NUMERICAL ANALYSIS OF DYNAMIC PERFORMANCE OF GRAVITY RETAINING WALL AND REINFORCED EARTH RETAINING WALL

T.Q. Ling[1],B. Yang[2], P. Shen[3], and T.G. Zhang[4]
1 Professor; School of Civil Engineering and Architecture, Chongqing Jiaotong University, CHINA; Email: lingtq@163.com
2 Master; School of Civil Engineering and Architecture, Chongqing Jiaotong University CHINA; Email: yb850827168@126.com
3 Master; School of Civil Engineering and Architecture, Chongqing Jiaotong University CHINA; Email: 515630130@qq.com
4 Master; School of Civil Engineering and Architecture, Chongqing Jiaotong University CHINA; Email: 564815114@qq.com

ABSTRACT

Numerical models of the gravity retaining wall and the reinforced earth retaining wall based on Flac3D were established in order to compare with the seismic performance based on the wall horizontal displacement time-distance curve, and analyze the influence of wall height and earthquake intensity on them. The results show that it is obviously different on dynamic performance between gravity retaining wall and reinforced earth retaining wall, the latter's seismic performance is better than the former.

Keywords: Gravity retaining wall, reinforced earth retaining wall, numerical analysis, Flac3D, dynamic performance

INTRODUCTION

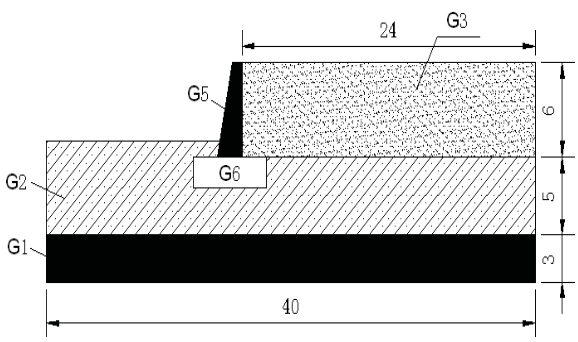
Gravity retaining wall (GRW) and reinforced earth retaining wall (RERW) are widely used in various civil engineering facilities, GRW is a kind of dualistic rigid structure with wall- backfill, RERW is a kind of ternary flexible structure with panel-reinforced material-backfill., Earthquake frequently take place in recent years. Some cases such as Wenchuan Earthquake, showed that the RERW has more dynamic performance over GRW. To meet the safety of structure and know clearly the performance of them, it is necessary and helpful to study the dynamic performances of them. In this paper, two Flac3D models of RGW and RERW were made in order to compare their dynamic performance.

NUMERICAL MODELS

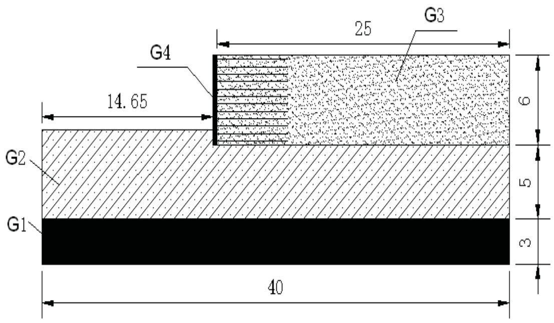
Geometric Models and Boundary Conditions

As shown in Fig 1, the length and height of two models are 40m, 14m respectively. Width of GRW along settlement joint is 10m and width of RERW 5m to save computing time. Material Group G1 is the rock foundation with 3m thick Material Group G2 is the underlying soil with 5m thick and Material Group G3 is the filling behind of the wall with 6m thick. Material Group G4 is the RERW panel with 6m high and 0.35m thick, using the spreading way by layers with 1m. Structure model of geogrid in Flac3D is used to represent the geogrid in the walls, length of geogrid is 6m and the vertical spacing between geogrid layers is 0.5m, Material Group G5 is the wall of GRW with slope back 90°, which is 6m in height, 0.8m in crown width, 2m in base width, Material Group G6 is the foundation, with 2m height and 6m width.

The basic models damping adopt local damping and the boundary conditions use free field boundary in Flac3D during the dynamic analysis process. There is not a contact surface in RERW because of more grille units and longer dynamic analysis time, but there are contact surfaces in GRW.



