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Chairman's report: Foundations

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Reinforcing materials in foundation soils are used as permanent applications. The main objective of reinforcing the soils is to improve its performance as a foundation material. For instance, to improve the bearing capacity or the stability and reduce the settlements. Several research workers from all parts of the world are working on this concept using both analytical and experimental approaches. Considerable progress has been achieved in the last four years, since the 1988 conference here. The developments in this period, and in particular the contributions made in this conference, have substantially improved our existing knowledge. Nonetheless, there is still a lot more scope for research in the future. In the 1988 conference there were 14 accepted papers on this theme, while in the present conference we have 22, eight of which were orally presented.

The papers presented in this conference on the theme of **foundations** cover the following applications:

(1) As reinforcements beneath embankments and footings on weak foundations
(2) As reinforcements in pavements for better performance
(3) As landfill liners over voids or sink holes or on grounds where subsidence is likely to occur
(4) To improve and reclaim very soft grounds or lowlands
(5) Fibre reinforced sand columns to strengthen the soft soil

The first paper by Gabr et al. entitled "Stability of geogrid-reinforced landfill liners over sinkholes" deals with plain-strain finite element analyses conducted to check the stability of geogrid-reinforced landfill liners over existing or potential sink holes. The use of geogrids to reinforce the landfill liner systems was found to reduce the induced tensile stresses. The magnitude of deformations were also found to be small. Thus, the potential for the collapse of landfill liners would be less. The analyses show how the arching phenomenon contributes to the redistribution of stresses within the soil mass adjacent to the void. Hence, the maximum stresses do not occur directly above the void.

The second paper "Laboratory model tests on the application of composite fabrics to soft clay ground" by Hirao et al., which was orally presented, explains about an innovative experimental set-up to estimate the frictional resistances between the geotextile and the soft clay. A footing was placed on top of geotextile over soft clay and loaded to determine its ultimate bearing capacity. Tensile forces were applied to the ends of the geotextile. These tensile forces were found to increase the frictional resistance frictional resistances, and thereby the bearing capacity. They conclude that composite geofabrics are the most efficient in producing higher friction or higher bearing capacities, owing to their greater surface roughness.

The next paper, which was orally presented, is "A comparative study of stability analysis methods for reinforced sand slopes" by Huang and Tatsuoka. Laboratory tests of strip footings, on both reinforced and unreinforced model slopes, were conducted to determine their bearing capacities. The bearing capacities were predicted by several methods such as: limit equilibrium methods and Modified Janbu's method (MJM). Most probable failure surfaces were also determined. In the MJM, the reinforcement forces were considered both at the base and between the slices. The authors claim that MJM yielded comparatively good and reliable results.

"The use of high strength link geotextiles over piles and voids" by Kempton and Jones, orally presented, describes a design method for the use of geotextiles to support embankments over land which is likely to be subjected to subsidence caused by collapse of old mine workings. The paper also discusses the criteria for the selection of long term geotextile properties for such permanent applications.

Most earlier studies dealt with the bearing capacities of isolated footings on reinforced soils. The paper by Khing, Das, and others, deals with laboratory model tests for determining the ultimate bearing capacity of two closely spaced strip foundations supported by geogrid reinforced sand, and the parameters affecting the bearing capacity. The parameters varied are the center to center spacing of the footings (S), width of the footing (B), number of reinforcement layers, vertical spacing of reinforcements, depth of the first layer below the footing, total thickness of the reinforced zone, width of reinforcements etc. Group efficiency and interference effects were studied. It was observed that the efficiency factor decreases with the increase in the S/B ratio. For the unreinforced soils, the soil efficiency factor was found to be greater than unity, for S/B values of 1.5 to 3.5. But for reinforced soils, the efficiency factor was found to be less than unity for the same above range of S/B values. This paper was orally presented.

