Benefit of Soil Testing for the Design of Reinforced Soil Structures

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Summary: Soil reinforcement is widely used in New Zealand in slip repair and wall construction. Methods for designing soil reinforced structures have become more conservative over the years with an increased knowledge regarding the long term performance of reinforcing materials. Concurrently the level of soil testing has not been maintained, increasing the level of conservatism. This paper analyses typical reinforced soil structures found in New Zealand using a range of soil strengths. Both reinforced slopes having a fine grained soil and soil reinforced walls using imported gravel are considered. The results are presented in a graphic form detailing the reinforcement length to height (L/H) ratio and reinforcement demand required to achieve stability. The analysis and results presented herein demonstrate that there is a benefit to both the designer and the client in achieving a more efficient and secure design when soil testing is carried out.

INTRODUCTION

Reinforced soil structures have been used for the repair of dropouts along State Highways in New Zealand since the mid-80's and is now accepted practice. The limited availability of level land for new road construction in housing subdivisions and motorway extensions has seen a further increase in the use of reinforced soil structures. The majority of these structures fall into two main categories:

- Reinforced Steep Slopes (RSS) having a vegetated face and using in situ soils that are generally fine grained with a level of cohesion.
- Mechanically Stabilised Earth Walls (MSEW) having a hard facing and using imported, non-cohesive soils.

Current methods for analyzing the stability of reinforced soil structures have undergone little change since their introduction in the early 70's. However, at the same time, our understanding of the performance of reinforcing materials, in particular polymer geogrids has increased dramatically. International studies into the performance of reinforced soil structures have highlighted a level of conservatism in design with the measurement of lower than predicted loads taken up by the reinforcing elements. The introduction of new design codes which include additional material reduction factors can further increase this level of conservatism if the soil to be used is not tested and the properties confirmed.

In New Zealand there is no specific requirement for the testing of soils used in the construction of reinforced soil structures. Where soil investigations have been carried out, laboratory testing that follows has minimal value in the determination of strength properties typically required in design. Conservative strength parameters are generally assumed resulting in excessive fill and reinforcement, putting further strain on our limited resources of good quality aggregates for use in MSEW construction.

This paper discusses the benefits offered through appropriate soil testing where reduced risk and design efficiency are weighed against the current conservative approach for determining soil strength parameters used in the design of reinforced soil structures.

SCOPE AND OBJECTIVE

This study will examine only the internal stability of reinforced soil structures assuming that in all cases the external stability is satisfied by a L/H ratio of 0.7, which thus forms the lower boundary of any cost analysis. The software program Reslope, which was originally developed for the US Corps of Engineers, has been used to analyse the following reinforced soil structures having a homogeneous backfill:

- Reinforced Steep Slopes (RSS) at two different face batters of:
  - 1H:1V (Silty Clay backfill)

  - 1H : 2.5V (Silty Clay backfill)
- Mechanically Stabilised Earth Walls (MSEW) at a face batter of:
  - 1H : 16V (Sandy gravel backfill)

Reinforcement properties and material strengths have been used for the analysis that conforms to the type of backfill in terms of installation damage and soil interaction. The reinforcement used is limited to extensible reinforcement which is characterized by having strain values that are comparable or greater than the backfill used. Therefore the active earth pressure coefficient used in the analyses remains constant from the crest to the base of the structure.

The objective of this investigation is therefore to confirm what height or size of RSS and MSEW justifies the cost of appropriate soil testing to gain a more efficient and cost effective design without placing risk on the design engineer or the client.

ASSESSMENT OF REINFORCED SOIL STRUCTURES

Background

A range of soil reinforcement and retaining design standards developed for British and American engineers are commonly used in New Zealand. All of these standards make reference to the use of triaxial or shear box apparatus to obtain design soil strength values. This requirement can be considered an essential part of the design process as the soil contributes between 75 – 80% of the internal shear strength of reinforced soil structures.

Method

A limit equilibrium analysis incorporating a log spiral failure mechanism for tensile capacity and pullout and a two part wedge analysis for sliding has been considered to assess the sensitivity of soil strength on the design and cost of reinforced soil structures. This approach has been chosen over a limit state method as there are less load factors and partial factors to consider that could influence the end result.

A competent foundation has been considered in all cases.

Reinforced Steep Slopes (RSS)

Input Data

The input data used for the analysis has been modeled to represent a typical slip repair below a road using in situ soils.

