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Frequency Response Analysis of Reinforced-Soil Retaining Walls with Polymeric Strips

Ali Komakpanah, Maryam Yazdi

Abstract**—**Few studies have been conducted on polymeric strip and the behavior of soil retaining walls. This paper will present the effect of frequency on the dynamic behavior of reinforced soil retaining walls with polymeric strips. The frequency content describes how the amplitude of a ground motion is distributed among different frequencies. Since the frequency content of an earthquake motion will strongly influence the effects of that motion, the characterization of the motion cannot be completed without the consideration of its frequency content. The maximum axial force of reinforcements and horizontal displacement of the reinforced walls are focused in this research. To clarify the dynamic behavior of reinforced soil retaining walls with polymeric strips, a numerical modeling using Finite Difference Method is benefited. As the results indicate, the frequency of input base acceleration has an important effect on the behavior of these structures. Because of resonant in the system, where the frequency of the input dynamic load is equal to the natural frequency of the system, the maximum horizontal displacement and the maximum axial forces in polymeric strips is occurred. Moreover, they were to increase the structure flexibility because of the main advantages of polymeric strips; i.e. being simple method of construction, having a homogeneous behavior with soils, and possessing long durability, which are of great importance in dynamic analysis.

Keywords**—**dynamic analysis, frequency, polymeric strip, reinforced soil.

I. INTRODUCTION

POLYMERIC strips are flexible composite strips made of polyester fibers which are protected by tough polyethylene sheathing to protect and increase frictional interlock with backfills in soil reinforcement. They are produced from high tenacity, multifilament polyester yarns placed in tension, co-extruded with polyethylene. The strength of this polymeric reinforcement is adjusted to suit the design loads. As far as the standard concrete panels (facings) all have the same number of connection points, this makes the system simple to construct. This optimizes the efficiency of the structure and allows the construction of very tall structures capable of withstanding high loads. According to the advantages of polymeric products, they are the most important variants in reinforced soil retaining wall projects. The proper interaction behavior with soils, the increased number of strips in soil mass causing a homogeneous behavior, and the simple method of construction are of these advantages. They have been used in many projects because of their long durability. While polyester is the load bearing element maintaining minimal deformation, the polyethylene sheathing maintains both the integrity of the product and encases the yarns which protect them from aggressive environment (such as high/low PH) and harsh installation conditions.

The behavior of the retaining walls reinforced with different materials such as steel or geosynthetic materials has been extensively examined both theoretically and experimentally on these structures in the previous studies under the static and working conditions in the literature since their evolution (Edgar et al., [1]; Wong et al., [2]; Ho and Rowe, [3]; Bathurst et al., [4]; Kazimierowicz -Frankowska, [5]; Skinner and Rowe, [6]). Over 25 years this dynamic behavior has been the focus of many studies (Richardson and Lee, [7]; Cai and Bathurst, [8]; Ling et al., [9]; Bathurst and Hatami, [10]; Matsuo et al., [11]; Perez and Holtz, [12]; Nova-Roessig and Sitar, [13]; Nouri et al., [14]; Won and Kim, [15]).

Numerical modeling is a valuable tool to increase the understanding of behavior of different structures. The effect of frequency is investigated with applying four similar accelerations with different frequencies equal to 1, 2, 3 and 5Hz.

II. WHAT IS POLYMERIC STRIP?

A polymeric strip is composed of polyester tendons encased in a polyethylene sheath and is manufactured with various grades under variable thicknesses. The composite is passed through rollers, cooled, cut to length and coiled to give a knurled finish on the sheath. It must also be indicated that the tendon is made of high-tenacity polyester fiber which should be concentrated into separate bundles and then coated with polyethylene. This is done through applying a vacuum die-coating process. One point to be made here is that the precast concrete facing units must be designed to incorporate suitable provision for the attachment of polymeric strips. The typical illustration, as shown in Figure 1, utilizes galvanized steel attachment loops which are casted into concrete and galvanized steel toggle bars (minimum diameter 25 mm) which are placed between attachment loops. At the time of installation, the polymeric strip is wrapped around the toggle bars.

