Improvement of shallow foundation using non-liquefiable recycle materials

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ABSTRACT

This paper provides initial findings regarding the utilization of tire chips in the form of vertical and horizontal layer placed beneath the shallow foundation. The effectiveness of such configuration was investigated numerically using PLAXIS 2D software. The user defined soil model (UDSM) - UBCSAND model of PLAXIS was used as the material model so that the liquefaction behavior able to be captured. Structural displacement, acceleration response and pore water pressure ratio were selected as the indicating factors to measure any improvement made. Furthermore, the effect of various intensity of the seismic motion towards the numerical model also discussed. In general, the presence of horizontal and vertical layer made of tire chips significantly improves the performance of the shallow foundation under the seismic motion in the previously stated indicating factors.

Keywords: shallow foundation, tire chips, numerical study, seismic load

1. INTRODUCTION

Ground improvement is one of the crucial aspects that need to be taken care of especially when the project involves reclaimed areas. Reclaimed soils, however, are generally prone to liquefaction. For instance, The 2011 Off the Pacific Coast of Tohoku Earthquake had affected many residential areas located in Urayasu City due to liquefaction. Houses and electric poles experienced moderate to severe degree of tilting while light underground structures were pushed upward. However, the damage was only limited to the area which the soils have not been properly improved. Nearby residential areas which were also built on reclaimed land, but with sufficient improvement experienced less damage due to liquefaction. There are several improvement techniques that can be used. Despite of it, nowadays, researchers all around the world were tending to integrate the need to improve the soil properties and characteristic and the preservation of the environment.

In contrast, the rapid increase in the number of scrap tires dumped each year has been an issue. Although an attempt to recycle these materials to generate energy has been made, the effort seems did not enough to reduce the piled of the waste. Consequently, the use of the abundant scrap tires has to be widely expanded so that it able to provide some other choice to support recycling. Due to this reason, the idea of utilizing used tires in construction has been getting more attention in the past decade. It can be utilized in the construction of embankments (Humphrey, 2008), tunnel (Kim & Konagai, 2001), shallow foundation (Tsang, 2008) and quay walls (Hazarika et al., 2008, Hazarika et. al, 2012).

2 MOTIVATION OF STUDY

A laboratory model of quay wall has been developed by Hazarika et al. (2008). His study proposed a unique technique which consists of cushion and vertical drains made of tire chips and installed behind the quay wall and also inside the soil backfill. The model was then simulated for an earthquake motion by using shaking table. His study found that the tire derived materials placed behind retaining wall was not only able to reduce horizontal displacement, but also minimize the seismic earth pressure that acts on the wall significantly.

In this study, however the technique was adopted and applied beneath the shallow foundation. The purpose of this study is to numerically evaluate the effectiveness of the tire chips material placed beneath shallow foundation Dynamic load was imposed at the bottom of the model. Since tire chips are one of the non-biodegradable materials, the long term stability of the material in the soil will not be an issue.

3 NUMERICAL MODEL AND SELECTION OF PARAMETER

Performance evaluation of the shallow foundation applied with the technique which describe previously was conducted using dynamic module of a commercial
finite element software, PLAXIS 2D. The numerical model consists of a shallow foundation placed on top of the liquefiable soil. The shallow foundation was modelled using linear elastic material while the liquefiable sand soil was modelled using the user defined soil model (UDSM). The PLAXIS version of UBCSAND model was used so that the development of excess pore water pressure inside sandy soil can be observed. Hence, the effectiveness of the technique to minimize the liquefaction risk able to be evaluated. Tire chips layer and vertical drains which was modelled using linear elastic model were installed inside the foundation soil as shown in Fig. 1.