The majority of RSS are constructed using soils that are characterized by having high fines content. These soils are sensitive to variations in moisture and therefore construction is limited to the summer months. The low cost for fill of approximately $\$10/m^3$ to place and compact makes these soils more preferable than imported materials. Cohesion has a significant effect on stability. However over the design life the level of cohesion is likely to decrease and has therefore been ignored for the analysis. This follows standard practice and recommendations contained in International publications and guidelines. The bulk density of the soil has been taken as $18kN/m^3$.

Groundwater is a major contributor to slip formation and therefore groundwater conditions are a key element in design. The analysis assumes drainage at the rear and base of the RSS and any long term infiltration of water into the reinforced soil block is represented by a non-dimensional pore water pressure (Ru) value of 0.15.

External loads are in the form of a traffic surcharge of 12kPa over a width of 7.5m and are located 1m back from the slope crest. Seismic loads have not been considered.

To investigate the influence of the backfill soil strength on the cost of the RSS the analysis has been carried out using a range of effective friction angles from 20^0 to 32^0. These represent the mobilized friction angles for clays which are typically found in New Zealand. It should be noted that the friction angle for clay used in reinforced slopes falls towards a large strain constant volume value to mobilise the tensile strength of the reinforcement along the full length of the failure surface.

Reinforcement

The reinforcement used has a long term design strength of 20kN/m and a soil interaction value of 0.8 for both pullout and direct sliding. The maximum allowable vertical spacing has been limited to 1m for 1:1 slopes and 0.5m for steeper slopes where wrap around construction is required to form the facing.

Geometry

To fully understand the benefits of soil testing a range of slope heights have been considered that start at 2m and increase at 1m intervals up to 8m to represent what has been typically constructed in New Zealand.

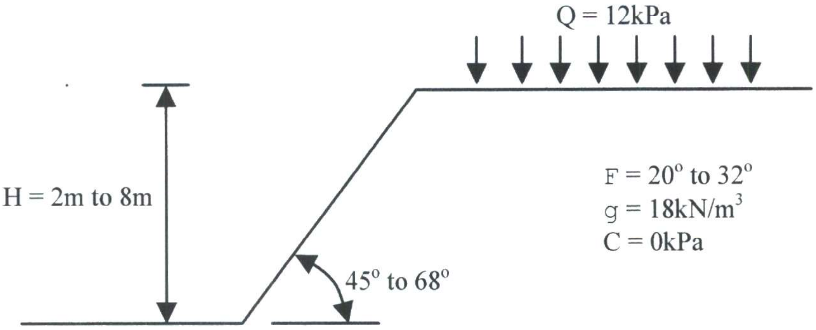

Figure 1. Layout of reinforced soil slope

Results

The results of the L/H ratio for a 1:1 slope looking at both reinforcement pullout and base sliding are detailed in figure 2. The low soil strength which is compounded by a pore-water pressure has produced a L/H ratio that reduces from 2.3 in the worst case down to the minimum of 0.7. This minimum is only achieved when the soil friction angle is above 29° in pullout and the wall height is above 2m. In the sliding analysis the lower bound value of 0.7 is not achieved and in all cases the reinforcement length is governed by base sliding. The curves confirm that a soil having a low friction angle and pore-water pressure generates a deeper failure surface and higher reactive force.

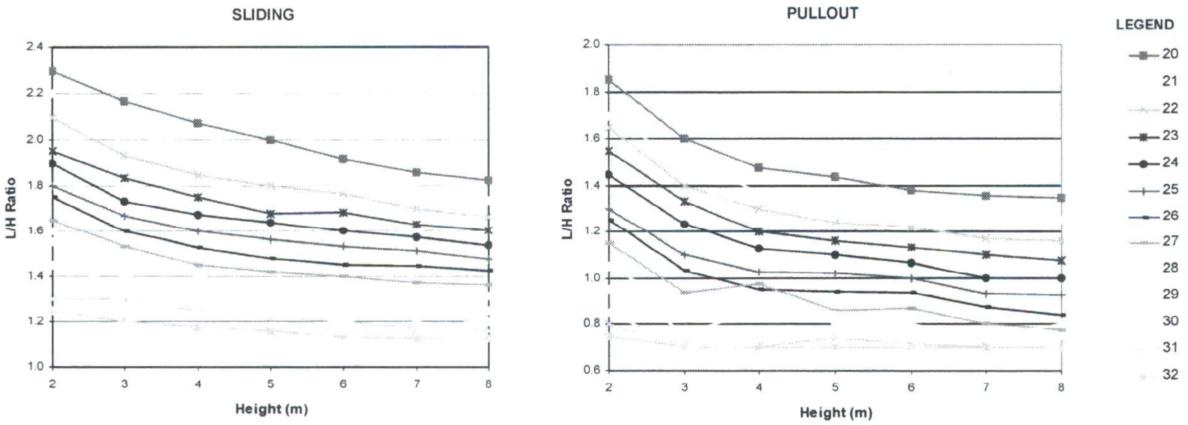

Figure 2. 1:1 Slope - Results for L/H ratio

The results for the 1:2.5 slope in figure 3 show L/H ratios that are lower than those for the 1:1 slope. Once again the threshold of 0.7 for the L/H ratio was not achieved in sliding with the 0.7 threshold in pullout achieved at 25° friction angle and height greater than 5m. It should be noted that curves for sliding are consistent for each friction angle. This differs in pullout where the number of reinforcement layers influences the required reinforcement length.

