Reviewing the Possibility of Using Marginal Soils as Backfill Materials for Mechanically Stabilized Earth Retaining Walls

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Abstract. Soils with less than 15% fines content are recommended as backfill materials for mechanically stabilized walls to maintain optimum performance and avoid any serviceability problems. However, the shortage and/or the high cost of such soils have encouraged civil engineers to find safe methodologies to employing the available native soils. To the authors' knowledge, these approaches have been reviewed in this paper, and their limitations have been discussed. Further, the article also examines the experimental techniques used to measure the interaction at the interface between the soil and the reinforcing elements due to their importance in fulfilling an accurate design.

Keywords: MSWs; backfill; frictional soils; interface tests; fines.

1. Introduction
Mechanically Stabilized Retaining Walls (MSWs) have been used to support roadways and bridge abatements in highway projects [1]. This rising attention in MSWs is mainly attributable to their unique characteristics such as flexibility, speed in construction, and cheapness compared to gravity or cantilever retaining walls [1]. MSWs have three core elements: backfill soil, reinforcing inclusions, and facing units [1]. The backfill possesses an essential effect on the overall behavior. Therefore, most of the standards and specifications call for using soils with no more than 15% of fines to maintain optimum performance and avoid any potential serviceability problems [1,2]. These may comprise extreme lateral movements, settlement, distortion, and excess pore water pressure build-up during selected occasions [1]. Nonetheless, this stipulation may choose MSEWs over conventional retaining structures an uneconomical selection. Consequently, efforts have been devoted to finding a safe approach to utilize marginal soils that do not comply with the standards mentioned above (i.e., fines content higher than 15%). This paper reviews these approaches and discusses their limitations. Besides, it reviews the experimental techniques used to measure the interaction at the interface between the soil and the reinforcement due to their significance in fulfilling an accurate design.

2. Suggested approaches
Several methodologies or approaches have been proposed to moderate the effects of high fines content on the internal and global stability of MSWs. In the subsequent sections, these proposed methods will be presented, and their limitations will be discussed.
2.1 Using Polymeric Type Reinforcement

After introducing mechanically stabilized earth walls with metallic reinforcement in 1966, geotextile and geogrids reinforced structures followed shortly thereafter. A key item that accompanied this alteration in reinforcement type was the nature of the backfill. Corrosion of metallic reinforcement was no longer a matter. Thus locally available marginal, fine-grained soils were usually used in place of highly frictional soils. For instance, geotextile is a permeable fabric that can reinforce, filter, separate drain, and protection when used in soils. It is typically manufactured from polypropylene or polyester. It is known that increasing the fines content (materials <0.075mm) in the backfill soils results in decreasing their permeability. During selected occasions, this leads to the build-up of hydrostatic pressure or excess pore water pressure.

However, Sua and Goodings [3] suggested that using geotextiles, particularly those with nonwoven fabric, as reinforcement makes it possible to use cohesive soils as backfills. This is due to the high permeability of this reinforcement kind. They state that using this type of reinforcement results in producing a draining cohesive backfill. Thus, any excess pore pressure can be dissipated quickly. While this technique may be proper, many reinforcing layers might be required to produce such a backfill, possibly making the construction cost high. Besides, Koerner and Koerner [4] reported 171 failed mechanically stabilized earth (MSE) walls, reinforced with geosynthetic materials, including 44 cases with excessive deformation and 127 cases of partial and total collapse of the wall. Figure 1 summarizes their study.

![Figure 1](image_url)

**Figure 1.** Nature of backfill soils utilized in 171 (100%) MSWs [4].

2.2 Surface Roughness

It has been reported in the literature that the interface shear strength increases with the increase of the surface roughness of the inclusions owing to the rise in the coefficient of interfacial friction [5-11]. However, this increment is limited [5]. There is a necessary roughness after which increasing the surface roughness does not affect the interface response; see Figure 2. Upon reaching critical roughness, shear failure occurs within the soil mass instead of the interface. Thus, increasing the surface roughness of reinforcing elements does not utterly solve using soils with high fines content as backfill materials.
2.3 Including Cohesive Soil Strength in the Calculations

