LOW PERMEABLE BACKFILL SOILS IN GEOSYNTHETIC REINFORCED SOIL WALLS: STATE-OF-THE-PRACTICE IN NORTH AMERICA

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ABSTRACT

The results of a survey of state agencies and private sector groups and a literature review is presented as the basis of this state-of-the practice report on the use of low permeable, marginal soils as reinforced fill in geosynthetic reinforced soil walls. Both the successful and not so successful performance of walls where marginal soils have been used is reviewed and the factors that contribute to some of the problems that have been reported are examined. The paper concludes with issues that must be controlled for the safe and continued use of marginal fill for reinforced soil wall construction.

INTRODUCTION

Reinforced fill makes up about 30 to 40 percent of the cost of a reinforced soil wall and high quality, permeable fill can cost two to three times that of lower quality, high fines soil. Therefore, the potential savings in using lower cost, marginal soil is significant. As a result, in the North American private sector market where design is not governed by national standards, marginal soils are routinely used. Correspondingly, significantly more problems have been reported with walls constructed in the private sector market than in the public sector, where national guidance documents and specifications preclude the use of high fines, lower quality soils. The current practice in public works projects is to use high quality granular fill with low fines content (i.e., less than 15% finer than 0.075 mm as required by AASHTO specifications and FHWA guidelines). In the private sector, the standard design guide (i.e., NCMA) suggests that backfill be limited to 35%, however it does not preclude a greater amount of fines, and a number of structures have been constructed with a much greater fines content (albeit some structures with not so successful results). On first review, it would appear from the anecdotal evidence that the number of problems is directly related to the use of marginal soils; however, other factors may contribute to this observation. Simply the number of geosynthetic walls constructed in the private sector is much greater than that in the public sector; therefore, all other factors being equal, there will be more reported wall problems in the private sector. There are also other factors that may contribute to the observed problems including construction quality control, testing of soils to obtain design characteristics, and design control, all of which are more lax in the private sector. Thus it is difficult and overly simplistic to say that marginal soils are the problem and should not be used.

Even with the reported problems, due to the financial incentive, the public sector has an interest in using marginal soil backfill in reinforced soil walls. In order to develop a better understanding of the reported problems that have occurred, a survey of public and private sector groups as well as a literature review was performed as part of NCHRP Project 24-22, " Selecting Reinforced Fill Materials for Mechanically Stabilized Earth (MSE) Retaining Walls". The results were used to establish a research project that will hopefully address design issues so that a wider range of reinforced fill can be used in the public sector as reported elsewhere in this conference. In this paper, the results of the survey and literature review, along with personal interviews and interaction with state and federal agencies as well as experience from the authors in evaluating some of the problem projects will be used to define the state-of-the-practice in the use of marginal soils in North America. The successful and not so successful performance will also be discussed and the factors that contribute to problems will be examined.

SURVEY OF CURRENT PRACTICE

A survey questionnaire was developed to determine current design and construction practice for reinforced soil wall fill. The respondents were informed that the survey was for permanent reinforced soil walls for typical highway applications (maximum wall height of about 7m (23 ft.)). The survey covered: a) reinforced fill type and properties; b) "high fines" and/or "high plasticity" reinforced fill (i.e. use of, economic implications of using, and unsatisfactory performance of walls when using); and c) enhancement of and special drainage provisions with "high fines" and/or "high plasticity" reinforced fill. The survey was sent to each state transportation agency, District of Columbia (D.C.) and Puerto Rico (52 total) and to industry representatives from the National Concrete Masonry Association (NCMA) and the Association for Metallically Stabilized Earth (AMSE). Responses were received from 49 state transportation agencies and the NCMA.

State Transportation Agency Responses

The survey responses indicate that, with only a few exceptions, state transportation agencies currently conform to AASHTO requirements regarding material type and properties of reinforced fill for reinforced soil walls. Thirty-two (32) of the responding states have modified the AASHTO specifications into a more specific state specification and fifteen (15) of the responding states reference the AASHTO specifications directly. Figure 1 presents the acceptable upper limit (i.e. material cannot be finer) of the gradation of materials acceptable for use as reinforced fill by the various state transportation agencies. For comparison purposes, the upper limit allowed by AASHTO is depicted by the dashed bold line in the figure.

