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Performance Behavior of Marginally Backfilled Reinforced Earth Wall

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Abstract. Over the years, granular soil has been the predominant backfill material for reinforced wall construction due to its high strength, good drainage characteristics, and constant engineering properties. However, due to lack of availability, transportation issues, and economic issues with this type of soil, the use of poorly graded marginal soil as backfill has increased. Marginals backfill are soils having fines and plasticity index greater than 15% and 6 respectively. The objective of this paper is to numerically compare the performance of reinforced earth wall with clean granular fill and marginal fill. For this purpose, 2D FEM was simulated in ABAQUS software. The numerical model's accuracy was first validated by comparing numerical results with experimental wall. The results of wall lateral deformation, reinforcement load and toe reaction in the wall are validated. Further parametric study is carried out to study the effect of surcharge, reinforcement length and spacing, wall height on wall lateral displacement. Based on the results of these simulations, several considerations for the design of reinforced earth wall are identified.

Keywords: Marginal Backfill, Reinforced Earth Wall, Reinforcement, Wall Displacement.

1 Introduction

Throughout the world there is an ever-increasing lack of available prime development space due to the increasing population and associated land development. As a result, structures that allow for maximum land utilization, such as retaining walls and reinforced earth wall (MSE wall), have become increasingly popular. Reinforced earth walls have been used widely as an economical alternative to traditional retaining walls. These is mainly due to faster construction, the ability to build in areas with limited access, the inherent flexibility of the system, which allows for large total and differential settlements to be accommodated, and significant cost savings, particularly when the conventional retaining structure must be piled.

One of the most important parameters in the design and construction of reinforced soil walls and slopes is the backfill material. Granular soil has long been the preferred backfill material for reinforced wall construction due to its high strength, good drainage, and consistent engineering properties that do not change significantly over time. However, the availability of high-quality granular material has frequently limited due to economical constraints and transportation issues etc. Such issues lead to the use of marginal soil as backfill. For example, India has a plenty of tropical soil, which is used as backfill material despite not meeting the select fill guidelines due to a scarcity of well-graded granular material.

Marginal backfills are generally less permeable and have poor drainage characteristics. Popular design codes recommend fines up to 15% and a plasticity index of not more than 6% when selecting backfill soil. Marginal fills are soils with a high proportion of fines that can be cohesive or non-cohesive in nature. When compared to select granular soil, such soils have poor engineering properties. The proportion of fines present in the backfill is known to control the shear strength of reinforcement. If there are a lot of fines in the soil, it can cause drainage problems in the wall. The small number of fines permitted ensures proper drainage along the wall and limits the generation of pore water pressures in the backfill soil. It was reported that the potential savings ranging from 20% to 30% was observed when replacing standard backfills with onsite marginal soils [1]. A very few studies [2–5] have also demonstrated the excellent performance of geosynthetic reinforced soil walls and slopes built with poor drainage backfills even after being subjected to heavy rainfall or rising groundwater conditions.

Numerical modelling of these structures has gained more popularity due to the extensive research scope in this field as the physical tests are more time consuming and less economical. The numerical tool can also be used as a validated tool for carrying out various parametric studies that provides the information on the influence of various parameters on the performance of the wall. Over the past several decades finite element analysis has emerged as a superior tool for the analysis in the field of civil engineering particularly geotechnical engineering. The finite element software ABAQUS [6] has been used in the present study to first validate the experimental wall constructed at RMC college Canada and then to carry out extensive parametric study.

2 Model Development and Validation

The base model for validation is the 3.6m high experimental wall with modular block facing constructed at RMC college, Canada [7, 8]. The wall was 8° batter with respect to the vertical. The base of the wall was considered to be rigid, so no foundation soil is used for analysis. Total 3 walls were constructed by varying the reinforcement stiffness, spacing and wall height. Fig. 1 shows the schematic representation of RMC test wall.

The backfill soil and concrete block facing are modelled as 2D deformable solid sections, whereas geogrids are modelled as wire sections. The properties used in the numerical analysis are same as the RMC wall as suggested by [8]. Backfill soil is homogeneous dry cohesionless soil having very less value of cohesion and is simulated by Mohr-coulomb failure criteria. The material properties of various components of RE wall is mentioned in Table 1.

