Study on combined failure mechanism of a breakwater due to Tsumani

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1. Introduction

On March 11, 2011, The Great East Japan Earthquake occurred, and caused tremendous damage not only to civil structures but societies in Tohoku region. By the tsunami generated by this earthquake, the breakwater suffered serious damage. Failure mechanism of the breakwater is complex. In this study, a series of centrifuge model tests and effective stress analyses are conducted to examine influence of the seepage in the rubble mound by the difference of water head in front and back of a breakwater.

2. Centrifuge model test

(1) Method

In the centrifuge model test, generalized scaling low is applied for breakwaters (21m height), and 1/200 model is used. Centrifugal acceleration applied was 25G. The model container can produce tsunami waves by dam breaking method. Two cases are conducted; In Case 1, seepage into the mound is permitted, while in Case 2, seepage into the mound is not permitted by covering the surface of the mound with a rubber membrane sheet.

(2) Results

In Case 1, when the tsunami arrives at the breakwater, scouring occurs on the front side of the mound. Then seepage water generated by difference of the water head in front and back of the model breakwater flow into the mound. Air bubbles on the back side of the breakwater also indicate a massive water seepage under the caisson. As a result, shear deformation was observed in the mound, then the caisson was collapsed. In Case 2, seepage was not observed, and the caisson did not collapse.

These results show that seepage has some influences on the failure of the model breakwater.

3. Effective stress analysis

(1) Method

In this study, a finite element analysis program formulated by the effective stress concept with the multi-spring mode (FLIP/TULIP(ver.5.1.0)) is used. The analytical model is taken as the same size as the prototype of the model test. At each nodal point and element on the upper stream of the caisson and the mound surface, the tsunami wave force and pore water pressure were given. Tsunami force was given by the method suggested by Tanimoto (1984). In this analysis, three cases are conducted. In Case 1, both tsunami wave force and seepage are given. In Case 2, only tsunami wave force is given. In Case 2, only seepage, i.e., water pressure on the surface of the upper stream mound, is given.

(2) Results

In Case 1, pore water pressure increased and effective stress in the rubble mound changed as the caisson moved. The deformation of the caisson was larger than the other two cases. In Case 2, pore water pressure did not increase, and the caisson did not collapse. In Case 3, pore water pressure increased, however, the caisson did not collapse. These results show that seepage has some influences on the failure of the breakwater.

4. Conclusions

Results of centrifuge model test showed a series of complex failure mechanisms; scouring of front mound, sliding and tilting of the model caisson due to shear deformation of the mound, and sliding of the model caisson due to wave force.
Results of effective stress analysis revealed a failure mechanism through visualizing effective stress distributions in the rubble mound. Effective stress in the mound was decreased due to uplifting of a caisson, which led to decrease of the bearing capacity of the mound, and failure of the break water. These results indicate that the effect of seepage in the rubble mound has to be considered in a construction of a resilient structure against tsunami.

These results show that suffering factor of the breakwater is not only wave force but also seepage into the mound.