All but two responding states limit the material passing the #200 sieve (< 0.075 mm) to no more than 15%, which conforms to AASHTO requirements. One of those states allows up to 25% passing the #200 sieve, however, indicating that they are experiencing an increasing number of construction related problems associated with the reinforced fill that is allowed by their specifications. They are currently working on several specification changes, including restricting the amount of soil passing the #200 sieve to no more than 15%. The other state indicated that they have allowed the use of materials with high fines content (i.e. greater than 25%, but generally less than 35%, passing the #200 sieve). These soils, however, have a high internal angle of friction. They do not allow a material with high plasticity.

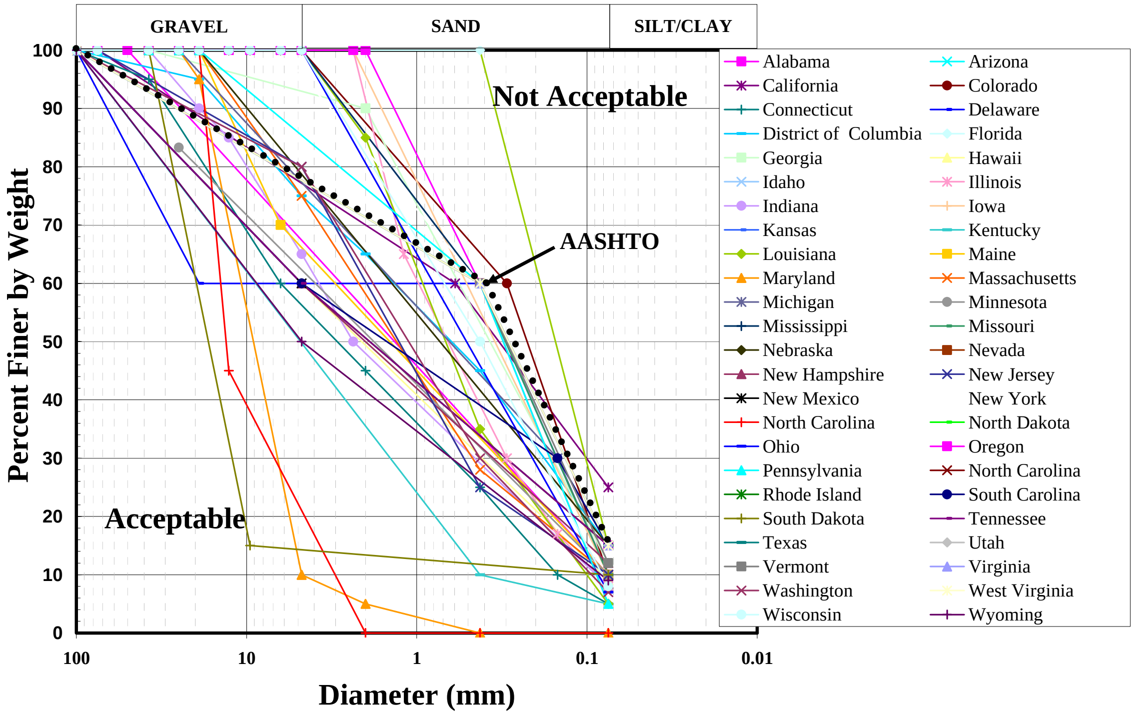

Figure 1. Acceptable "upper" gradation limit for reinforced fill from State responses to the survey.

Most of the states compact their soils based on 95% of AASHTO T99 or ASTM 698, with a few states (14%) having a greater density requirement. However, there was a much greater disparity in moisture requirements. About half of the respondents use -2 % to +2 % of optimum moisture, with some states using -3 % to 0 % and a few states allowing -3 % to + 3 %. One state allowed up to +4 % above optimum and two states allow moisture contents down to -4 % below optimum.

