Use of Low Carbon and Low Cost (LC^2) Materials in Climate Change Adaptation Measures

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ABSTRACT: Material recycling of waste tires, which reduces the release of greenhouse gases, for protecting coastal structures from potential natural hazards is proposed here. A new technique using waste tires behind sea walls to protect them from the damage due to impact force of tsunami is described. Cultivation of suitable plants inside the tires was proposed and field tests on planting trees that can grow in saline soil conditions were performed to see whether tire structures can preserve the greenery of the area. A physical model for tsunami impact force simulation was also developed to evaluate the reduction effect of tsunami impact force by the tire structures. Results of this research, if implemented, is not only expected to contribute towards economic countermeasures against natural hazards, but also will go a long way towards providing a sustainable solution for infrastructure development in the future.

KEYWORDS: Cost reduction, Impact load, Low carbon, Scouring, Waste tires

1. INTRODUCTION

Rapid increase in the number of scrap tires each year has been an issue of concern in many developed and developing countries. In Japan, about 87% of generated scrap tires are recycled. However, a major share of the recycling goes towards generating energy by burning them. Such thermal recycling, however, release CO_2 to the atmosphere, and thus is partly responsible for climate change. Figure 1 shows an illegal dumping site in Akita Prefecture, Japan. Low carbon generating recycling can be one of the solutions towards environmental preservation so that recycling of such materials does not endanger the climate.

Figure 1 Illegally dumped scrap tires (Akita, Japan)

Climate change-induced disaster and natural disasters (such as earthquake, tsunami, rainfall etc.) has becoming the top priorities of many governmental policies throughout the world. The goal of this research, therefore, is to develop a low cost technique for coastal structures that can prevent scouring of foundation soils, and at the same time is environmentally friendly. The technique uses recycled waste tires, which are Low Carbon and Low Cost (LC^2) materials, as a reinforcing measure of civil engineering structures to prevent compound damage of such structures during tsunami and high tidal wave. Such reinforcing technique could mitigate the damage to geotechnical structures during rainfall induced erosion and scouring induced damage during tsunami as well as high tide, and at the same time could also be an effective method of recycling of waste tires, since use of tires as materials reduces the release of CO_2 by one fourth as compared to thermal recycling.

In this research, attention was focussed on the protection of coastal structures. To protect coastal structures such as seawall from impact force of tsunami and tidal wave, a new concept of using waste tire structure behind seawall is introduced. A physical model for impact force simulation was developed to evaluate the reduction effect of impact force by the tire structures. To evaluate the reduction effect, Tsunami Overflow Test was conducted in the laboratory. In addition, considering the aesthetic, cultivation of suitable plants inside the tires is proposed. Field tests on planting trees that can grow in varieties of soil conditions were performed to see whether the developed technique can preserve the greenery of the surrounding.

2. TSUNAMI RESISTANT SEA WALL PROTECTED BY USING WASTE TIRES

Any countermeasures, to protect seawalls from future damage during tsunami, require the knowledge of damage mechanism of seawalls due to tsunami. The mechanism of damage, which is mainly due to scouring at the back of the structures, can be divided into two stages (Hazarika, 2011). In the first stage tsunami (Leading wave) overflows the seawall and in the second stage tsunami returns back to the land side (called backrush). When tsunami overflows the seawall it collides with the seawall foundation, and due to rapid overflow, the soils of the seawall embankment is scoured due to the impact of water resulting in outflow of concrete panel covering of sea wall embankment. On the other hand, when tsunami returns back to landside, the force of backrush hits the wall with a huge impact force, and as a result seawall collapses completely due to reduced strength of the foundation and the structure. Examples of failures of many seawall and breakwaters during the 2011 Great East Japan Disaster are reported in Hazarika et al (2012a, 2012b).

Therefore, to protect seawall from damage due to earthquake and tsunami, we need to provide two measures simultaneously: (a) Protection of soils behind the seawall due to tsunami impact force and (b) Protection of concrete cover behind the seawall due to force of backrush. In this research, to protect seawall from impact force of tsunami, a new concept of using waste tire (a resilient material) structures behind seawall was developed as shown in Figure 2.

