Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(1) (2022) 39-42
DOI: 10.22060/ceej.2021.18379.6862

Experimental and Numerical Study on the Seismic Performance of MSE/Soil Nail Hybrid Walls

N. Ahmadi[1], M. Yazdandoust[2]

[1] Department of Civil Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
[2] Department of Civil Engineering, University of Qom, Qom, Iran

ABSTRACT: In this study, a series of 1-g shaking table tests using variable-amplitude harmonic excitations were performed on 0.8 m high MSE/Soil nail hybrid wall models to investigate the seismic behavior of this innovative retaining system. Ten finite element models were also prepared with different wall heights and nail lengths to carry out a parametric study. Findings showed that in models with constant length of steel strip, the deformation mode of MSE/Soil nail hybrid walls highly depends on the length of nails and the combination of a base sliding and overturning deformation mode was observed as the predominant mode of deformation. Irrespective of different nail lengths, the pattern of the observed failure mechanisms included a moving block and a combination of a reverse curve and flat failure surface with certain intersection point. Also, a range of $\Delta x/H$ = 0.55 - 1.10 % as a transitional level from quasi-elastic to plastic state and based on starting the development of active wedge failure, a range of $\Delta x/H$ = 5.0% - 5.6 % as a transitional level from plastic to failure state were determined. On the other hand, according to the significant increase in wall displacements by decreasing the L/H ratio of 0.7, L/H= 0.7 was presented as the critical ratio in seismic conditions.

Review History:

Received: May, 08, 2020
Revised: Aug. 18, 2020
Accepted: Aug. 20, 2020
Available Online: Jul. 03, 2021

Keywords:

MSE/Soil nail hybrid wall
Dynamic failure mechanism
Seismic Performance levels
Shaking Table Test
Numerical modeling

1- Introduction

The ease of implementation and economic efficiency of MSE/Soil nail hybrid retaining walls have caused their use quickly spread universally as a permanent retaining system in recent years. Although the seismic behavior of each of the components of the hybrid retaining walls (MSE wall and soil-nailed wall) has been investigated separately [1-5], the behavior of the hybrid reinforced wall as a combination of soil-nailed mass and MSE wall has not been well known. To enhance the future use of this system in engineering practices, the performance and behavior of this system need to be further investigated. Therefore, the current study attempted to investigate the seismic performance of the first type of MSE/Soil nail hybrid walls using experimental and numerical methods. For this purpose, first, a series of reduced-scale uni-axial shaking table tests were carried out on the five wall models with different nail lengths under different input motion parameters for investigating the performance of hybrid walls. The quantitative and qualitative responses of the walls to base shaking in terms of facing displacements, the geometry of the failure surface, the boundaries of performance levels and the acceleration amplification were studied and identified. Then, based on the numerical analysis, a parametric study was carried out to determine the seismic performance of hybrid walls with different heights and nail lengths under harmonic loading whit different base accelerations and cumulative absolute velocities.

*Corresponding author's email: M.yazdandoust@qom.ac.ir

2- Physical Model Tests

A series of 1-g shaking table tests were carried out on hybrid walls at the Centrifuge and Physical Modeling Center at Tehran University. Taking account of the height of walls studied by other researchers and the selected scale factor (N = 10) and considering the limitation in the height of the box container, 0.8 m was selected as the total height of hybrid wall models. To study the models in the same geometrical conditions and the elimination of additional geometric variables, the steel-strip reinforced zone and the soil-nailed mass were considered with equal heights (H1 = H2 = 0.45 m). To construct the different parts of the hybrid wall models (foundation, backfill, soil-nailed mass and steel-strip reinforced zone), a wet mixture of Firuzkooh 161 sand and Firuzkooh silt with different relative densities was used. As recommended by FHWA [6], a relative density of %85 was selected to construct the reinforced zone in the MSE portion. Other zones of these models (foundation, backfill and soil-nailed zone) were constructed of a medium state of density (%56). By considering the pull-out behavior as the main criterion to scale down the reinforcement elements, the reduced-scale metal strip and nail were selected based on the similitude rules and scaling factor (1:10). To reinforce the main portions of hybrid retaining wall models (soil-