One of the problems in evaluating the use of marginal soils is its definition. The state agencies were also asked to define marginal soils. Most defined standard soils as meeting their specific specifications. Thirty-eight (38) state transportation agencies provided responses indicating their definition of a "high fines" reinforced fill. The responses are summarized in Figure 2. As can be seen from the figure, most respondents consider a soil containing "fines" in excess of 15% as a "high fines" reinforced fill. Thirty-five (35) state transportation agencies provided information as to their definition of a "high plasticity" reinforced fill. The responses are summarized in Figure 3. Most respondents consider a soil with a plasticity index greater than six as exhibiting "high plasticity".

Only two agencies indicated that they allow the use of high fines and/or high plasticity soils in the reinforced zone of MSE walls and both of those agencies indicated unsatisfactory MSE wall performance, in some cases, where "high fines" reinforced fill was used. Problems noted included: excessive lateral deformation of wall; vertical settlement of reinforced fill; and movement/cracking and aesthetics/staining facing problems.

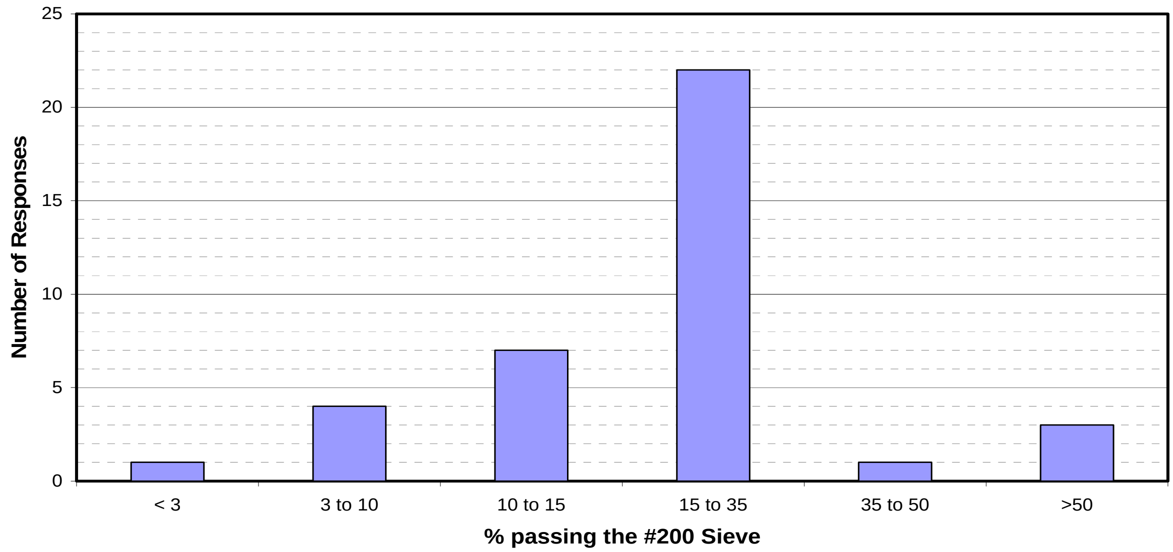

Figure 2. Definition of “high fines” reinforced fill from State responses to survey.

