Hindawi
Shock and Vibration
Volume 2017, Article ID 9043518, 10 pages
https://doi.org/10.1155/2017/9043518

*Research Article*

# Analysis of Dynamic Coupling Characteristics of the Slope Reinforced by Sheet Pile Wall

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Received 2 January 2017; Revised 6 March 2017; Accepted 26 March 2017; Published 19 April 2017

Academic Editor: Carlo Rainieri



Large deformation of slope caused by earthquake can lead to the loss of stability of slope and its retaining structures. At present, there have been some research achievements about the slope reinforcement of stabilizing piles. However, due to the complexity of the structural system, the coupling relationship between soil and pile is still not well understood. Hence it is of great necessity to study its dynamic characteristics further. In view of this, a numerical model was established by FLAC$^{3D}$ in this paper, and the deformation and stress nephogram of sheet pile wall in peak ground motion acceleration (PGA) at 0.1 g, 0.2 g, and 0.4 g were obtained. Through the analysis, some conclusions were obtained. Firstly, based on the nephogram of motion characteristics and the positions of the slip surface and the retaining wall, the reinforced slope can be divided into 6 sections approximatively, namely, the sliding body parts of A, B, C, D, and E and the bedrock part F. Secondly, the deformation and stress distributions of slope reinforced by sheet pile wall were carefully studied. Based on the results of deformation calculation from time history analysis, the interaction force between structure and soil can be estimated by the difference of peak horizontal displacements, and the structure-soil coupling law under earthquake can be studied by this approach.

## 1. Introduction

Sheet pile wall is a typical supporting structure with advantages of safety, reliability, and low cost, which is widely used in the railway engineering, road engineering, and so forth. The disaster investigation of the great Wenchuan earthquake shows that the sheet pile wall has excellent seismic performance [1]. But the researches of dynamic coupling characteristics of the sheet pile wall and the surrounding soil of slope are relatively few. Most of the research focuses on the pile foundation, pile wharf, and so forth. For example, Takahashi et al. [2] studied the seismic performance of pile wharf in the earthquake and analyzed the damage phenomena and failure mechanism of pile wharf caused by seismic permanent deformation; Abdoun et al. [3] studied the dynamic response of the pile foundation in the earthquake by dynamic centrifuge model test; Jiao et al. [4] analyzed the dynamic responses of the sheet pile wharf with separated relieving platform under horizontal seismic loadings; the Kobe and El Centro waves were taken to the numerical model, and it was found that the dynamic responses of the sheet pile wharf were affected by the dynamic characteristics, such as spectrum, wave energy density, and wave total energy.

For the slope reinforced by sheet pile wall, Satoh et al. [5] studied the status of slope reinforced by steel stabilizing pile in earthquake from dynamic centrifuge model test; Tao [6] studied the distribution law of pile stress and deformation in different seismic force by FLAC$^{3D}$; Wang et al. [7] studied the deformation law of cohesive soil slope reinforced by stabilizing pile through centrifuge model test. It divided the slope into four regions and compared the horizontal displacement of four regions in the same height; Giarlelis and Mylonakis [8] proposed the study about the dynamic properties of a cantilever wall. The dynamic linear wall-soil-structure interaction analysis was carried out to investigate the effect of the presence of the cantilever wall and its flexibility on the induced acceleration of the retained soil; Conti et al. [9] investigated the physical phenomena that control the dynamic behavior of embedded cantilevered retaining walls and confirmed that the embedded cantilevered retaining walls experienced permanent displacements even before the

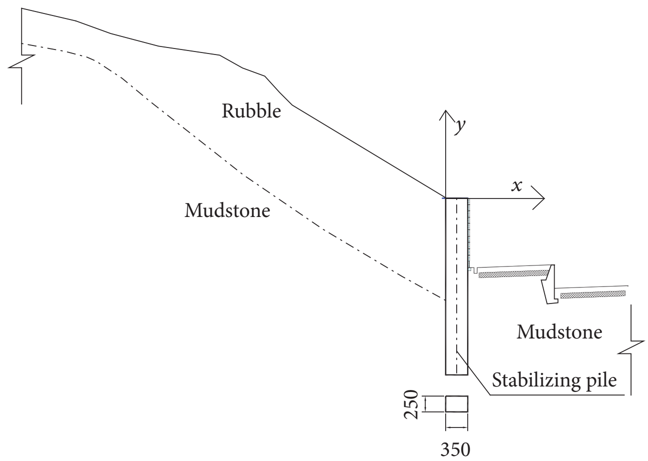



Figure 1: The design drawing of sheet pile wall.

acceleration reaches its critical value, corresponding to full mobilization of the shear strength of the soil.

Recent numerical studies of the dynamic behavior of embedded retaining walls, both cantilevered [10, 11] and with one level of support [12–14], have shown interesting aspects related to the soil-structure interaction and the constitutive modelling of the mechanical behavior of the soil under cyclic loading. In addition, Rainieri et al. [15–17] carried out a series of researches based on the Operational Model Analysis method, through refining the embedded retaining wall model by optimizing the correlation between experimental and numerical estimate of the dynamic properties of the soil-wall system and made some encouraging results. But the above researches are still not comprehensive, because the dynamic coupling characteristics of slope and structure were not taken as the focus research object. Qu et al. [18, 19] studied the seismic response of the slope and the sheet pile wall by shaking table test and proposed some reasonable values of seismic coefficient $C_z$, but the dynamic coupling of sheet pile wall and soil was not studied.