(a) Gravity retaining wall



(b) Reinforced earth retaining wall

Fig. 1 Sectional view of the basic models (unit: m).

Calculated Parameters and Seismic Waves

Parameters for the models are shown in Table 1, Table 2 and Table 3. Software called Seimosignal is used to do some treatments of filtering and baseline correction on the original data of seismic wave. Then data of seismic wave was input into Flac3D in the form of command. The acceleration time-distance curve of seismic wave is shown as Fig 2. The seismic wave can be divided into three sections. The first section is from 0s to 4s, the second section is from 4s to 12s, and the third section is from 12s to 20s. The seismic duration is 20s, the peak range of horizontal acceleration is -0.403 g ~ 0.305 g, and that of vertical acceleration is -0.105 g ~ 0.130 g.

Table 1 Parameters of wall and soil.

Group	Density /$kg \cdot m^{-3}$	Bulk modulus /Mpa	Shear modulus /Mpa	Cohesion /kpa	Tensile strength /Mpa	Internal friction Angle /°
G1	2300	3.0×10^3	2.0×10^3	7.0×10^6	1.0	40
G2	2000	30	10	30	0.0	35
G3	1900	8.0	3.0	30	0.0	30
G4	2300	1.5×10^4	1.3×10^4			
G5	2400	1.5×10^4	1.3×10^4			
G6	2000	35	15	50	0.0	35

Table 2 Parameters of geogrid.

Item	density /$kg \cdot m^{-3}$	E /Mpa	v /Mpa	thickness /mm	cs_scoh /kpa	cs_sk /Mpa	cs_sfic /°
Geogrid	1200	25×10^9	0.3	3	2.0	2.5	30

Table 3 Parameters of interface between geogrid and soil.

Item	k_n /Mpa	k_s /Mpa	coh/kpa	tens/Mpa	fric/°	dila/°
Interface	100	100	0	0	10	0

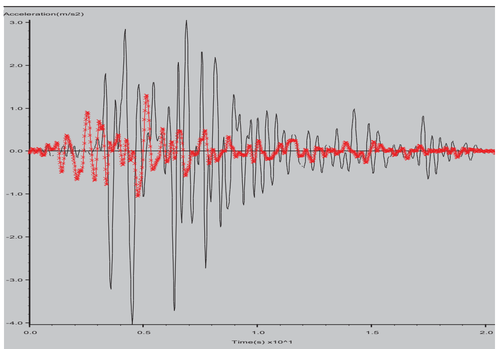


Fig. 2 Seismic wave acceleration time-distance curve.

DYNAMIC ANALYSIS

Gravity Retaining Wall

Horizontal displacement time-distance curve

Four monitored points named A, B, C, D, were marked every 2m from wall heel along height of the concrete wall. As seen in Fig. 3, the dynamic response stages of monitored points are matched well with those of seismic waves. In the first stage, the horizontal displacement of the four monitored points are basic coincide. In the second stage, the wall horizontal displacement appears sharp fluctuation, which starts diverge after 4s. In the third stage, the wall horizontal displacement keeps tiny changes. The wall horizontal displacement increases with wall height, its biggest horizontal displacement occurred in the part on the top. The GRW shows obvious phenomenon of rotating around the wall toe and of horizontal shifting especially after the second stage of the seism. This suggests that the integrity and stability of GRW has been obviously decreased after the main shock.

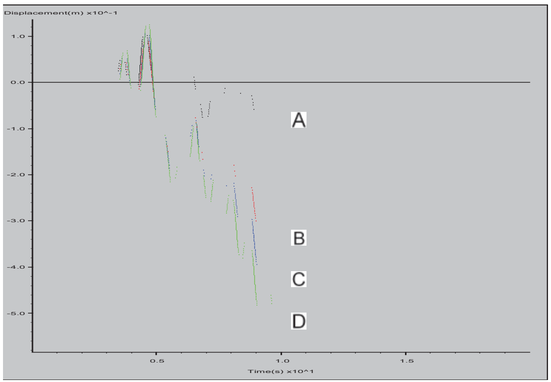


Fig. 3 Monitoring point horizontal displacement time-distance curve of GRW.