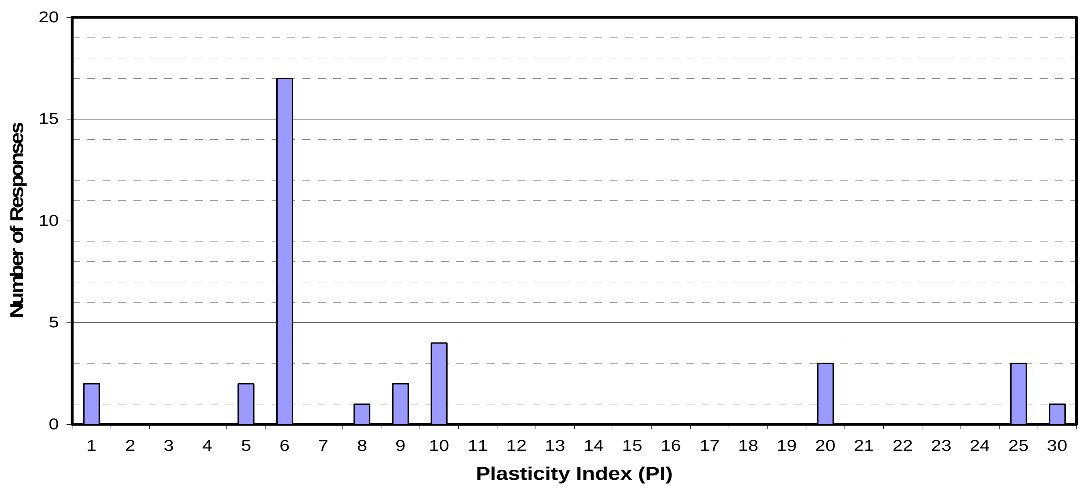

Figure 3. Definition of “high plasticity” reinforced fill from State survey responses.

It is clear from the responses that, for state transportation agencies to adopt the use of “higher” fines soils in reinforced fills in the future, the properties of “high fines” reinforced soils and associated design/construction controls that give acceptable performance must be clearly defined.

U.S. Industry Responses

The following industry responses represent those of the National Concrete Masonry Association (NCMA) as an organization and three individual member firms of that organization (two independent consultants, one GRS wall vendor). The three respondents follow AASHTO specifications for MSE walls with metallic reinforcement and NCMA specifications for MSE walls with geosynthetic reinforcement. One of the consultants stated that they use their own project specific specifications. All four respondents base their compaction of 95% of ASTM 698.

However, as with the state agencies moisture content requirements varied with two of the respondents requiring moisture contents between -2 % to +2 % of optimum moisture, one respondent allowing moistures to range from -2 % to +4 %, and one of the consultants indicating that moisture control was not applicable (your fired!).

Only NCMA and one of the consultants provided a response to their standard gradation specification requirements for reinforced fill. The NCMA specification allows up to 35 % less than 0.075 mm (i.e. passing the #200 sieve). The consultant respondent restricts the amount finer than 0.075 mm to a maximum of 10 %. Both recommendations are for geosynthetic reinforcement only. The NCMA recommends allowing soils with a plasticity index of up to 20 % to be used in a reinforced fill. One the consultants agreed with this recommendation, while the other would restrict the maximum acceptable plasticity index to 10 %.

The responses from private industry regarding the definition of "standard reinforced fill" are extremely varied with one of the consultants responding that reinforced fill type is selected on a project by project basis and clay reinforced fill is often used, but select granular soil is also used frequently. The other consultant indicated that standard reinforced fill has a Plasticity Index of less than 25% and Liquid Limit less than 45. NCMA responded that standard fill has a maximum 35% less than 0.075 mm as recommended in their design guide.

The definition of marginal reinforced fill was equally varied. "High fines" classified by the amount passing a #200 sieve was indicated by one consultant as 3 to 10% percent, the second consultant indicated 15 to 35% and NCMA stated 35 to 55% percent. There was better agreement on the classification of "high plasticity" reinforced soil with NCMA and one of the consultants indicating PI > 20% and the other consulting indicating PI > 25%.

With regard to allowing the use of either "high fines" or "high plasticity" marginal fill, one of the consultants indicated that only high fines soils are allowed, the other indicate that both "high fines' and high plasticity soils are allowed. NCMA indicated that marginal soils are not recommended in their guidelines, but they are aware of structures designed with NCMA guidelines using high fines soil."

When asked "What additional testing (during construction) and/or restrictions do you impose when using "high fines" and/or "high plasticity" reinforced fill?." NCMA stated the following: "NCMA recommends that a geotechnical engineer be retained to evaluate the time-dependent nature of the proposed reinforced fill, and that additional consideration be made for the inclusion of subsurface drainage collection (i.e. chimney drains at rear of reinforced fill zone, blanket drain at foundation/reinforced fill interface). NCMA recommends a plasticity index less than 20 to ensure material classifies as SC, ML or CL per USCS."