Miyata and Bathurst [12] state that several MSWs have been erected in Japan using marginal soils with a fines content of 35% reinforced with steel straps. Miyata and Bathurst [12] proposed that the applied tensile force calculated by the North American technique is overestimated due to the exclusion of cohesive components from the calculations. This can be very significant, especially if the component is comparatively large [12]. They, therefore, introduce equivalent secant friction angle, $\phi_{sec}$, in place of original friction angle $\phi$ to calculate $T_{max}$, taking into account the contribution of soil cohesion. This is shown in Figure 3. The figure shows a significant increase in the friction angle with low frictional strength and an essential normalized cohesive strength component. Miyata and Bathurst [12] re-calculated the tensile forces of steel strips reported in the literature using $\phi_{sec}$. It appears that even though their calculations resulted in lower tensile forces than those reported values initially, including the cohesion component in the design might not be safe because it can be affected by the backfill moisture status.

Figure 2. The critical value of surface roughness [5].

Figure 3. Secant friction angles variations with normalized cohesion and original angle of friction [12].
2.4 Sandwiching
Stresses in reinforcing elements are transferred to soils by two mechanisms. The first mechanism will be triggered if a shear displacement coincides with the shear stress in a direction parallel to the inclusion's length [13]. Simultaneously, the second mechanism is stimulated if a bearing pressure has been developed on the transverse part of the reinforcement [13]. Further, the shear stress is inversely proportional to the distance from the soil's interface and the inclusion [14]. Sridharan et al. [14] state that soils with moderately low frictional characteristics can be utilized at a distance from the interface without impacting the shear strength. They, in other words, propose using only a thin layer of highly frictional soils around the reinforcement to mobilize the shear strength at the interface. Table 1 shows the sand thickness of the different tests carried out in the study, and Figure 4 shows the results of the pullout tests. Although this technique can demonstrate good performance in the early life of the structure, the performance might deteriorate gradually due to the possibility of fines migration.

| S1 number | Bulk Material | Thickness of sand layer around reinforcement (mm) |
|-----------|---------------|--------------------------------------------------|
| 1         | Sawdust       | 0                                                |
| 2         | Sand          | Full                                             |
| 3         | sawdust       | 5                                                |
| 4         | Sawdust       | 10                                               |
| 5         | Sawdust       | 15                                               |
| 6         | Kaolin clay   | 15                                               |

Table 1. Details of sand-layer thickness [14].

![Figure 4](image)

Figure 4. Pullout test results [14].

2.5 An Efficient Drainage Systems
Koerner and Koerner [4] states that installing a proper drainage system makes it possible to use marginal soils as backfill materials. Such a system can prevent the build-up of excess insufficient water pressure
on the wall facing, leading to extreme lateral movement or collapse of the wall [4]. Additionally, they suggest sealing the wall's upper ground surface using an impervious layer, geomembrane, or providing proper surface slope to preclude water infiltration [15,16]. Even though these solutions might be viable, their success is dependent on the quality of implementation, which could not always be guaranteed.

![Diagram](image)

Figure 5. Moving the internal drainage system behind the reinforced soil zone [4].

### 2.6 New form of reinforcing elements

Lami and Airey [1] proposed and investigated tapered straps as a potential alternative to the conventional forms of reinforcing elements, such as flat steel strips, ribbed steel strips, steel grids (with or without kinks), and geosynthetic materials. A series of laboratory pullout tests were performed to study the effects of fines on the tapered straps' pullout capacity embedded in silty sand. The silt content ranges from 0 to 60%. It has been found that the performance of the tapered straps is better than the performance of the flat and the ribbed straps under all the stress levels and silt contents. See Table 2. Similar nature of the response was reported for inextensible mesh-type reinforcement [17]. However, before accepting higher fines contents with tapered straps, further studies are recommended since the pullout resistance is a single component of the MSEWs systems, and the reductions in soil stiffness and soil permeability as a consequence of adding the fines needs to be considered [1].

