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Dynamic behavior assessment of geosynthetic reinforced soil walls

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ABSTRACT: The design methods for geosynthetic reinforced soil walls are still based on the conventional methods that had been proposed for steel strips reinforcements. The recent studies from experimental to analytical show the requirements to better understanding the behaviour of such structures in static and especially in dynamic loadings. To assess dynamic behaviour of such flexible structures, this study attempts to model them numerically. The main variable parameters in the modelling are the stiffness of reinforcements and the flexibility of facing. A finite difference software that is suitable for dynamic analysis specifically ill-conditioned materials was used here for modelling. Although the variation of reinforced stiffness or flexibility of facing could affect the permanent displacement of the wall, the results show that no strong difference between the developed forces in reinforcements will be occurred. It means that approximately the same forces will be produced in the reinforcements and in such a case displacement is an important factor. According to these results a displacement based design is recommended for geosynthetic reinforced soil walls.

1 INTRODUCTION

Beside all of the advantages of geosynthetic reinforced soil structures and their performance during earthquakes, behaviour of such structures has not been completely understood yet. Some attempts to better evaluate dynamic behaviour of geosynthetic reinforced soil walls (GRSW) dates back not to more that ten recent years. On the other hand, these recent studies have been focused almost on experimental and theoretical aspects and little attention carried out on numerical modeling. It seems that complexity of dynamic behaviour of soil, geosynthetic and especially their interaction cause the lack of dynamic numerical studies.

While finite element method has been frequently used by most of the researchers (e.g., Yogendrakumar et al. 1992, Cai and Bathurst 1995, Fujji et al. 1996, Ling et al. 1995 and Helwany et al. 2001), works of Bathurst and Hatami on dynamic modelling of GRSWs confirmed the power of finite difference on dynamic behaviour assessment of such structures.

Using, FLAC, a finite difference method software, Bathurst and Hatami (1998) determined the effects of some parameters like reinforcement stiffness, reinforcement length and toe condition of wall for various dynamic loadings and compared their results with previous experimental and theoretical experiences. In another study with the same software (Hatami and Bathurst 2000) they study the effects of structural design on fundamental frequency of reinforced soil retaining walls.

In addition to type of reinforcement, something that differs GRSWs from other conventional reinforced soil walls is their variety in types of facings. To evaluate this parameter in this paper in a similar finite difference program, CA2 (Fakhimi 1990), with approximately the same model previously used by Bathurst and Hatami (1998), authors have studied the effects of facing flexibility on dynamic behaviour of GRSW.

2 TYPE OF FACINGS

According to the difference between nature of concrete and polymeric materials, geosynthetics as reinforcement and concrete as wall cannot be connected together directly. Based on this problem three typical configurations are recommended for facing system to be used in GRSWs that are plotted in Fig. 1. These facings are got stiffer from wrapped up to panel facing (top to bottom in Fig 1.). This property can impose different dynamic responses to the structure during earthquake and may affect the behaviour and respectively the design methods of these kinds of walls and should be clarified.

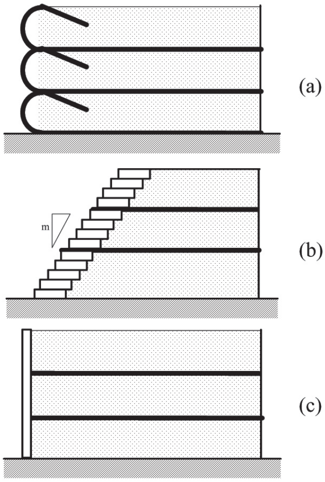

Figure 1. Different types of facing for GRSWs (from top to bottom: Wrapped up facing, segmental block facing and panel facing).

3 PROBLEM FORMWOK

3.1 *Geometry and material property*

According to Figure 2 and 3, a six meters high wall of granular materials has been reinforced with six geosynthetic layers of four meters length that are equally distributed through the height. This arrangement is a very common format for geosynthetics reinforced soil walls. One meter very stiff foundation is located under the wall to eliminate foundation effects on the stability analysis. To model the interaction between backfill soil and adjacent elements, two thin layers of soft soil are used as semi-interaction elements. This technique is an efficient replacement for interface elements to decrease calculation time especially for dynamic analysis and has been used previously by Bathurst and Hatami (1998). Properties of soil, foundation and thin layers are listed in Table 1.

Four typical stiffness values were chosen for reinforcement layers to cover wide range of different geosynthetics properties. It should be noted that while reinforcements are modelled as an elasto-plastic material, large values of yield stress makes it to stay in elastic zone. Therefore plastic zones will be taken place only in backfill soil. Reinforcement properties are shown in Table 2.

