SOME ASPECTS OF THE BEHAVIOUR OF REINFORCED HIGHWAY EMBANKMENTS ON SOFT CLAY

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DEDICATED TO

MY PARENTS

MY WIFE

ISLAM AND AHMAD

CERTIFICATE

This is to certify that the thesis entitled, "**SOME ASPECTS OF THE BEHAVIOUR OF REINFORCED HIGHWAY EMBANKMENTS ON SOFT CLAY**" being submitted by **Mr.Mahmoud Abdel Megeed A. Aly** to the Indian Institute of Technology, Delhi, for the award of the degree of **DOCTOR OF PHILOSOPHY** in Civil Engineering is a record of the bonafide research work carried out by him. Mr.Aly has worked under our guidance, he has fulfilled the requirements for submission of this thesis, which to our knowledge has reached the requisite standard.

The material contained in this thesis has not been submitted in part or full to any other University or Institute for the award of any degree or diploma

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ABSTRACT

ABSTRACT

Embankments are often required in the construction of road, motorway and railway networks, in dams and retention dykes, in irrigation and flood control works, harbour installations and in the runways of airports. Reinforced embankments appeared in 1960's with modern uses of soil reinforcement. The subsequent development of geosynthetics for soil reinforcement and stabilisation is one of the most important applications of geosynthetics in civil engineering construction. It encompasses reinforced embankments on soft soils, reinforced steep embankments, reinforced soil retaining structures etc. The objective in each of these cases is to increase the stability of soil either locally or globally. For construction of embankments on soft soils, geosynthetic materials are used as reinforcement at the contact of the embankment and foundation to provide support over soft soils. Geosynthetics are also used for multi-layer reinforcement of the embankment slopes.

The analysis and design methods for reinforced embankments are often based on limit equilibrium method (LEM) and finite element method (FEM). The conventional limit equilibrium methods are extended to include the effect of reinforcement. These methods proved successful in explaining the action of the reinforcement and quantifying the improvement in stability. However, other details of reinforced embankments can not be found from limit equilibrium techniques. The finite element method provides details of deformations, stresses, soil-reinforcement interface behaviour and development of failure. The constitutive models used to study the behaviour of reinforced embankments up to failure are mostly based on Mohr-Coulomb yield criterion. The effect of drainage of the foundation soil has not been widely investigated. The foundation soil properties considered in the previous works are restricted to typical properties of soft clay deposits in some particular regions such as Canada, the USA, the UK, Brazil and Japan.

The present research programme attempts to investigate the reinforced highway embankments resting on soft clay foundation using both limit equilibrium and finite element methods. The reinforcement located at the base of embankment, extends to its full base width. Typical properties of soft clay deposits from some regions in India have been adopted. To achieve the objectives of the present study, two computer programs DESEMB and VISCP, written in Fortran 77, have been developed on ICL 3980 system and PC-486 UNIX machine having 33 MHz speed and 32 MB RAM at the Indian Institute of Technology, Delhi.

The program DESEMB has the facility to design the embankment geometry and reinforcement using an extended limit equilibrium technique using total stress analysis and includes safety requirements against sliding failure, squeezing failure of foundation soil, bearing capacity failure and rotational failure. Different cases of foundation soil, viz. constant cohesion and cohesion increasing linearly with depth for limited and unlimited foundation depths have been incorporated in the program. For checking against rotational failure, a slip circle analysis using simplified Bishop method is used.

The finite element method is used for understanding the behaviour of geosynthetic reinforced highway embankments with wide crest width founded on a soft clay foundation. The program VISCP has been developed for the analysis. Effective stress analysis has been used in the program. Coupled consolidation, undrained and fully drained conditions have been incorporated in the program VISCP. The elasto-viscoplastic algorithm proposed by Zienkiewicz and Cormeau (1974) has been adopted to obtain elasto-plastic solution. The program VISCP has the provision for eight-noded isoparametric solid elements to simulate the foundation soil and embankment fill, six-noded interface (joint) elements to simulate clay-reinforcement interface and fill-reinforcement interface and three-noded line elements to simulate the reinforcement.

Modified Cam-clay model for clay foundation, Mohr-Coulomb yield criterion for embankment fill and interface elements and von Mises yield criterion for axial reinforcement (line) elements have been used. Simulation of embankment construction in stages (layers) has been incorporated in the program VISCP. Six test problems have been successfully analysed to verify the code of the program VISCP.

A systematic parametric study of various factors such as stiffness of the reinforcement, depth of foundation soil, clay properties, embankment side slopes and drainage of foundation soil which influence the behaviour of reinforced embankments has been conducted, to study the effect on deformations behaviour, stress distributions and yielding zones of the foundation soil, soil-reinforcement interface behaviour, tensile forces and strains in the reinforcement and on the maximum height of embankment. From the parametric studies carried out using finite element method and extended limit equilibrium technique the following important conclusions are drawn.

1. The reinforcement has marked influence in reducing the horizontal displacements in the foundation soil along its full depth. However, its effect on the vertical displacements is restricted to the upper portion of the clay foundation.
2. With respect to the effectiveness of the reinforcement in reducing the deformations in the foundation and increasing the maximum height of embankment, marginal effect is noted by using reinforcement with stiffness modulus value more than about 4000 kN/m.
3. The effect of the reinforcement on the effective horizontal stresses and shear stresses in the foundation soil is more evident than its effect on the effective vertical stresses. The reinforcement has significant influence on the effective horizontal stresses and shear stresses near the embankment shoulder and toe. This influence also extends to large depths in foundation.

4. The role of reinforcement in providing inward-directed shear stresses to restrain the foundation surface from lateral movements is clearly observed in the case of stiffer reinforcement with modulus values greater than 2000 kN/m. The use of a less stiff reinforcement reduces the values of the outward shear stresses.
5. The nature of distribution and magnitude of shear stresses at soil-reinforcement interface are markedly affected as the stiffness of the reinforcement increases.
6. The effectiveness of the reinforcement in reducing the deformations in the foundation soil is very high for shallow foundation depths. This effectiveness decreases significantly with increase in the foundation depth.
7. The reinforcement tensile forces and strains increase with increase in the foundation depth, particularly for high values of reinforcement stiffness modulus.
8. The reinforcement has greater influence on the maximum embankment height for shallow foundation depths. The percentage increase of embankment height considerably decreases with increase in foundation depth.
9. The effectiveness of the reinforcement in reducing the deformations in the foundation and increasing the embankment height essentially depends on the properties of clay and the adhesion strength at clay-reinforcement interface.
10. For the case of partially drained (coupled consolidation) condition of foundation soil the effect of the reinforcement in reducing the horizontal displacements in the foundation is more pronounced than its effect on the vertical displacements. The role of the reinforcement generally decreases with increase in time after construction of embankment.

A systematic design procedure based on extended limit equilibrium approach has been proposed for the design of reinforced embankments resting on soft soil foundation using the computer program DESEMB. From the analysis with DESEMB, it has been found that for the case of deep soft soil deposits with strength increasing linearly with depth, the depth of the sliding surface at failure into the foundation soil increases as the stiffness modulus of the geosynthetic reinforcement increases.

Simple design charts have been developed using finite element method for the design of geosynthetic reinforced highway embankments with wide crest width resting on soft clay foundation.

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