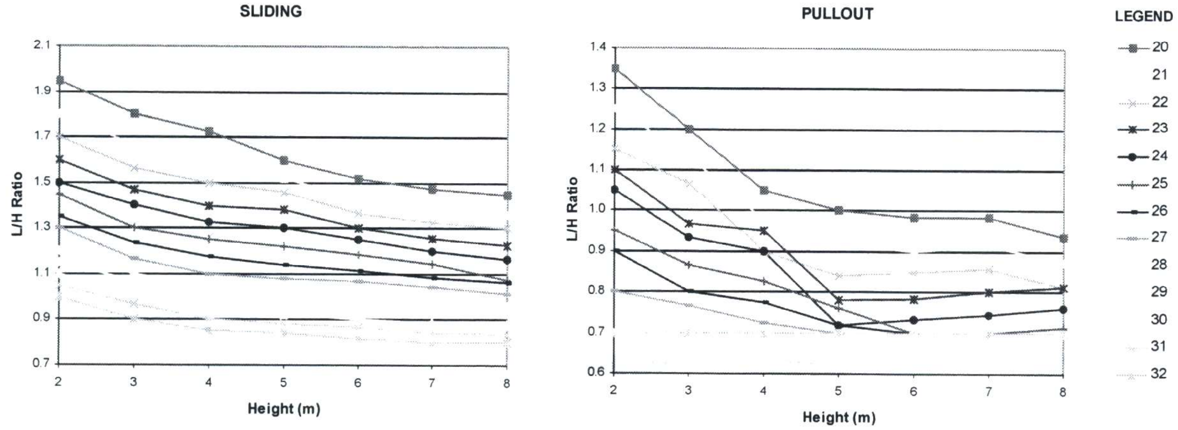

Figure 3. 1:2.5 Slope - Results for L/H ratio

The results for the reinforcement demand required for stability are detailed in figure 4 for both the 1:1 slope and 1:2.5 slopes. The increase in demand is more pronounced above 4m and as the slope angle gets steeper. The baseline strength requirement also doubles from the 1:1 slope to the steeper 1:2.5 slope.

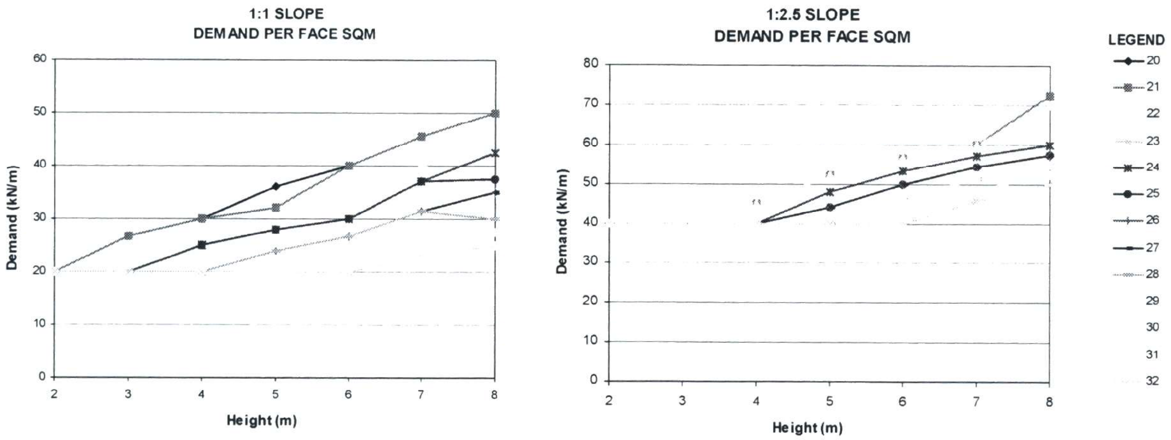

Figure 4. Reinforcement demand for RSS

Mechanically Stabilised Earth Walls (MSEW)

Input Data

The input data used for the analysis has been modeled around a segmental block retaining wall having a near vertical face and using imported granular fill.