It can be seen from the above that there is little research focusing on the slope reinforced by sheet pile wall, especially for the research about the dynamic coupling characteristics, whether it is based on the numerical simulation or experiment. Therefore, in this paper, sheet pile wall model based on prototype slope was established by FLAC$^{3D}$; the displacement and plastic states were calculated. The purpose of this paper is to explore the displacement deformation characteristics of slope reinforced by sheet pile wall and study the dynamic interaction mechanism of pile-soil system under the ground motion. The results of this study can provide a reliable theoretical basis for revealing the seismic mechanism of slope reinforced by sheet pile wall.

## 2. Numerical Analysis

*2.1. The Establishment of the Numerical Model.* The numerical model is on the sheet pile wall of the left bank slope of a highway in China. The colluvium ($Q_4^{C+dl}$) is over the slope surface and is mainly composed of silty clay, rock, and a small amount of gravel soil. The bedrock is mudstone ($J_{3sn}$) with a small amount of sandstone, and the slope aspect of bedrock is 245°; the natural slope angle is 27°. The slope is in a naturally stable state, but prone to landslide in heavy rainfall or earthquake. The length of model is about 85 m, and the height is about 75 m; both of them were designed based on the results of field measurements. To reduce the time of calculation in the premise of ensuring the accuracy, the thickness of the model is 15 m, and this thickness can represent the mechanical deformation behavior of the whole slope. The length of stabilizing pile is 28 m, the embedded depth is 17 m, and sectional dimension size is 3.5 m × 2.5 m. The retaining plates are set between the piles. The size of the numerical model is designed based on the prototype, with a slight simplification. The design drawing of sheet pile wall is shown in Figure 1. The FLAC$^{3D}$ model is shown in the Figure 2.

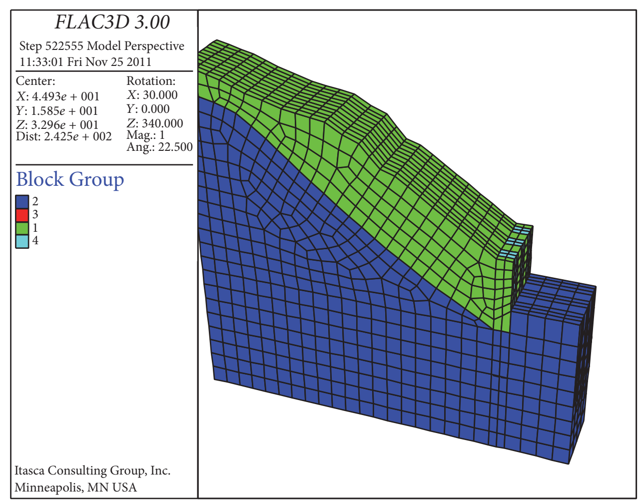



Figure 2: The FLAC$^{3D}$ calculation model.

*2.2. The Selection of Calculation Parameters.* Because the model based on the site is often more persuasive, the relevant

Table 1: Material parameters.

| Material | Calculation model | Volume Weight | Cohesion | Internal friction angle ($\varphi$) | Bulk modulus | Shear modulus | Elastic modulus | Poisson ratio |
|---|---|---|---|---|---|---|---|---|
| | | kN/m$^3$ | kPa | ° | kPa | kPa | kPa | |
| Sliding body | Mohr-Coulomb | 19 | 19 | 24 | $8.04E+04$ | $3.71E+04$ | — | — |
| Bedrock | Mohr-Coulomb | 24 | 50 | 40 | $4.44E+05$ | $3.33E+05$ | — | — |
| Pile | Elastic | 25 | — | — | $1.72E+04$ | $1.29E+07$ | — | — |
| Retaining plate | Elastic | 25 | — | — | — | — | $2.8E+07$ | 0.2 |

parameters (volume weight, cohesion, internal friction angle, etc.) of sliding body and bedrock were from the field tests, and the relevant parameters of pile were designed from Chinese Code for Construction of Concrete Structures [20], and the pile is made of C30 concrete.

In the procedure, the sliding body, bedrock, and pile are simulated by the zone unity. The retaining plates are simulated by the shell structure elements; the thickness of shell is 0.3 m. The bottom of the model is a static boundary condition. The free field boundary condition is used around the model. In addition, the model uses a 5% local damping ratio to approximate the damping effect of the soil during seismic wave propagation. The parameters of the model are shown in Table 1.

*2.3. Seismic Loading.* The numerical model is established based on the prototype site, which is designed according to the China's Highway Engineering Seismic Code [21]. According to the code, the foundation condition of prototype is the Class II site; El Centro is a typical example used in this site. In addition, as the first successfully collected record of seismic waves, El Centro (Imperial Valley-1940) wave was widely used in the history analysis of structure, due to the uniformity of the amplitude of acceleration spectrum distributed over the periodic range [22]. Therefore, the El Centro seismic wave was chosen to input. In order to study the dynamic response characteristics of the reinforced slope in VII, VIII, and IX intensity zones, the PGA of the wave is adjusted to 0.1 g, 0.2 g, and 0.4 g according to Chinese Classification Standard for Seismic Fortification Intensity [23]. In addition, considering that the bottom of the model is mudstone, whose strength is relatively low, the acceleration or velocity cannot be applied to the model directly in FLAC$^{3D}$. The stress time history is converted by the horizontal velocity from the seismic time histories (namely, $\sigma_s = -2(\rho C_s)v_s$). The ground motion actually lasts for a long time, but most of amplitude section of seismic velocity time history has been included in the primary 30 s. To save the computation time, the primary 30 s is taken as the loading time. The horizontal velocity time history is shown in Figure 3.