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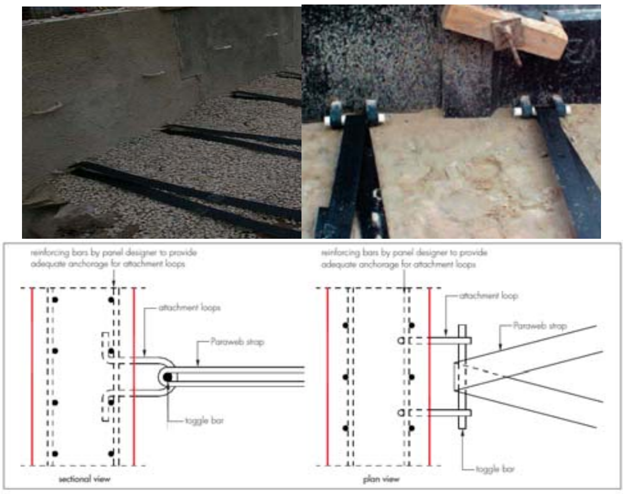

Fig. 1 Typical schematic connection details

III. Description of the Numerical Modelling

A. Natural Frequency of System

One of the main steps in designing reinforced soil retaining walls and usual walls is determining the frequency of natural vibrations. The current reinforced soil retaining walls with usual heights (H<10 m) along with the backfills are counted as short period structures. Hence, the vibrating response of such walls to the powerful movements of the earth is affected by the natural vibration frequency of these structures [16].

The numerical studies of reinforced soil retaining walls have shown that the period of natural vibrations of such walls is not affected by the reinforcements toughness, length, and the territorial conditions of the walls. Also, the grained soil resistance of the backfills, defined by internal frictional angle, will not have a considerable effect on the period of the natural vibrations of such walls [16].

According to the above-mentioned points, it can be concluded that a change in model parameters in various experiments has no influence over the change in period of the natural vibrations of the walls. In order to gain the natural frequency of the structure by building a wall sample based on the above-mentioned characteristics in FLAC, the structure has been analyzed dynamically without external loading and staticity for a second under its weight. Then, by controlling the location change of a point in a structure, the cycles of coming and going in a second will be amount to the natural frequency of the structure.

In the following figure, the result of this analysis has been shown. Accordingly, the natural frequency of the wall is almost 3 Hz. In Fig. 2, the result is as follows. Generally, it can be said that to estimate initially the simple frequency, an appropriate approximation is benefited by using the relation of Vs/4H, as shown in (1) and (2).

$$V_s = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{1.3461E7}{1800}} = 86.477 m/s^2 \qquad (1)$$

$$f = \frac{V_s}{4H} = \frac{86.477}{4 \times 7.5} = 2.9 Hz \qquad (2)$$

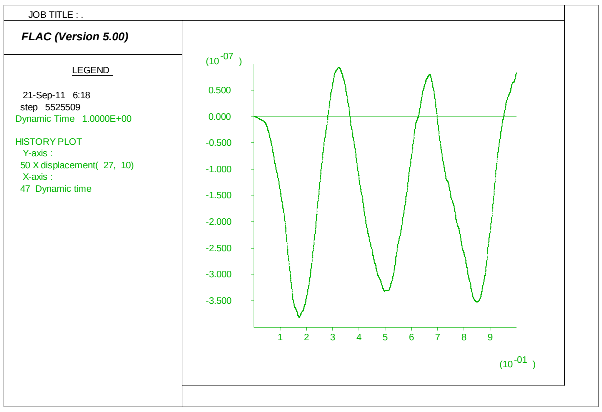

Fig. 2 Internal structure of polymeric strip

B. General Specifications

All analyses have been made with FLAC 2D. Since grained soil is used to construct reinforced walls, it was used as the material of walls in this study. For modeling the soil elements, Mohr-Coulomb Model was employed. In addition, strip elements were used for modeling the polymeric strips. For facing, the beam element was benefited. To achieve more accurate results, interface elements were used, since using these elements will increase the calculation time. Model dimensions were selected in a way to prevent any effect of boundaries. Foundation was rigid in all models; in other words, it was assumed that the wall is constructed on a rigid and strong base with the heights of 7.5m. This was done to eliminate the effect of foundation for the purposes of the present study.

C. Boundary and Fixity Situations

For the lower boundary of the models rigid fixity in both X and Y directions were considered. At first, in static analysis of the left boundary of models, rigid fixity in X directions was considered to estimate initial stress. Along the same lines, free field boundaries were replaced in dynamic analysis to absorb the earthquake waves.

