NEW TECHNOLOGIES WITH CONCRETE BLOCKS FOR TSUNAMI PROTECTION AND LONG-PERIOD WAVE ABSORPTION

by

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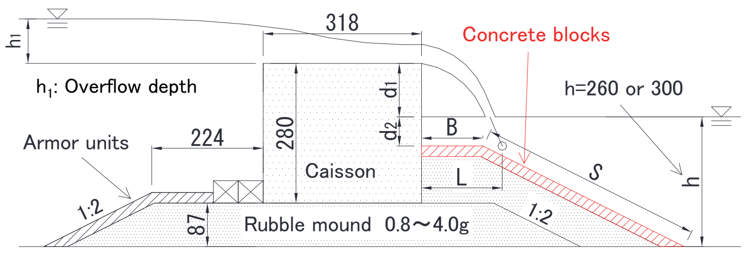
1. INTRODUCTION

In Recent years, tsunami and long-period waves have caused problems in Japan. Numerous breakwaters were seriously damaged by the 2011 Off the Pacific Coast of Tohoku Earthquake Tsunami. On the other hand, many ports suffered disturbance in cargo handling due to ship motion caused by long-period waves. This paper presents new methods using concrete blocks for tsunami protection and long-period wave absorption as countermeasures to such problems.

2. TSUNAMI PROTECTION USING CONCRETE BLOCKS

In the 2011 Off the Pacific Coast of Tohoku Earthquake Tsunami, one of the causes of failure was a scouring of the rubble foundation and subsoil on the harbor-side of breakwaters due to the tsunami overflow. One possible countermeasure is placement of a widened protection using additional rubble stones behind the breakwater to prevent the sliding of the caisson. Installing concrete blocks on the rubble mound on the harbor-side would also be required to prevent scouring around the rubble mound. A simple and highly accurate stability estimation method for concrete blocks covering the rubble mound against tsunami overflow is proposed. The method is based on a series of hydraulics experiments conducted in a wide range of condition. A schematic layout of the breakwater model and concrete blocks used in the experiments are shown in Fig. 1 and Fig. 2 respectively. The experiments were carried out by changing the shape of the harbor-side rubble mound, harbor-side water level. The stability limits of the concrete blocks were examined. The main results are as follows. 1) The stability of the concrete block is greatly influenced by impingement position of the overflow jet. 2) The stability of the concrete blocks increases as the harbor-side water level rises. 3) The failure modes of the concrete blocks are divided roughly into two modes. One is the overturning mode caused by the rotation of the block. The other is the sliding mode caused by the external force exceeding the frictional force. 4) The overflow depth of the stability limit was almost proportional to the nominal diameter of the block in the case of the overturning mode, while it was nearly independent of the size of the block in case of the sliding mode. 5) The holes in the concrete blocks enhance the stability due to the reduction of the uplift forces.



Units in mm

Figure 1: Countermeasure against Tsunami of Breakwaters

Figure 2: Concrete Blocks

Empirical formulae for the stability estimation were derived based on the experimental results. In these formulae, the overflow depth is used to represent the external force. The overflow depth of the stability limit corresponding to each failure mode can be obtained by the two formulae expressed as follows:

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Overturning mode : $$\frac{h_1}{(S_r - 1)D_n} = N_{S1} = f\left(\frac{B}{L}, \frac{d_2}{d_1}\right) \quad (1)$$

Sliding mode : $$\frac{h_1}{(S_r - 1)S} = N_{S2} = f\left(\frac{d_2}{d_1}\right) \quad (2)$$

where, h_1 is the overflow depth, S_r is the specific gravity of concrete with respect to seawater, S is the slope length of the harbor-side rubble mound, N_{S1} and N_{S2} are the stability numbers, B is the crown width of the harbor-side mound, L is the impingement position of the overflow jet, d_1 is the crown height of the caisson above the harbor-side water level, and d_2 is the submerged depth above the armor units (regarding the definition of symbols, see Fig. 1). Stability numbers N_{S1} and N_{S2} are functions of B/L and d_2/d_1, which are the parameters representing the influence of the impingement position and the harbor-side water level respectively. The stability numbers for each concrete block were determined through the experiment. This calculation method has already been used for actual design in Japan.

2. LONG-PERIOD WAVE ABSORPTION USING CONCRETE BLOCKS

In many ports, it has been reported that long-period waves cause troubles in cargo handling. As a countermeasure to this, a wave absorbing mound installed on the harbor-side of the breakwater has been proposed (Fig. 3). Because of the low wave absorbing performance of such conventional mound type structures, the required width to absorb the long-period waves becomes more than 30m. It is important to reduce the size of the structure to apply to various site conditions. The crown height of a conventional mound type structure is almost equal to that of the caisson. On the contrary, we proposed a submerged mound type structure covered with concrete blocks. The basic concept of this proposed structure is to level the crest elevation to the water surface to establish high efficiency in energy dissipation on the surface of the crown.

A series of hydraulic model experiments was carried out to evaluate the wave absorbing performance. The reflection coefficient was obtained from the recorded water surface elevation. Throughout these experiments, it became clear that the reflection coefficient of the submerged type is smaller than that of the conventional type, independent of the wave period. The wave absorbing mechanism was investigated using hydraulic model experiments and numerical analysis. It was concluded that the cause of energy dissipation of the submerged type is related to significant increase in the flow velocity inside the concrete blocks due to flow contraction on to the crest. Fig. 4 shows the design diagram of mound widths of conventional type with armor stones and submerged type with tetrapods. B^* is an equivalent width of the structure taking the effect of the water depth into account. The appropriate width of the structure under the allowable value of reflection coefficient is determined by using this design diagram. A submerged type has already been designed by using the method and constructed in Japan.

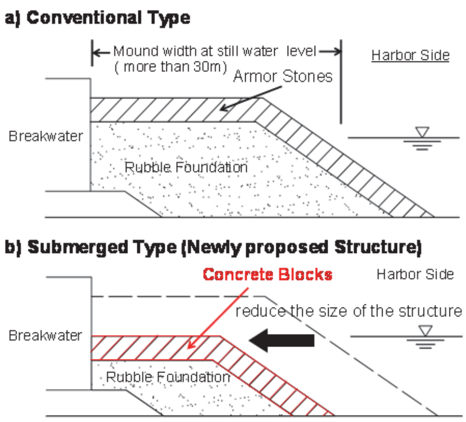

Figure 3: Long-period Wave Absorbing Structure

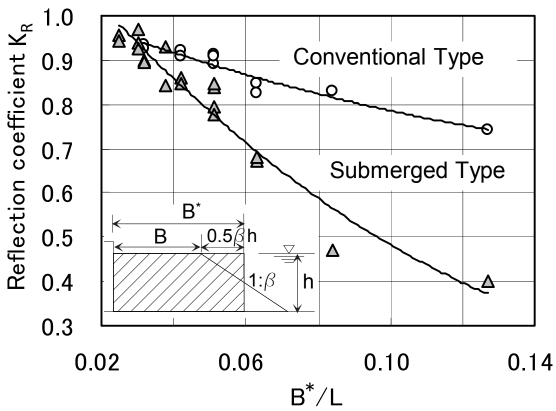

Figure 4: Design Diagram of Mound Width