GROUND IMPROVEMENT WITH ORIENTED GEOTEXTILES AND RANDOMLY DISTRIBUTED GEOGRID MICRO-MESH

by

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CERTIFICATE

This is to certify that the thesis entitled **"GROUND IMPROVEMENT WITH ORIENTED GEOTEXTILES AND RANDOMLY DISTRIBUTED GEOGRID MICRO-MESH"** submitted by **Mr. Faisal Hassan Shamsher** to Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy is a record of the bonafide research work carried out by him. Mr. Faisal Hassan Shamsher has worked under our supervision for the submission of this thesis, which to our knowledge has reached requisite standard.

This thesis, or any part thereof has not been submitted to any other University or Institution for the award of any degree or diploma.

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TO THE MEMORY OF MY FATHER

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ABSTRACT

In India, reinforced soil construction has enormous potential in view of the vast tracts of soft alluvial soil deposits and loose aeolian deposits. Various types of geosynthetics have begun to be manufactured indigenously. Thus, it is imperative to understand the behaviour of reinforced soil thoroughly so that they can be effectively utilized in ground improvement with confidence.

This thesis attempts to assess the influence of geosynthetic reinforcement on the behaviour of granular materials under triaxial conditions and to examine the extent of improvement through analytical and model studies. More specifically, the proposed research includes:

i) a study of the in-isolation stress-strain behaviour of woven and nonwoven geotextiles and unoriented geogrids to understand the relationship between their secant modulus and strain,

ii) a study of the triaxial behaviour of large diameter specimens of sands reinforced with oriented layers of woven and nonwoven geotextiles and geogrids,

iii) a study of the triaxial behaviour of large diameter specimens of sands reinforced with randomly distributed micro-mesh elements of geogrids,

iv) a comparison of the experimental findings with available prediction methods of ultimate axial load at failure,

v) an experimental comparison of bearing capacity behaviour of footings resting on geogrid micro-mesh reinforced sand as well as single layer geogrid reinforced sand through limited large scale laboratory model studies, and

vi) an analysis of the experimental data to assess the bearing capacity and settlement aspects of footings resting on reinforced sand over clay bed.

Chapter 1 of the thesis, gives introduction to the present work along with a brief description of the principle of reinforced soil technique and its advantages. In **Chapter 2**, the available relevant literature has been reviewed. The test equipment used is described along with the detailed experimental procedures and test programme in **Chapter 3**.

An extensive laboratory testing programme was carried out using woven (GTW) and nonwoven (GTNP) geotextiles and geogrid (GG) as a circular discs reinforcement and randomly distributed geogrid micro-mesh (GMM) reinforcement (square grids of sizes 30 x 30 and 50 x 50 mm). Four sands S1 (uniform fine grained sand), S2 (medium to coarse grained), S3 (sub-angular particles) and S4 (coarse grained sand) ranging from fine grained sand to coarse grained sand are used for the studies.

In-isolation strength tests were conducted on the geotextile (woven and nonwoven) through strip and wide strip tensile tests in both machine and cross-machine directions. Conventional consolidated drained triaxial tests were conducted on specimens (100 mm diameter x 200 mm high) of sand with and without reinforcement at a deformation rate of 0.2 mm/minute. The number of horizontal reinforcement discs provided was upto 7. The quantity of geogrid micro-mesh used was upto 1.4%. Confining pressures upto 400 kPa were generally applied. In all, a total of 173 traixial tests were conducted using different combinations of sands and geosynthetics.

Model tests on footing were carried out in a rigid steel tank having overall dimensions 1240 x 910 x 800 mm. After filling the bottom 400 mm with granular soil S1 under controlled compaction conditions either a top layer of GMM was provided or a GG was provided below a designated depth from the top. In case of GMM (50x50 mm mesh size) the percentage was either 0.72% or 1.4% (by weight). The thickness of the top layer was varied from 0.5 to 1.5 B and the size of the grid in the later case was varied from B to

5B. The tests were performed on sand S1 under both loose as well as dense conditions.

A detailed analysis of the test results presented in **Chapter 4** brings out the followiong salient observations.