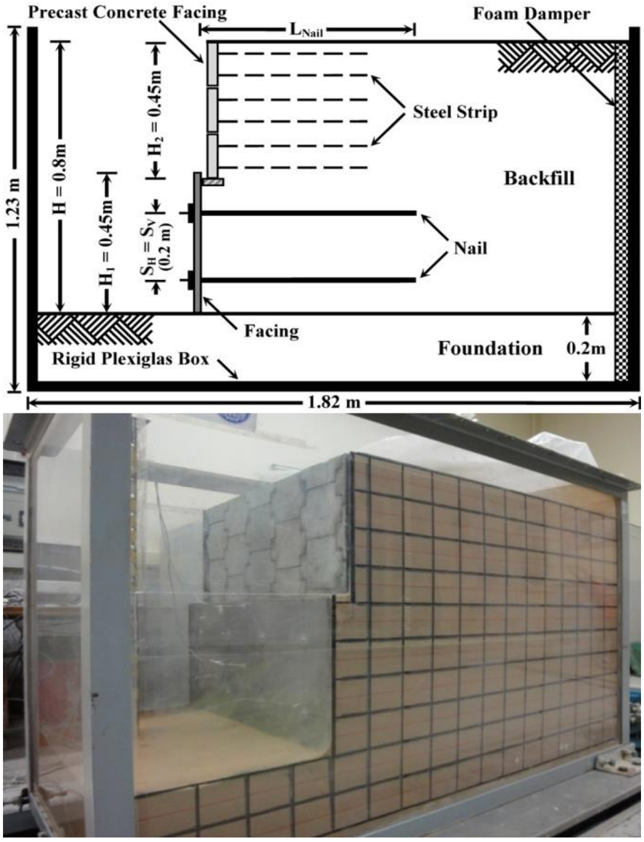

Fig. 1. The schematic geometry and pictures of the hybrid wall model

nailed mass and MSE zone), uniform lengths of nail and steel strip were used. Since, in seismic conditions, the minimum value of nail length to wall height ratio L/H = 0.7 has been recommended by FHWA [7], physical models were constructed with the values of L/H = 0.5, 0.6, 0.7, 0.8 and 0.9. Selecting this range of values made it possible to investigate the seismic behavior of hybrid walls which have been reinforced with different lengths of the nail, greater and less than the minimum recommended value. It should be noted that in all models, based on the minimum recommended length of reinforcement FHWA [7], the reinforced soil portion (MSE wall) was constructed of steel strips with the value of L/H_2 = 0.7. The models were shaken using a variable-amplitude harmonic excitation and their response was measured by four displacement transducers (LVDT) and thirteen accelerometers installed in the models. The schematic geometry and picture of the hybrid wall models have been shown in Figure 1.

3- Numerical studies

In order to perform numerical studies, FLAC software was used. All numerical models were prepared by selecting two categories including 6, and 9 meters, for the height of the wall and five categories including 0.6H, 0.8H, 1.0H, 1.2H and 1.4H for the length of nails. To select the geotechnical parameters, it has been tried to consider soil type effects by introducing 3 kinds of soil profiles, which are represented as 1 to 3 in 2800 standard of Iran. Considering and using geotechnical parameters from many boreholes representing 3 kinds of soil types in different regions of Iran, geotechnical parameters for modeling the different parts of the model were chosen. After preparing the numerical models, harmonic loads were applied to the foundation level and the dynamic analysis was performed. During each of the dynamic analyses, the history of horizontal wall displacements as a representative of the seismic performance were recorded. Regarding the studies investigated by Yazdandoust [8], harmonic load frequency, maximum acceleration and cumulative absolute velocity instead effective time were considered in based of soil type and regions seismic risk categories.

4- Results and Discussion

As illustrated in Figure 2, the pattern of failure mechanisms in all models was similar regardless of the nail length and this failure pattern included a moving block which was delineated by a combination of a slant and reverse curve with certain intersection point. Among all the geometric parameters of the failure surface, only the angle of inflection point was a function of the length of nails, so increasing the length of nails led to the increase in the angle of inflection point.