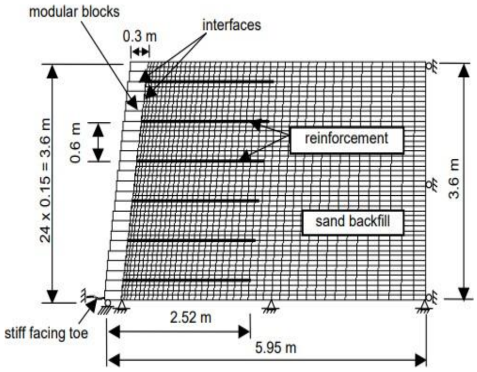


Fig. 1. Schematic representation of the RMC wall [9].

Table 1. Material properties used for present model.

Backfill Soil		**Concrete block**	
Density (kg/m^3)	1680	Youngs modulus (MPa)	20
Angle of internal friction (°)	44	Poison’s ratio (Unitless)	0.2
Dilation angle (°)	11	Density (kg/m^3)	2500
Cohesion (kPa)	1	**Geogrid**	
Poisson’s ratio	0.3	Axial stiffness (KN/m)	119
Youngs modulus (MPa)	48	Youngs modulus (MPa)	37.8
		Poisson’s ratio	0.3

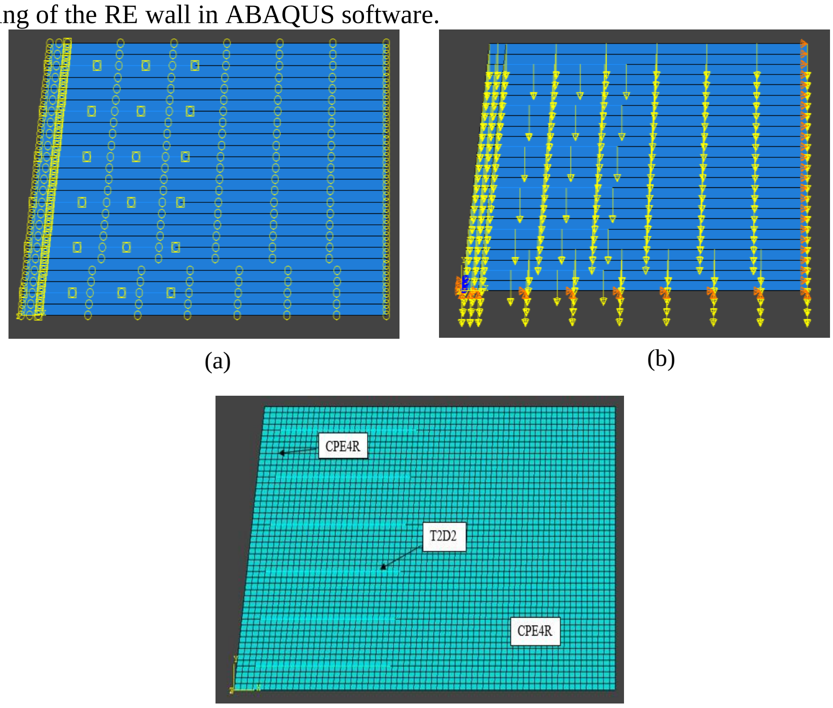
The concrete blocks used in the facings are 30cm wide and 15cm in height and are modelled as linear elastic material. Total six number of biaxial polypropylene geogrids has been provided at spacing of 0.6m in the backfill. The length of geogrid is 2.52m, which is provided according to the design specifications of the RE wall.

2.1 Interactions, Loading and Boundary Conditions

Various interactions are provided to the different parts of the RE wall. To analyze the behavior of block-backfill soil contact, ABAQUS surface to surface interaction is selected. Another interaction is provided between the concrete blocks. The contact pair interaction all with self was selected to see the behavior in the field to include all the surfaces of the facing units. Apart from the above two interaction a general contact was applied to the whole model to verify that the no part of the structure is left un interacted. For reinforcement embedded region constraint was selected.

The far back end of the wall is restrained in horizontal direction (roller connection) but allowed to move in vertical direction to allow for the possible settlements to occur. Bottom part of the model is fixed in both vertical and horizontal direction (hinged connection). Gravity loading is applied to the whole model and no surcharge was considered for the validation purpose.