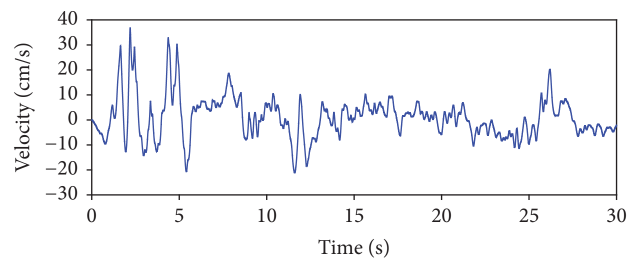



Figure 3: The horizontal velocity after artificial processing.

## 3. Deformation Analysis

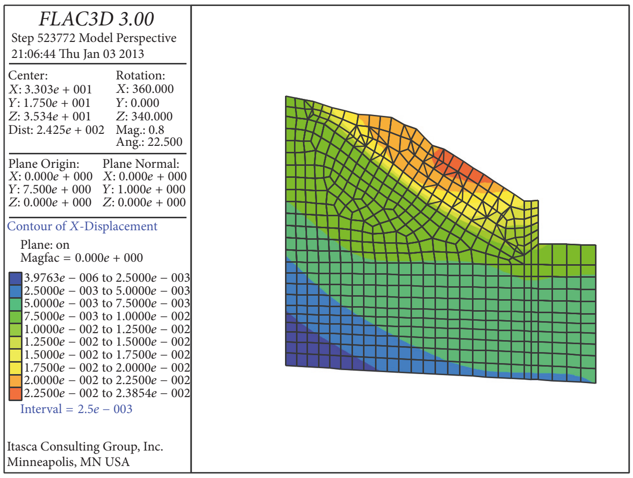
The residual deformation nephogram and plastic deformation state of slope reinforced by sheet pile wall under loading conditions with PGA at 0.1 g, 0.2 g, and 0.4 g can be obtained by the numerical calculation, as shown in Figures 4 and 5.

From Figure 5, it can be found that, with the increasement of PGA, the change of the plastic state of model shows some interesting characteristics. Firstly, the shear-tensioning zone transferred from the inside of slide body to the surface. Secondly, the shear-tensioning zone extends downwardly from the upper part of the landslide body.

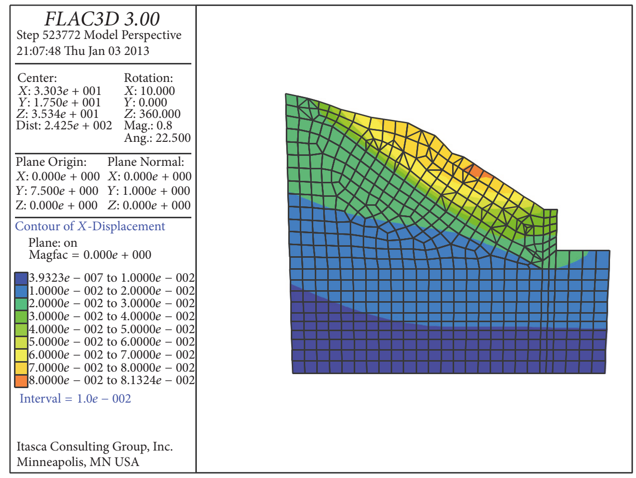
In addition, the displacement has obvious partitioning characteristics. Based on the numerical calculation, the slope can be divided into 6 sections, namely, the A, B, C, D, and E of the landslide section and F of the bedrock section, as shown in Figure 6. The A to D sections are divided approximately according to the pile location, surface S and surface W. The determination of surfaces S and W is described later in this paper. The deformation characteristics of each region appear different.

As the bedrock zone, the residual deformation of F is relatively consistent and is not affected by the reinforced structure; E is the slope zone which is above the supporting structure. The lateral deformation of E is small, and the horizontal displacement distribution of E is similar to the natural slope. Supporting structure is mainly acting on A, B, C, and D. The residual displacement of A and C is larger than that of B and D, namely, A > B and C > D, the boundary of A and C and B and D is the surface W, and the position of surface W is about 1/2 of cantilever segment. Because the stabilizing pile mainly depends on the soil resistance of the embedded section of pile, the limit effect of the lower place of cantilever section is better than the top.

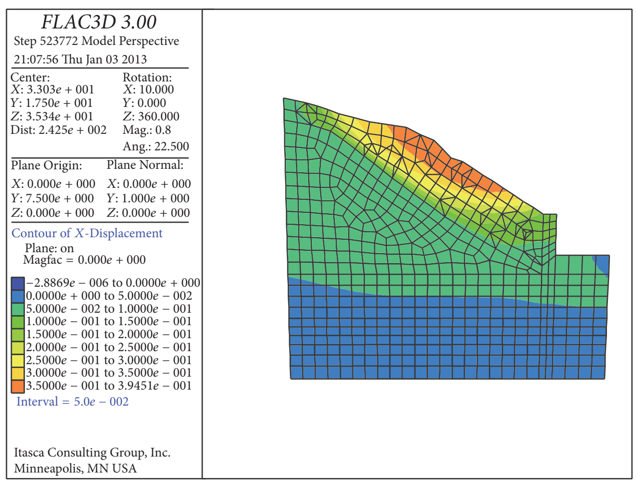
After the earthquake, the residual displacement of F is not changing basically, but the residual displacements of other