D. Seismic Loading

The seismic loading should be calculated exactly, because its amplitude initially increases and decreases with time. In this study, the horizontal base acceleration presented in (3), has a maximum input base acceleration amplitude equal to 0.2g. To evaluate the effect of frequency on the response of reinforced soil retaining walls with polymeric strips, the frequency of dynamic loads (f in (3)), was chosen equal to 1, 2, 3 and 5Hz as shown in fig.3.

$$\ddot{u}(t) = \sqrt{\beta . e^{-\alpha t} . t^{\zeta}} . Sin(2\pi . f . t) \; ; \; \beta=55; \; \alpha=5.5; \; \zeta=12 \qquad (3)$$

General properties of polymeric reinforcements including the values of horizontal and vertical distances of reinforcement, strip length and other material properties such as facing, backfill soil and foundation used in the analyses were presented in Table1.

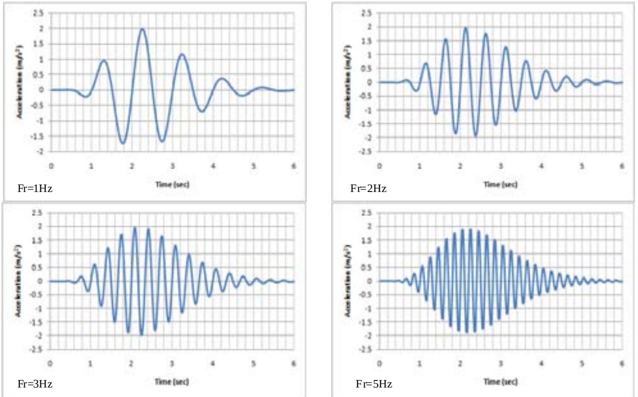

Fig. 3 Time-acceleration diagram with different frequencies

E. Model Properties

TABLE I
MATERIAL PROPERTIES USED IN THE FINITE DIFFERENCE SIMULATIONS

Backfill Soil	
Model	Elastic Perfectly Plastic Mohr-Coulomb
γ (Unit Weight)	18 (KN/m^3)
ϕ (Soil Friction Angle)	34°
ψ (Dilation Angle)	4°
E (Elastic Modulus)	35 (Mpa)
ν (Poisson's Ratio)	0.3
Foundation	
Model	Linear Elastic
γ (Unit Weight)	20 (KN/m^3)
E (Elastic Modulus)	25 (Gpa)
ν (Poisson's Ratio)	0.2
Facing	
Model	Linear Elastic
γ (Unit Weight)	22.5 (KN/m^3)
E (Elastic Modulus)	25 (Gpa)
Height	2 (m)
Width	0.02 (m)
Interface	k_n= 1e 8 k_s = 1e 8
Concrete Foundation	
Model	Linear Elastic
γ (Unit Weight)	25 (KN/m^3)
E (Elastic Modulus)	25 (Gpa)
ν (Poisson's Ratio)	0.25
Reinforcement (Polymeric strip)	
Model	Elastic Perfectly Plastic
Calculation width	1 (m)
Number of strips per calculation width	2.67
Strip length	5.25 (m) = 0.7H
Strip width	0. 09 (m)
Strip thickness	0.002(m)
Young's moudulus (E)	7.54×10^6 (Kpa)
γ (Unit Weight)	Negligible
T_y (Yield Stress)	40 (KN/m)
Compressive Strength	Negligible
Interface	K_b=200 (MN/m/m) S_b=1000 (KN/m)
Interface coefficient (Ci)	0.8

IV. RESULTS

Static and dynamic analyses of all walls have been made and each dynamic analysis took about 36 hours.

A. Static Analyses

The static model has been made step by step and at the end of each step, it has been balanced. The way that the unbalanced forces became zero, has been illustrated in Fig. 4.

Also, general displacement of the wall and failure surface constructed in static model has been illustrated in Figures 5 & 6. In Figures 7 & 8, the distribution of reinforcements forces in static state in different layers and the maximum produced forces in them in the wall height have been demonstrated. As shown in these figures, there is no force produced at the end of lower balances of the reinforcements, so it is possible to decrease the length of lower layers of the reinforcements. It is justifiable by the failure surface. On the other hand, the maximum amount of produced forces in lower layers is more than the upper layers. In these parts, if necessary, more powerful reinforcements can also be benefited.