Meshing the part or assembly is one of the most important steps in simulating the structure in software. Backfill soil and modular concrete blocks are modelled as 4 node bi-quadratic plane strain, quadrilateral, reduced integration elements, hourglass control (CPE4R). All the elements are quad shaped and arranged in structured method. Reduced integration is used due to counter for the computational problems and time insufficiency. Geogrids are modelled as truss elements which is 2 node linear truss elements (T2D2). Total of 3228 elements are provided in the meshing. Fig. 2(a)- (c) shows the graphical representation of interactions, loading & boundary conditions and meshing of the RE wall in ABAQUS software.



(a) (b)

(c)

Fig. 2. FEM in ABAQUS showing a) interactions b) loading and boundary conditions c) meshing.

3 Results and Discussions

3.1 Validation Results

Total three experimental walls were constructed by Hatami and Bathurst [8] , for different reinforcement length and spacing. For wall 2 reinforcement stiffness was doubled and for wall 3 stiffness has been kept same but spacing is increased. The three experimental walls are validated for maximum facing displacement. Fig. 3 shows the comparison of numerically predicted wall displacement and experimentally predicted by Hatami and Bathurst [8].

The results obtained from software are well in comparison with the experimental walls. The slight deviation can be seen in the results due to the value of cohesion taken higher for the backfill soil for the results to get converged. Maximum displacement can be seen in wall 2 which is having lowest geogrid stiffness among all the three walls. The facing displacements observed in wall 3 is very similar to that of wall 1. This might be due to the result of the wall height. If wall height is increased and reinforcement spacing is also increased then the actual behavior of the displacement in RE wall can be successfully monitored, same will be discussed in parametric study in further section of the report.

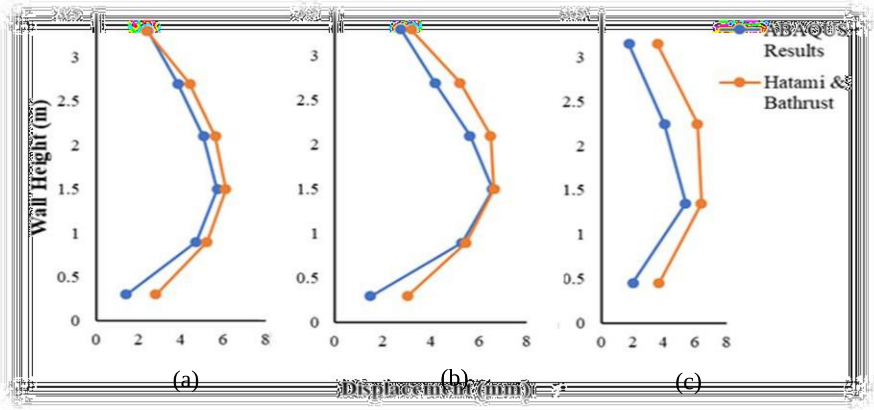


Fig. 3. Comparison of wall horizontal displacement along facing in a) Wall 1 b) Wall 2 c) Wall 3.

3.2 Parametric Study

A parametric study has been carried out to investigate the wall displacement under the effect of various factors such as reinforcement length and spacing, wall height, backfill properties and surcharge loading. The purpose of parametric study was to identify the possible outcome that may result in improved design specifications. Following assumptions has been considered for the parametric study: 1) The soil has been assumed to be homogeneous soil, the soil does not have any layers. 2) Ground water table presence is not considered (soil is in dry condition). 3) Mohr coulomb failure criteria is assumed.

Influence of backfill soil strength parameters on wall displacement

Backfill is an important component that affects the performance of reinforced earth wall. Cohesion and angle of internal friction are two important parameter that defines the strength of the soil. Foundation soil has been included in the numerical model for analysis. Properties of geogrid and concrete blocks used are same as that used for validation model.

Table **2** shows the different backfill parameter that has been used to carry out parametric study.

Table 2. Different backfill parameter used in the study.

Case	Cohesion c (kPa)	Angle of internal friction (degrees)	Modulus of elasticity E (MPa)	
			Case a)	Case b)
a)	3	44	48	48
b)	10	36	48	35
c)	16	30	48	20

The wall height considered for the study is 3.6 m. All other parameters have been taken from the validation model. Only backfill cohesion and angle of internal friction is altered. Maximum displacement of 8.73mm has been observed when modulus of elasticity is kept constant in all the three cases. Fig. 4 shows the displacement contour of wall horizontal displacement for all the three cases.

