# Three dimensional geosynthetics as cushion for load reduction - Field trial and numerical simulation

Hemanta Hazarika
*Akita Prefectural University, Akita, Japan*
Kazuhiro Kaneda
*Takenaka Corporation, Chiba, Japan*
Yasuhiro Mae
*Sekisui Plastic Co. Ltd., Tokyo, Japan*
Noboru Mikami
*Nittoc Construction Co. Ltd., Tokyo, Japan*

**Keywords:** Controlled yielding, numerical simulation, pressure reduction, SYS model, tire chips

**ABSTRACT:** If there exists a highly compressible material between the backfill soil and a retaining wall, the backfill soil approaches the active state even without any wall displacement. In this paper, this mechanism has been evaluated through a field test and its numerical simulation. Highly compressible tire derived geosynthetics (tire chips) was used as cushion in the trial testing. In the numerical simulation, the modified Cam clay model with super-subloading yield surface and rotational hardening (SYS Cam clay model) was used. The earth pressures for both the backfill conditions (conventional sandy backfill and backfill with cushion) were calculated, and the pressure reduction mechanism was clarified.

## 1. Introduction

Tire derived geomaterials (tire chips, tire shreds) have now been well recognized in geosynthetics community due to their multifaceted potentials in various civil and geotechnical engineering practices. Advantages of using such materials are manifold: they are lightweight, have high vibration absorbing capacity, high elastic compressibility and high hydraulic conductivity. In addition, they perform in three dimensions when used as geosynthetics. Due to myriads of such potentials of these three dimensional geosynthetics, in many applications they are becoming preferred materials as compared to some marketed geosynthetics products. A comprehensive collection of papers on recent researches and applications of tire derived geomaterials worldwide can be found in Hazarika and Yasuhara (2007) that includes the special report by Humphrey (2007). Such geosynthetics can be used for upgrading and stabilizing retaining structures by making use of their compressible characteristics. One potentially innovative application is to utilize them as cushion sandwiching retaining structure and the backfill (Hazarika et al 2008). In such application, the compressible property of tire chips can be exploited to control the deformation of the soil-structure system, a technique, known as the Compressible Inclusion (Horvath 1997). In addition, tire chips permits good drainage of the backfill due to their highly permeable nature. Compressible Inclusion technique enables to control the deformation of the structure (under both static and dynamic loading), resulting in a substantial reduction of the load on the structure, and thus minimizing the cost as well as the post construction deformation. Such controlled yielding technique using other compressible product such as EPS (Expanded Polystyrene) was numerically evaluated by Karpurapu and Bathrust (1992).

In this paper, a full-scale field investigation and its numerical simulation are described for a retaining wall with a compressible layer of tire chips sandwiching the wall and the backfill. The static earth pressures and their time variations at various locations along the wall height were monitored for several days. The effectiveness of using such recycled geomaterial as sandwiched cushion in reducing the load, and thus enhancing the stability of structure was demonstrated via the field test results. Presence of a compressible cushion makes the backfill approaching to a quasi-active state even without any displacement of the wall. This mechanism has been numerically evaluated and the reduction mechanism of the earth pressure was clarified. The influences of the Poisson ratio and the Young Modulus of the compressible tire chips on the pressure reduction capability were also numerically evaluated.

## 2. Field Testing Program

### 2.1 Test model and setup

The field tests were conducted at a site located in Chiba prefecture, Japan. Figure 1 shows the cross sectional view of the test set up. A 1.0 m deep trench was made in an area covering 5m in length and 6m in width. A precast retaining wall 1.5 m in height and 2 m in width was placed on a cast in-situ concrete base as shown. Trench was filled with cohesionless soil on both sides of the installed wall simultaneously so that the wall does not experience any displacement during backfilling. The backfilling was done up to a height of 2.0 m, and was compacted using vibratory roller. By placing sufficient weight using sand-filled bags (capacity 1 ton) on its front, the wall was made as rigid and non-yielding as possible thus ensuring a state close to the at rest state. On the central part of the wall (Fig. 2), five earth pressure cells were installed to measure the horizontal thrust.