Table 1. Material properties of backfill soil.

			Thin Layer between:	
	Backfill Soil	Foundation	Block-Soil & Soil-Foundation	Block-Foundation
Model	M-C	Elastic	M-C	Elastic
γ (KN/m^3)	20	20	20	22
ϕ	35°	–	20°	–
ψ	5°	–	0	–
E	35 (Mpa)	25 (Gpa)	35 (Mpa)	35 (Mpa)
ν	0.3	0.2	0.3	0.2

Table 2. Material properties of reinforcements.

Model	Elastic Perfectly Plastic (1D)
γ	Negligible
K (Stiffness = EA)	500 (KN/m) → Extensible Polymeric Geotextile 1000 (KN/m) 5000 (KN/m) 10000 (KN/m) → Very Stiff Geogrid
Ty (Yield Stress)	200 (KN/m)
Sectional Area	0.002 (m^2)
Interface	Grout Interface Angle = 35° Kb = 2 × 103 (MN/m/m) Sb = 1 × 103 (KN/m)
Compressive Strength	Negligible
Length	L/H = 0.75

3.2 *Facing*

GRSWs benefits from several kinds of facings. Based on this fact, using the same and exact form in modeling would not be useful and no proper comparison could be performed. Here to model the flexibility functioning of facings in GRSWs, a typical facing with only one variable parameter is considered. The facing is constructed with 20 cm × 20 cm concrete blocks where the variable parameter is the property of material located between blocks that models block-block interaction. If the property of such layers is chosen the same as blocks, it produces continues concrete panel facing. Otherwise by decreasing the elasticity, a more flexible facing will be modeled. Table 3 shows the property for two typical Rigid (E = 25 GPa) and Flexible (E = 25 MPa) facings.

Table 3. Material properties of facing elements.

	Blocks	Layer between blocks
Model	Elastic	Elastic
γ (KN/m^3)	22	22
E	25 (Gpa)	25 (Gpa), 25 (Mpa)
ν	0.2	0.2

3.3 *Boundary condition*

According to stiff layer of foundation, at bottom of the model x- and y-displacement are restricted for both static and dynamic analysis. However for right and left side of the model only x-displacement was restricted in static analysis to account for the in-situ stresses at the end of construction. In dynamic analysis free-field boundary that eliminates the wave reflection was used at both sides.

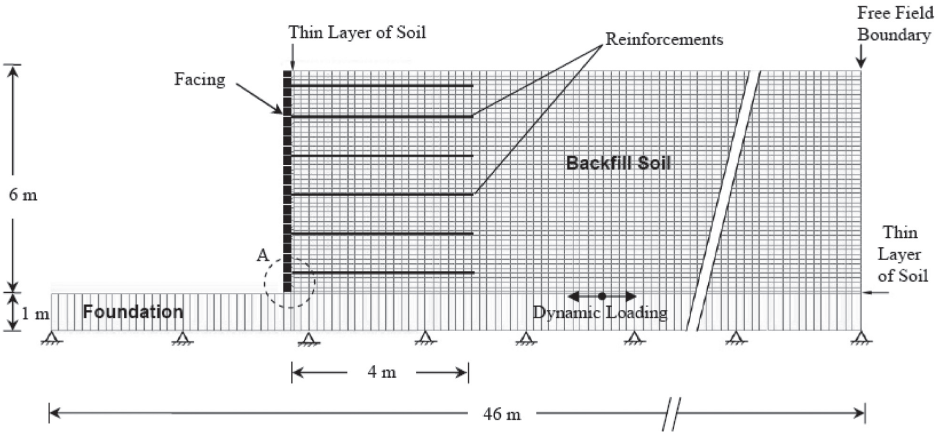

Figure 2. Geometry and configuration of model.

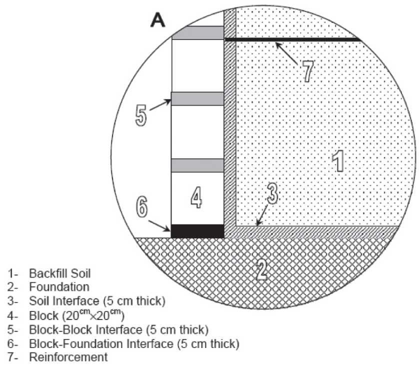

Figure 3. Detail A in figure 2.