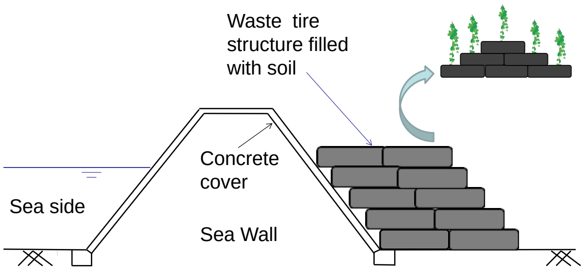


Figure 2 Protection of seawall against tsunami by using waste tire structure

This tsunami disaster mitigation technique combines three important factors that we modern day engineers must deal with: cost reduction, environmental protection and disaster mitigation (Yasuhara, 2010). In order to validate the aforementioned technique, which aims to prevent scouring of sea wall foundation and resulting damage during tsunami, the following field tests and model tests were performed; (1) Field Planting Test (Field test): to know the growth rates of plants inside the tire, field tests were performed in which various types of plants were cultivated inside tires filled with soils as well as tire chips mixed soils. Tire chips are sustainable materials, which are finding increasing application in Geotechnical Engineering, due to their cost-performance benefit (Hazarika, 2012; Hazarika, 2013; Hazarika et al., 2010). (2) Tsunami Overflow Test (Model test): to evaluate the absorption capacity of tsunami impact force and the dispersion effect of the tire structures, Tsunami Overflow Tests (TOT) were conducted by placing the model tires behind the seawall in different laying style and different filling conditions of tires.

3. FIELD TEST ON PLANT CULTIVATION INSIDE TIRES

From aesthetic point of view, tire structures with filled soil on the back of a seawall is not appealing. Therefore, cultivation of suitable plants inside actual tires (used passenger car tire) was conducted in field using a yard inside the Ito campus of Kyushu University, Fukuoka, Japan. It is to be noted that plants are to be grown inside the tires near the coastal area, where the soil conditions will be generally saline. Concentrated component of salt (Na) can damage plant tissue whether it contacts above or below the ground. High salinity can reduce plant growth and may even cause plant death. Saline soils generally occur along the coastline and barrier islands where sea water may enter, and collect in the soil (Appleton et. al., 2009). Therefore, plants to be selected are such that their growth can be sustained under certain saline condition.

3.1 Selection of plants

The availability of plants is dependent on the location and season of the particular place. Furthermore, before selecting the plants, cold hardiness zone and heat tolerance zone should be checked well. Therefore, plants were selected such that they can grow easily in a wide range of weather condition, and they can be cultivated easily inside the tires in a coastal area. After careful observation of the characteristics of different locally available plants, Kirinsou and Dechondra (Figure 3) were finally selected to be grown inside actual tires (Figure 4), since; these plants can grow in a wide range of climate as well as soil condition.

3.2 Field test preparations

Tires were filled with soil with a dry density of 1.426 g/cm^3. Tires also were filled with soil and tire chips (10 % by volume) with a dry density of 0.47 g/cm^3. The idea was to observe 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. In this study 10 % of tire chips (Size < 2mm) were mixed with soil to maintain an optimum balance between the strength and growth condition of plants, as high tire chip content may affect the growth of the plants.

3.3 Test conditions

Field tests were conducted for three cases: Case a (2 layers vertical), Case b (3 layers vertical) and Case c (stepped 3 layers) as shown in Figure 5. 2 layers and 3 layers tire were used to observe how the plants will grow inside the tires filled with different thickness of soil. In 2 layers and 3 layers vertically placed tires, large surface area will be available for the plants to grow, whereas when slopped tires are placed (Case c), the surface area will be reduced. Therefore, to observe the growing condition of plants in reduced soil surface area, slopped 3 layers 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 layers vertical tire as a filling material.