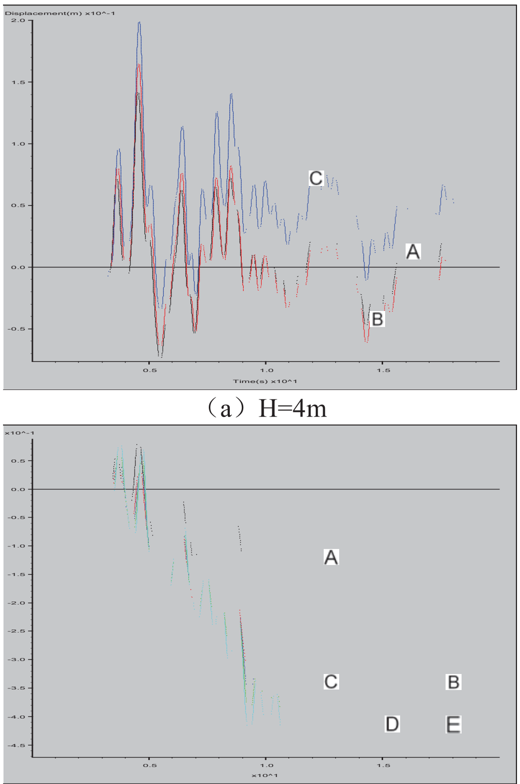
Influence of earthquake intensity

Table 4 Wall crown horizontal displacement of GRW with different earthquake intensity.

Condi-tions	Max positive horizontal displacement /m	Max negative horizontal displacement /m	Final horizonta displacement /m
1	0.080	-0.188	-0.159
2	0.136	-0.584	-0.562
3	0.137	-0.827	-0.807

To control the influence of earthquake intensity on retaining walls, the seismic waves of the models are amplified 0.5 times and 1.5 times in working conditions 1 and 3. The shape of the horizontal displacement of the monitoring point is essentially similar to which are shown in Fig 3, but their amplitude and later interval obvious increase with earthquake intensity. As seen in Table 4, the maximum negative horizontal displacement is as 2.35 times, 4.30 times and 6.03 times separately as the maximum positive horizontal displacement of wall under the three working conditions. The max positive horizontal displacements of wall are equivalent to 58% and 100% of the basic model compared with working conditions 1 and 3, the max negative horizontal displacement 33% and 142%, and the final displacement 29% and 144%. The results show that dynamic response of the maximum negative horizontal displacement increases much stronger with increase of earthquake intensity. The final horizontal displacement is closer to the max negative horizontal displacement.

Influence of wall height



（a）H=4m

（b）H=8m

Fig. 4 Monitoring point horizontal displacement time-distance curve of GRW with different wall height.

Table 5 Wall crown displacement eigen value of GRW with different wall height.

Wall height	Max positive horizontal displacement /m	Max negative horizontal displacement /m	Final horizontal displacement /m
4m	0.200	-0.037	0.041
6m	0.136	-0.584	-0.562
8m	0.088	-0.472	-0.432

Comparing Fig. 4 with Fig. 3, the monitored point time-distance curves of the wall with 6m high are different from those with 6m and 8m high, which is much less in the maximum horizontal displacement and the final horizontal displacement, the shape of the horizontal displacement time-distance curve is similar to those with 8m high, but the response of the latter horizontal displacement is much fiercer than the former one. Table 5 shows that the seismic performance of GRW is influenced in some degree by some factors such as the upper width and basement width other than the wall height.

Other factors

While the depth of base of the GRW model increased from 1m to 2m, the maximum negative horizontal displacement in the wall crown reduces from -0.472 m to -0.334m, nearly decreased by 30%. Meanwhile the maximum positive horizontal displacement in the wall crown increases from 0.088 m to 0.152m, which is increased by 73%, and the final horizontal displacement in the wall crown reduces from -0.432m to -0.273m, which is decreased by 37%. It shows that increase of depth of base will improve the seismic behavior to some extent.