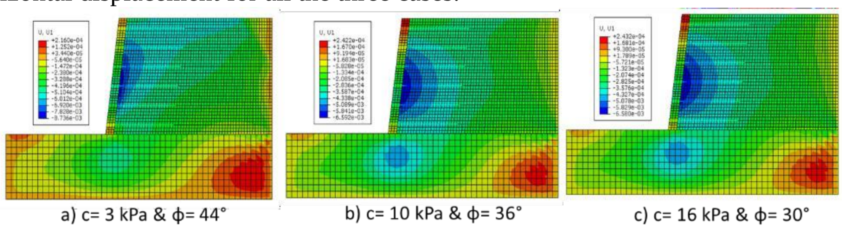


Fig. 4. Horizontal Displacement along the wall for different soil strength.

To predict the influence of soil strength on behavior of RE wall value of modulus of elasticity is also enhanced. By enhancing the value of modulus of elasticity, maximum wall displacement of 13.18mm has been observed. Fig. 5 shows the displacement contour of wall horizontal displacement for different value of E.

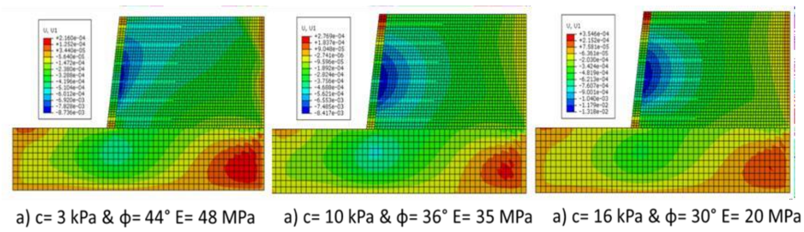


Fig. 5. Horizontal displacement along the wall for different value of E.

Fig. 6 and 7 show the graphical comparison of wall horizontal displacement for both the cases. The displacements are measured at equal spacing where geogrids are placed.

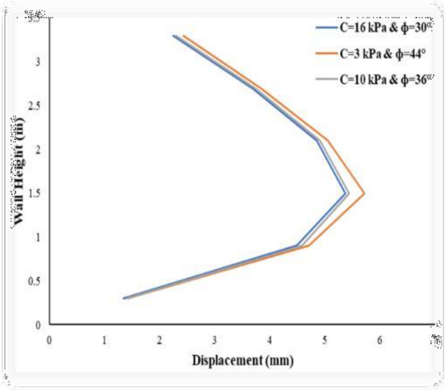


Fig. 6. Comparison of horizontal displacement for different soil strength.

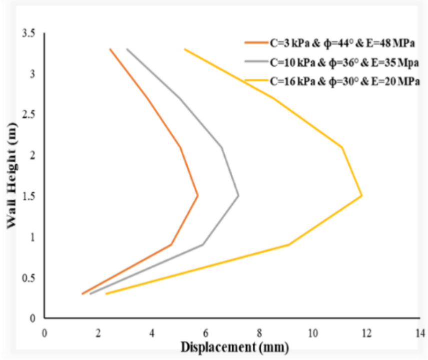


Fig. 7. Comparison of horizontal displacement for different value of E.

Influence of surcharge loading on wall displacement

The wall height of 3.6m is used to analyze the performance of reinforced earth wall under various surcharge loading. The backfill properties have been taken as the one which compiles with that of marginal fill. For all the models, cohesion value of 16 kPa and angle of internal friction equal to 30° has been taken. Separate step has been created in ABAQUS for the application of surcharge Two surcharge values of 40 & 50 kPa is applied at top surface of the backfill. **Fig. 8** shows the displacement contour for the wall horizontal displacement.

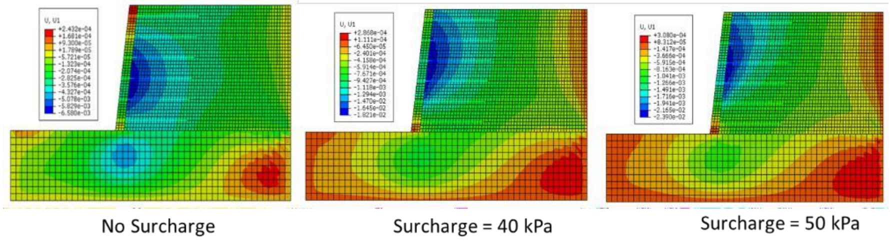


Fig. 8. Horizontal wall displacement with different surcharge value.