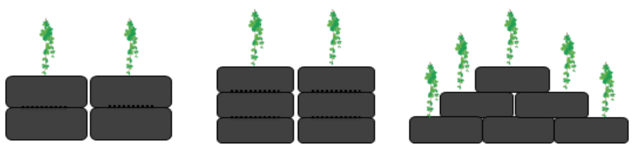
Each tire was filled with soils in three layers and each layer was compacted well to maintain the optimum dry density. Weights of the soil and tire chips to be added (10 % in this case) were calculated based on the total inner volume of the tire. The growths of the two different plants (Dechondra and Kirinsou) were observed in the field from the July 2013 (beginning of plantation) to September 2013.

(a) Kirinsou

(b) Dechondra

Figure 3 Selected plants for the tests

Figure 4 Waste tires used in the test



Case a
(2 layers)

Case b
(3 layers)

Case c
(3 layers in slope)

Figure 5 Configurations for tire placement

3.4 Test observations

Figures 6 and 7 are the photographs showing the states of growth of Kirinsou and Dechondra respectively for Case a, Case b and Case c. These photographs were taken at the beginning of July 2013 and end of September, 2013. It can be seen that the two plants 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.

Filling: Tire chips + soils Placement: Two layers (vertical)

Filling: Soils Placement: Three layers (vertical)

Filling: Soils Placement: Three layers (stepped)

(a) In the beginning of planting (July 2013)

Filling: Tire chips + soils Placement: Two layers (vertical)

Filling: Soils Placement: Three layer (vertical)

Filling: Soils Placement: Three layers (stepped)

(b) At the end of September, 2013

Figure 6 State of growth (Kirinsou)

Filling: Tire chips + soils
Placement: Two layers (vertical)

Filling: Soils
Placement: Three layers (vertical)

Filling: Soils
Placement: Three layers (stepped)

(a) In the beginning of planting (July 2013)

Filling: Tire chips + soils
Placement: Two layers (vertical)

Filling: Soils Placement:
Three layers vertical)

Filling: Soils Placement: Three layers (stepped)

(b) At the end of September, 2013

Figure 7 State of growth (Dechondra)

Even though the growth of the two plants from the July 2013 to the September 2013 was very impressive, the harsh winter made the plants vanish. With the advent of spring, (April, 2014) Kirinsou was found to grow again naturally. However, the growth rate of Dechondra was observed to be rather slow. Furthermore, it was also observed that the growth rates of these plants in two different filling materials (10% tire chips mixed with soil and only soil) were the same. Therefore, after the winter season, observations were made only for Case a (2 layers vertical) and Case c (Stepped 3 layers) as shown in Figures 8 and 9 respectively.

Case a

Case b

Figure 8 Growth of Kirinsou after the winter season (Case a and Case b) in April, 2014

Case a

Case b

Figure 9 Growth of Dechondra after the winter season (Case a and Case b) in April, 2014

4. TSUNAMI OVERFLOW TEST (TOT)

The ability of tire to reduce the impact force of tsunami, can be different according to the number layers of tire, type of filling materials and pattern of placing of tires. Therefore, to observe and evaluate the optimum condition that can maximize the reduction of tsunami impact force, tsunami overflow test (Referred hereafter as TOT) were conducted under various conditions (changing the number and laying style of tires, using different filling materials).

4.1 Test model

A new apparatus for TOT was developed in Geotechnical Engineering Laboratory of Kyushu University. In this apparatus, 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 apparatus developed in this research is shown in Figure 10. The model seawall (height 60 cm and crown width 12 cm) is placed inside the soil box. There is a hinge gate above the model seawall that stores water and can reproduce the overflow phenomena of tsunami. A constant hydraulic pressure is maintained by storing a fixed amount of water, which is pooled on the landside to reproduce the tsunami overflow. In order to allow overflow at a constant rate, the hinged gate was connected to a weight (1.53 kg) by means of a wire and a pulley as shown in Figure 10. The gate can be kept closed by fixing two pins in front of the gate as shown in the figure so that the water to be overflowed can be stored.

By pulling up the pin, the gate can be opened, resulting in the overflow of stored water behind the gate. A series of tests were performed with different test conditions under constant overflow condition. The reduction of water impact force due to model tires was recorded using load cells.