The two consultants indicated that approximately 1 in 100 walls have experienced problems with lateral deformation and facing movement and cracking. One of the consultants indicated that about 1 in 20 have aesthetics/staining problems and that they were aware of 1 collapse in about 500 projects constructed with either "high fines" or "high plasticity" soils used for the reinforced fill.

NCMA indicated that they are aware of poor GRS wall performance related issues with "high fines" reinforced fill, but they do not maintain statistical records. NCMA also indicated that the following factors have contributed to unsatisfactory performance of MSE walls: (1) reinforced fill materials with fines content at or greater than 50% fines, (2) poor or no surface or subsurface water control, resulting in excess poor pressures not considered in the design, (3) instances of inappropriate construction practices, (4) inadequate compaction, (5) improper reinforcement placement, and (6) improper control of soil moisture contents.

With regard to special drainage, the responses indicated that NCMA endorses all forms of drainage control for MSE walls, when "high fines/high plasticity" soils are used for reinforced fill. In fact, they have published a guidance manual (Segmental Retaining Wall Drainage Manual; NCMA Publication Number TR 204), which provides general guidelines for incorporating drainage details and systems into MSE wall design and construction. One of the consultants indicated that they do incorporate the drainage feature in their wall designs when using fine grain soils and the other indicated that they do not (fired again!).

The use of "high fines" and/or "high plasticity" soils for reinforced fill is much more common in the private sector. However, presently, there was no rational economic basis provided for including such soils in the reinforced fill zone of reinforced soil walls.

LITERATURE REVIEW

From the published literature, 22 cases of walls with metallic reinforcement and 75 cases of walls with geosynthetic reinforcement were identified. There are very few reported case histories of the use of metallic reinforcement with "high fines" and/or "high plasticity" soils. Of the half dozen or so metallically-reinforced walls constructed with "high fines" and/or "high plasticity" soils, the performance of these walls varied; but, more often than not, serviceability problems occurred. Of the 75 reinforced walls with geosynthetic reinforcement, forty- four of the cases are located in the United States (U.S.) and 31 are located in nine other countries. The majority of the walls were constructed in the period between 1980 and 2000. The earliest wall was constructed in 1974 in the U.S. The tallest wall is 35 meters high and is located in Taiwan.

The types of reinforcement used in these 75 walls included both geotextiles and geogrids. There were a variety of wall facing types, including modular concrete blocks, full height pre-cast panels, vegetated, metal mesh, used tires and timber lagging, etc.

The soil types in the reinforced zone of the walls were not well documented, particularly for the international cases. In general, the soil types can be categorized into three groups: silty sand with clay, sand, and gravel. Furthermore, the percentage of soil that is finer than 0.075 mm (# 200 Sieve) is also noted. The highest "fines" content were greater than 50% in a number of domestic cases.

In these 75 cases, the performance of 23 walls was not acceptable, due either to collapse or excessive deformation of the walls. Fifteen of the failure cases occurred in the U.S. and eight in other countries. The information indicates that water pressure in or behind the reinforced fill was the major cause for the excessive deformation or collapse of the walls. In most of the unacceptable cases, silty sand and clay soils have contributed to the problems in the stability of the walls. Most of the remaining walls with acceptable performance were reported to have been constructed with sand and/or gravel; however, eight of the walls were constructed with high fines, granular soils and two of the walls were constructed with silt and clay type soils.

The characterization of the soil properties was limited to the friction angle of the soil and density in some cases. Regarding the field test procedures for the reinforced fill soil, no information was found. Only a few cases provided the compaction method used during the placement of the reinforced fill soil.

Two well instrumented test walls constructed with marginal reinforced fill were identified from the literature search. The first was the Algonquin test wall constructed in 1988 as part of an FHWA "Behavior of Reinforced Soil" study. The wall was reinforced with metallic grids and non-plastic silt (90 % < 0.075mm) was used to construct the reinforced fill zone to compare the performance of fine grain soils with high quality backfill used to construct other test walls at the site. An increase in lateral movement of the wall face (on the order of 50 % greater than walls constructed with low fines reinforced fill) was observed during construction of the wall. A significant increase in deformation (approximately twice the initial deformation) was observed over the first winter season and was attributed to frost effects. Another important observation was the significant force measured directly beneath the facing panels, which was over five times greater than the weight of the panels themselves. This increase was attributed to downdrag stresses on the back of the facing units.