Maximum displacement of 18.21mm and 23.90mm has been observed for the surcharge value of 40 kPa and 50 kPa respectively. Fig. 9 shows the graphical comparison of wall horizontal displacement for different surcharge value.

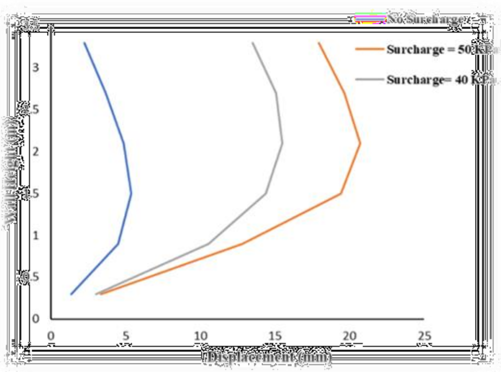


Fig. 9. Comparison of horizontal wall displacement for different surcharge value.

Influence of reinforcement spacing & stiffness on wall displacement

Geogrid has been provided in the current study as reinforcement. Properties of geogrid have been taken same as that of validation model. All the other parameters have been kept same, only geogrid spacing & stiffness is changed to monitor the performance of RE wall. According to Indian code IRC (SP:102-2014), maximum spacing between two layers should not increase by 800 mm. For the present study three different cases has been taken into consideration. In one case geogrid spacing is decreased from 600mm to 300mm and stiffness is kept same, and, in another case, stiffness is increased or doubled. Fig. 10 shows the displacement contour of the wall horizontal displacement.

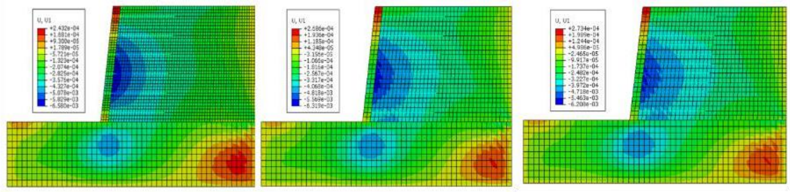


Fig. 10. Horizontal displacement for different reinforcement spacing and stiffness.

By using higher reinforcement stiffness, displacements is decreased in wall by 5%. By increasing spacing between the reinforcement and using higher stiffness, the wall horizontal displacement is reduced by 7%. Graphical Comparison of wall displacement for different reinforcement spacing and length can be seen in Fig. 11.

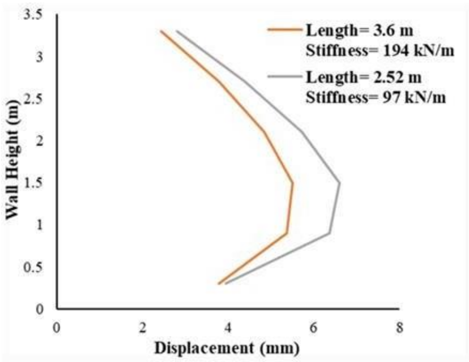


Fig. 11. Comparison of wall displacement for different reinforcement spacing and stiffness.

Influence of reinforcement Length on wall displacement

According to Indian code IRC (SP:102-2014) for design of reinforced earth wall the minimum reinforcement length to be provided is equal to 0.7 times height of the wall (L/H=0.7). Wall height of 3.6 m is considered in the present study. To predict the influence of reinforcement length on wall displacement length of reinforcement is taken equal to height of the wall height(L/H=1). Fig. 12 shows wall displacement for different reinforcement length and stiffness.

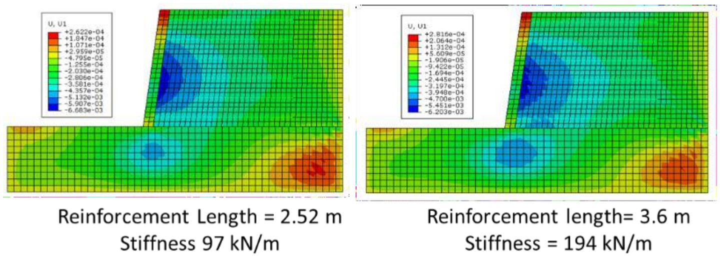


Fig. 12. Horizontal displacement for different reinforcement length & Stiffness.