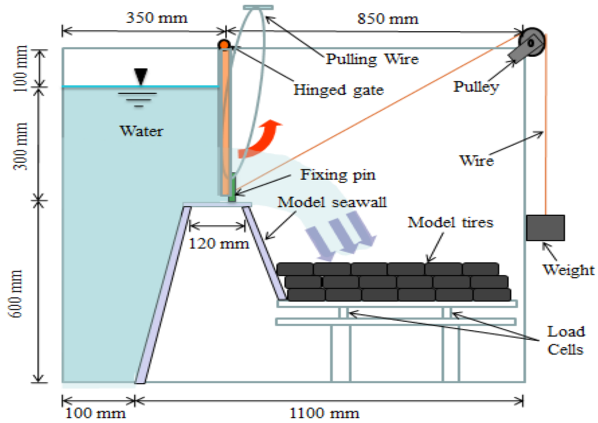


Figure 10 Cross sectional view of the Tsunami Overflow Test (TOT) apparatus

4.2 Model and the data acquisition system

In this study, model tire with outer diameter 85 mm, inner diameter 45 mm and thickness 21 mm was used, which is shown in Figure 11. In order to provide sufficient rigidity, tires should be filled with some suitable materials. Soils and tire chips (size less than 2 mm) were selected as the filling materials as they are easily available in the desired quantity. At the same time, the stiffness of tire structure should be determined depending on the number of tire layers and laying pattern of tires so that the stiffness values can be compared and co-related. (Hazarika et al., 2013a; Hazarika et al., 2014; Pradhan et al., 2014).

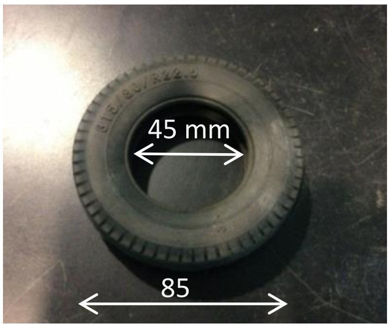


Figure 11 Model tire used in the test

Model tires were connected together using thin binding wires so that they cannot spread out due to the impact force of water (Figure 12). In addition, the whole tire assembly was fixed to prevent it from horizontal displacement during the experiment. In actual practice, however, the tires behind the wall should be properly fixed into the ground to function properly.

Figure 12 Connecting the tires

Arrangements of the load cells are shown in Figures13 and 14 respectively. Five load cell tables (Named as Table 1, Table 2, Table 3, Table 4 and Table 5) were constructed, which were made of acrylic plates. Each table was connected with two load cells (bolted) as shown in Figure 13. Individual tables were not connected to each other. The average value of the impact force was calculated using the values recorded by the two load cells in each table.

