Environmentally friendly and cost reducing technique towards tsunami disaster mitigation of coastal structures

Hemanta Hazarika

i) Professor, Kyushu University, 744 Motooka Nishi Ku, Fukuoka 819-0395, Japan.

ABSTRACT

In order to protect coastal structures from the damage due to impact force of tsunami, a new concept of using waste tires behind such structures is introduced in this paper. A physical model for tsunami impact force simulation was developed to evaluate the reduction effect of tsunami impact force by the tire structures. From aesthetic point of view, cultivation of suitable plants inside the tires is also proposed. Field tests on planting trees that can grow in saline soil conditions were performed to see whether such structure can preserve the greenery of the area.

Keywords: environment, impact load, scouring, tsunami, waste tires

1 INTRODUCTION

The mega earthquake (magnitude Mw = 9.0) on March 11, 2011, officially known as the 2011 off the Pacific Coast of Tohoku Earthquake, Japan, is one of the five most powerful earthquakes in the world overall since record-keeping by strong motion seismograph began in 1900. Several compound disasters followed the earthquake including record-breaking tsunami and widespread liquefaction that brought devastating damage to many infrastructures (Hazarika, 2011). While surveying the tsunami disaster areas immediately after the disaster, the author was amazed to discover a retaining wall (made of recycled tires) that miraculously survived the disaster (Hazarika et al., 2013). Ironically, this tire retaining wall is located just about 150 m away from a completely collapsed sea wall. A factory building situated on the backfill ground of the retaining wall was damaged by the tsunami, and a natural slope nearby this tire retaining wall was eroded by the tsunami. Why this tire retaining wall was neither damaged by the earthquake nor by the inundation and scouring due to the tsunami was the source of inspiration of research presented in this paper.

Damage investigations due to earthquake and tsunami showed that the damage of sea walls is mainly due to scouring at the back of the structures by tsunami impact force and backrush force of tsunami (Hazarika et al., 2012). The goal of this research is to develop an earthquake-resistant and tsunami-resistant low cost technique for coastal structures that can prevent scouring of foundation soils, and at the same time is environmentally friendly. The technique uses waste tires as a tsunami-resistant reinforcing measure of civil engineering structures to prevent compound damage of such structures during tsunami. Considering the aesthetic, the tires are also planted with suitable plants to preserve the greenery. Such reinforcing technique could mitigate the damage to structures during earthquakes as well as tsunami, and at the same time could also be an effective method of recycling (Hazarika, 2013; Hazarika et al., 2010) the large number of scrap tires generated each year, which are posing great environmental degradation.

In this research, to protect coastal structures such as seawall from impact force of tsunami, a new concept of using waste tire structure behind the seawall is introduced (Fig. 1). A physical model for tsunami impact force simulation was developed to evaluate the reduction effect of tsunami impact force by the tire structures. To evaluate the reduction effect of impact force, Tsunami Overflow Test was conducted in the laboratory for a sea wall with tires behind it.

In addition, cultivation of suitable plants inside the tires is proposed in this research. Field tests on planting trees that can grow in saline soil conditions were performed to see whether such technique can preserve the greenery of the area.
2 TSUNAMI OVERFLOW TEST

To evaluate the tsunami impact force absorption and the load dispersion effect of the tire structures, Tsunami Overflow Tests (TOT) were conducted by placing model tires behind the seawall in various configurations and different filling conditions of tires.

2.1 Description of the test model and test method

A new model for Tsunami Overflow Test (referred hereafter as TOT) was developed in Geotechnical Engineering Laboratory of Kyushu University. In this test, a model soil box made of acryl (1200 mm in length, 300 mm in width and 1000 mm in height) was used to reproduce the overflow phenomenon of tsunami. The schematic diagram of the TOT model used in this research is shown in Fig. 2. The model seawall is placed inside the soil box. There is a hinge gate just above the model seawall that functions as a water storing mechanism, and can reproduce the overflow phenomenon of tsunami. The gate is fixed to the top of seawall by using a pin. This gate is also attached to a weight using wire as shown in Fig. 2. When the pin is pulled up, the gate will be opened and the stored water behind the gate will overflow the seawall.

The ability of tires to reduce the impact force of tsunami, will be different according to the number of tire layers, types of filling material and type of placing of tire (configurations). Therefore, to determine and evaluate the optimum condition that yields the maximum reduction of the tsunami impact force, TOT were conducted under various test conditions (number and laying style of tires, filling materials, etc.). In the tests, model tires were used instead of actual tires.