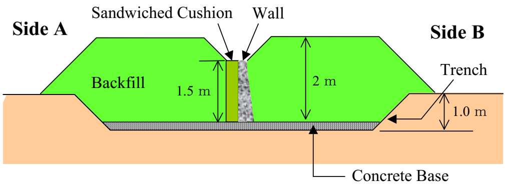



Figure 1. Overview of the test site

### 2.2 Testing process and test materials

Two cases were examined in the field trial: Case I in which backfill consists of soils alone, without any cushion behind the wall (Figure 2), and Case II in which tire chips cushion (30 cm thick) was used (Figures 1 & 3). As stated before, the purpose of using tire chips layer was twofold: one is to perform as a sandwiched cushion to reduce the at-rest pressure, and the other is to act as a drainage enhancing layer. The testing process involves placing the tire chips cushion behind the wall first. The tire chips cushion layer was prepared by filling tire chips inside bags made from geotextiles and placing them one above another (As seen in Figure 3). Geotextiles are required to wrap the tire chips so that they do not mix with the surrounding soils. Such confinement also makes the placing and execution of backfilling and cushioning easier.

Tire chips of average grain size 20 mm was used in preparing the cushion. The average dry density of the tire chips achieved after filling and tamping was 0.587 t/m$^3$. The linear elastic modulus tire chips at 100 kPa confining stress is 1.064 MPa. The backfilling was accomplished by stage backfilling method using vibratory roller. After backfilling each layer, the density and the water content were measured. A surcharge load of 8.3 kPa (using sand-filled bags) was applied at the top of the backfill. A similar surcharge was placed on the opposite site of the wall (side B in Figure 1) as well to impose sufficient load on the front so that the wall remains unyielding. The recordings of the earth pressures cells were taken at each stage of the backfilling and surcharging using the data acquisition system. They were then monitored for seven days.

Well-graded Masado (decomposed granite) was chosen as the backfilling material. This cohesionless backfill material has the in place average dry density, $\rho_d$= 1.696 t/m$^3$ and relative density, $D_r$= 76 % with an angle of internal friction of 40$^o$.

Figure 2. Case I

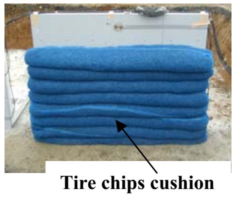



Figure 3. Case II

### 2.3 Typical test results

Figure 4 shows the distribution of earth pressure recorded. The values shown here are at the end of the monitoring period (seven days). The unfilled circles represent the earth pressures in sandy backfill, and the filled circles represent those with sandwiched cushion. It can be seen that the tire chips cushion resulted in a substantial reduction of the pressures against the retaining wall.

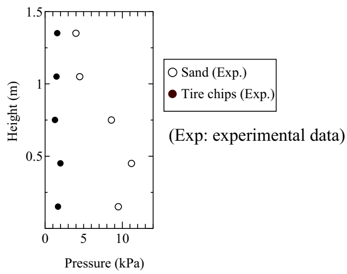



Figure 4. Earth pressure against the retaining wall

## 3. Numerical Simulations

### 3.1 Calculation procedures

In order to simulate the field test described above, a finite element analysis was carried out using the SYS Cam-clay model developed by Asaoka et al. (2002). The SYS Cam clay model is an elasto-plastic model that takes into the account the soil structure, over consolidation and anisotropy. Table 1 shows the elasto-plastic parameters, the evolution parameters and the initial conditions of the analysis.

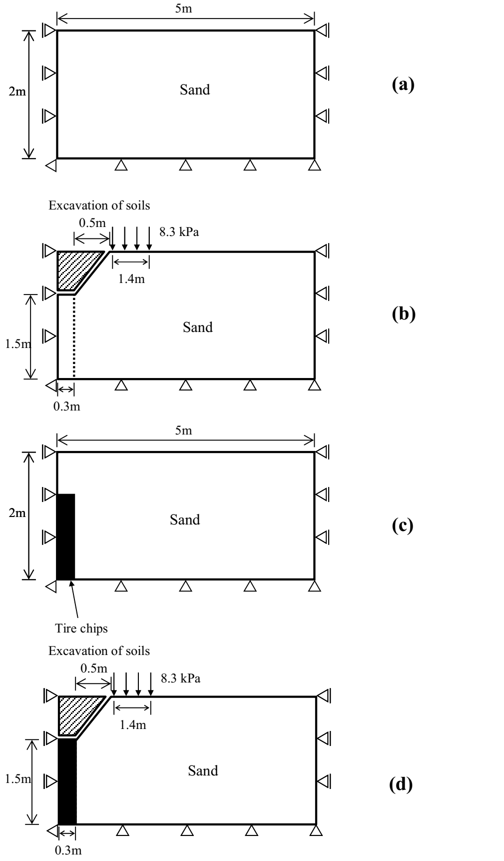



Figure 5. Calculation stages (initial conditions)