(a) Residual displacement nephogram in the PGA 0.1 g




(b) Residual displacement nephogram in the PGA 0.2 g




(c) Residual displacement nephogram in the PGA 0.4 g

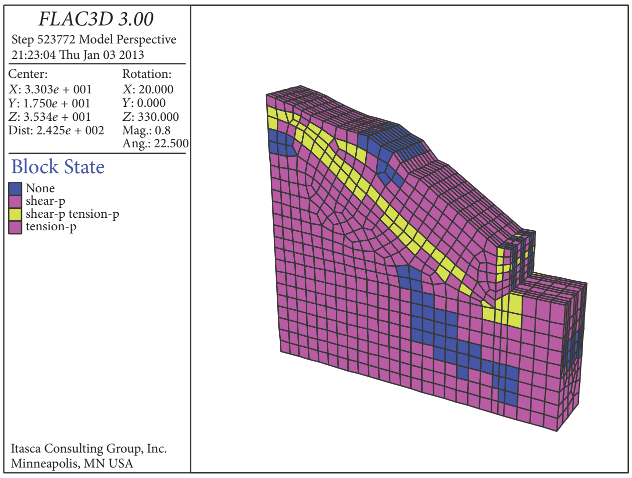
Figure 4: Residual displacement nephogram.

sections have increased. Plastic collapse first appears at the slip surface, and the plastic zone expands with the increase of seismic coefficient. Then the tensile and shear failure appears in the trailing edge of slope of E section. Under the working condition of PGA at 0.4 g, the whole E section is in the plastic deformation, which is prone to the phenomenon of instability. It means the earthquake displacement response in the reinforced slope is amplified from bottom to top, and the earthquake has the potential to accelerate slope sliding.

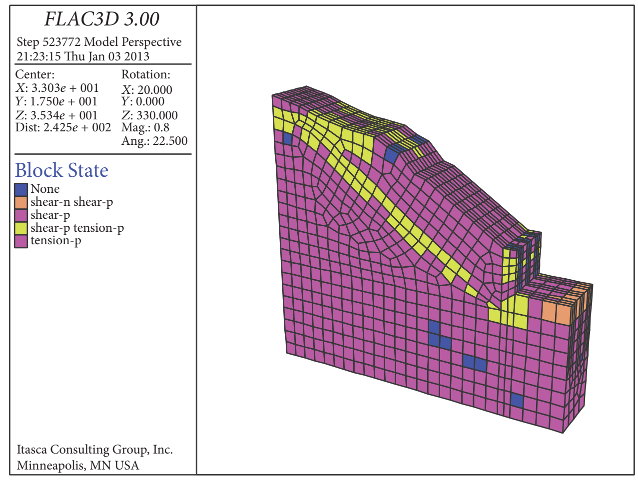
In order to study the deformation law of reinforced slope, a series of different heights of measuring points were selected to study the horizontal residual displacement of the soil in 0.4 g, as shown in Figure 7.

It can be found that the residual deformation is consistent in the bedrock of slope, and the horizontal displacement is relatively small. But the residual displacement close to the slide surface rises obviously. It means that the sheet pile wall does have some support action to slope, but the sliding body of the slope still shows the slide tendency under earthquake, and zoning characteristics appear obviously. The displacement of upper body is greater than the lower one. In addition, the residual horizontal displacement curves have obvious peak point in different height, and the change trend of horizontal displacement on both sides of the peak point is different. Therefore, the peak points can be the separations, and the surface S can be obtained if the separations in different height were connected, as shown in Figure 7. The soil on both sides of the S surface shows different deformation laws in loading process; the A and B section without the restraint effect of the pile show large horizontal displacement because they are far from the pile, but the displacements of C and D are quite small because they are close to the pile. Hence the residual stress of A is greater than C, and B is greater than D. Combination of the above conclusions, A > B and C > D, it can be obtained that the size of deformation of each section is A > B > D and A > C > D. The displacement of B and C is depending on the sliding surface inclination angle, the sliding body thickness and the material, and so forth.

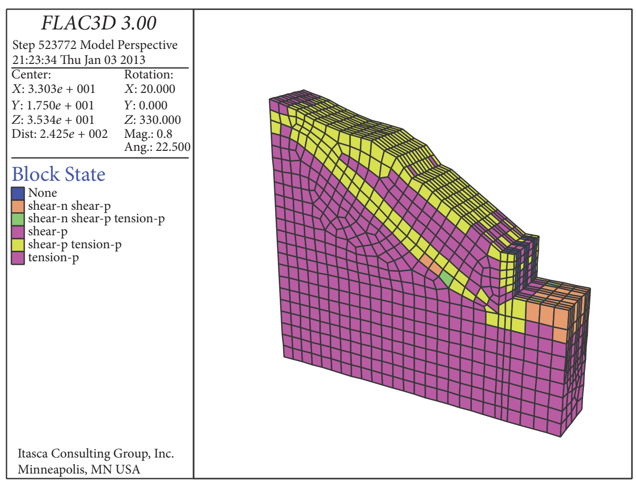
The PGA 0.4 g was taken as an example; the residual displacement of pile and soil after the earthquake was analyzed,




(a) Plastic deformation state diagram in the PGA 0.1 g




(b) Plastic deformation state diagram in the PGA 0.2 g




(c) Plastic deformation state diagram in the PGA 0.4 g

Figure 5: Plastic deformation state diagram.

as shown in Figure 8. Displacement of the soil in front of the pile and behind the pile can reflect the earthquake force of the pile body accurately, as shown in Figure 8. The residual displacement of cantilever pile top and the soil show a large difference, so the pile and the soil may separate under the ground motion.