There are five load tables (Table 1 to 5) in the landside of this apparatus. Each load tables are supported with two load cells as shown in Fig. 3.

During the test, model tires were (Fig. 4) connected together with thin wires so that they do not displace due to the impact force of water. Also, the whole tire structure was fixed to protect it from horizontal movement during the experiment. In the data analysis of this test, average value of the two load cells (in each table) were taken, and then the maximum values of them were determined.

2.2 Test conditions

The following test cases were examined as shown in Fig. 5. Vertically laying cases (Case 2: two layers, Case 3: three layers) and alternately laying case (Case 5: slopped three layers). As shown in Fig. 6, three different filling conditions of tire were examined: (1) Hollow tire (without any filling) (2) Tire filled with Masado (locally available composite granite soils) and (3) Tire filled with tire chips (TC) of maximum grain size 2 mm.

(a) Case 2 (b) Case 3 (c) Case 5

Fig. 5. Configurations for tire placement
2.3 Test results

Figure 7 shows the values of the water impact force (recorded in load Table 3 of Fig. 3). Two typical cases are shown in the figure. One with no tire placed on the back of sea wall. The other in the case of sea wall reinforced by slopped tire structures using 3 layers (Case 5 of Fig. 5). Comparison of the results shows that there is a considerable reduction (more than one third) of the impact force.

Figure 8(a) ~ (c) show the results of the three different filling conditions of the tires shown in Fig. 6. From the figures it is clear that three layers of tire placement gives better reduction than the two layers. Also, it can be seen that the tires filled with soil in stepped three layer configuration gives the maximum reduction of the impact force. However, in the case of vertically layered tires, there is no significant difference whether the filling materials are soils or tire chips.

Figure 9 shows the result of maximum value of impact loads recorded by each load table (Table 1 to Table 5) due to overflown water. In the figure, the peak values of each load table with respect to the different conditions of tire placement are indicated. It can be observed that the largest value of load, which is expected to cause the most serious damage limited to this model apparatus, gradually decreases with the introduction of tire layers behind the seawall. Paying attention only to load table 3, as compared to the case without tire, Case 5 (tire filled with soil) shows the smallest value of impact force. On the other hand, Case 5 (Hollow tire) shows the largest value of impact force.
3 FIELD TEST ON PLANTING OF TIRES

From aesthetic point of view, waste tires on the back of seawall along with filled materials do not look appealing. Therefore, cultivation of suitable plants inside of tire was planned. Field test, therefore, were conducted in a field constructed inside Ito campus of Kyushu University.

3.1 Selection of plants

Saline soils generally occur along the coastline and barrier islands where sea water may over wash, and collect in the soil. Concentrated component of salt (Na), can damage plant tissue whether it contacts above or below ground parts. High salinity can reduce plant growth and may even cause plant death (Appleton et. al., 2009). For plants which were to be cultivated inside the tires near the coastal area, the ground water with which they come into contact will be generally salty. Therefore, plants for the field tests are to be selected such that they are able to resist saline condition.

The availability of plants is, however, dependent on the location and season of the particular region. Furthermore, before selecting the plants, cold hardiness zone and heat tolerance zone should be checked well. We tried to find plants in our location that can grow easily in a wide range of weather condition so that it can be cultivated inside the tires in coastal area. After careful observation of the characteristics of different available plants, Kirinsou and Dechondra plants were finally selected as a suitable plant to cultivate inside the tire (Fig. 10).

3.2 Field preparation for cultivation

Plants were cultivated inside waste passenger car tires (Fig. 11) by filling those with two different materials: pure soils and soils mixed with tire chips. In case of pure soils, tires were filled with soil under the dry density of 1.426 g/cm$^3$. In case of tire mixed soils, tires were filled with soil and tire chips mixture (90% soils; 10 % tire chips) under the dry density of 0.47 g/cm$^3$ so as to see the effect of tire chips as a filling material in the growth of plants. According to Cetin et al. (2006), up to 20% coarse grained tire-chips and 30% fine grained tire-chips can be used as a lightweight filling material to increase the shear strengths. Therefore, in this study 10 % of tire chips (Size < 2mm) were mixed with soil to keep the balance between the strength and the growth conditions of the plants (Pradhan et al., 2014).