The loading condition of the field test was simulated as described in Figure 5. As shown in Figure 5(a), at first a horizontal backfill surface was created. The void ratio was set at 0.53 to match the experimental conditions and the state of the structure and initial anisotropy were assumed to be constant. The confining pressure due to the self weight of the sand was calculated and the over consolidation ratio of the soil was found. The soil was then excavated in order to create the sloping side of the backfill shown in Figure 5(b). Thereafter, a surcharge load of 8.3 kPa was imposed and calculations were continued until steady state was reached in order to estimate the earth pressures against the retaining wall. Next, the 30 cm thick zone of sand behind the wall was replaced by tire chips cushion as shown in Figure 5(c). The forces on the nodes of the finite elements representing the sand were first calculated. Then the forces due to the weight of the tire chips replacing the sand were calculated, and the differential forces resulting from these two components were applied to the nodes. Finally, the soil wedge (shaded part in Figure 5(d)) was removed. Surcharge load of 8.3 kPa was then applied, and the simulation was continued until steady state was attained, and the earth pressure on the wall was calculated.

Table 1. Material parameters

| | |
|---|---|
| [Elasto-plastic parameters] | |
| Compression index λ | 0.05 |
| Swelling index κ | 0.017 |
| Critical state constant M | 1.00 |
| Void ratio at *p*'=98 kPa | 1.51 |
| Poisson's ratio | 0.3 |
| Soil specific gravity | 2.65 |
| [Evolution parameters] | |
| Degradation parameter of over consolidated state *m* | 0.05 |
| Degradation of parameter of structure *a* | 1.0 |
| Degradation of parameter of structure *b, c* | 1.0 |
| Evolution parameter of β $b_r$ | 3.0 |
| Limit of rotation $m_b$ | 0.7 |
| [Initial conditions] | |
| Initial void ratio *e* | 0.53 |
| Initial value of $1/R^*$ (state of structure) | 3.0 |
| Initial coefficient of earth pressure at rest $K_0$ | 0.6 |
| Initial slope of axis of rotation | 0.231 |
| Coefficient of permeability *k* (cm/sec) | $4.0\times10^{-2}$ |

Figure 6 shows the finite element mesh used to simulate the field tests after excavating the shaded part in Figure 5(d) along with the boundary conditions used. In order to simulate the change of confining pressures with depth, a parametric study was conducted by changing the Young's modulus of the tire chips depending on the confining pressure and they are shown in Table 2.

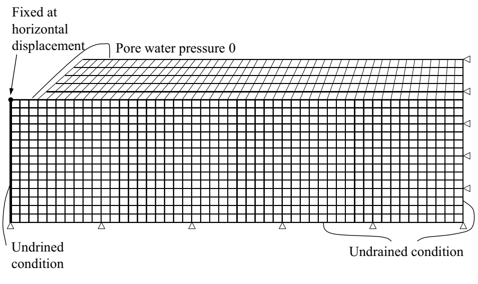



Figure 6. Finite element mesh

Table 2. Elastic parameters

| [Elastic parameters] | Type 1 | Type 2 | Type 3 |
|---|---|---|---|
| Young's modulus E (kPa) | 40,60,80 | 400,450,500 | 40,60,80 |
| Poisson's ratio $\nu$ | 0.1 | 0.1 | 0.4 |
| Specific gravity (g/cm$^3$) | 1.15 | 1.15 | 1.15 |
| At rest coefficient, $K_0$ | 0.1 | 0.1 | 0.6 |

### 3.2 Calculation results

Figure 7 shows the calculated results using the Type 1 parameters in Table 2. Similar to the results presented in Figure 4 for the field tests, a lower earth pressure is predicted when there were tire chips sandwiched between the wall and the sand. Figure 8 shows the distribution of shear strain for sandy backfill (Case I) and for backfill with the tire chips cushion (Case II). The shear strain is greater in the upper portion of the soil volume in Case I, while in Case II, the sand body has shifted toward the retaining wall, forming a distribution resembling a shear zone. This explains why the earth pressure was reduced, as the backfill soil had deformed in the active state. Kaneda et al. (2007) numerically investigated the influence of the backfill density on such pressure reduction capability of the cushion.

