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Chairman's report: Embankments

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INTRODUCTION

The chairman introduced the discussion with reference to the principles of limit state evaluation of designs. The approach most likely to clarify the decision-making process in design was to demand the analysis of certain critical events, comprising clearly defined limit modes and design situations. Limit modes are the various independent classes of behaviour which could lead to failure, and design situations are the various contrasting combinations of imposed loads and hostile environments which - taken together - are judged to encompass all foreseeable situations which the facility should survive.

Three limit modes might be relevant for reinforced soil structures, addressing issues of strength, toughness, and deformation. Each mode would involve alternative mechanisms which might stem from the behaviour of in situ soils, engineered fills, reinforcing materials, or associated structural elements - either failing singly or in combination.

Design situations should cover the period of construction, extreme working states, and foreseeable classes of accident including such natural incidents as flood and earthquake.

This approach to limit state design requires the engineer to adopt a much broader definition of "failure" in terms of the contravention of a list of performance requirements which would range from concerns over safety (strength calculations relevant to extreme loads and degraded materials), to issues of serviceability (deformation calculations linked to limits set by considerations of repair and maintenance costs, or user discomfort). Objective calculations are wanted which are capable of predicting any critical event. In particular, the direct treatment of deformations and serviceability should lead to cost saving where existing "factor of safety" design methods are too conservative, while addressing anxieties inherent in the use of compliant materials such as geosynthetics. Any such advance is wholly dependent on the scientific evaluation of performance data such as can be achieved only through discussions such as this.

Contributions made by delegates during the ensuing discussion referred to both the deformation and rupture of reinforced embankment systems, and with particular reference to three design situations:

i) soft clay foundations
ii) steep slopes
iii) earthquake effects

SOFT CLAY FOUNDATIONS

A discussion took place on the subject of geogrid mattresses, following their mention in the special lecture by J.P.Gourc. G.Heymann asked whether he could offer more information on the cost-effectiveness of geogrid mattresses, and in particular whether they were found to reduce displacements. Gourc replied that he had observed the creation of a good stiff mattress, but that he himself had more questions than answers about cost effectiveness. He did not know how to design a cellular mattress, especially in relation to the shearing resistance to be adopted in an overall limit equilibrium calculation. Neither did he know the relative efficiency of mattresses compared with the same amount of flat sheets. Another contributor thought that Duncan had studied mattresses at VPI and had found that they were not cost efficient compared with flat sheets. However, J.Paul said that mattresses were used a lot in the UK, that he had some evidence that the confinement produced by cells was 70% higher than the equivalent mass of sheets, and that Smith of Manchester University was using finite element analysis to study these interactions.

The paper by H.Oikawa raised a number of points of discussion. He had shown the results of embankments up to 16 m high constructed with berms over narrow valleys with up to 16 m of peat and soft clay. He compared the function of multiple sheets of wire net reinforcement laid flat within the embankment berms with and without the additional use of 0.4 m diameter sand piles installed at 1.8 m centres through the peat. N.Sabhahit referred to the principal finding, namely that sand piles were seen to reduce lateral displacements in the soft soil, and that the tensions mobilised in the reinforcement were then negligible. He thought that the action of the reinforcement might then be simply to direct the load from the embankment on to the sand piles. The soft soil, being unloaded, would then strain insufficiently to mobilise large tensions in the reinforcement.

However, the data showed that considerable vertical settlement occurred in the sand pile section, so the pile action of the sand inserts does not seem to have been significant in this case. The strains in the soft clay remained large, but became vertical. The chairman believes that the radial consolidation around the sand piles, acting as drains, can explain the observations. The consequential radial soil displacements around each drain act as centres of cylindrical cavity contraction which absorb the general lateral displacements due to shear which would otherwise accumulate and create large lateral displacements beneath the edges of the embankment. Maheetharan of W.S.Atkins Consultants in the UK has observed the same phenomenon in finite element calculations using the Cambridge package, CRISP. The mechanism relies on simultaneous consolidation around the drains as the general body of soft clay shears in an undrained fashion. It can therefore be simulated properly only by FE programs such as CRISP which feature coupled deformation-consolidation processes.