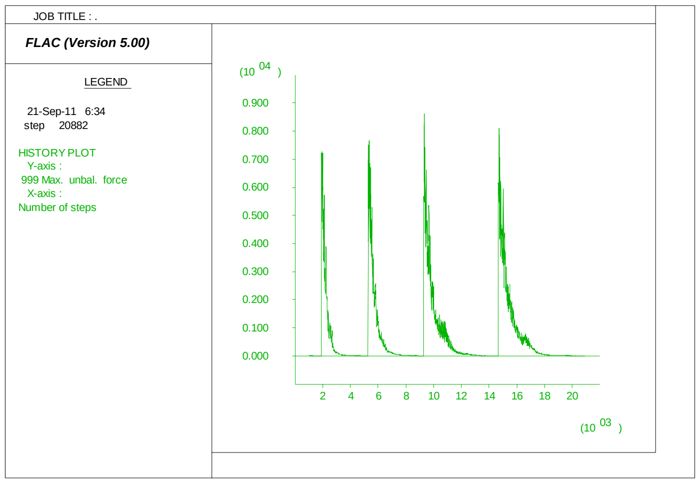

Fig. 4 The history of unbalance forces in stage construction models

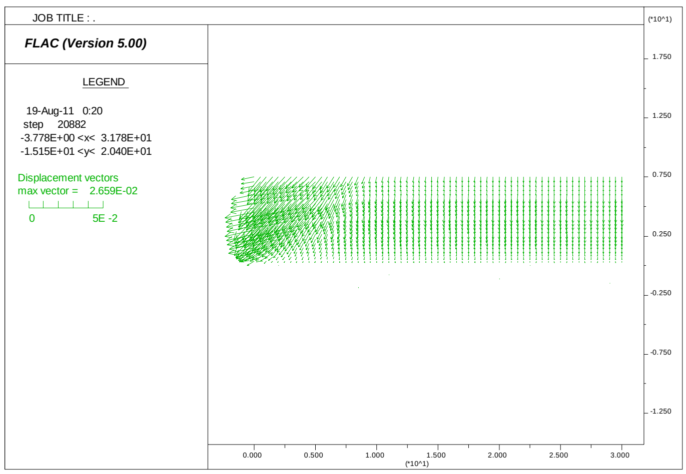

Fig. 5 Total displacement vectors of the wall after static analysis

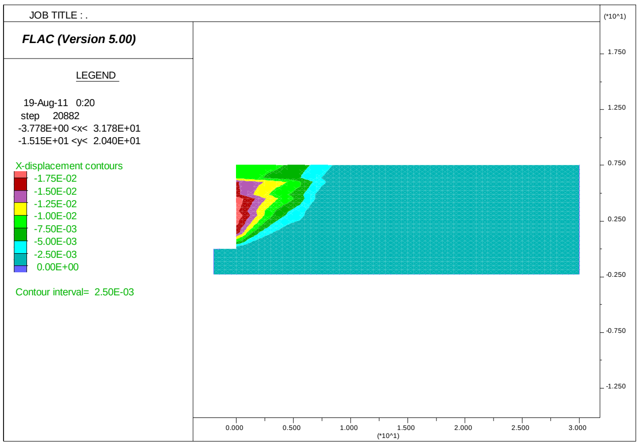

Fig. 6 Failure surface of the wall after static analysis

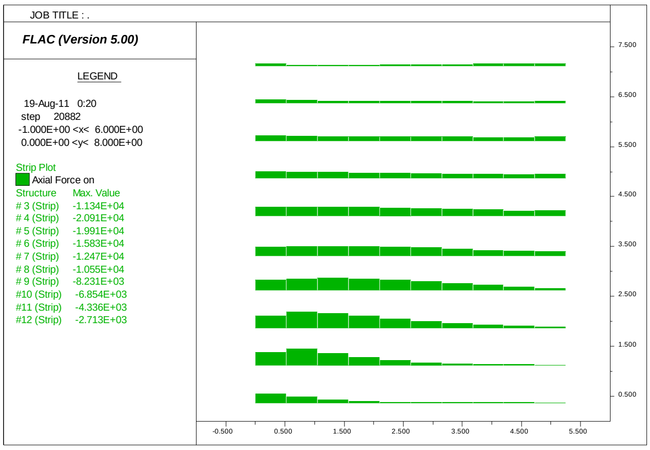

Fig. 7 Mobilized reinforcement axial forces in different layers after static analysis