In addition, the vertical residual displacement distribution nephogram of the slope under the PGA 0.2 g is shown in Figure 9. It can be found that the vertical residual displacement of slope reinforced by sheet pile wall did not show obvious zoning features as horizontal displacement.

## 4. Dynamic Coupling Analysis of Structure and Soil

Dynamic interaction of soil and structure has changed the movement characteristics of the natural slope soil, and the existence of the slope has changed the dynamic performance of the structure. The structure and the slope interact with each other, making the dynamic coupling of sheet pile wall and slope become quite complex. The correct understanding of dynamic coupling of sheet pile wall and slope is the foundation of seismic design work. Rainieri et al. [17] discovered that the dynamic response of the overall system

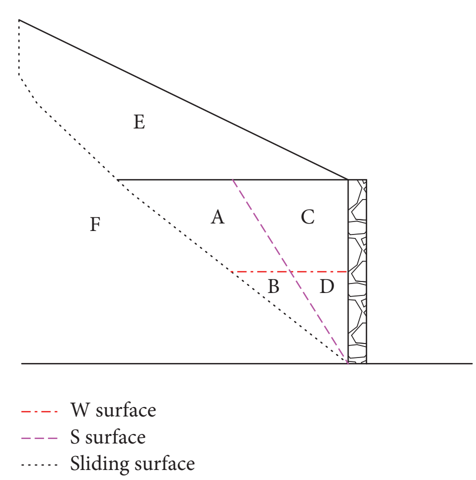



Figure 6: Displacement feature partition.

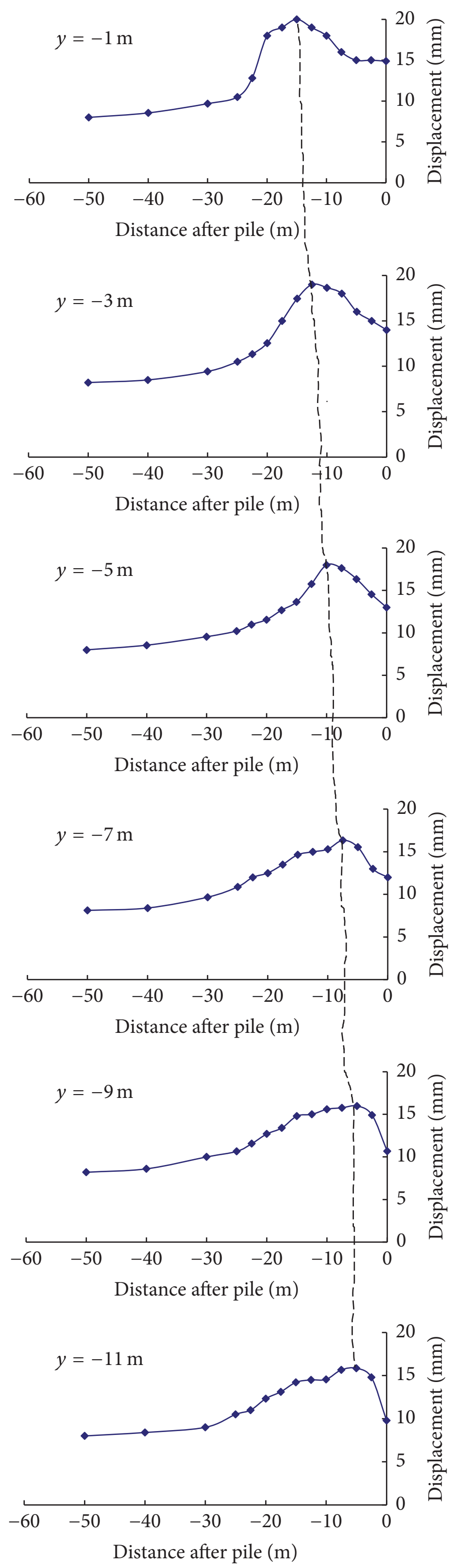



Figure 7: The distributions of horizontal residual displacement in the PGA 0.4 g.

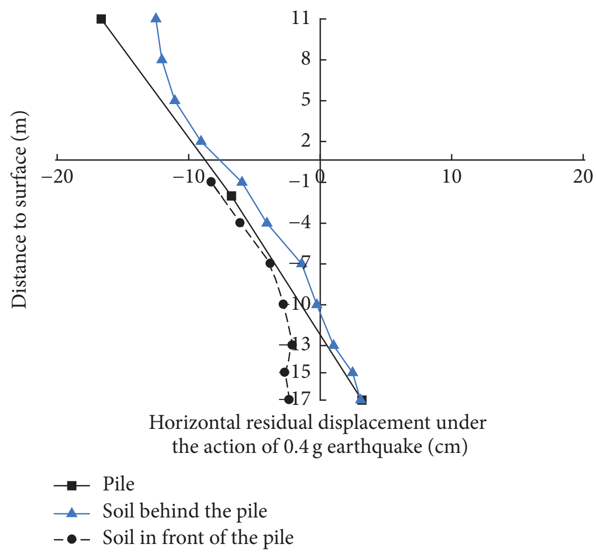



FIGURE 8: The residual displacement distributions of sheet pile wall and soil in front of the pile and behind the pile.