H.Ohta recalled a study he had made of the use of lime-soil mixtures in soil berms, together with steel mesh reinforcement, in similar embankments to those shown by Oikawa. It was necessary to obtain secant Young's modulus for the lime-soil mixture which accounted for the increases observed during the three month hardening period. Computer simulations then compared well with field observations in the early loading stages, but inclinometers later showed deterioration due to progressive failure which was not replicated in the FE analysis. It was difficult to make exact predictions for the three-dimensional case of embankments crossing narrow infilled valleys, but FE analysis did show that if hardened lime-mix failed in tension its contribution disappeared.

J.P.Gourc asked Oikawa whether he could account for the measurement, reported in the paper, of higher tensions in the upper sheet net than in the lower. Bending theory for the lateral distortion of embankments would have predicted the opposite, due to the relative contractions of the upper layer, which would have been taken to be closer to the neutral axis for an embankment settling like a trough. He felt that more work should be devoted to rationalising multi-layer reinforcement systems. Oikawa in reply simply wanted to emphasise the difficulty of measuring tensions in sheet or net reinforcement on site.

M.D.Bolton pointed out that the depth of soft clay was significant in determining whether embankment reinforcement could reduce settlements and improve stability. Centrifuge model tests were being conducted by Sharma at Cambridge University using model geotextiles and geogrids to reinforce models of 6m high embankments with 1:2 side slopes built in flight over either 8 m or 4 m layers of soft clay with a shear strength of about 10 kPa. K.Rowe responded that the relative ineffectiveness of reinforcement over deep uniform clay layers should not have been surprising, taking account of the fact that bearing capacity was uninfluenced by foundation friction in these circumstances. Improvements might be expected either for shallow layers or where strength increased significantly with depth.

STEEP SLOPES

K.Rowe asked three questions of P-J.Erban in relation to his paper on the numerical simulation of a full-scale test on a geogrid reinforced retaining wall, using the ANSYS finite element program. He noted that Erban had difficulty predicting failure, and asked:

i) whether the author had tried modelling with more realistic angles of dilation φ, bearing in mind that the associated flow rule with $\varphi = \phi = 39°$ implies far too much dilation;

ii) whether more elements were not necessary, perhaps by an order of magnitude;

iii) whether full or partial integration had been used.

Erban in reply explained that he had not wished to evaluate a special model, but rather one that could be used easily in practice. He had therefore restricted his calculations to the Mohr Coulomb failure criterion with associated flow. The decision regarding numbers of elements represented a compromise to achieve calculation times which were practicable. The analyses were made with partial integration.

J.T.H.Wu wanted to make two points in relation to the finite element simulation of interfaces simulated as a series of segments. Two spring constants were often specified, K_s in shear and K_n for normal stress, up to a friction limit for sliding. Model tests are sometimes used to determine K_s and K_n, but stiffness is related to size, so the size has to be right. Secondly, K_n may be chosen to be very large in compression, but this can lead to inaccuracies in the estimation of normal stresses. This in turn could lead to errors in the determination of possible sliding, and the implied shear strength of the interface.

EARTHQUAKE EFFECTS

M.Fukuoka made some comments in relation to the paper by D.D.Genske dealing with the probabilistic reliability analysis of geotextile reinforced walls in earthquakes. If the critical horizontal inertia forces act outwards as shown in the paper, the ground accelerations should be directed back towards the fill, not outwards as reported. Furthermore, if soils were loose they could be compacted by the earthquake, leading to settlement and an increase in earth pressure. Finally, measured accelerations at the top and base of walls in the field are different due to amplification effects. Genske replied that he had only studied the probabilistic side of the question, and had not considered these questions of mechanics.

V.N.Ghionna addressed a question to J.G.Collin following his paper on the field observation of reinforced soil structures under seismic loading. He asked what factor of safety should be chosen in pseudo-static analyses, and whether it might not be better to evaluate displacements using the sliding block approach of Newmark. Collin responded that whereas a factor of safety of 1.5 was used in static applications, this was reduced to 1.1 or 1.15 in the analysis of earthquakes. The result is that static conditions dominate the design. Newmark's method needs to be applied after further research.