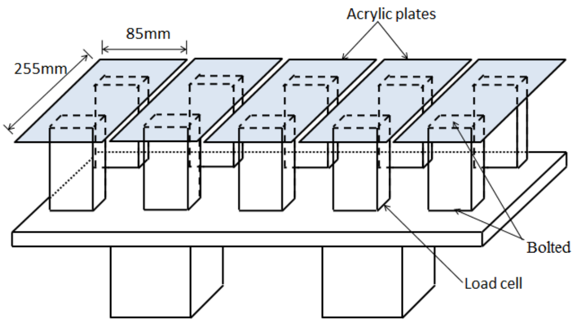


Figure 13 Load cell table and load cells

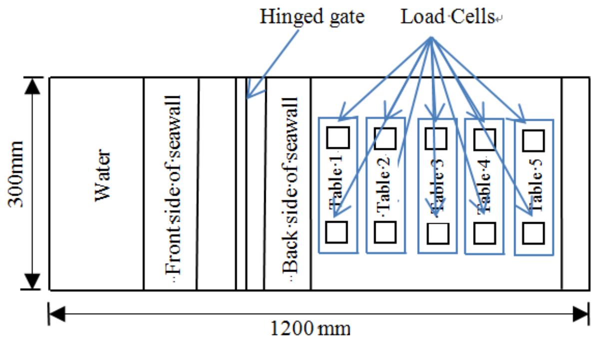


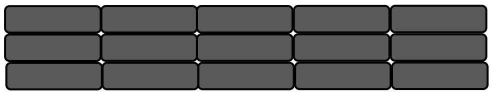
Figure 14 Placement of the load cells

4.3 Test conditions

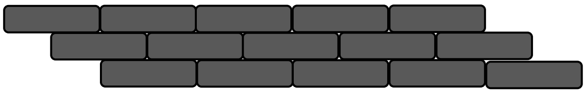
In order to determine the maximum reduction of water impact force, the tire structure was constructed using different laying pattern as well as different filling conditions (materials). The following laying patterns of model tires were used (Figure 15): Case 2 (2 layers vertical), Case 3 (3 layers vertical) and Case 5 (slopped 3 layers). 2 layer and 3 layer tires were used to observe whether the reduction of water impact force will be affected by the depth of the filling material. Slopped 3 layer tires were used because this will be more practical in the actual sea wall construction.

Tires were filled with two kinds filling materials: pure soils and tire chips (size less than 2 mm). The dry density (ρ_d) of soil filling was 1.43 g/cm ^{3}, while that of tire chips was 0.47 g/cm ^{3}. Hollow tires (without any filling) were also used in the test. The conditions of filling are displayed in Figure 16.

(a) Case 2 (2 layers vertical)



(b) Case 3 (3 layers vertical)



(c) Case 5 (Slopped 3 layers)

Figure 15 Laying style of tires

(a) Hollow tires (without filling)

(b) Soil filling

(c) Tire chips filling

Figure 16 Filling patterns of tires

4.4 Results and discussion

For each test condition, the average values of the two load cells in each load table were calculated, and they were plotted against time which is shown in Figures 17(a)-17(c). From these plots, the maximum value in each load table can be determined for different tire laying patterns.

Figure 17(a) shows the results using hollow tires under the different laying conditions. The graph indicates that by changing the laying style of tires from Case 2 to Case 5, the impact force of water could be decreased from 39 N to 26 N.

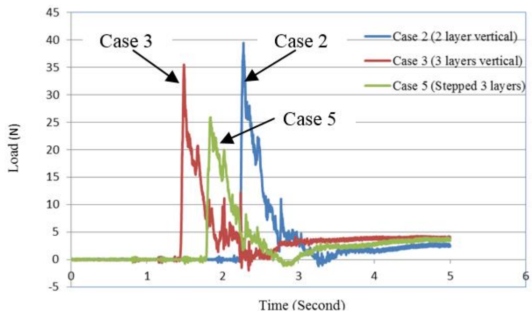
Figure 17(b) shows the performance of soil filled tires under the different laying conditions. The graph clearly indicates that by changing the laying style of tires from Case 2 to Case 5, the impact force of water could be decreased from 26 N to 18 N.

Similarly, Figure 17(c) shows the performance of tires filled with tire chips under the different laying styles of tires. In this case, the impact force of water could be decreased only up to 22 N. In this case, the effect of laying patterns on the reduction performance is not significant as compared to the conditions when they are filled with soils.

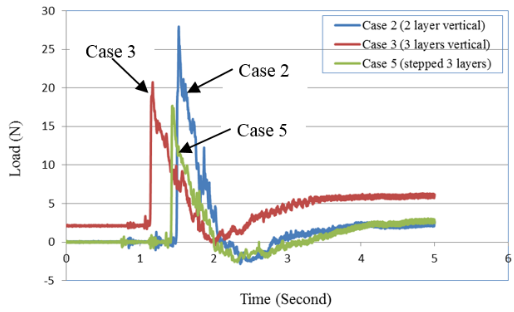
The trends in the measured data in Figures 17(a)~17(c) indicate that by changing the laying style of tires from Case 2 to Case 5, the impact force could be gradually decreased in all the filling conditions of tire. Also, tires filled with soils lead to the significant decrease of the impact load as compared to tires filled with pure tire chips. Therefore, it can be said that, instead of using pure tire chips, mixing tire chips with soils (as discussed in section 2 on field test) can be a viable alternative when applying the technique in actual field conditions.