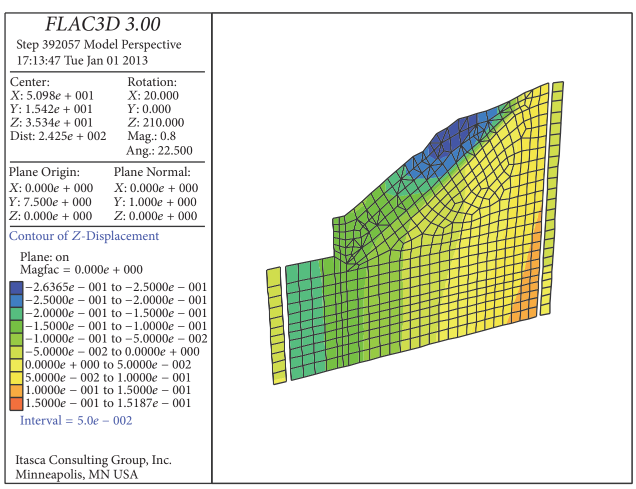



FIGURE 9: The vertical residual displacement nephogram of the slope reinforced by sheet pile wall.

is definitely guided by the natural frequencies of the soil domains on either side of the wall by OMA (Operational Model Analysis) based numerical simulation. From the perspective of frequency, the study of interaction between natural frequency of soil pile and frequency of the seismic wave to represent the seismic response of the soil-structure system is an effective method. In this method, the natural frequency of the structure and the spectral characteristics of the seismic wave are taken into consideration. Therefore, it is not suitable for our study which is about differential displacement under different PGA of the same seismic wave. Fortunately, the Winkler foundation beam method provides a solution for us. According to the Winkler foundation beam method, the difference of peak horizontal displacement can reveal the stress of soil and the pile to some extent. Based on the beam model on Winkler foundation, the stabilized pile was considered as the elastic beam analogue, and the soil was considered as continuous elastomer; the interaction between the soil and the pile was stimulus by continuously distributed spring. In the Matlock model, one of the most widely used models, the system was composed of the frequency independent nonlinear spring and the linear damper. In the nonlinear spring, the load is proportional to the displacement. In a word, the difference of displacement of soil and pile can reflect the pressure between soil and the pile qualitatively.

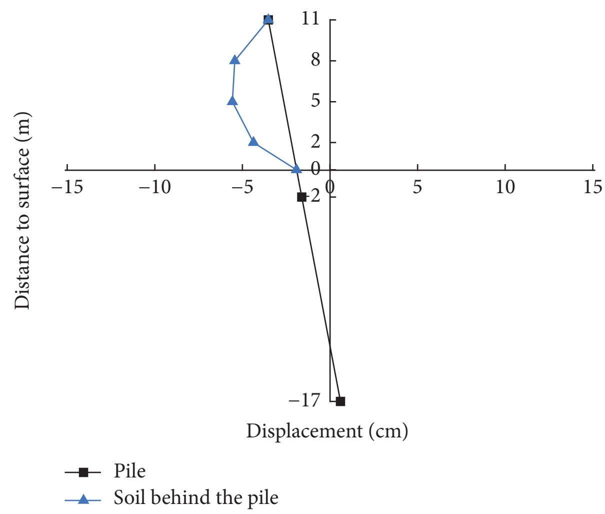



FIGURE 10: Displacement of pile and soil in the static condition.

As a result, this paper took a series of experiment points in front of the pile and behind the pile (all of them are about 20 cm from the pile) and compared the horizontal displacement of those points and the sheet pile wall.

For the static condition, if there is no displacement of the sliding body after excavation, the resistance of sheet pile wall should be the static earth pressure or active earth pressure. However, the actual situation is that after the excavation the sliding body will slide along the sliding surface under the influence of gravity and promote the pile to a certain degree of deflection; then, the state of stress is balanced again. In this state, the soil near the sheet pile wall is compressed. The compressed soil results in excess displacement and this excess displacement represents the interaction of pile and soil in static status.

The displacement of pile and soil in the static status is shown in Figure 10.

It can be found that the displacement of soil behind the pile is significantly larger than the pile, which indicates that, even under the static conditions, the pile is subjected to landslide thrust from the sliding body and the distribution of landslide thrust should be roughly curved. In addition, the displacement of the embedded section does not seem to be presented. The reason is that in the static state the bedrock does not show any significant displacement.

The analysis of dynamic state is carried out on the basis of static state; the increment of the difference of displacement of pile and soil can represent the dynamic interaction of pile and soil.