The second was a geosynthetic reinforced fill wall constructed at the Louisiana Transportation Research Center (LTRC) in 1998, using silty clay soils as the reinforced fill. The LTRC test wall was constructed at the LTRC Pavement Research Facility. It consisted of a 6 m high vertical wall with modular block facing. It was constructed using medium plastic (PI = 15) silty clay soils for the reinforced fill. The wall was reinforced with various types of geogrids. The test wall was constructed to evaluate the behavior of MSE walls constructed with silty clay soils, through comparison of predicted performance and field measurements. The results were published by Farrag et al, 2004.

BACKFILL PROPERTIES THAT IMPACT DESIGN AND PERFORMANCE OF REINFORCED SOIL WALLS

The case histories reviewed in the last section clearly indicate that while there may be a significant savings in using lower quality backfill, property values must be carefully evaluated with respect to influence on both internal and external stability. These properties include the permeability, both drained and undrained strength characteristics, deformation characteristics, environmental effects, and moisture-density relationships with respect to design properties and construction control. The survey of state and industry representatives indicate that these properties are not currently considered, even when marginal soils are used.

Permeabiltiy

Permeability of the reinforced fill is an important operational property. As the percentage of fines of the reinforced fill increases, its permeability decreases. As discussed by Zornberg et al., 1998, wetting of "high fines" MSE reinforced fill from infiltrating groundwater, rainfall or other sources of water (e.g. snow melt, etc.) can allow pore water pressures to develop within the reinforced fill zone. Surface water drainage and drainage from the retained soil zone are also of concern with respect to development of pore water pressures behind or within the reinforced fill zone. Positive pore water pressures affect the stability of a MSE wall in two important ways. Positive pore water pressures produce a horizontal seepage force on the reinforced fill that decreases stability. Positive pore water pressure also reduces the shear resistance of the reinforced fill soil. The magnitude of these effects on wall design and performance are well covered by Koerner and Soong, 1999. Their study indicates that without drainage, the total force against the wall can be twice that of a properly drained reinforced fill soil.

Strength Characteristics

The internal frictional strength of the reinforced fill is an important property influencing the maximum tensile force in the reinforcing layers; although the maximum tensile force is also related to the type of reinforcement in the MSE mass (i.e. extensible or inextensible). Figure 4 shows the variation in normalized reinforcement tensile force versus angle of internal friction (φ) of the reinforced fill for a MSE wall with a horizontal reinforced fill surface, for both extensible and inextensible reinforcement. For every one degree reduction in frictional strength of the reinforced fill, there is an approximately 5 percent increase in the reinforcement tensile force. Thus, with "high fines" soils, the required reinforcement strength will typically be greater than for a "low fines", granular soil. Both total and effective shear strength parameters should be evaluated in order to obtain an accurate assessment of horizontal stresses, sliding, compound failure (behind and through the reinforced zone) and the influence of drainage on the analysis. Both long-term and short-term pullout tests as well as soil/reinforcement interface friction tests should be performed. Pullout and interface friction may also be significantly lower in poorly draining soils (e.g., Chew et al., 1998) necessitating that tests be performed to determine these property values for design.

Deformation Properties

One of the more serious issues with "high fines" reinforced fill is the anticipated increase in vertical and horizontal deformation, both during and after construction. During construction, the elastic modulus of the MSE reinforced fill is an important property value (see Christopher, 1993). "High fines" soils tend to deform more than clean, granular soils, and the deformation may be time dependent. Therefore, the compressibility characteristics of these soils may have to be evaluated, depending upon the nature of the MSE structure. Increased deformation creates several issues that must be addressed in design including:

- Maintaining wall alignment during and after construction.
- Potential deformation of supported structures and utilities.
- Downdrag on the back of facing units and facing connections.
- Increased potential for tension cracks.

