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USE OF POOR DRAINING BACKFILLS FOR REINFORCED SOIL STRUCTURES

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ABSTRACT

The cost of reinforced soil structures have been proven to be cheaper and easier to construct than traditional reinforced concrete retaining walls. These cost comparisons were commonly carried out by fellow researchers in countries where the granular backfill material are abundant. In several other countries such as Singapore, Malaysia etc., very few reinforced soil structures are constructed due to the relative cost of the backfill which has to be imported. This paper details previous technical studies which have shown that the poor draining backfills are suitable for reinforced soil structures if employed with the proper reinforcing element. A cost comparison of using poor draining backfills and granular backfills are also provided.

INTRODUCTION

Reinforced soil structures have been employed for a substantial length of time. The system undoubtedly works by frictional mechanism, with the three main elements, reinforcement, granular backfill and wall facing playing vital parts in the overall function of the system. Of late, the keen market forces globally, has caused the increase in supply and as such competitive prices of the reinforcing element and facings. These price changes have therefore allowed the reinforced soil system to be even more competitive than traditional reinforced concrete (RC) structures. However, in several countries (such as Singapore, Malaysia and Thailand for example), the component that controls the application of reinforced soil systems, is the granular backfill. This is due to the relative high cost incurred in importing the granular backfill for use in reinforced soil structures. The option then would be the use of poor draining backfills.

At present, employment of poor draining backfills for reinforced soil structures is not well accepted due to the lack of sufficient data and experience with such material. This lack of information, has also prevented the authorities from providing guidelines for the use of poor draining backfills in reinforced soil structures. It is interesting to note however that the first reinforced soil structure ever constructed employed cohesive backfill (Puig and Blivet, 1973), while the first fabric-reinforced soil structure built in the USA was constructed with low quality backfill (Bell and Steward, 1977). This trend stopped early either due to recommendations from government agencies or due to the development of codes of practice which prohibited the use of the poor draining materials.

This paper will looks at the technical and cost component of reinforced soil structures construction for both granular and poor draining backfills. Attempts will be made to detail the parameters to be used for poor draining backfills in reinforced soil structures.

REINFORCED SOIL MECHANISM USING POOR DRAINING SOILS

The reinforced soil structure is made up largely of three components, the reinforcing elements, backfill and facing elements. The latter most may not be employed in most structures which are not vertical. The backfill is at all times considered to be frictional (granular) backfills in nature with not less than 15% passing the 63μm test sieve. Similarly, the American, German and European codes have provided for guidelines on the maximum quantity of fines in the fill to be used as backfill material.

When Vidal (1970) introduced the reinforced soil mechanism to the Civil Engineering market, the main component stabilising or maintaining the reinforced soil structures equilibrium was the frictional component between the granular backfill and the reinforcing material. The use of granular materials in addition to providing full friction and easy to compact and handle, also allowed pore water pressure issues to be non-existent.

Technical Considerations

The main concern of using poor draining backfill for the reinforced soil structures is

a. Difficult to compact

b. Build up of pore water pressures, causing reduction of frictional resistance

c. Large creep or slip movements.

d. Coefficient of interaction between the geosynthetics and soil may be low

e. Chemical attack

Most highways, embankments, bridge approaches employ cohesive soils for their construction, and require relatively stringent compaction requirements and proper geosynthetic selection. Compaction therefore should not be a problem if geosynthetics are included.

Pore pressures are a component of poor drainage and construction practice and may be overcome with proper site and material selection control. When employing granular soils in reinforced soil structures, the pore pressures do not build up, regardless of the rate of construction or rainfall. With poor draining soils however, the rate of construction has to be monitored to ensure minimum pore pressure build-up. The first reinforced soil triaxial tests employing poor draining backfill soils was carried out by Ingold (1979) reinforced with aluminium foil or porous discs. The results reported showed a loss of axisymmetric compressive strength of up to 50% with respect to unreinforced soil when aluminum foil was employed. The loss of strength was believed to be caused by the excessive high pressures. When the porous discs were employed, the compressive strength increased with pore water pressures decrease to strengths larger than the unreinforced samples. Fourie and Fabian (1987) reported similar behaviours. In other quick undrained triaxial tests using impermeable reinforcement carried out by Ingold (1985), it was reported that high degrees of saturation caused reduction in strength.

Shear box tests performed by Jewel and Jones (1981) with geogrid reinforcements placed at angles to the direction of shear showed that the reinforced poor draining soil (kaolin) was both stiffer and stronger than unreinforced clay. Pull out tests with various poor draining soils under drained and undrained conditions were carried out by Christopher and Berg (1990). The results showed that the drained pullout resistances were not necessarily greater than undrained ones. The coefficient of interaction was also relatively higher than expected.