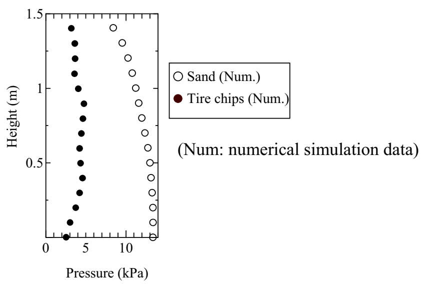
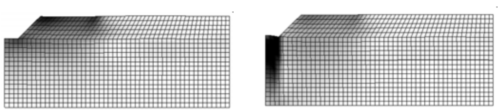



Figure 7. Earth pressure against the wall



(a) Sandy backfill (b) Tire chips cushion

Figure 8. Distributions of shear strain

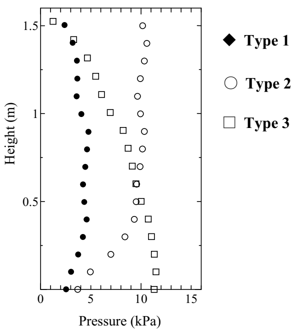



Figure 9. Results from the parametric study

Figure 9 shows the results of calculations when the material constants of the tire chips were varied as displayed in Table 2. When Poisson's ratio ν was 0.1 and Young's modulus was high (Type 2), the earth pressure was reduced in the deeper locations of the cushion, while there was little change in the upper locations. When Young's modulus were the same as in Case 1, but ν was increased to 0.4 (Type 3), there was a reduction in earth pressure in the upper locations with no effect in the deeper locations.

## 4.Summary and Conclusions

A field investigation on a retaining wall and its numerical simulation is described here, wherein tire chips were used as compressible cushion behind a rigid retaining wall. Based on the test results, it can be concluded that instead of using tire chips merely as a lightweight substitution for the backfill, an economic and cost-effective alternative is to use it as compressible cushion. The use of sandwiched cushion behind a rigid retaining structure leads to more than 50% reduction of the pressure mainly due to the controlled yielding of the wall and the backfill, which generates a quasi-active state within the backfill. Besides acting as a compressible agent and reducing the load, the tire chips cushion also functions as good drainage layer implying twofold benefit of such applications.

## References

Asaoka, A., Noda, T., Yamada, T., Kaneda, K. & Nakano, M. 2002. An elasto-plastic description of two distinct volume change mechanisms of soils. *Soils and Foundations*, Vol. 42(5), pp. 47-57.

Hazarika, H., Kohama, E., & Sugano, T. 2008. Underwater shake table tests on waterfront structures protected with tire chips cushion. *Journal of Geotechnical and Environmental Engineering, ASCE,* Vol. 134 (12), pp. 1706-1719.

Hazarika, H. & Yasuhara, K. 2007. *Scrap Tire Derived Geomaterials - Opportunities and Challenges -*, Taylor & Francis, London, UK.

Horvath, J.S. 1997. The compressible inclusion function of EPS geofoam. *Geotextiles and Geomembranes*, Vol. 15, pp. 77-120.

Humphrey, D. N. 2007. Tire derived aggregates as lightweight fill for embankments and retaining walls. *Special Invited Paper, Scrap Tire Derived Geomaterials. -Opportunities and Challenges- Hazarika & Yasuhara (Eds)*. Taylor & Francis, London, pp. 56-79.

Kaneda, K, Hazarika, H., & Yamazaki, H. 2007. Numerical simulations of earth pressure reduction using tire chips in sand backfill, *Journal of Applied Mechanic,* Japan Society of Civil Engineers, Vol. 10, pp. 467-476 (In Japanese).

Karpurapu, R., & Bathrust, R.J. 1992. Numerical investigation of controlled yielding of soil-retaining wall structures. *Geotextiles and Geomembranes*, Vol. 11, pp. 115-131.