Also, to determine the boundaries of performance levels of soil-nailed walls for use in the performance base design method, based on the formation of initial cracks and failure surface, a range of $\Delta x/H$ = 0.55 - 1.10 % as a transitional level from quasi-elastic to plastic state and based on starting the development of active wedge failure, a range of $\Delta x/H$ = 5.0 - 5.6 % as a transitional level from plastic to failure state were determined and recommended.

According to the results, for MSE/Soil nail hybrid walls that have been reinforced with constant length of steel strip, L/H= 0.7 can be presented as the critical ratio in seismic conditions so that in the specified seismic situation, the reduction in L/H of 0.7 leads to significant horizontal displacement of the MSE/Soil nail hybrid walls. This ratio is the key criteria in the performance-based design for the selection of the appropriate nail length. Moreover, given the proper convergence between the maximum normalized horizontal displacement and L/H ratio at different levels of acceleration and duration, the maximum normalized horizontal displacement of the MSE/ Soil nail hybrid walls can be defined as a function of L/H ratios and seismic parameters for use in the performance-based design method.

It was observed that the amplification factors are nonlinear with elevation and the accelerations are amplified more on top of the wall in all models. This nonlinearity was greater at the wall facing than at the reinforced zone and backfill soil. It was also observed that the acceleration amplification factors increase with the increasing magnitude of peak acceleration and decrease with increasing nail length.