**Table 2.** Enhancement in the pullout capacity due to the presence of the wedges. Reproduced from [1].

| Fines content Normal stress % | Increase in capacity 1.2° wedge 25 kPa (%) 76 kPa (%) | Increase in capacity 3.6° wedge 25 kPa (%) 76 kPa (%) |
|-------------------------------|-----------------------------------------------|-----------------------------------------------|
| 0                             | 32 (%) 28 (%)                                | 21 (%) 17 (%)                                 |
| 10                            | 22 (%) 41 (%)                                | 13 (%) 41 (%)                                 |
| 20                            | 35 (%) 37 (%)                                | 26 (%) 36 (%)                                 |
| 30                            | - (%) - (%)                                  | 63 (%) 53 (%)                                 |
| 40                            | 205 (%) 124 (%)                              | 217 (%) 108 (%)                               |
| 60                            | 141 (%) 56 (%)                               | 200 (%) 103 (%)                               |

### 3. Soil-inclusion interaction testing methods

In general, the interface can be defined as a discontinuity that results from putting two materials adjacent to one another [18]. An accurate assessment of the interaction at the interface between the soil and the reinforcing elements is crucial in fulfilling a successful design. This interaction can be investigated using experimental and/or numerical methods.
3.1 Pullout test

Although the choice of the test used is a matter of debate, the pullout test has been recognized to offer a better measurement and simulation [19]. The test can be done either in a soil laboratory or the field. The laboratory test involves burying a reinforcing element in the middle of a box of soil, applying normal stress at the top of the soil, then measuring the forces or the shear stresses required to pull the inclusion out for a particular horizontal displacement, using either a proving ring or a loading cell. In the field test, however, the normal stress applied on the surface of the inclusion is a function of the burial depth. When it is compared with the field test, the laboratory test is strongly affected by the test's boundary conditions. These include the box's dimensions, the surface roughness of the interior faces of the box, especially the frontal face, and the stiffness of the loading plate [19].

3.2 Alternative testing methods

Kishida and Uesugi [20] review four interface shear tests. The outcomes of their revision are reproduced and illustrated in Table 3.

4. Summery

Although soil reinforcement techniques have been used to improve poor quality in situ soils, this is not usually the case with MSEWs. The standards and the specifications of these structures require high frictional backfill materials with no more than 15% of fines to sustain outstanding performance and avoid any potential serviceability issues. However, employing marginal, native soils in place of high frictional soils as backfill materials is a desirable alternative. This is due to their abundance and cheapness in addition to the savings potential. Many approaches have been suggested in the literature to alleviate the negative impact of fines (more than 15%) on the performance of MSEWs. Upon reviewing the available approaches, it can be deduced that although the 15% limit may sound conservative, the available techniques calling to increase this limit do need further investigations. Regarding the interface tests, it can be seen that each one of the mentioned tests has its limitations in simulating the actual conditions found in reinforced soil structures. Therefore, it is evident that two or more of these tests and techniques must make a comprehensive understanding of the interaction between the soil and the reinforcing elements at the interface.

Table 3. Review of interface testing apparatus. Reproduced from [20].

| Testing Apparatus | Reference | Advantages | Disadvantages |
|-------------------|-----------|------------|---------------|
| Direct shear      | [21,22]   | commonly available device  
simple system  
Simple preparation  
Simple procedure | Displacement factors unable to be separated (sliding displacement and displacement due to sand deformation)  
Interface area reduced with increase in displacement |
| Annular stress    | [23,24]   | Geometrically similar to skin friction of piles and friction of steel reinforcement | Normal stress on interface unknown  
Stress concentration at the ends |
Ring Torsion

Endless ring interface
No stress concentration at ends
Constant interface area
Displacement factors observed by X-ray photography (sliding displacement and displacement due to shear deformation of sand)

Complicated system and procedure
Difficult to prepare uniform sand mass in a ring shape
Difficult to finish surface roughness of metal ring uniformly

Simple shear

Constant interface area
Simple preparation
Simple procedure
Displacement factors measured separately (sliding displacement and displacement due to shear deformation of sand)