There was no subsequent change in wall displacement when only reinforcement length was changed. However, wall displacement is decreased by about 7% by increasing length and stiffness of geogrid. Fig. 13 shows the graphical comparison of wall displacement for different geogrid length and stiffness.

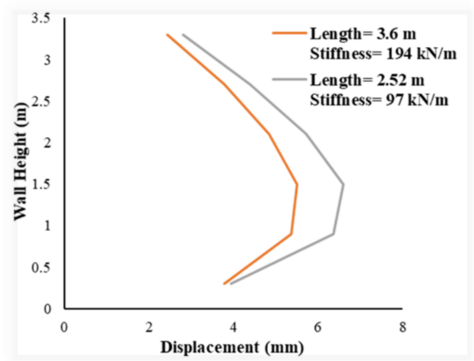


Fig. 13. Comparison of wall displacement for different reinforcement Length & stiffness.

Influence of different wall heights on wall displacement

The influence of wall height on performance of reinforced earth wall has been investigated by considering three different wall height of 3.6m, 6.0m &9.0m. Reinforcement length for all the walls has been taken as 0.7 times the height of the wall. Reinforcement spacing of 600mm is kept constant for all the three walls. All other material properties have been kept same as that for validation model. Fig. 15 shows the graphical comparison of the wall displacement for different wall height.

The smooth displacement curve is obtained for smaller wall heights (3.6 & 6m), whereas curve deviates in case of wall having greater height. Increased horizontal displacement for greater wall height might be due to negligible effect of toe restraint as compared to that in wall with smaller heights. Displacement contours of different wall height of all the three walls is compared in ABAQUS viewport and same is shown in Fig. 14.

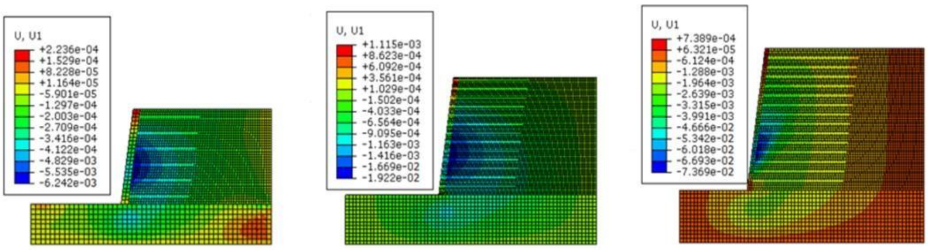


Fig. 14. Horizontal displacement in wall for different wall height.

Depth of foundation soil has been varied for different wall height. Increase in wall horizontal and vertical displacement is observed with increase in wall height. Maximum horizontal displacement of 6.24mm, 19.22mm and 73.69mm is observed for the wall height of 3.0m,6.0m and 9.0m respectively.

4 Conclusions

In the present study an attempt has been made to evaluate the performance of reinforced earth wall by using marginal soil as backfill. For this purpose, 2D finite element model has been simulated in ABAQUS software. Based on the results of these simulations, following are the major considerations for the design of reinforced earth wall with marginal soil as backfill

- The numerical simulation results show reduced wall facing displacement up to 33% when backfill soil strength parameters where altered at constant modulus of elasticity. This might be due to the cohesive nature of marginal fills and no effect of moisture content considered in the study. However, wall displacements were seen to be increased by 50% when modulus of elasticity of backfill soil was changed with increased value of cohesion.
- Significant increase in wall displacement was observed when surcharge has been introduced in the numerical model.
- With increase in wall height increase in horizontal and vertical displacement was observed. Facing displacements less than 1% of wall height is achieved for wall height up to 9.0m.
- When reinforcement length to wall height ratio is increased to 1.0, whereas suggested by code is 0.7, there is generally little variation in wall displacement. However, for increased geogrid stiffness with its length overall 5% reduction in wall displacement is resulted.
- When spacing between geogrid layers is halved along with increased stiffness, wall displacements are lowered up to 7%. It concluded that the decreasing of reinforcement spacing is more effective than the increasing of reinforcement length to reduce wall horizontal displacements.

Although there exist some design guidelines, further research seems to be needed in relation to use the of marginal fills, such as instrumentation and long-term monitoring of already existing and newly planned reinforced earth walls with marginal fills. Marginal backfill soil can be used as an alternative to select granular fill while taking into consideration the fact that reinforcement designs are properly adopted.

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