Kurumada et al. report on earth spreading using geotextiles over soft ground to improve the bearing capacity of weak ground, with some case histories, in their paper entitled "Earth spreading on very soft ground by geotextile reinforcement". It also discusses the material characteristics, methods of laying the geotextiles and earth spreading work.

The paper entitled "Settlement reduction due to extensible reinforcement strip" by Madhav and Pitchumani, employs the elastic continuum approach to predict the shear stresses mobilized at the interface of an extensible strip reinforcement and the soil, and the subsequent reduction in the surface settlements. Parameters such as the effect of the length and the depth of the strip, and aspect ratio of the loaded area on the reduction in surface settlements were also studied. The paper was orally presented.

The paper by Makiuchi and Minegishi "An estimation of improvement effects of geotextile on bearing capacity of soft ground" deals with laboratory tests similar to the earlier paper by Hirao et al. There was found to be a remarkable increase in the bearing capacities and reduction in the settlements with the increase in the tensions at the ends of the geotextile. Prediction equation for bearing capacity is given by modifying the Terzaghi's theory. The paper again highlights the point that the frictional force or the tension in the geotextile influences the bearing capacity of poor grounds.

Mhaiskar and Mandal's paper entitled "Comparison of a geocell and horizontal inclusion for paved road structure" compares the efficacy of a geocell structure with horizontal inclusions over soft clay ground, through experimental and finite element investigations. Geocell was found to yield the best desired results. Little benefit was found by introducing horizontal inclusions at sand/clay interface (BCR = 1.1). However, reinforcing the sand (overlying the clay) was found to yield larger benefits (BCR = 2 to 3). This is a very interesting observation for practical applicability.

Miyazaki and Hirokawa's paper "Fundamental study of reinforcement of sand layer in model test", deals with experimental study in the laboratory. It deals with model strip footings loaded on the surface of sand. The soil tank is provided with grids on it and the shear strains were measured through photographs. It is concluded that there is the most effective way of arranging the reinforcing layers for increased strength or bearing capacity of sand bed.

Al-Mosawe and Al-Dobaissi highlight the resistance of reinforced earth to impact loading in their paper "Reinforced earth response to impact loading". They discuss the parameters that effect the performance (impact resistance) such as depth of the topmost reinforcing layer (u), number of layers (N), stiffness and aperture size of the geogrids in sands. Impact resistance was found to increase with N, with aperture sizes and when (u) is near about (B/3), where B is the width of the footing. An improvement as much as twice that of the unreinforced soil for the same impact energy used was observed.

Nishigata and Yamaoka theoretically consider the reinforcement mechanism of geotextile in unpaved roads based on the model test results. The geotextile was found to provide lateral restraint to the subgrade soil, and thus prevent its local shear failure. The geotextile was also found to confine the aggregate layer. The bearing capacity was found to increase by as much as 2-3 times. Prediction equations for ultimate bearing capacity are proposed. Design charts to determine the aggregate thickness are also given in their paper "Ultimate bearing capacity of unpaved road reinforced by geotextile", which was orally presented.

The paper "Numerical analysis of the behavior of clay foundation beneath reinforced embankment" by Oka et al. deals with finite element analyses conducted for an embankment reinforced at the base and overlying a clay foundation. The performance of embankment was found to depend on soil-structure interaction between the foundation, the embankment fill and the geogrid reinforcement. Geogrid reinforcement was found to reduce the lateral displacements more significantly than the vertical settlements. The role of the rigidity of the embankment and filling rate of the embankment were also studied.

The next paper "Reinforcement effect of geotextiles on pavement with weak subgrade" by Omoto et al. investigates the reinforcement effect and the mechanism of geotextiles used in pavements on weak subgrades through laboratory repeated loading tests. Improvement was measured in terms of increase in the CBR values of the subgrade. Both the geogrid and the non-woven fabrics were shown to reduce the cumulative deformation under repeated loading, and improve the CBR of weak subgrade without much increase in the subbase course thickness. Design curves for determining the required subbase course thickness for different traffic volumes are proposed.