M.D.Bolton remarked that the application of a safety factor of 1.1 seemed a meaningless gesture when it was considered how uncertain was the acceleration level, frequency content, and duration of the possible seismic loading. Of even greater concern was the uncertainty regarding the soil strength parameter to which any safety factor might be applied. Tests carried out by Steedman at Cambridge had shown that the angle of shearing of dense granular fill behind a retaining wall dropped from over 50° to less than 35° when a shear rupture band formed to permit the relative sliding of soil blocks envisaged by Newmark. The dilation and softening of granular soils, and their possible liquefaction if saturated, are the critical issues. Arbitrary safety factors are of no assistance.

SUMMARY

Many detailed questions have been raised by authors and discussers regarding the behaviour of reinforced embankments, including uncertainties on the composite action of mattress foundations compared with multiple sheet reinforcements, the influence of drains in soft sub-soils, the selection of peak or critical state strengths for soils, the earth pressures to be anticipated on facing systems in both static and seismic conditions, and the non-linear behaviour of both soils and synthetics. How can answers be framed to such questions over the next few years?

Ample evidence exists that model tests, and especially centrifuge model tests carried out on reconstituted soils, are the most reliable way of researching the details of mechanisms, whether of collapse or of deformation under working loads. Conditions can then be scientifically controlled, parameters varied, tests repeated and - above all - limit state events can be observed economically and safely. The observers of structures in the field can rarely permit collapse to take place, so that observations are remote from limiting conditions of safety. Equally, structures can not be removed and re-built, certainly not on the same foundations, so the difficult problem of instrument reliability can not be resolved by repetition of the test. Fortunately, centrifuge testing laboratories are now widely available and the clarification of behaviour mechanisms in reinforced soil structures can confidently be expected, both for existing technologies and for new techniques yet to be devised.

Finite element simulations can be highly effective once the basic mechanisms have been elucidated, but not before. Experience in many fields suggests that a physical phenomenon must be seen, described and understood before numerical simulations can be relied upon even to be in the right ball-park. Much more attention needs to be paid to the concept of validation of numerical simulations. Validation to a numerical modeller or quality auditor might only mean "does this program produce the nominally accepted answer to a standard problem ?". To an engineer, the concept of validity refers to the comparison between simulation and reality. Finite element analyses must be checked against simple centrifuge models for each given class of problem. Not every flaw in the design process can be found this way, but programs which can not even simulate a uniform model can safely be discarded.

Validated computer codes, and engineers proficient in their use, will increasingly find a place in the design office. Extremely powerful PCs can be installed on an engineer's desk capable of investigating complex geometries and interactions for the capital outlay of one month's salary. Sensitivity studies will then replace the blanket conservatism which characterised the ground engineering of the last generation, at least in schemes of significant cost.

Certain aspects of behaviour can best be studied in the field, particularly those concerning workmanship or design details, technological processes such as soil compaction, or materials such as geotextiles which are not easily scaled. Furthermore, the complex path-dependent response of soils means that final assurance concerning the means of predicting deformations would be obtained only from a site trial. It is also difficult to represent the complex consolidation behaviour of soft soils due to uncertainty about spatial and temporal changes in soil permeability. This requires a strategy for sampling or in situ testing to be developed by field engineers.

Field studies are essential if clients are to gain confidence in design analyses. As structures are increasingly designed against a serviceability criterion, it will be necessary to demonstrate that deformations are neither too large or (considering costs) too small. If clients are purchasing reinforcement they will wish to have it proved that tensions are developed in service, that such tensions cause increases in soil confinement leading to reduced soil displacements, and that the cost of the reinforcement and its placement offers good value for money in comparison to alternative ways of achieving the same effect.

The session shows that we have made an advance towards a methodology by which a full understanding of reinforced embankments could be gained, but that considerable efforts must yet be made in employing that methodology to answer some fundamental questions which still remain.