Reinforced Earth Retaining Wall

Horizontal displacement time-distance curve

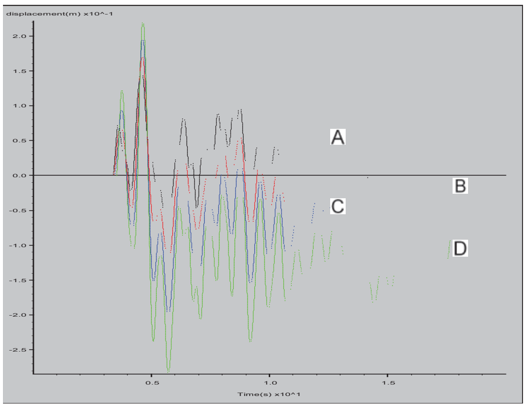


Fig. 5 Monitoring point horizontal displacement time-distance curve of RERW.

Comparing Fig. 5 with Fig. 4, it can be seen that both retaining wall have enough capacity to resist earthquake, and the shape of time-distance curve is similar in the first stage of the earthquake, and the horizontal displacement response of RERW is much fiercer than GRW, and reinforcement materials have obvious stretch-sliding, while GRW obviously exists some phenomenon of rotating around the wall toe and horizontal sliding with the strengthening of the seismic shock. And it is difficult to restore, if it happens, because of the backfill loading. The dynamic responses are different between GRW and RERW. The final horizontal displacement of the monitoring point is shown in Table 6 below. In the same condition, the final horizontal displacement of RERW were reduced by 140%, 94%, 84%, 77% when compared with GRW, its seismic performance is obviously better than RGW.

Table 6 Final horizontal displacement of the basic models.

type	A/m	B/m	C/m	D/m
GRW basic model	-0.071	-0.343	-0.452	-0.562
RERW basic model	0.028	-0.019	-0.072	-0.128

Influence of earthquake intensity

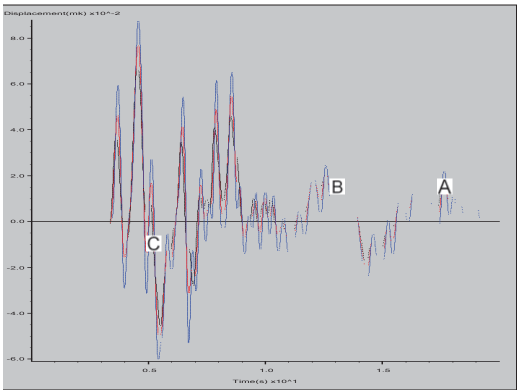
To be convenience, this paper still enlarge the seismic data 0.5 times and 1.5 times, while the other parameters still remain the same with the basic model, the shape of the monitored point horizontal displacement is similar to that are shown in Fig 6, but their amplitude and later interval obviously increase with earthquake intensity just like GRW

Table 7 Wall crown displacement of RERW under different earthquake intensity.

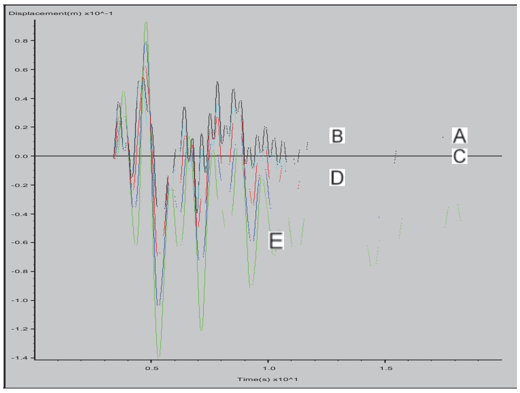
Condi-tions	Max positive horizontal displacement /m	Max negative horizontal displacement /m	Final horizontal displacement /m
1	0.130	-0.213	-0.115
2	0.222	-0.284	-0.128
3	0.231	-0.515	-0.387

As shown in Table 7, the maximum positive horizontal displacements of working conditions 1 and 3 are equivalent to 59% and 104% of the basic model, the max negative horizontal displacement 75% and 181%, and the final displacement 90% and 302%. The max negative horizontal displacement separately are as 1.64 times, 1.28 times and 2.23 times as the max positive horizontal displacement of wall in the three working condition, the final horizontal displacements are equal to 54%, 45% and 75% of the max negative horizontal displacement, which are 72%, 23% and 48% of GRW. The results show that the dynamic response of the max negative horizontal displacement is much severer than the max positive horizontal displacement, moreover the final horizontal displacements are equal to 30%~50% of the max negative horizontal displacement , which is much lesser than GRW.

