Numerical simulation of a resilient reinforcement technique for breakwater foundation

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1 INTRODUCTION

The Great East Japan earthquake (M_W=9.0) stroked off the east coast of Japan on 11th March 2011. The earthquake triggered powerful tsunami. It caused huge damage by not only inundation but also tsunami-debris (Hazarika et al. 2013). The Kamaishi breakwater (Iwate Prefecture, Japan) collapsed and failed to block tsunami generated by the Great East Japan Earthquake. The main reasons of failure of the breakwater were (Arikawa et al. 2012) (i) Large water level difference between harbor side and sea side of the breakwater, which created high water pressures on the breakwater (ii) Dynamic water pressures due to tsunami wave that imposed a huge horizontal forces on the breakwater (iii) Decrease in bearing capacity due to increase in pore water pressure (iv) Scouring of foundation mound, toe erosion and joint failure. The stability and safe performance of breakwater is very important for protection of structures. It is, therefore, of utmost importance to develop and build tsunami-resistant structures. Hazarika et al. (2014) proposed a new reinforced foundation for breakwaters using (i) gabion mound (foundation rubbles and gabions) and protective gabion (rubbles and gabions) and (ii) reinforcing these with steel sheet piles in order to reduce the collapse of breakwaters due to compound disasters brought by earthquake and tsunami. In this paper, the effectiveness of the proposed technique against earthquake loading was evaluated through numerical analyses.

2. NUMERICAL MODELING

Hazarika et al. (2014) performed series of shaking table tests to evaluate the effectiveness of the proposed reinforced foundation for breakwaters against earthquake loadings. Breakwater at Miyazaki port (Miyazaki Prefecture, Japan), which is likely to be affected by predicted Nankai trough earthquake, is chosen as a prototype for shaking table tests. The prototype to model ratio was 64. Model breakwaters (caisson type), made of aluminum, were filled with silica sand and lead ball to adjust the weight and center of gravity. Sheet piles were made of steel plates (200 mm height, 400 mm width and 3.2 mm thickness). The foundations soil was constructed using two layers of sand (Toyoura sand). Lower layer is the bearing layer with relative density 90%. Upper layer is the foundation layer with relative density 60%. The rubble mound was made of number 6 gravel with a relative density D_r=60%. The protective gabion was made of number 7 gravel and wire mesh (steel wire of diameter 0.63 mm). The breakwater model for shaking table test is shown in Fig. 1.

Numerical simulations were performed using FLAC. The purposes of these simulations were to confirm the effectiveness of the proposed reinforcement technique against earthquake loadings as well as to make clear the mechanism of the reinforcement. The dimensions, material properties and all other parameters were taken according to the shaking table tests. The conventional Mohr-Coulomb constitutive model has been used for dynamic analyses. For effective stress analysis, the formula proposed by Martin et al. (1975) and Byrne (1991) has been adopted. In order to simulate the seismic behavior of liquefiable layer (seabed layers), the Finn built-in constitutive model was used. This is a coupled effective stress model that works with combining Mohr-Coulomb criterion and volume change-based pore water pressure buildup models. The foundations soils and rubble mound were modelled as Finn model (Martin et al., 1975). The breakwater is modelled as elastic material. A constant damping ratio of 5% was assigned to the model. Height and width of the breakwater was 20 cm and 21 cm respectively, and of unit length in the plane strain direction. The dynamic loading was applied in the form of sinusoidal wave at the base of the foundation soil (lower layer). Frequency of the wave was 15 Hz. Amplitude of the sinusoidal wave was 400 Gal. The continuation time of the earthquake loading was 8 second. The numerical model of the unreinforced breakwater foundation is shown in Fig. 2.

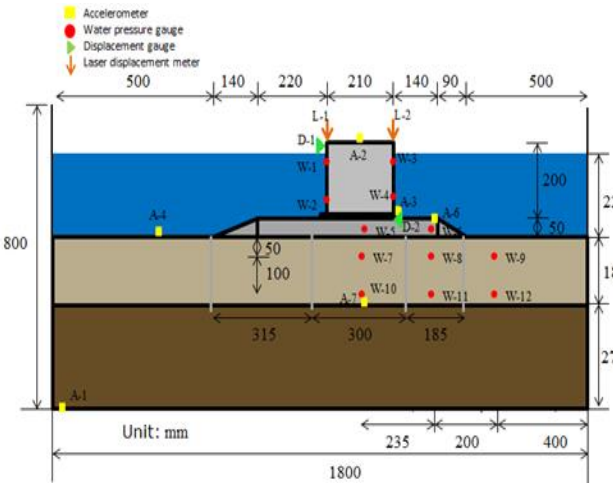

Fig. 1 Resilient reinforced foundation for breakwater.