Influence of Reinforcement with Oriented Layers:

i) In general failure envelopes that were linear for unreinforced sand become bilinear on reinforcement. Upto critical confining pressure there is an increase in ϕ', beyond which only c' is found to increase whereas ϕ' remains at the unreinforced value.

ii) A comparison of the computed values of the reinforcement induced confining stress ($\Delta\sigma_3$) with the experimentally measured values indicates that $\Delta\sigma_3$ increases with σ_3 upto a critical confining pressure beyond which there is little change. The general variation is shown to be hyperbolic.

iii) The differences between the behaviour observed for woven and nonwoven geotextiles reinforcement is examined in the context of their in-isolation tensile strength-stress behaviour.

iv) Both reinforced as well as unreinforced sands exhibit a hyperbolic stress-strain behaviour. The predicted ultimate strengths are found to be higher than the measured deviator stress at failure, but upon substituting the relevant values of strain, the prediction improves.

v) The initial tangent modulus of reinforced specimens obtained from the hyperbolic plots is seen to generally remain the same as the unreinforced one, but for some exceptions. However, the secant modulus at around 4% and 6% strain is considerably larger when compared to the unreinforced one. Yet, the secant modulus at failure is usually much smaller with reinforcement in view of the large failure strains.

vi) The total axial load (P_{max}) on the specimen was calculated and compared as per the original model (Broms 1977) and the modified model (Chandrasekaran et al. 1989). The results confirm the earlier observations by Broms that the values predicted by the original model are higher and match with the prediction by the modified model. However, the modified model is found to yield varying values of multiplication factor. The current studies conducted at higher confining pressures and higher $r/\Delta H$ than Broms have revealed that the choice of a single multiplication factor α, (say, 0.45) also yields reasonably sound predictions. The same observation has been confirmed by analysing other published data on specimens 38mm and 1200mm in diameter.

Influence of Randomly Distributed Micro-Mesh Reinforcements

The results clearly indicated that the GMM increased the deviator stress developed at any strain level which confirms the ability of the mesh element to strengthen the soils both at peak and at residual levels.

i) The peak stresses in the soil-mesh mixture occurred at slightly higher axial strain than the sand alone at lower cell pressure.

ii) Generally the failure envelope was bilinear, similar to the one observed with horizontal reinforcement.

iii) The stress-strain relationship is generally hyperbolic. The predicted ultimate strengths are found to be higher than the measured deviator stress at failure, but upon substituting the relevant values of strain, the prediction improves.

iv) A particular soil gradation is more effective in improving strength behaviour. This is attributed to the interaction with the soil particles through surface friction as well as the interlocking mechanism, which is found to be dominant in sand S3.

v) The initial tangent modulus and secant modulus at failure increase with confining pressures (σ_3) curvilinearly upto a certain value of σ_3 beyond which either they remain constant or increase marginally.

vi) A comparison of the behaviour with disc reinforced geogrid and micro-mesh reinforced sand (S3) reveals that the improvement in strength is marked at the low confining pressure for the former case. This improvement decreases and the strength is nearly the same with the micro-mesh at the confining pressure of 200 kPa. The variation of secant modulus is different for the two cases.

Large Scale Laboratory Model Tests on Footing: Two types of reinforcements were studied viz., single layer of geogrid (GG) placed at various depths below a square footing and beds of geogrid micro-mesh (GMM) reinforced sand S1 of various thicknesses, placed over the unreinforced sand. Investigations were conducted for sand in both loose as well as dense conditions.

It is clearly observed that the introduction of geogrid as single layer or as micro-mesh reinforcement improves the bearing capacity. In case of the geogrid layer reinforcement, it is found that at u/B = 0.5 to 1 and b/B = 3 yield higher BCR values. In the case of GMM there was a steady increase in the BCR with an increase in D/B upto 1, beyond this value the influence is marginal.

In **Chapter 5** the triaxial test results have been further utilized to bring out the relevance and applicability in typical field situations:

Shallow Foundation

i) An analytical approach has been developed to understand the bearing capacity and settlement aspects of footing resting on micro-mesh reinforced sands S1 and S3 as well as a single layer of geogrid reinforced granular fill S3 over clay bed. The computation of the ultimate bearing capacity has been carried out by the two-layer analysis of Meyerhof (1974).

ii) It is observed that the BCR increases with increase in H/B upto a value of around 1.5; beyond this, the increase is almost insignificant in all the cases studied. It is also observed that BCR increases with increasing micro-mesh percent. Similar results have been obtained in case of single layer reinforcement.

iii) The consolidation settlement for the above case has also been evaluated. The method suggested by Fox (1948) has been used to compute the axial interface stresses required for the settlement calculation. The settlement is found to reduce marginally.

iv) The above analysis clearly reveals that both the micro-mesh as well as geogrid layer contribute significantly towards improving the BCR. However, their contribution towards settlement reduction is only marginal.

Granular Trenches or Columns:

The load bearing capacity of soft soils can also be improved by using short granular piles or stone columns. Their effectiveness can be improved further by reinforcing the granular trench with micro-mesh or fabric layers. Computations clearly revealed the significant influence of using reinforced sand, in comparison to the unreinforced case.

Chapter 6 summarizes the main findings of this investigation.

CONTENTS