Although there are cases of using finer grained soils in MSEW construction the majority of walls are designed using cohesionless quarried materials having a high friction angle. The cost of these materials varies depending on the distance from source. For the purpose of the cost analysis a value of $35/m^3 has been used for placement and compaction. The bulk density of the soil has been taken as 19kN/m^3.

The analysis assumes that the rear and base of the MSEW contains drainage systems to ensure a fully drained reinforced soil block.

External loads are the same as those for the RSS with a traffic surcharge of 12kPa over a width of 7.5m and are located 1m back from the slope crest. Seismic loads have not been considered.

To investigate the influence of the backfill soil strength on the cost of the MSEW the analysis has been carried out using a range of effective friction angles from 30^0 to 42^0. These represent the peak friction angles which are typically found in New Zealand. Measured stains of geosynthetics used in actual walls are generally lower than predicted and more closely match the peak friction angle of the fill used. Friction angles currently used in MSEW design tend to follow more closely constant volume friction angles.

Reinforcement

The reinforcement used has long term design strength of 15kN/m and a soil interaction value of 0.95 for both pullout and direct sliding. Post construction strain levels are assumed to be within the 1% allowable to assure that wall deformations are within acceptable limits. The maximum allowable spacing has been limited to 0.6m as a multiple of the standard 0.2m segmental block height as well as following accepted practice for MSEW wall design in seismic areas using a segmental block facing.

Geometry

The same wall heights used for the RSS analysis have been considered for the analysis of MSEW. These start at 2m and increase at 1m intervals up to 8m which are typical of what has been constructed in New Zealand.

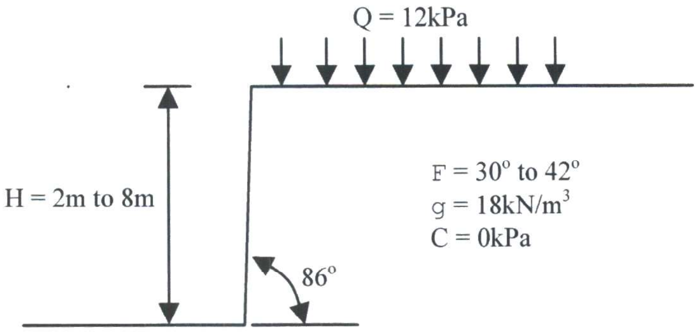

Figure 5. Layout of mechanically stabilised earth wall

Results

The results for the L/H ratio for the MSEW fall below the minimum L/H ratio of 0.7 across the full range of friction angles in terms of both reinforcement pullout and base sliding as detailed in figure 6.

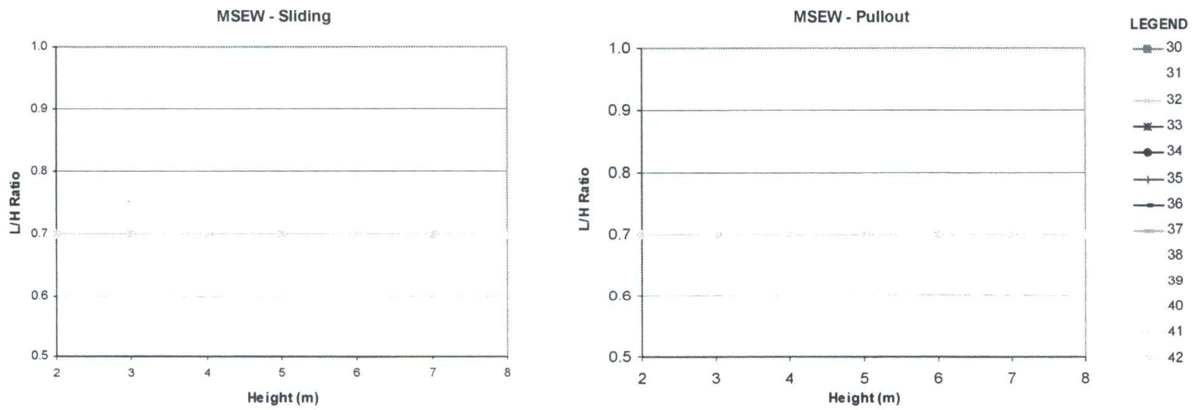

Figure 6. MSEW - Results for L/H ratio

The higher friction angles typically adopted for MSEW design result in a lower demand level on the reinforcement when compared to the 1:2.5 slope and similar values to that of the 1:1 slope. Once again the demand level shown in figure 7 increases more dramatically at wall heights above 4m.