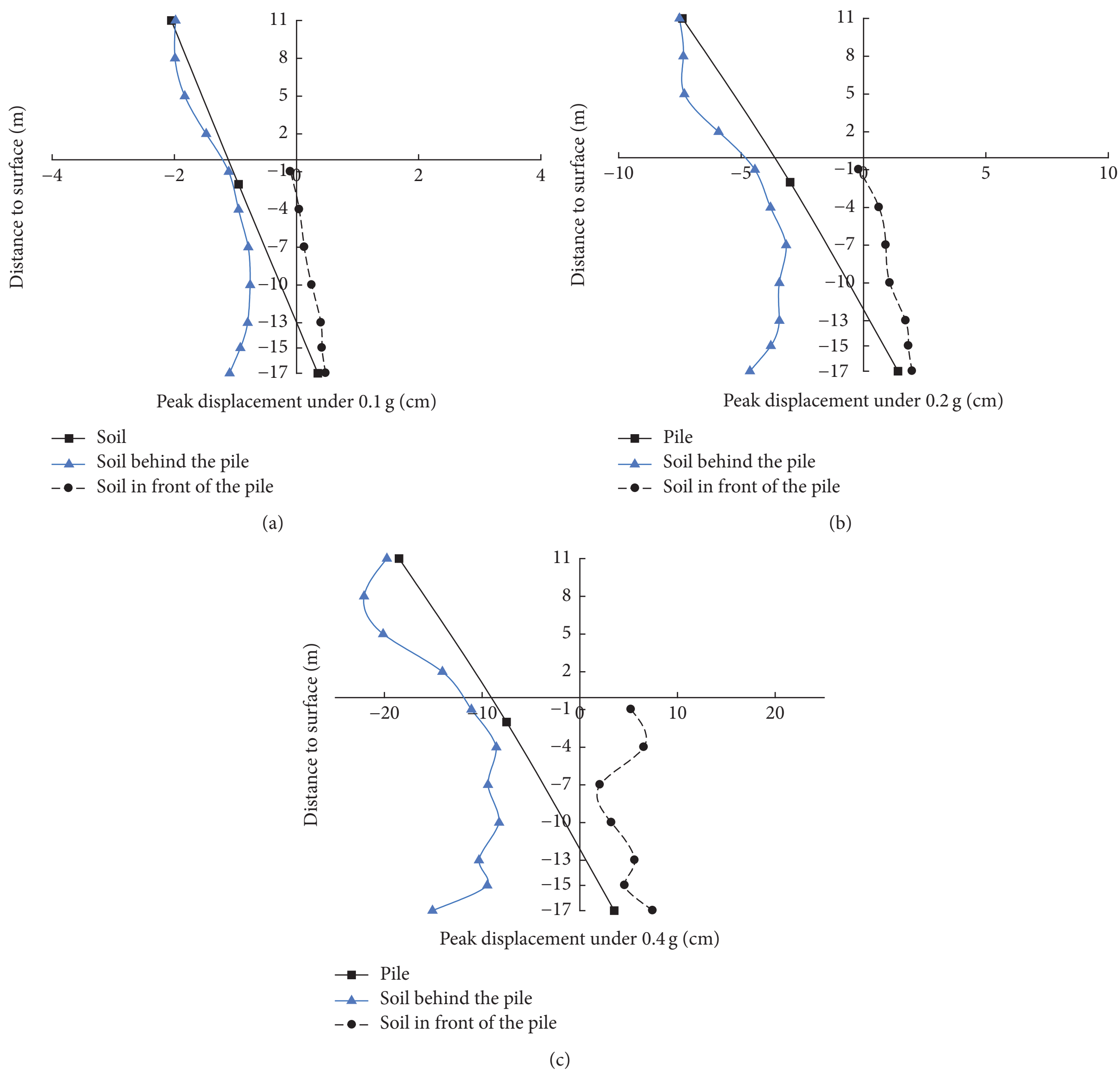



FIGURE 11: The peak displacement distribution of sheet pile wall and soil.

It should be noted that the peak pressure of structure and soil were concerned in the process of seismic design; to keep with the matching, the peak displacements were chosen to study but not the residual displacement. The peak displacements of measuring point and the sheet pile wall are shown in Figure 11.

In addition, because the stiffness of the sheet pile wall is much bigger than soil, the sheet pile wall will rotate when earthquake happens, and the displacement of sheet pile wall is increased with the height, as shown in Figure 11.

In Figure 11, it can be found that the horizontal displacement of sheet pile wall and the soil has different deformation behavior under ground motion. Based on the difference of peak horizontal displacement, the interaction force of structure and the soil can be estimated, according to the Winkler foundation beam method. The existence of sheet pile wall largely changes the horizontal displacement of surrounding soil, and the dynamic interaction between soil and structure can be reflected by the difference of the displacement of them. For the cantilever pile, the difference of peak horizontal displacement between cantilever and the soil reflects the earthquake landslide thrust, and the distribution of landslide thrust basically obeys the laws. The greatest difference of peak horizontal displacement appears in the middle and lower parts of the pile, which reveals the biggest soil pressure appears in this place. And the difference of peak horizontal displacement between the soil in front of the pile and the soil behind the pile in the embedded parts reflects the soil resistance of pile, which means the biggest soil resistance appears at the −17 m of the pile.

With the increase of PGA, the difference of peak horizontal displacement between pile and soil increased radically, especially in the PGA 0.4 g; difference of peak horizontal displacement increases sharply at the place of little bit deeper part in front of the pile and the −17 m part behind the pile, which was shown clearly in Figure 10. Plastic deformation of those two parts is the main reason of those phenomena.

Because the deformation modulus of soil is obviously depending on the stress path and stress state, this method can only obtain the distribution of pile-soil interaction forces and the schedule changes approximatively. However, this method is of important significance in the study of dynamic interaction between structure and soil.

## 5. Conclusions

A finite difference model was built by FLAC$^{3D}$. The principle of Winkler foundation beam method was applied to the residual displacement result of the model; the dynamic coupling characteristics of pile-soil were obtained. The conclusions of the study are as follows.

(1) Under the ground motion, the horizontal residual displacement of the back slope of the wall has obviously regional characteristics. The slope can be divided into 6 sections based on the position of sliding surface and the sheet pile wall, namely, A, B, C, D, and E of the landslide section and F of the bedrock section. The residual deformation of F section is comparatively unanimous in the seismic action; the E section has the maximum residual deformation; the residual deformation of A and C sections is greater than the B and D sections.

(2) The vertical residual displacement of slope supported by the sheet pile wall has no obvious zoning characteristics.