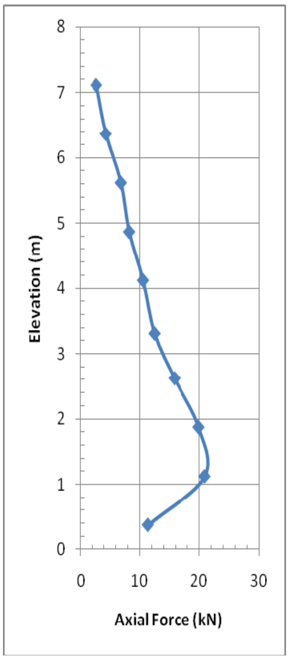

Fig. 8 Maximum mobilized reinforcement axial forces in wall height after static analysis

B. Dynamic Analyses

The normal maximum displacement in dynamic state defined by AASHTO equals 10A in inch in which the maximum velocity of A is based on g. For a constructed model with the maximum velocity of 0.2g,

(10) (12) (25) =50 mm

Figure (9) and (10) illustrate the comparison between final displacement of wall and maximum displacement of wall under loading with different frequencies in different wall balances, respectively. As it can be seen, there is a considerable increase in wall displacement when loading frequency stands close by the natural frequency of the reinforcement with polymeric strips is in the same standard range determined by AASHTO.

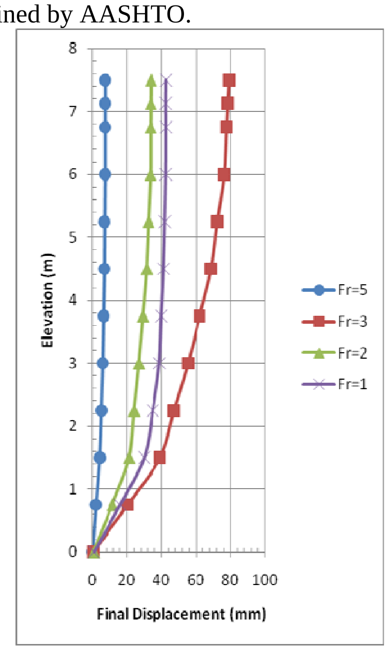

Fig. 9. Comparison of final displacements

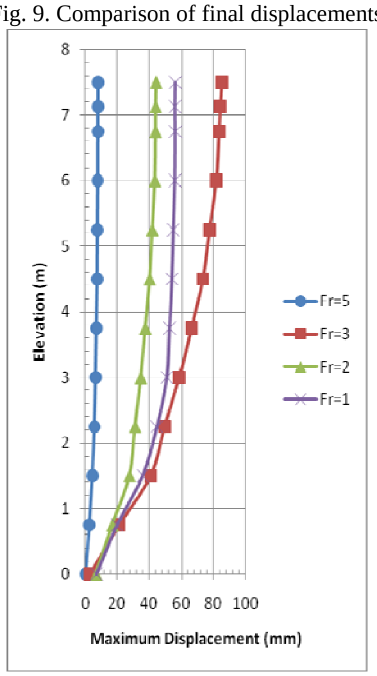

Fig. 10. Comparison of Maximum displacements

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The final displacement rate and maximum wall are the most when Fr=3 Hz and the reason is that loading frequency is close to the natural frequency of the wall and also the occurrence of intensity phenomenon. The results also show that irrespective of 3 Hz frequency, the frequency increase of loading from 1 Hz to 5 Hz decrease the final (range of) maximum displacement and the wall. It can be said that the lower frequencies have a destructive effect on the reinforcement walls.

Fig. 11 illustrated the comparison between produced forces in polymeric strips in wall height under loading with various frequencies. Along the results attained from wall displacement, by applying 3 Hz frequency on the wall, the maximum force rate in reinforcement due to the occurrence of intensity phenomenon is caused. Also, the least produced force in reinforcement is because of the 5 Hz frequency. Generally, it is visible that, except reinforcements of the lowest layers (due to their closeness to the back foundation), reinforcements force increases from the highest to the lowest. Moreover, the maximum rate of produced forces in reinforcements (regardless of loading frequency rate) has been occurred in one-third of the lower part of the wall, showing that using more powerful reinforcements seems necessary.