Figure 18 shows the result of maximum value of impact loads recorded by each load table (Table 1 to Table 5) due to overflowed 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 and Case 5, it can be seen that as compared to the case without tires, the case of tires filled with soil shows the smallest value of impact force. On the other hand, the case with hollow tires shows the largest value of impact force.

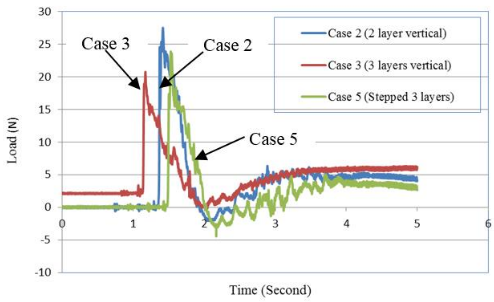
From Figure 18 it can be seen that the highest value of impact load was recorded in Table no. 3 (Refer to Figure 14), therefore, the discussions that follow will be in relation to the data recorded in that load table. Also, since the stepped arrangement of tires leads to the maximum reduction of impact load, the discussion will be limited to only that particular case (Case 5 of Figure 15).



(a) Hollow tires



(b) Tires filled with soils



(c) Tires filled with tire chips

Figure 17 Variation of the impact force

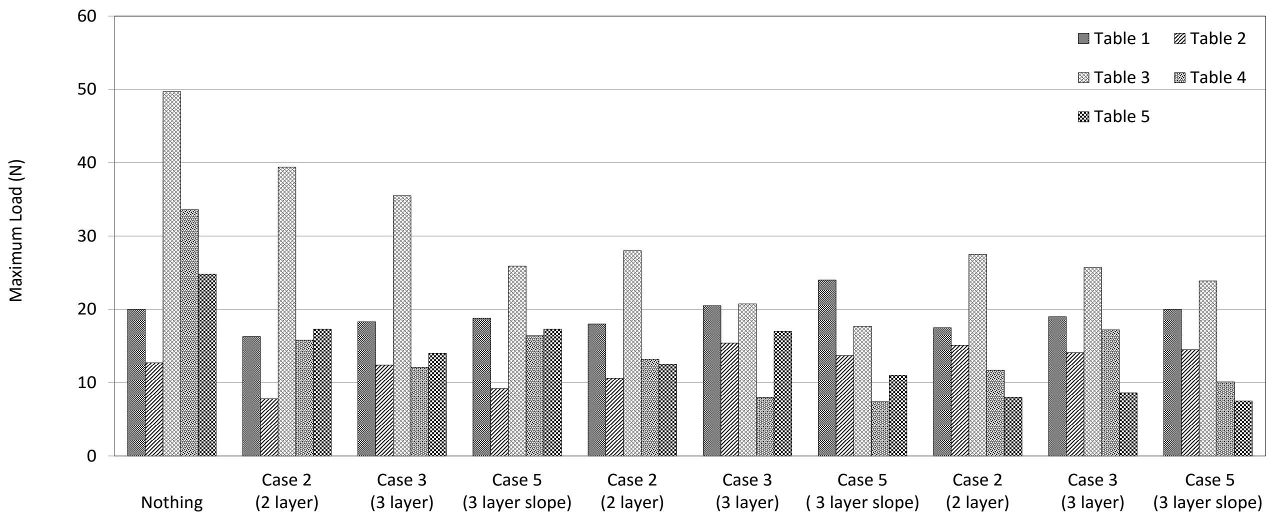
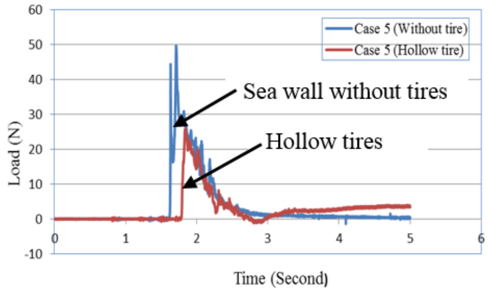