With geotextiles, Fourie and Fabian (1987), showed that under undrained shear conditions, the non-woven geotextile performed better than wovens and grids. The contact efficiency was nearly 1.0 for non-woven geotextiles. For the pull-out tests under undrained conditions, the wovens and non-woven geotextiles performed equally, but the limitations were dependent on the strengths of the materials as opposed to the pull-out failure resistance. Under drained conditions, the pullout resistance was similar to granular materials. Conclusions drawn by the researchers have shown that woven geotextiles can reinforce clays under drained conditions, while under undrained conditions, transmissivity of the geotextile material is important.

Chew et.al.(1997), carried out several pull-out tests with poor draining soils and woven geotextiles. They showed that with woven geotextiles, the pullout resistance was not affected by inflow of water into the soil mass. The woven geotextiles allowed the permeation of water thus preventing a build-up of pore water pressures.

Jones et. al. (1996) carried out several small scale laboratory tests to determine the behaviour of poor draining soils reinforced with various combinations of geosynthetic materials. To provide strength, high strength grids were employed while a second non-woven geotextile was employed at the top or bottom for the purpose of drainage. The results reported showed that two component materials for the strength and drainage placed together had a lower strength than the components acting alone. The reason cited was the possible slip between the two components. Further tests carried out with non-woven geotextiles with integral strength properties proved to have performed the best. The non-woven component of the geotextile allowed the pore pressures to dissipate, while the strength component was provided by the polypropylene strands integrated into the geotextiles.

With the advent of high strength geotextiles with good transmissivity characteristics, the chances are that creep movements will be negligible. In previous structures constructed with granular soils, strains recorded were usually less than 1% (Yogarajah et.al. 1992). The creep movements for poor draining soils reinforced with woven geotextiles may be estimated to be in the region to those experienced by reinforcements employed in granular materials.

The research findings point to the direction of integral non-woven geotextiles with high strength and good drainage characteristics being suitable for reinforcing poor draining backfills. In most countries where the reinforced soil concept has taken a large portion of the retaining wall market granular backfills are still being employed. The reason for this is two-fold viz a viz: the cost of the granular material is low and the codes do not allow for alternative materials. In Asian countries such as Singapore and Malaysia, reinforced soil structures are used on a lower scale due to the high cost of granular backfill. Below is a cost comparison between granular backfills and residual backfills that could be employed for reinforced soil structures.

Cost Comparison

The cost of reinforced soil structures may be divided into two main categories:

a. Cost of installation

b. Cost of materials i.e. reinforcements, facing, backfill.

$T_c = C_i + C_m$

where

T_c is the total cost of structure
C_i is the cost of installation
C_m is the cost of materials such as reinforcement (C_r), backfill (C_b) and facing (C_f).

When comparing the cost of reinforced soil structures employing different backfills, the components of material is affected the most. This is especially true if the cost of granular backfills (C_b^g) are high.

Backfill

The volume of poor draining backfills such as residuals soils are abundant in many countries thus lowering the costs drastically. In many of these places the cost of the backfill will largely be the cost of transportation. In Singapore for example, the cost of residual backfill soils (C_b^r) is approximately 20% of the cost of granular backfills (C_b^g). This cost may reduce if the soil is from the site of installation. With the present practice, the cost of handling residual materials is approximately 1.3 times more than granular materials.

Reinforcements

With the above technical discussion it is deemed that when employing poor draining soils, non-woven geotextiles with a high strength and drainage characteristics are required. At present, materials with such properties are readily available in the market although not in large varieties. The cost at present is compatible to the geogrids of similar strengths which are being used for granular soils. With the advent of structures with poor draining soils being commonly employed, the cost of these materials is predicted to drop. With present design practices, the reinforcement lengths employed is dependent on the coefficient of interaction between the reinforcement and poor draining backfills. The present values employed are in the range of 0.5 - 0.7, although tests have shown that the figures may be a high as 1.0. When compared to reinforced soil with granular back fills the coefficient of interaction is approximately 0.9 - 1.0. Although several research findings have shown that woven geotextiles have similar coefficient of interaction in poor draining soils as in granular soils, the recommended coefficient of interaction by several suppliers is approximately 0.65. The quantity and thus cost of reinforcement used in poor draining soils may be 1.5 times that of those in granular materials.

This therefore leads to the following:

$$T_c = C_i + C_m$$

for granular soils,

$$T_c^g = C_i^g + C_m^g$$

$$C_m^g = C_b^g + C_r^g + C_f^g$$

where

C_b^g is the cost of granular backfill
C_r^g is the cost of reinforcements for use with granular backfill
C_f^g is the cost of facing

in poor draining soils,

$$T_c^r = C_i^r + C_m^r$$

$$Cm^r = C_b^r + C_r^r + C_f^r$$

where

C_b^r is the cost of poor draining backfill
C_r^r is the cost of reinforcements for use with poor draining backfill
C_f^r is the cost of facing

In the two cases, the facing costs are similar. The cost of installation for poor draining soils are 1.3 that of granular soils (1.3 C_i^g), while the cost of reinforcements are 1.5 times that used in the latter materials. Thus the cost of a reinforced soil structure backfilled with poor draining soils may be calculated as follows:

$$T_c^r = C_i^r + C_b^r + C_r^r + C_f^r$$

$$T_c^r = 1.3\ C_i^g + 0.2\ C_b^g + 1.5\ C_r^g + C_f$$

When comparing the overall cost of constructing a reinforced soil structure with granular and poor draining backfill, the cost of facing may be eliminated.