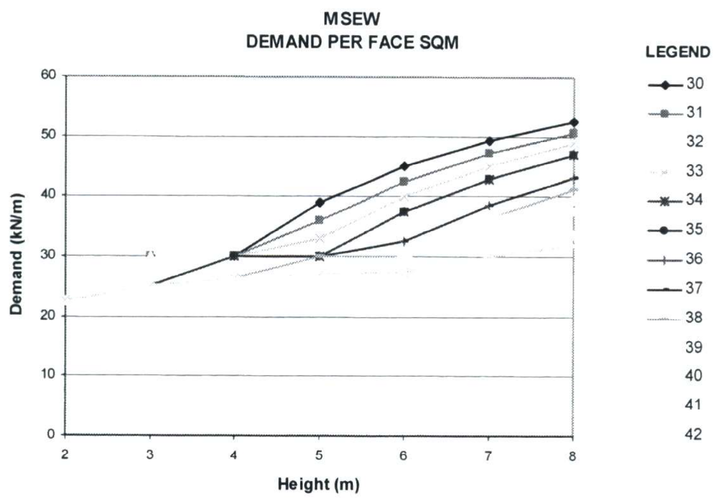

Figure 7. MSEW - Reinforcement demand for RSS

TESTING

Various design codes make reference to both shear box and triaxial testing to determine the shear strength of the soils. Verbal quotes from soils laboratories in the Auckland region have put the cost of a triaxial test between NZ$1200 to NZ$1500 for consolidated drained triaxial test.

COST ANALYSIS

A cost analysis of three reinforced soil structures is summarized in table 1 below demonstrating the average saving in the total installed cost for every 1^{o} increase in soil strength.

Table 1. Average saving for each incremental increase in soil strength

Structure Type	2m	4m	6m	8m
1:1 RSS	3.7%	5.3%	6.5%	7.1%
1:2.5 RSS	4.1%	5.1%	6.0%	6.7%
MSEW	0.0%	0.5%	1.9%	2.6%

It is interesting to note that there are no savings for the MSEW below 4m in height and at 4m a single saving of 4.9% is achieved resulting from a reduction in the reinforcement layers with an increase of soil strength from 35^{o} to 36^{o}. This averages out at 0.5% across the range of friction angles considered.

Table 2 shows the average installed cost and table 3 the minimum size of reinforced soil structure required to cover the cost of $1500 for soil testing based on a 1^{o} gain in soil strength.

Table 2. Average installed cost per face m^2

Structure Type	2m	4m	6m	8m
1:1 RSS	$132	$167	$188	$245
1:2.5 RSS	$155	$180	$226	$287
MSEW	$298	$320	$351	$397

Table 3. Size of structure in face area required to cover soil testing cost

Structure Type	2m	4m	6m	8m
1:1 RSS	309	170	122	85
1:2.5 RSS	279	189	123	86
MSEW	n/a	3040	602	330

The size of structure is based on a 1° gain in soil strength. In New Zealand 35° is commonly used for granular fill whereas proper testing is likely to show a strength at least 3° to 5° above this value. This would reduce the size of MSEW required to cover the cost of testing especially for walls above 4m in height.

CONCLUSIONS & RECOMMENDATIONS

The L/H ratio is generally used by engineers to set minimum reinforcement length requirements for reinforced soil structures having varying heights over the length of the structure. This ratio is shown to vary considerably for slopes constructed with fine grained soils where base sliding is the governing failure mechanism for determining reinforcement length. The use of a L/H ratio for walls shows a much higher level of reliability.

The size of RSS required to cover the cost of soil testing for just a 1° increase in soil strength is typical of the size found in dropout repairs along New Zealand State Highways and marginally smaller than those found in subdivisions and other new works. The benefits are less noticeable in MSEW where the minimum L/H ratio of 0.7 governs the design.

The results show that the reinforcement demand increases more dramatically for slope and wall heights greater than 4m. This can be attributed to the upper limits placed in reinforcement spacing and minimum reinforcement strengths that provide excess capacity for low height structures.

The benefits of soil testing are clearly evident across the full range of RSS heights and offer a lower cost to the client and a lower level of risk to the design engineer. In the case of the MSEW, the immediate benefits are gained for wall heights greater than 4m where a granular fill is used. The results of the analysis for walls do however highlight that lower quality granular backfill having reduced strength properties can be considered for these structures without having a noticeable increase in the reinforcement strength and length requirements. The use of these lower strength fills that still offer a drained structure could allow quarry operators to optimize the efficiency of their operation by offering a wider range of materials for MSEW construction.

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