Influence of wall height



（a）H=4m



（b）H=8m

Fig. 6 Monitoring point horizontal displacement time-distance curve of RERW with different wall height.

The monitoring point horizontal displacement time-distance curve of RERW with 4m and 8m height are shown in the Fig 6, the seismic waves is the ones of the working conditions 1. As seen in the Fig 6, three monitoring points horizontal displacement time-distance curve are nearly coincident when wall height is 4m, and its max positive horizontal displacement, the max negative horizontal displacement and the final horizontal displacement are much lesser which are 92%, 43% and 23% with 8m height. The results show that the max positive horizontal displacement will obviously increase with increase in wall height while the change of the maximum negative horizontal displacement is lesser, meanwhile the dynamic response and the probability of instability is obviously increased. Because of the limitation of length, the other factors on the seismic behavior such as the depth of base of retaining wall, backfill and the soil layer under the foundation soil are not discussed here.

CONCLUSIONS AND SUGGESTIONS

By the method of numerical analysis, difference between dynamic performance and seismic mechanism and difference between GRW and RERW are figured out in the paper. However dynamic response is more complex and many influence factors exist, some conclusions cannot be made at this time. The conclusions and proposal in the paper are as follows:

a. The dynamic response performance of GRW and RERW depend on to some extent on the seismic waves and the structure characteristics of the retaining wall itself, earthquake intensity and wall height have great influence on seismic performance of those structure.

b. Because of the difference of structure form and mechanical characteristics, the horizontal displacement time-distance curve has obvious distinction between GRW and RERW. But both of the monitored point horizontal displacements appear differentiation in the main shock stage, and the latter shows better stability performance, dynamic coordination and seismic performance.

c. It is obviously different between GRW and RERW for the seismic mechanism, the former mainly depends on the wall to balance active earth pressure of the backfill, which is inclined to emerge rotating around the wall toe and horizontal sliding under earthquake action, while the latter principally rests with the flexible structure of panel-reinforcement material - backfill which greatly reduced shear failure to the foundation soil and the wall horizontal displacement.

d. It suggests that the wall horizontal displacement of retaining wall should be qualified as one of the calculated indexes of the specifications.

REFERENCES

Fakharian, K., Attar, I.H. (2007). Static and seismic numerical modeling of geosynthetic-reinforced soil segmental bridge abutments. J. Geosynthetics Interational 14(4), 228-243.

G. Q. Yang, (2010). The theory of geogrid reinforced earth structure and engineering application M Science Press, Beijing, China.

Liu, H.B. and Ling, H. (2004). Elastic-plastic finite element on the design parameters of geogrid reinforced soil retaining wall. Chinese Journal of geotechnical engineering. 26(5): 668-673.

ITASKA Consulting Group, inc. (2005). Fast Language Analysis of Continua in 3 Dimensions, Version 3.0, User's Manual.

JTJ 015-91 Highway Reinforced Earth Engineering Design Specifications. Communications Press, Beijing, China.

Yuan, J., Zeng S.P., Zhu, Y.Q. et al (2008). Analysis of elastic-plastic on reinforced embankment under earthquake action. Journal of Tongji University. 36(4): 483-487.

Latha, G.M., Krishna, A.M., 2008. Seismic response of response of reinforced soil retaining wall models: influence of backfill relative density. Geotextiles and Geomembranes 26(4): 335-349.

Ling, H.I., Liu, H., Kaliakin, V.N., Leshchinsky, D., (2004). Analyzing dynamic behavior of geosynthetic -reinforced soil retaining walls. Journal of Engineering Mechanics, ASCE 130(8): 911-920.

Wu, Y.S. (2006). The Dynamic Characteristics and Seismic Design Method of Reinforced Soil Retaining Wall Master Thesis, Hunan Univ. Changsha, China.

Chen, Y.M. and Xu, D.P. (2008). FLAC/FLAC3D foundation and engineering example M water conservancy and hydropower press Beijing, China.

Zhang J M, Shamoto Y, Tokimatsu K. (1998). Seismic earth pressure theory for retaining walls under any lateral displacement. Soils and Foundations. 38(2):143-163.