(3) Based on the difference of peak displacement of pile and soil, the dynamic coupling characteristics of slope reinforced by sheet pile wall can be obtained.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

This study is supported by the National Natural Science Foundation of China under Grant no. 41602332 and Foundation for Research and Science and Technology of Southwest Petroleum University under Grant no. 2013XJZ020.

## References

[1] J. Zhang, H. Qu, Y. Liao, and Y. Ma, "Seismic damage of earth structures of road engineering in the 2008 Wenchuan earthquake," *Environmental Earth Sciences*, vol. 65, no. 4, pp. 987–993, 2012.

[2] A. Takahashi, J. Takemura, Y. Kawaguchi, O. Kusakabe, and N. Kawabata, "Stability of piled pier subjected to lateral flow of soils during earthquake," in *Proceedings of the International Conference Centrifuge 98 (IS-Tokyo '98)*, vol. 1, pp. 365–370, Tokyo, Japan, 1998.

[3] T. Abdoun, R. Dobry, T. D. O'Rourke, and S. H. Goh, "Pile response to lateral spreads: centrifuge modeling," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 129, no. 10, pp. 869–878, 2003.

[4] Z. Jiao, H. Tan, T. Mei, and X. Hu, "Numerical analysis on dynamic responses of the sheet-pile wharf with separated relieving platform under horizontal seismic loads," *Journal of Coastal Research*, vol. 73, pp. 270–276, 2015.

[5] H. Satoh, N. Ohbo, and K. Yoshizako, "Dynamic test on behavior of pile during lateral ground flow," in *Proceedings of the International Conference Centrifuge*, pp. 327–332, 1998.

[6] Y.-H. Tao, *Stress analysis of sheet pile structure under earthquake [M.S. thesis]*, Southwest Jiaotong University, 2008.

[7] L.-P. Wang, G. Zhang, J.-M. Zhang, and C. F. Lee, "Centrifuge modeling of cohesive soil slopes reinforced by stabilizing piles," *Chinese Journal of Geotechnical Engineering*, vol. 31, no. 7, pp. 1075–1081, 2009.

[8] C. Giarlelis and G. Mylonakis, "Interpretation of dynamic retaining wall model tests in light of elastic and plastic solutions," *Soil Dynamics and Earthquake Engineering*, vol. 31, no. 1, pp. 16–24, 2011.

[9] R. Conti, G. M. B. Viggiani, and F. Burali D'Arezzo, "Some remarks on the seismic behaviour of embedded cantilevered retaining walls," *Geotechnique*, vol. 64, no. 1, pp. 40–50, 2014.

[10] S. P. Madabhushi and X. Zeng, "Seismic response of flexible cantilever retaining walls with dry backfill," *Geomechanics and Geoengineering*, vol. 1, no. 4, pp. 275–289, 2006.

[11] S. P. G. Madabhushi and X. Zeng, "Simulating seismic response of cantilever retaining walls," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 133, no. 5, pp. 539–549, 2007.

[12] S. Iai and T. Kameoka, "Finite element analysis of earthquake induced damage to anchored sheet pile quay walls," *Soils and Foundations*, vol. 33, no. 1, pp. 71–91, 1993.

[13] L. Callisto, F. M. Soccodato, and R. Conti, "Analysis of the seismic behaviour of propped retaining structures," in *Proceedings of the Geotechnical Earthquake Engineering and Soil Dynamics IV Congress*, pp. 1–10, May 2008.

[14] U. Cilingir, S. K. Haigh, S. P. G. Madabhushi, and X. Zeng, "Seismic behaviour of anchored quay walls with dry backfill," *Geomechanics and Geoengineering*, vol. 6, no. 3, pp. 227–235, 2011.

[15] C. Rainieri and G. Fabbrocino, "Performance assessment of selected oma techniques for dynamic identification of geotechnical systems and closely spaced structural modes," *Journal of Theoretical and Applied Mechanics*, vol. 49, no. 3, pp. 825–839, 2011.

[16] C. Rainieri, G. Fabbrocino, and F. S. De Magistris, "An integrated seismic monitoring system for a full-scale embedded retaining wall," *Geotechnical Testing Journal*, vol. 36, no. 1, pp. 1–14, 2013.

[17] C. Rainieri, A. Dey, G. Fabbrocino, and F. S. de Magistris, "Interpretation of the experimentally measured dynamic response of an embedded retaining wall by finite element models," *Measurement*, 2016.

[18] H.-L. Qu and J.-J. Zhang, "Research on seismic response of anti-sliding sheet pile wall by shaking table test," *Rock and Soil Mechanics*, vol. 34, no. 3, pp. 743–750, 2013.

[19] H. L. Qu, R. Li, J. J. Zhang, H. Hu, and D. Zhang, "A novel approach for seismic design of anchored sheet pile wall," *Tehnicki Vjesnik*, vol. 23, no. 2, pp. 455–463, 2016.

[20] China National Standard, "Code for construction of concrete structures," GB 506666-2011, Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2011 (Chinese).

[21] China National Standard, "Specification of seismic design for highway engineering," Ministry of Transport of the People's Republic of China JTG B02-2013, 2013 (Chinese).

[22] F.-E. Udwadia and M.-D. Trifunac, "Comparison of earthquake and micro tremor ground motion in El Centro, California," *Bulletin of the Seismological Society of America*, vol. 63, no. 4, pp. 1227–1253, 1973.

[23] China National Standard, "Standard for classification of seismic protection of building constructions," GB 50223-2008, Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2008 (Chinese).