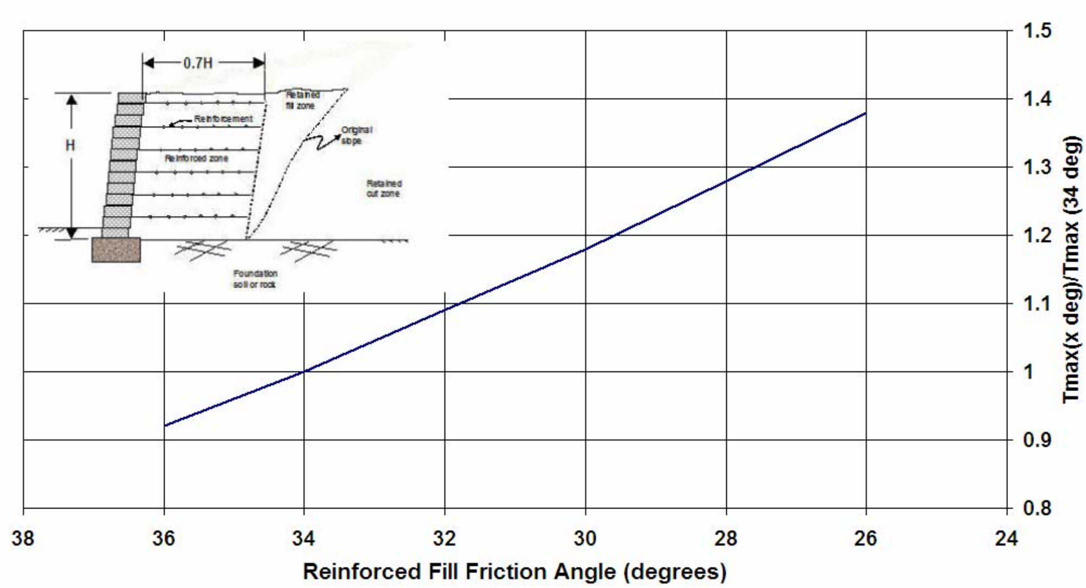

Figure 4. Strength of reinforced fill (ϕ) versus normalized reinforcement tensile force.

With regard to wall alignment, greater care will be required during construction to meet alignment and grade requirements. The magnitude of post construction movement should be estimated and provided to the designers of supported facilities. Where tolerances do not allow for post construction deformation (i.e., bridge abutments), high fines reinforced fill should not be used. The surface of MSE structures using high fines fill should be monitored after construction to confirm that deformation has subsided before construction of supported structures. Downdrag issues may require greater overfilling at connections, beveled and/or rounded edges on the back of modular blocks and stress relief mechanisms in rigid connections. Compression layers could also be placed between blocks to allow the facing units to move downward with the fill.

Moisture-density control (i.e., compaction control) is essential for controlling short and long term deformation as well as achieving and maintaining design strength values. Fine grained soils places only a few percent dry of optimum (as little as 1 or 2 % depending on the soil type) have a tendency to strain soften, loosing strength and increasing their deformation response for both loading and soil/reinforcement interaction (i.e., increased movement should be anticipated). Hydrocompaction (i.e., compaction due to wetting) is also possible in dry fine grained soils, creating even greater potential for long term movement. Clayey soils placed wet of optimum will consolidate and thus deform over time. Therefore, hydrocompaction test should be performed on soils at the dry extremity of the moisture controlled condition (especially is silt type soils are used for reinforced fill) and consolidation test should be performed on soils at the wet extremity of the moisture controlled condition (especially if clayey soils are used) in order to accurately predict long term movement.