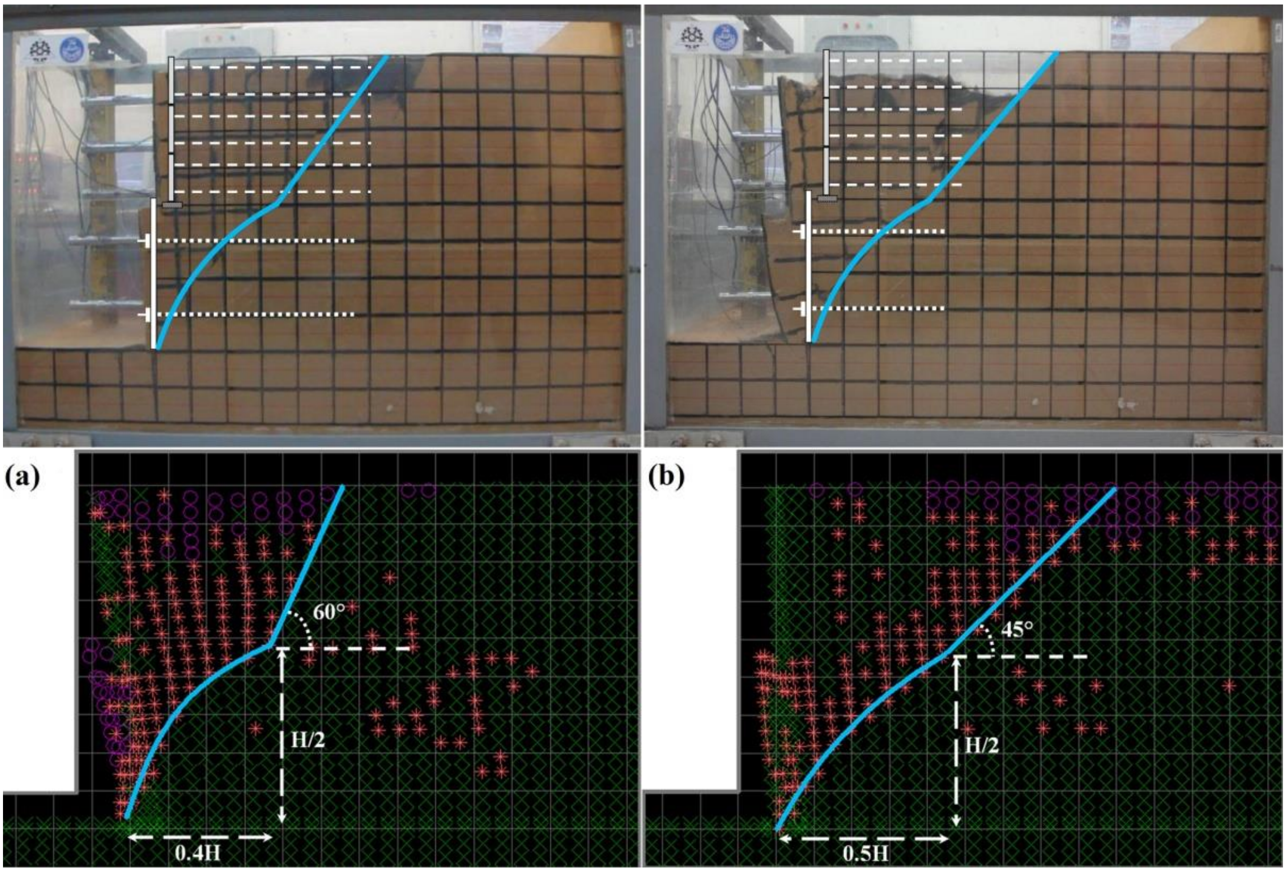

Fig. 2. The geometry of the failure mechanism of hybrid walls with: (a) L > 0.7H; (c) L < 0.7H

5- Conclusion

The main conclusions regarding physical and numerical models can be summarized as follows:

1) The combination of a base sliding and rotating deformation mode was observed as the predominant mode of deformation. It was found that the deformation mode of hybrid walls highly depends on the length of nails, so with increasing nails length from 0.5H to 0.7H, the base sliding deformation mode faded and the bulging deformation mode in the MSE zone appeared gradually.

2) The pattern of the observed failure mechanisms in all models was similar regardless of the nail length. This failure pattern includes a moving block which is delineated by a combination of a slant and reverse curve with certain intersection point

3) To determine the boundaries of performance levels of MSE/Soil nail hybrid walls for use in the performance base design method, based on the formation of initial cracks and failure surface, a consistent range of $\Delta x/H' = 0.55 - 1.10$ % represents a transitional state of the walls from quasi-elastic to plastic state and based on starting the development of active wedge failure, a range of $\Delta x/H' = 5.0\% - 5.6$ % representing a transitional state of the walls from plastic to failure state were determined and recommended.

4) According to the significant increase in wall displacements by decreasing the L/H ratio of 0.7, L/H= 0.7 was presented as the critical ratio in seismic conditions for MSE/Soil nail hybrid walls which have been reinforced with constant length of steel strip.

5) It was concluded that the most acceleration amplification occurred at the reinforced zone and only at low levels of peak acceleration (amax < 0.5 g), the assumption of constant amplification factor at all elevations of the backfill in pseudo-static design can be true.

References

[1] L.P. Wang, G. Zhang, J.M. Zhang, Nail reinforcement mechanism of cohesive soil slopes under earthquake conditions. Soils and Foundations, 50(4) (2010) 459–469.

[2] L. Wang, G. Chen, S. Chen, Experimental study on seismic response of geogrid reinforced rigid retaining walls with saturated backfill sand. Geotext. Geomembr., 43(1) (2015) 35-45.

[3] A.M. Krishna, G.M. Latha, Modeling the Dynamic Response of Wrap-Faced Reinforced Soil Retaining Walls. Internatoinal Journal of Geomechanics, 12(4) (2012) 439-450.

[4] A. Komak Panah, M. Yazdi, A. Ghalandarzadeh, Shaking table tests on soil retaining walls reinforced by polymeric strips. Geotextiles and Geomembranes, 43(2) (2015) 148-161.

[5] C-C Huang, J-C Horng, W-J Chang, J-S Chiou, C-H Chen, Dynamic behavior of reinforced walls-Horizontal displacement response. Geotextiles and Geomembranes, 29(3) (2011) 257–267.

[6] FHWA, Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, vol. I. Federal Highway Administration and National Highway Institute, Washington DC. NHI-10-024, (2009).

[7] FHWA, Geotechnical Engineering Circular No. 7, Soil Nail Walls Reference Manual. Federal Highway Administration and National Highway Institute, Washington DC, NHI-14-007, (2015).

[8] M. Yazdandoust, Laboratorial and Numerical Studies on Reinforced Soil and Earth whit Steel Elements, PhD Thesis, (2013).

HOW TO CITE THIS ARTICLE

N. Ahmadi, M. Yazdandoust , Experimental and Numerical Study on the Seismic Performance of MSE/Soil Nail Hybrid Walls, Amirkabir J. Civil Eng., 54(1) (2022) 39-42.

DOI: 10.22060/ceej.2021.18379.6862