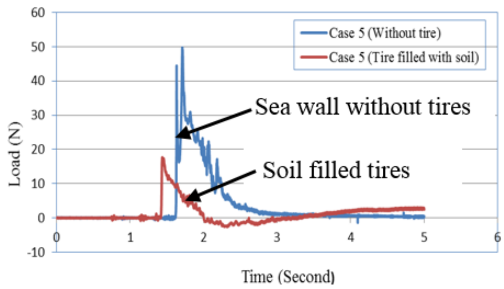
Figure 18 Variation of maximum impact force for all the cases recorded in all the load cell tables

Figures 19(a)-19(c) show the results for the three different filling conditions of tires. The maximum value of impact load without any tires behind the sea wall was recorded to be 50 N. In case of hollow tires, the impact load could be reduced to 25 N, implying 50% reduction of load. In case of tires filled with soils, the impact load could be reduced to 18 N, implying 64% reduction of load. In case of tires filled with tire chips, the impact load could be reduced to 23 N, implying 54% reduction of load. Therefore, it can be concluded that tire filled with soils is the most effective solution. The above results, thus, indicate that the reduction of impact force using tire is sensitive to the laying patterns of tires and the filling materials of the tires.

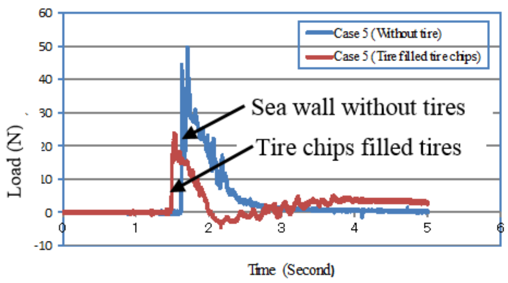
An interesting observation, made from these results. is the time required for the force to come to the static equilibrium position after reaching the peak (magnitude of load becomes equal to zero again). In the case of structure with no countermeasures, the time taken to come to equilibrium state was about 1.5 second. In the case of countermeasure with hollow tires, the value came down to about 1.0 second. In the case of soil filled tires and tire chips filled tires, the values came down to 0.6 second and 0.4 second respectively.



(a) Reduction capabilities of hollow tires tires



(b) Reduction capabilities of soil filled tires



(c) Reduction capabilities of tire chips filled tires

Figure 19 Impact load reduction for slopped 3 layers (recorded in Table 3)

5. CONCLUSIONS

The following are the some of the main conclusions derived based on this experimental research.

a) Planting trees/shrubs inside the tires are possible, and the greenery and natural harmony could be maintained through such plantations.
b) The materials used for filling tires (pure soils or mixtures of tire chips and soils) do not have any significant effect on the growth of plants.
c) By placing filled tires behind sea walls, tsunami impact force can be reduced considerably, thereby protecting the damage of such structures from impact force and resulting scouring/erosion.
d) The tires must be filled with soils and with other materials to have certain stiffness, so that they would be able to absorb the impact force of tsunami.
e) Increasing the thickness of vertically placed tire layers from two to three reduces the impact force.
f) Maximum reduction of the tsunami impact force takes place when the slopping configuration of the tires is used.

Application of the technique developed here, is expected to contribute towards reducing the global warming by cutting down the release of greenhouse gas, and thus, can be an effective adaptation measure against climate change. The technique also has very high potential for adopting in developing and emerging economies, especially in Asia, where alarming rate of use of cars as the mode of commuting are already creating problems of stockpiling and illegal dumping, which in turn are placing a huge burden on our environment.

6. ACKNOWLEDGMENTS

The financial assistance for this research was provided by Kyushu University under university's P & P research grant for Education and Research in Asian Region. The author gratefully acknowledges this support. The author would also like to acknowledge the contributions of Mr. Kiran Hari Pradhan and Mr. Nozomu Hirayu, former students of Geotechnical Engineering Laboratory, Kyushu University in conducting the tests and data processing. The author's special thanks go to Mr. Yasushi Nishimoto, President, Venti Quattro Co. Ltd., Fukuoka, Japan, for arranging the waste tires used in the field tests of this research. Last but not the least, the author's great appreciation also goes to Mr. Michio Nakashima, technician of Geotechnical Engineering Laboratory for his help and effort in developing the laboratory testing apparatus.

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