Collapse Mechanism of Composite Breakwater under Continuous Tsunami Overflow and its Countermeasure

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ABSTRACT
The collapse mechanism of breakwater and countermeasures under the continuous tsunami overflow were investigated using a drum centrifuge. A 1/70-scaled model, representing a 10 m high prototype breakwater, was set in the waterway in the drum centrifuge to 1) reproduce the caisson collapse mechanism and 2) investigate the effect of countermeasure by placing the embankment over the breakwater foundation mound using rubble materials and filter units. The study found that the caisson failure was due to the scouring of rubble mound and the seepage flow. Moreover, placing the embankment over the mound by using rubble materials or filter units was confirmed effective against breakwater instability.

KEY WORDS: Centrifuge Model Test; Tsunami Overflow; Composite Breakwater; Seepage; Scour; Embankment.

INTRODUCTION
In the 2011 off the Pacific Coast of Tohoku Earthquake, many breakwaters were severely damaged by the tsunami. As the results of disaster investigations, four major disaster patterns that cause damages to breakwaters were suggested, namely: 'wave force', 'overflow and scouring', 'breakwater head scouring', and 'wave backrush force' (Tohoku port and harbor, tsunami and earthquake prevention disaster technical committee, 2011). As for the “overflow and scouring” pattern, tsunami overflows the breakwater and scours the backfill materials behind the caisson. Finally, the caisson slips, over-turns, and collapses. This type of mechanism and effect of embankment behind the caisson were investigated by 1G large-scale waterway model tests (Arikawa et al. 2013). They found that the breakwater failure was caused from backfill scouring by tsunami overflow which reduce the bearing capacity of foundation.

Imase et al. (2011) and Kasama et al. (2013) quantitatively investigated, from numerical simulations and model tests, the possibility of breakwater failure caused by seepage flow originated from the differential water pressure of the inner and outer breakwater. Sassa et al (2014) and Takahashi et al. (2014) investigated the failure mechanism of breakwater and quantitate the effect of the embankment from the points of both overflow scouring and seepage flow by using centrifuge model tests. However, the influence of scouring ground around breakwater and seepage by continuous tsunami overflow including checking method were not clarified.

Under these circumstances, the impact on the structure and foundation due to tsunami had been examined using a drum centrifuge which is equipped with two types of tsunami generation techniques (dam break type or piston type) (Miyake et al. 2009; Sawada et al. 2013; Miyamoto et al. 2014).

In this study, the tsunami disaster mechanism and the effect of countermeasure of backfill behind the caisson were investigated with a drum centrifuge equipped with a circulation pump which was newly developed by Miyamoto et al. (2015).

TSUNAMI OVERFLOW TESTS
Test Apparatus and Model
A series of tests was performed with a drum centrifuge (radius = 1.1 m) owned by Toyo Construction Co., Ltd. Fig. 1 shows the cross-sections of a typical testing model container in drum centrifuge. It is capable to use as a waterway apparatus in the centrifugal force field, because there is no border in experimental field to circumferential direction. A long extension of the experimental area, which increases proportionally to the centrifugal acceleration applied in the tests, is one advantage of this test system. Long-term and continuous tsunami overflow was generated by using circulation pump in model container. The series of model tests was conducted at 70 G in centrifugal force field (modeling scale by 1/70). Table 1 shows the scaling rules for centrifuge model tests performed in this study (adapted from Takahashi et al., 2013).

The composite breakwater model was composed by gravel mound and aluminum caisson. The mound was composed by gravel with a grain size of 4.75-9.5 mm (corresponding to about 30-70 cm in prototype scale) and porosity of 45%. The dimension of caisson of 10 cm in height and 10 cm in width was considered to represent the caisson in...