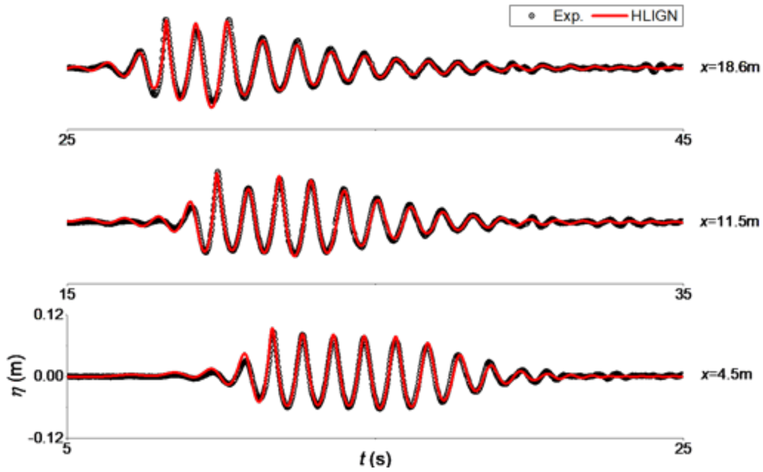

Fig. 5 Comparison of time series of wave evolution in the tank, measured by the wave gauges, in laboratory (dot), and calculated by HLIGN model (line), for case SR1016, Severe breaking.

Following some suggestions of Tian [3], excellent agreement is obtained in Fig. 5 between the experimental measurements and the results of HLIGN equations with wave breaking model.

5 CONCLUSIONS

The evolution of deep-water gravity wave groups with high steepness is studied in this paper. Laboratory experiments on the modulation of strongly nonlinear wave trains are conducted in deep water to investigate the wave breaking effect. The envelop profile of surface elevation time series depends on the evolution of the wave train with different initial wave steepness. One distinct envelop peak is observed at the leading side of the evolved wave train for the mild breaking case (SR1012). However, two envelop peaks with similar elevation are observed for the severe breaking case (SR1016) as the evolution of wave train. Good agreement is observed between the laboratory measurements and the calculations given by HLIGN equations with wave breaking model. More quantitative results and discussions will be presented on the workshop.

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