3.4 *Loading and damping*

To clearly amplify the responses of structure a time-history acceleration, illustrated in Fig. 4, is used with predominant frequency of 3 Hz that is close to the natural frequency of structure. This time-history was scaled to 0.2 g and 0.4 g. For PGA = 0.2 g an 8% local damping and for PGA = 0.4 g a 10% local damping was chosen to model the dynamic behavior of backfill soil.

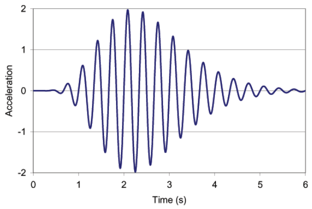

Figure 4. Applied time-history acceleration.

4 RESULTS

4.1 *Amplification of acceleration*

At top of the wall the value of acceleration will be amplified. Figure 5 compares the amplification factor between top and bottom of the wall for different values of reinforcement stiffness. It seems that flexibility of facing decreases the amplification. Also increasing in reinforcement stiffness increases the amplification; however it makes little effects on flexible facings.

4.2 *Lateral displacement*

Results of lateral displacement at seven points along the height of wall during six seconds of dynamic loading for PGA = 0.2 g and K(reinforcement stiffness) = 1000 KN/m are plotted in Figure 6.

Although the lateral displacement of flexible facings is approximately two times more than rigid facing, it has softer behavior during loading. Figure 7 shows all of the results.

4.3 *Plastic zones*

Searching for the sliding surface is very popular in traditional limit equilibrium analysis. However this approach can be followed in numerical modeling,

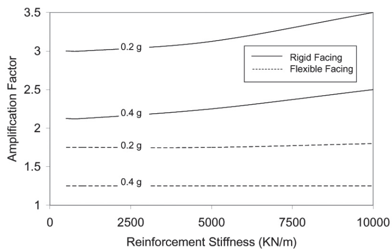

Figure 5. Amplification of acceleration.

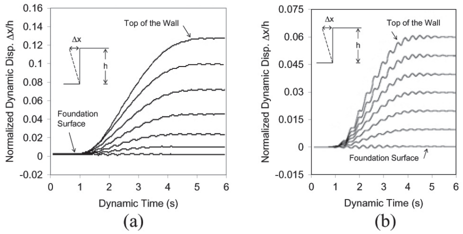

Figure 6. Time history for lateral displacement (a) flexible and (b) rigid facing.

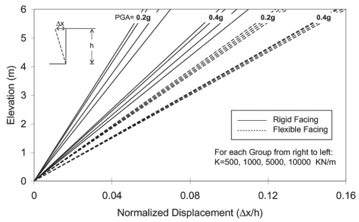

Figure 7. Maximum lateral displacement at top of the wall.

too. Therefore, determining traditional slip surface in numerical modeling is commonly an aim of recent researches to find the relations between these two approaches of analysis.

Results of this study are schematically plotted in Fig. 8. This figure shows plastic points after 6 seconds of dynamic analysis in two categories that are the same for all of the results.

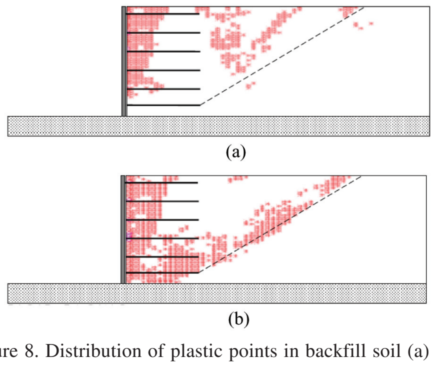

Figure 8. Distribution of plastic points in backfill soil (a) flexible and (b) rigid facing.

Plastic analysis clarifies those plastic points have been reduced dramatically behind the flexible facing compared to rigid facing.

5 CONCLUSION

Briefly it can be said that type of facing affects the behavior of such structures. The principal results of this study are as follows:

(a) Flexibility of facing decreases the amplification of acceleration along the height of wall.
(b) GRSWs with flexible facing have softer and smoother behavior during dynamic loading. Flexibility results in less two-way displacement and lateral displacement will be occurred gradually outward.
(c) Increasing in stiffness of facing or reinforcement (length or material stiffness) decreases the displacement and increases the forces in reinforcements and stresses in soil.
(d) Plastic zones for flexible facings are distributed uniformly behind wall that may make the wall more stable; however it has no strong logical support.

In conclusion it can be claimed that constructing flexible facings for GRSWs when the lateral displacement is not the controlling factor of design is more appropriate than rigid or stiff facings.

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