The most serious issue is related to post construction tension cracks. The relatively brittle nature of compacted "high fines" soil makes it prone to tension cracks that tend to form at the back of the reinforcement zone, as settlement occurs in the reinforced fill. The corresponding low permeability of high fines fill allows for pore pressure to develop from surface water entering the crack(s). A number of wall failures have been attributed to this development of pore pressure in tension cracks. To preclude the development of tension cracks directly behind the reinforced soil mass and provide increased overall stability, consideration should be given to extending the lengths of the upper level reinforcements. A chimney drain at the back of the reinforced soil mass could be used to provide pore pressure relief, and the ground surface should be sloped away from the wall face, or otherwise treated, to reduce the availability of surface water to the reinforced zone. In any case, chimney drains should especially be used on cut slopes as recommended by the Federal Highway Administration (Elias and Christopher, 1997).

Environmental Effects

Environmental effects become an important consideration relative to the performance of MSE walls containing "high fines" reinforced fill. These include shrink/swell potential, frost susceptibility, hydro-compaction potential, and susceptibility to surface tension cracks.

Alternate wetting and drying of "high fines" fill can cause shrink/swell to occur as well as the formation of micro-cracks. Under alternate cycles of wetting and drying, these micro-cracks begin to grow and spread throughout the reinforced mass. Pore water pressure can result from water infiltration into the reinforced zone.

The frost susceptibility of soils increases with increasing "fines" content. In cold climates, freeze-thaw effects can cause a volume increase (i.e., increase in lateral movement) during freeze and strength reduction during thaw. Gravels and sands with greater than 20% to 15% fines and silts are categorized as high frost susceptible soils by the US Army Corps of Engineers.

As previously discussed, wetting of "high fines" soil compacted dry of optimum moisture from infiltration of groundwater or surface water can cause swelling and strength reduction, which in turn can result in increased movements/deformations. This is particularly true for soils that are placed and compacted well dry of optimum moisture content.

An increase in electro chemical properties is also associated with increased fines in the soil. The fines often contain salts and, thus an increase in fines often corresponds to a higher reduction factor for chemical degradation. A careful evaluation of sodium and chloride content is required.

CONCLUSIONS

The results of the literature search and survey indicate that reinforced soil walls on transportation projects are generally conservatively designed, with "low fines" reinforced soils. Private sector reinforced soil walls are less conservatively designed, and use a variety of reinforced soils (NCMA allows for 35% < 0.075mm). It is also clear from the literature that reinforced soil consisting of fine-grained soils (either "high" fines or "high" plasticity) and pore pressure resulting from lack of drainage in the reinforced zone were the principle reasons for serviceability problems (excessive deformation) or failure (collapse).

However, on further review, it appears that a higher quantity of fines could be safely allowed in the reinforced fill, provided the properties of the materials are well defined and controls are established to address the design issues. We have calculated that the potential savings from replacing AASHTO reinforced fill materials with marginal reinforced fill materials could be in the range of 20 to 30% of current reinforced soil wall costs.

Permeability of the reinforced fill is an important operational property. As the percentage of fines of the reinforced fill increases, its permeability decreases. Wetting of "high fines" reinforced fill from infiltrating groundwater, rainfall or other sources of water (e.g. snow melt, etc.) can allow pore water pressures to develop within the reinforced fill zone. Positive pore water pressures affect the stability of a reinforced soil wall in two important ways. Positive pore water pressures produce a horizontal seepage force on the reinforced fill that decreases stability. Positive pore water pressure also reduces the shear resistance of the reinforced fill.

When using "high fines" (low permeability) soil as reinforced fill, it is imperative that either any possible water be kept out of the reinforced zone by collecting and discharging it away from the reinforced zone, or else pore pressures must be included in the analysis and design of geosynthetic reinforced soil walls.

One of the more serious issues with "high fines" reinforced fill is the anticipated increase in vertical and horizontal deformation, both during and after construction. "High fines" soils tend to deform more than clean, granular soils, and the deformation may be time dependent. Therefore, the compressibility characteristics of these soils may have to be evaluated, depending upon the nature of the reinforced soil structure.

Environmental effects become an important consideration relative to the performance of reinforced soil walls containing "high fines" reinforced fill. These include shrink/swell potential, frost susceptibility, hydro-compaction potential, and susceptibility to surface tension cracks.

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