*Stress concentration at the ends

References

[1] Lami, M. and Airey, D., 2018. Pullout resistance of tapered metal straps in fills with high fines contents. Journal of Geotechnical and Geoenvironmental Engineering, 144(2), p.06017017.
[2] Jones, C.J., 2013. Earth reinforcement and soil structures. Elsevier.
[3] Suah, P.G. and Goodings, D.J., 2001. Failure of geotextile-reinforced vertical soil walls with marginal backfill. Transportation research record, 1772(1), pp.183-189.
[4] Koerner, R.M. and Koerner, G.R., 2013. A data base, statistics and recommendations regarding 171 failed geosynthetic reinforced mechanically stabilized earth (MSE) walls. Geotextiles and Geomembranes, 40, pp.20-27.
[5] Uesugi, M. and Kishida, H., 1986. Influential factors of friction between steel and dry sands. Soils and foundations, 26(2), pp.33-46.
[6] Uesugi, M. and Kishida, H., 1986. Frictional resistance at yield between dry sand and mild steel. Soils and foundations, 26(4), pp.139-149.
[7] Karmokar, A.K., Kabeya, H. and Tanaka, Y., 1994. Pullout experiments with cohesionless and cohesive soils for reinforcement application. Sen'i Gakkaishi, 50(12), pp.608-614.
[8] Yasufuku, N. and Ochiai, H., 2005. Sand-steel interface friction related to soil crushability. In Geomechanics: Testing, Modeling, and Simulation (pp. 627-641).
[9] Dove, J.E., Frost, J.D., Han, J. and Bachus, R.C., 1997. The influence of geomembrane surface roughness on interface strength. In Proc. Geosynthetics (Vol. 97, No. 1, pp. 863-876).
[10] Frost, J.D. and Han, J., 1999. Behavior of interfaces between fiber-reinforced polymers and sands. Journal of geotechnical and geoenvironmental engineering, 125(8), pp.633-640.
[11] Frost, J.D., DeJong, J.T. and Recalde, M., 2002. Shear failure behavior of granular–continuum interfaces. Engineering Fracture Mechanics, 69(17), pp.2029-2048.
[12] Miyata, Y. and Bathurst, R.J., 2012. Measured and predicted loads in steel strip reinforced c– φ soil walls in Japan. Soils and Foundations, 52(1), pp.1-17.
[13] Elias, V., Christopher, B.R., Berg, R.R. and Berg, R.R., 2001. Mechanically stabilized earth walls and reinforced soil slopes: design and construction guidelines (updated version) (No. FHWA-NHI-00-043). United States. Federal Highway Administration.
[14] Sridharan, A., Murthy, B.S., Bindumadhava and Revanasiddappa, K., 1991. Technique for using fine-grained soil in reinforced earth. Journal of geotechnical engineering, 117(8), pp.1174-1190.
[15] Berg, R.R., Samtani, N.C. and Christopher, B.R., 2009. Design of mechanically stabilized earth walls and reinforced soil slopes–Volume II (No. FHWA-NHI-10-025). United States. Department of Transportation. Federal Highway Administration.

[16] Bernardi, M., Collin, J.G. and Leschinsky, D., 2009. Design Manual for Segmental Retaining Walls. Third ed. National Concrete Masonry Association, Herndon, VA, p. 281.

[17] Tin, N., Bergado, D.T., Anderson, L.R. and Voottipruex, P., 2011. Factors affecting kinked steel grid reinforcement in MSE structures. Geotextiles and Geomembranes, 29(2), pp.172-180.

[18] Yi, S.W., 1998. Influence of surface topography on interface strength and counterface soil structure. Doctoral dissertation, Georgia Institute of Technology.

[19] Palmeria, E.M. and Milligan, G.W.E., 1989. Scale and other factors affecting the results of pullout tests of grids buried in sand. Geotechnique, 39(3), pp.511-542.

[20] Kishida, H. and Uesugi, M., 1987. Tests of the interface between sand and steel in the simple shear apparatus. Géotechnique, 37(1), pp.45-52.

[21] Potyondy, J.G., 1961. Skin friction between various soils and construction materials. Geotechnique, 11(4), pp.339-353.

[22] Desai, C.S., Drumm, E.C. and Zaman, M.M., 1985. Cyclic testing and modeling of interfaces. Journal of Geotechnical Engineering, 111(6), pp.793-815.

[23] Brumund, W.F. and Leonards, G.A., 1973. Experimental study of static and dynamic friction between sand and typical construction materials. Journal of Testing and Evaluation, 1(2), pp.162-165.

[24] Miyamoto, J., Kishida, H., and Kobayashi, H., 1975. Influence of high lateral pressure on coefficient of friction between sand and model pile. Proc. Z & h Japan Nat. Conf: Soil Mech. Fdn Engng, pp. 487490 (in Japanese). Japanese Society of Soil Mechanics and Foundation Engineering.

[25] Yoshimi, Y. and Kishida, T., 1981. A ring torsion apparatus for evaluating friction between soil and metal surfaces. Geotechnical testing journal, 4(4), pp.145-152.