Then, the model was subjected to seismic excitation of the 1995 Hyogo-ken Nanbu earthquake as shown in Fig. 2. The seismic motion was imposed in the numerical model by using prescribed displacement set at the base of the model. Standard fixities and standard earthquake boundaries were applied to the model. Standard fixities restrained translation in the horizontal direction for both sides of the model while at the same time, the translation was restrained in both horizontal and vertical direction at the bottom of the model. On the other hand, the standard earthquake boundaries include absorbent boundaries on both sides of the model as well as the prescribed acceleration at the base. The finite element mesh of the model is shown in Fig. 3 while the dimension of the shallow foundation and the proposed technique is shown in Fig. 4.

The properties of tire chips and soil used in this study were tabulated in Table 1 and Table 2 respectively. The properties of the liquefied soil used in this study were adopted from Galavi et al. (2013) due to the similarity of the material model chosen. However, his study highlighted on the failure mechanism due to liquefaction of the quay wall located in Rokko Island during the Hyogo-ken Nanbu earthquake occurred in 1995. Meanwhile, the shallow foundation in this study was modelled using non-porous linear elastic material with Young’s modulus (E) and Poisson ratio (ν) of 30000 kPa and 0.2 respectively.

Moreover, Point A (2500,1200) and Point B (2500,900) located at the top and bottom center of the shallow foundation respectively was selected in order to compare the displacements and accelerations experienced in each of the finite element models. In this paper, the effectiveness of the tire chips layer and vertical drains placed beneath the shallow foundation were only discussed in terms of displacement and acceleration response of the foundation and also the development of pore water pressure.

| Table 1. Properties of tire chips |
| Parameters | Symbol (unit) | Values |
| Unit weight | γ (kN/m³) | 6.62 |
| Young Modulus | E (kN/m²) | 2600 |
| Poisson’s ratio | ν (-) | 0.11 |
| Damping ratio | h (-) | α = 1x10⁻³, β = 0.01 |

Fig. 1. Layout of the numerical model.

Fig. 2. Input strong motion record of the 1995 Hyogo-ken Nanbu earthquake.

Fig. 3. Finite element mesh generated.

Fig. 4. Finite element mesh generated.
Table 2. Parameters of liquefied soil as used in the UBCSAND model (Galavi et al. 2013)

| Parameters                              | Symbol (unit) | Values |
|-----------------------------------------|---------------|--------|
| Peak friction angle                     | $\phi_p$ (°)  | 34     |
| Constant volume friction angle          | $\phi_{cv}$ (°) | 33     |
| Elastic shear modulus number            | $k_e G$ (-)   | 934    |
| Elastic bulk modulus number             | $k_e B$ (-)   | 654    |
| Plastic shear modulus number            | $k_p G$ (-)   | 380    |
| Elastic shear modulus index             | $n_e$ (-)     | 0.5    |
| Plastic shear modulus index             | $n_p$ (-)     | 0.4    |
| Elastic bulk modulus index              | $m_e$ (-)     | 0.5    |
| Effective cohesion                      | $c'$ (kPa)    | 0      |
| Failure ratio                           | $R_f$ (-)     | 0.78   |
| Densification factor                    | $\text{fac}_{\text{hard}}$ (-) | 0.45 |
| Post liquefaction factor                | $\text{fac}_{\text{post}}$ (-) | 0.02 |
| Tension cut-off                         | $\sigma_t$ (kPa) | 0      |
| Corrected standard penetration test     | $(N_{1})_{90}$ (-) | 10  |

4 RESULTS OF NUMERICAL SIMULATION

4.1 Displacement

In this section, the displacements of the numerical model at the end of the dynamic time are discussed. Fig. 5 and Fig. 6 show the contour of the total displacement for the conventional and improved model as a result of the dynamic load. Maximum displacement recorded mainly at the base of both models due to the imposed load at the bottom. As can be seen in these figures, an unsymmetrical displacement contour observed inside the foundation soil under the footing of the conventional model while in the improved model, a symmetrical displacement contour pattern observed.

The unsymmetrical contour displacement pattern shows in the conventional model may be due to the effect of large vertical displacement of the foundation soil and the footing. The vertical displacement of the top of the foundation (Point A) is shown in Figure 7. The presence of tire chips beneath shallow foundation can reduce the movement of the shallow foundation in vertical direction.