3.3 Test conditions

Field tests were conducted for three cases: Case a (2 layer vertical), Case b (3 layers vertical) and Case c (3 layer slope) as shown in Fig. 12. 2 layer and 3 layers tire were used to observe how the plants will grow inside the tires filled with different thickness of soil. In 2 layer and 3 layer vertically placed tires, large surface area will be available for the plants to grow, whereas when slopped tires are placed, the surface area will be reduced. Therefore, to observe the growing condition of plants in reduced soil surface area, 3 layer sloped tires were used in the test. In addition, to study the effect of tire chips in the growth of plants, 10 % of tire chips (Size < 2mm) were mixed with soil and used inside two layer vertical tire as a filing material.

4. Test results

Figures 13 and 14 are photographs showing the state of growth of Kirinsou and Dechondra respectively for Case a, Case b and Case c. These photographs were taken at the end of July 2013 and beginning of September, 2013.

It can be seen that the two plants (Dechondra and Kirinsou) grow well during the period (July 2013 to September 2013). Also, the growth rate of these plants does not depend on the filling materials and the thickness of the soil layers. After the winter season Kirinsou was found to grow again naturally. However, the growth rate of Dechondra was observed to be rather slow.
CONCLUSIONS

Tsunami Overflow Test revealed that the stepped arrangement of tires results in the maximum reduction of tsunami impact force as compared to the other arrangement of tires. Therefore, tsunami impact force can be reduced considerably by placing filled tires (with a suitable material) behind sea walls to protect the damage of such structure from impact force and...
resulting scouring and erosion. In this research, effect of water impact force only due to leading wave of tsunami was considered. In the future, effect of the backrush of tsunami is also necessary to investigate.

Field test shows that the greening effect could be maintained by planting trees inside the tires and could be one of the effective methods for recycling of waste tires. In addition, the filling materials of tires do not have any significant effect on the growth of plants.

The technique presented in this paper could be one of the effective technology, which could prevent scouring of the seawall foundation during tsunami. The concept presented here combines three important factors that we modern day engineers must deal with: cost reduction, environmental protection and disaster mitigation (Yasuhara, 2010). Establishment of the technique is expected to provide a new guideline for not only the scientific and technological fields, but also the environmental and cost performance aspects. The results of this research, thus, can go a long way towards providing a sustainable solution for infrastructure development in the future.

ACKNOWLEDGMENT

The financial assistance for this research was provided by Kyushu University under P & P research grant for Education and Research in Asian Region. The author gratefully acknowledges this support.

REFERENCES

1) Appleton, B., Green, V., Smith, A., French, S., Kane, B., Fox, L., Downing, A. and Gilland, T., (2009): Trees and shrubs that tolerate saline soils and salt spray drift, Virginia Cooperative Extension, Publication 430-031, 1-9.
2) Cetin, H., Fener, M. and Gunaydin, O. (2006): Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material, Engineering Geology, 88, 110-120.
3) Hazarika, H. (2011): Historic tsunami and associated compound disaster triggered by the 2011 great east Japan earthquake A reconnaissance report, Keynote Paper, Geosynthetics India’ 2011, Chennai, India, KN57 - KN75.
4) Hazarika, H. (2013): Paradigm shift in earthquake induced geohazards mitigation -Emergence of nondilatant geomaterials-, Invited Keynote Lecture, Proceedings of the annual conference of Indian Geotechnical Society, Roorkee, India, CD-ROM.
5) Hazarika, H., Hara, T. and Furuichi, H. (2013): Soil-structure interaction during earthquake and tsunami - Two case studies from the latest disaster in Japan, Eighteenth International Conference on Soil Mechanics and Geotechnical Engineering, Paris, France, 131-142.
6) Hazarika, H., Kasama, K., Suetsumu, D., Kataoka, S. and Yasufuku, N. (2012). Damage to geotechnical structures in Waterfront Areas of northern Tohoku due to the March 11, 2011 tsunami disaster, Indian Geotechnical Journal, Indian Geotechnical Society, Vol. 43, No. 2, 137-152.
7) Hazarika, H., Yasuhara, K., Karmokar, A.K., Kikuchi, Y., and Mitarai, Y. (2010): Multifaceted potentials of tire derived three dimensional geosynthetics in geotechnical application and their evaluation, Geotextiles and Geomembranes, Vol. 28, 303-315.
8) Pradhan, K., Hazarika, H., Hirayu N., Fukumoto, Y., Yasufuku, N. and Ishikura, R., (2014): Experimental evaluation of tsunami impact force absorption by scrap tires, Proceedings of the Japanese Geotechnical Society Special Symposium on the Great East Japan Earthquake, Tokyo, 782-787.
9) Yasuhara, K. (2010): Global warming induced climate change adaptation measures from geotechnical perspectives, Proceedings of the 65th National Conference of Japan Society of Civil Engineers, 953-954.