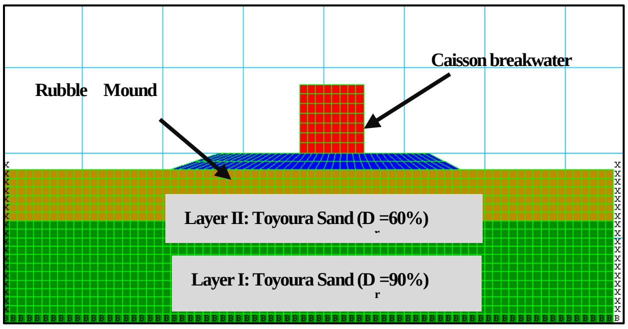

Fig. 2 Numerical model of unreinforced breakwater foundation

RESULTS AND DISCUSSIONS

In order to evaluate the effect of base area of the caisson on the breakwater performance, numerical analyses were performed for different base areas of the caisson (0.75A, A and 1.5A), where A is the base area of the caisson that was used in shaking table test. Fig. 3 shows settlement of the caisson (measured at top right corner) for different base areas of the caisson. It can be seen that settlement decreases with increases in base area. Fig. 4 shows horizontal displacement of the caisson (measured at top right corner) for different base areas of the caisson. The horizontal displacement is maximum for base area=0.75A, while horizontal displacement is almost same for base area A and 1.5A.

Fig. 5 shows the settlement of the caisson for different weights (0.75W, W and 1.5W) of the caisson. Where W is the weight of the caisson that was used in shaking table test. The settlement of the caisson was measured at top right corner of the caisson. It was found that the settlement of the caisson increases with decrease in weight of the caisson.

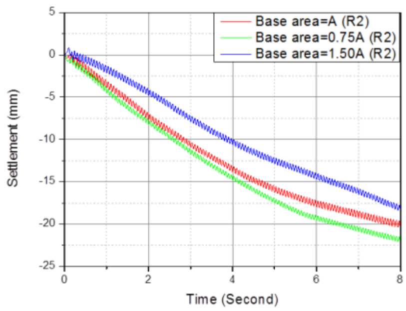

Fig. 3 Settlement of the caisson for different base areas of the caisson (breakwater)

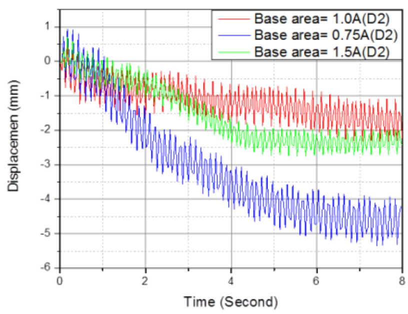

Fig. 4 Horizontal displacement of the caisson for different base areas of the caisson

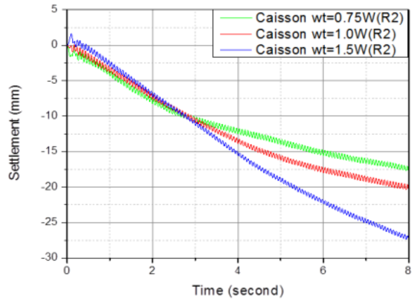

Fig. 5 Settlement of the caisson for different weights of the caisson

3. CONCLUSIONS

The numerical simulations were performed to confirm the effectiveness of the proposed reinforcement technique against seismic loads as well as to make clear the mechanism of reinforcement. The following conclusions could be derived based on this research.

1. The settlement of the caisson decreases with increase in base area of the caisson and settlement of the caisson increases with increase in weight of the caisson.
2. There was no clear trend found for horizontal displacement of breakwater for different weight and base areas of the breakwater caisson.

For an efficient reinforcement technique for breakwater foundation, more detailed studies are needed. Further studies are going on for it.

ACKNOWLEDGEMENT

This study was funded by the Japan Iron and Steel Federation under priority themes research grant. The authors express their deep gratitude for this financial support.

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