However, the effectiveness of the tire chips material to reduce the movement in horizontal direction seems quite insignificant as shown in Fig. 8. This may be due to the size of the width and thickness of the tire chips layer and vertical drains which is relatively small when compared to the whole numerical model.

4.2 Acceleration

The acceleration response at Point A and Point B which located at the top and bottom center of the foundation are presented in this section. Horizontal and vertical acceleration experienced by Point A is shown in Fig. 9 and Fig. 10 respectively, while Fig. 11 and Fig. 12 show horizontal and vertical acceleration responses at Point B. Generally, the presence of tire chips installed beneath foundation is able to reduce the acceleration due to earthquake shaking especially in the vertical direction.

4.3 Excess pore water pressure ratio

Pore water pressure ratio (PPR) can be calculated using the following equation:

$$\text{PPR} = \frac{\Delta P_w}{P'_o}$$

Where, $\Delta P_w$ is the excess pore water pressure while $P'_o$
is the initial effective stress.

The pore water pressure ratio of the conventional case at the end of the simulated time is shown in Fig. 13. As can be seen in the figure, the distribution of the pore water pressure reached 1.0 in the area located at the bottom left of the foundation.

On the other hand, the presence of tire chips in the form of vertical and horizontal layer beneath shallow foundation able to mitigate severe liquefaction inside soil as shown in Fig. 14. The maximum value of the pore water pressure ratio reached during the entire simulated time shows the range value between 0.8 to 1.0 as can be seen in the figure. Although that risk of liquefaction still exist inside the foundation soil, but the value are much lesser compared to the conventional case. This might happen because the intensity of the seismic motion used in this study is quite high. With the peak value of approximately $8 \text{ m/s}^2$ imposed on the bottom of the model, it was obvious that the proposed dimensions of the numerical model unable to sustain the impact. Therefore, in order to accurately investigate the effect of the tire chips beneath the foundation, it is recommended to either widen the dimension of the numerical model or reduce the magnitude of the seismic motion. The latter option was chosen and discussed in the next section.

4.4 Effect of the intensity of dynamic load

In this section the effect of various intensity of seismic motion is discussed. Numerical model of shallow foundation with and without the presence of tire chips in the form of a layer and vertical drains beneath it were subjected to 0.5PI and 0.25PI (with 1.0PI equivalent to the full intensity of dynamic load as shown in Fig. 2).
Fig. 15 and Fig 16 show the development of pore water pressure ratio (PPR) at the end of the simulated time (i.e. 20s) for the seismic motion of 0.5PI. It was clearly seen that at the end of the simulation time, the soil experienced the increased in pore water pressure ratio from approximately 0.3 until up to 1.0 throughout the soil depth especially on the left side of the foundation. However, these increased able to be controlled by the installation of tire chips layer and vertical drains beneath the footing.

In contrast, the seismic motion of 0.25PI seems did not liquefy the soil in generally as can be seen in Fig. 17. The pore water pressure ratio developed in the middle of the ground surface but did not trigger the liquefaction. However, the improvement made by the technique proposed can be observed in Fig. 18 where the pore water pressure ratio developed are slightly lower compared to the one without any improvement.

5 CONCLUSION

This paper provides the initial findings regarding the improvement of the shallow foundation using tire chips. Tire chips in the form of horizontal and vertical layer were installed inside the foundation soil. Numerical models were created using PLAXIS 2D and dynamic load of 20s was imposed at the bottom of the models. Generally, the presence of tire chips beneath the foundation able to reduce vertical displacement and acceleration so that the shallow foundation did not damage severely due to earthquake. Moreover, the technique proposed also able to minimize the risk of liquefaction of the foundation soil. In the future, an experimental model plan to be developed so that comparative results can be made. Last but not least, the effectiveness of the technique proposed in several other indicating parameters also plan to be measured.

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