Figure 1, shows a cost comparison for reinforcement component alone for structures of height 3.0m and above. The reinforcement costs are based on average local prices. It is seen that for the same height of structure, the cost of reinforcements alone in poor draining soils are relatively higher than the cost of reinforcements for granular soils. This increase in cost is due to the relatively larger volume of reinforcements that will be required due to the proposed lower coefficient of interaction.

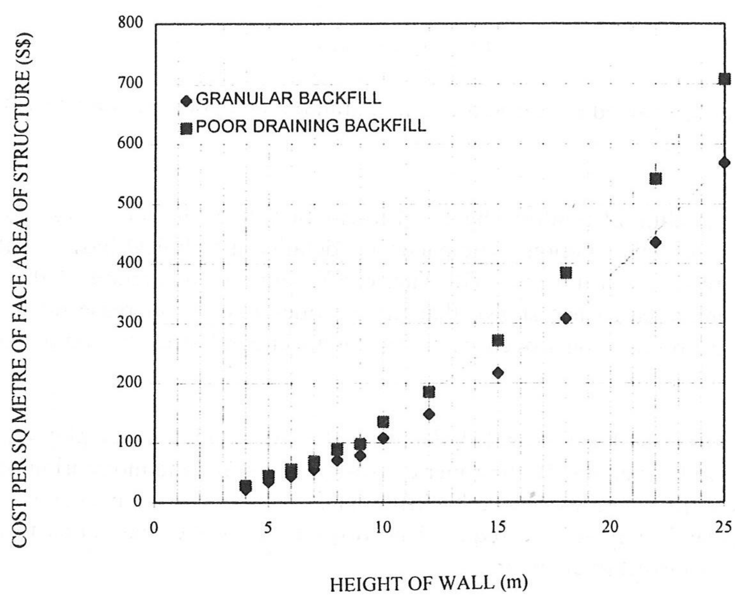

Fig. 1 Cost of reinforcing materials for reinforced soil structures using granular and poor draining backfills.

However, when considering the costs of the total structure (excluding facings), Fig. 2, there is a marked difference in the overall costs. The marked difference is obvious through all the height variations in the structure. The cost of reinforced soil structures with granular soils may be between 1.2 and 1.8 times the cost of structures constructed using poor draining soils.

DISCUSSION AND CONCLUSION

Reinforced soil structures have been constructed to date largely employing granular backfills. In several countries where the cost of granular backfills are relatively high, the cost of reinforced soil structures may not be a feasible option.

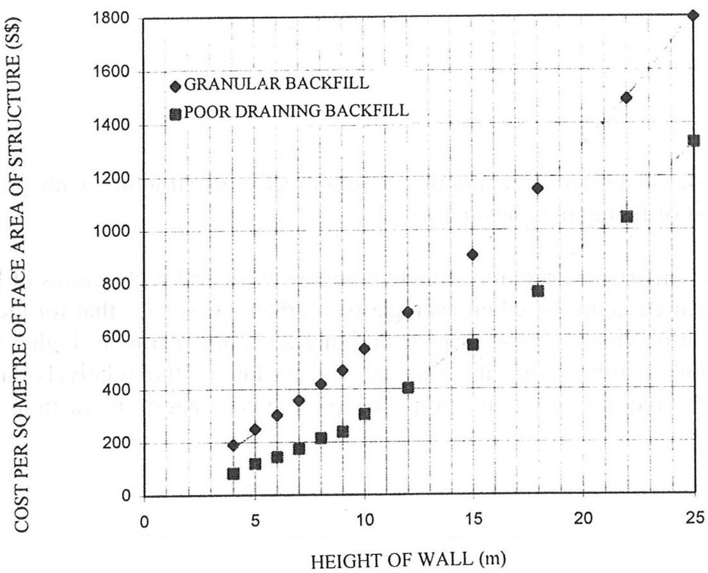

Fig. 2 Cost of reinforced soil structures using granular and poor draining backfills

With the present understanding of reinforcement/soil interaction, poor draining backfills for reinforced soil structures may be a feasible solution. The paper has detailed a technical basis for the use of poor draining soils in reinforced soil structures. Till date, coefficients of interaction of 0.5 to 0.7 are still being employed. Recent research has shown that these values may be increase up to 0.9 if proper drainage is allowed. At present, non-woven geotextiles with integral strength component seems to be ideal for poor draining soils.

The cost comparison has also been provided detailing the advantages of employing poor draining backfills for reinforced soil structures. With proper construction control and monitoring of structures, the system may be suitable in countries where backfill materials are the main cost of reinforced soil structures. Further research may still be required however to draw the line, so as to ensure that the materials employed are not excessively poor.

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