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Forces on Breakwaters by Standing Waves with Water Overtopping

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ABSTRACT

Forces on vertical breakwaters exerted by standing waves with water overtopping were studied in this paper. In experiments, vertical breakwaters with various heights under the action of a set of incident wave conditions were conducted in a two-dimensional wave channel. The relationship between the height of the breakwater and the wave crest height in overtopping waves was first examined. The standing-wave pressure due to water overtopping was then analyzed based on the experimental results. The theoretical Fourier solution for the nonovertopping standing-wave pressure was also presented and compared with the experiment. Experimental results showed that the standing-wave force on the seaside wall due to water overtopping was reducible about 18% maximum, when compared with the situation of a nonovertopping wave on the breakwater. The empirical formula for estimating the force on the seaside of the breakwater by the overtopping wave was proposed in this study. This paper also presented an example for estimating the net maximum wave force on a vertical breakwater when the transmitted wave in the harbor due to overtopping was considered.

INTRODUCTION

Wave overtopping occurs when the crest of the breakwater is lowered below the maximum water surface elevation. This phenomenon is allowable for the design of maritime structures that reduce the wave force on the wall and save construction costs. Thus the estimation of the quantity of wave overtopping has become an essential part of the design of breakwaters. Most previous studies paid attention only to the volume rate of wave overtopping, rather than its influence on wave forces in breakwaters.

Wave overtopping is a complicated phenomenon arising from the interaction of the incident wave and the structure. Most studies of the features of wave overtopping were examined by means of experiments, such as Saville and Caldwell (1953) for a vertical wall, Sibul (1955) for an inclined wall, and Iwagaki et al. (1965) for effects of incident waves and mean water level on wave overtopping. The formula for wave overtopping rate given by Weggel (1976) was summarized in the Shore Protection Manual (1984) for various structure types. Alternatively, Endo and Miura (1983) obtained a relationship between wall height and wave crest height in wave overtopping, also based on experimental results. Recently, Umeyama (1993) proposed a theoretical approach for estimating wave overtopping.

The wave force on a wall is essential in designing a breakwater. The theoretical solution for wave forces using a perturbation method to the fourth order of the standing wave was presented by Goda (1967), and compared well with their experimental results. Owing to the residual pressure from the perturbation solution found at the free surface, Goda (1967) used a mathematical correction in computing the pressure distributions on the vertical wall. Goda's illustrations have been preferred in many practical designs. Instead of the perturbation solution, Tsai and Jeng (1994) proposed a numerical Fourier approximation for a standing wave of finite amplitude in water of uniform depth. Their high-accuracy solution showed null residual pressure at the free surface. Tsai and Jeng (1994) pointed out that the Fourier solution has a legitimate validity in shallow water, whereas the perturbation solution is well in its region of validity, such as $d/L > 0.1$.

It is known that the wave force on a breakwater is reducible from the effects of wave overtopping, compared to that of nonovertopping standing waves on a wall. Up to date, however, the effect of wave overtopping the wave force on a breakwater has not yet been obtained using theoretical approaches because of the existence of the nonlinear nature of wave overtopping. When the wave overtopping is occurring, the Shore Protection Manual (1984) proposed that the wave pressure on the breakwater may be calculated by a truncated distribution result from a vertical profile of the nonovertopping standing-wave pressure. However, the error may become large when the amount of wave overtopping is significant. In this paper, a series of experiments is conducted in a two-dimensional wave channel for examining the force exerted by the standing wave with water overtopping. For simplicity in application, empirical formulas for wave forces are proposed in this investigation. The numerical Fourier solution presented in Tsai and Jeng (1994) is also extended in this paper to estimate the wave force on a wall by the nonovertopping standing wave as the wave period, height and water depth are given. The theoretical solutions are used to compare with the experimental data.

EXPERIMENTS

In the experiment, a set of incident wave conditions was designed to attack a vertical breakwater with variable crest heights for examining wave forces on walls by the standing wave with water overtopping. The experiment was conducted in a two-dimensional wave channel that was 100 m long, 2 m wide and 2 m high. The side walls at the observation sections of the channel consisted of strengthened glass plates. A piston-type wave generator system, controlled by a D/A converter and a PC computer, was mounted at the other end of the channel. Though this wave generator system can generate irregular waves, only regular waves were generated in this investigation.

The sketch of the experimental setup is shown in Fig. 1, in

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KEY WORDS: Standing waves, water overtopping, vertical breakwater, wave forces, Fourier solutions.