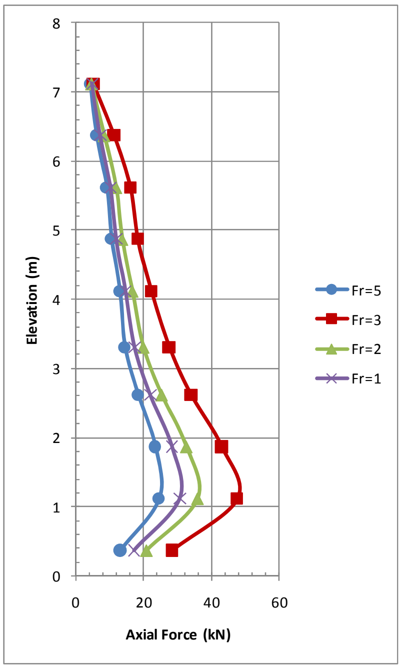

Fig. 11. Comparison of maximum mobilized reinforcement axial forces in wall height under different frequencies

Along the same line, by viewing surface failure and mobilized forces to provide the appropriate length, it is possible to decrease reinforcement's length from top to down. For example, in reinforcements layers for the wall with 3Hz frequency (the worst state) have been demonstrated (Figures 12 & 13).

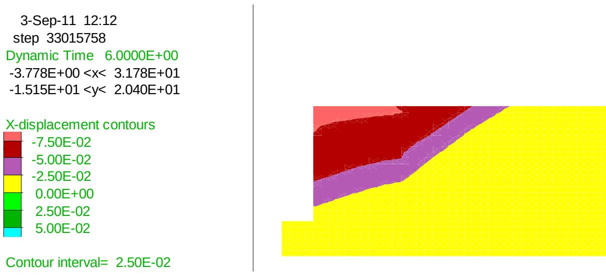

Fig. 12. Failure surfaces under dynamic loading with Fr=3Hz

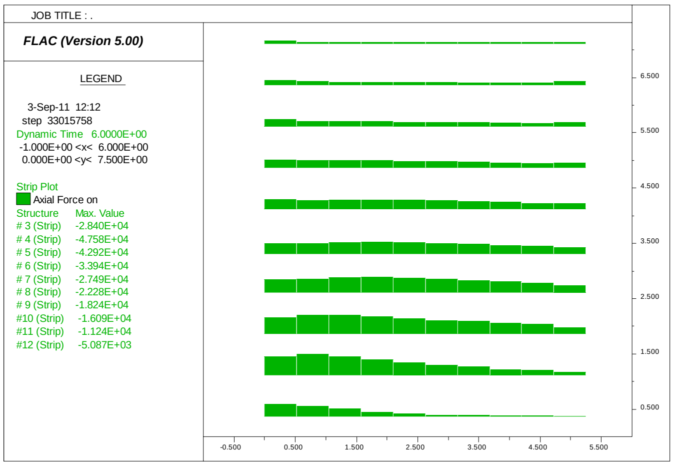

Fig. 13. Mobilized reinforcement axial forces in different layers under dynamic loading with Fr=3Hz

V. Conclusion

This study was conducted on frequency response analysis of reinforced soil retaining walls with polymeric strips by using numerical analysis called Finite Difference Method and the static and dynamic analyses have also been made. The diagrams of the maximum forces of reinforcements and horizontal displacement of the wall versus wall heights have been presented. The results are as follows:

1) The natural frequency of reinforced soil system with polymeric strips equals 3Hz which is coordinated with $f = \frac{V_s}{4H}$.
2) Based on the fact that in dynamic and static analyses of reinforcements the lower layers at their end can bear the least force (Figures, 7 & 13), it may be possible to decrease the reinforcements length.
3) As the reinforcements forces in static and dynamic analyses increase from top to down (Figures 8, 11), it is appropriate to use more powerful reinforcements (with more tension resistance) in lower layers.
4) Accordingly, it is suggested that, in reinforced soil retaining walls with polymeric strips in lower layers, powerful reinforcements and less than 0.7H, and in upper layers we can use weaker reinforcements which are higher than 0.7H.
5) As far as the natural frequency of the system is 3Hz, with

applying the input dynamic load with the same frequency, the system will be in the resonance state and the maximum forces in reinforcements and also the maximum displacement in the wall become obviously visible.

6) Regardless of intensified frequency, the results show that a decrease in mobilized forces frequency of reinforcements wall displacement increases.
7) By comparing reinforced soil retaining walls displacement with polymeric strips under different frequencies according to AASHTO Standard, it is understood that all mobilized displacements are less than the normal rate, except in resonance state.

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