The paper by Al-Refeai entitled "Strengthening of soft soil by fiber-reinforced sand column" deals with triaxial tests conducted on fiber reinforced granular columns surrounded by an annulus of soft soil, and confined by a constant radial pressure. This simulates a single column in a semi-infinite soft soil. 0.2% by weight of fiber content was found to effectively (i) increase stress resistant properties of sand without any reduction in soil density, permeability and ductility (ii) increase bearing capacity (iii) reduce compressibility. Most economical and practical depth of fiber reinforced sand layer in sand columns was determined to be about one column diameter.

The paper "Reinforcement of soft ground with thin vertical wall" by Shimizu and Inui, studies a thin vertical wall installed in the subsoil, in the shape of a closed hexagon in plan view, open at top and bottom. Different materials such as: card board, paper and four types of geotextiles were utilized in their study. The size of the wall (side length, a, and height, h) was found to play an important role in increasing the bearing capacity. The horizontal stiffness and the tensile strength of the reinforcing materials used were also found to increase the bearing capacity. At larger settlements, soil particles tend to move outward from beneath the walls, and thereby the load carrying capacity was found to decrease.

Soni et al. ("Effect of reinforcement length on bearing capacity") discuss an analytical approach to calculate the required length of reinforcements (L) below foundations in sands based on Rankine's theory. L is found to increase with the angle of internal friction (phi), decrease with increase in (u/B) ratio, where u is the depth of the first layer below the footing and B is the breadth of the footing. They claim to have obtained good agreement with the experimental results of earlier studies. Design charts for calculating L are given in terms of phi and u/B ratios.

Takemura et al. investigate the failure mechanisms of soil reinforced with high strength geogrids from centrifugal tests in their paper "Bearing capacities and deformations of sand reinforced with geogrids". They contend that just before the load intensity reaches its peak, a rigid soil block is formed under the footing irrespective of the replacement conditions, and that this block behaves as an embedded footing. Quoting from their abstract, at the peak, the geogrid breaks and slip lines develop very rapidly, followed by a sharp decrease in the bearing capacities. The modes of failure after the peak are found to be influenced by the placement conditions of the geogrids. The bearing capacities are similar even for different conditions, where observed slip lines are similar.

Tanabashi et al. discuss in their paper "Numerical analysis for bearing capacity improvement of soft clay ground reinforced with geotextiles", a finite element technique for estimating the improvement in bearing capacity and the deformation characteristics of soft clay ground reinforced with geotextiles. Soil is regarded as an elasto-plastic model which is able to represent the critical mode of the soil behaviour.

Verma and Jha discuss a technique of reinforcing the in-situ soil or the existing footings in their paper "Three dimensional model footings for improving subgrades below existing footings". They use vertical reinforcements in the form of steel rods pushed into the soil around the footing. The improvement is found to be a function spacing and extent of reinforcement (L=1.5B).

Yagi et al. discuss a method of stability analysis for reinforced earth structures they call the Generalized Limit Equilibrium Method (GLEM). In their paper

"Stability analysis of reinforced earth structures", which was orally presented, they compare the results of their analysis with experimental observations.

In the final paper "Model investigations of reinforced undermined base bearing capacity", by Zhusupbekov et al., they discuss laboratory model tests of footings underlain by a reinforced base. Influence of horizontal strains, improvement in bearing capacity, and reduction in settlements, are highlighted. The paper was orally presented.

In conclusion, it could be said that the analytical and experimental approaches in the last four years have become more elaborate and refined. Particular emphasis seems to have been placed in understanding the fundamental behaviour of reinforced soils, such as the frictional resistance between the reinforcement and the surrounding soil, and the tension in the reinforcements. Innovative experimental set-ups have been developed for this purpose. Centrifugal tests are also being conducted to study and investigate the various aspects.

Attempts are being made to correctly evaluate the amount of reinforcement required for optimum results, and predict the bearing capacity and the settlements to a fair degree of accuracy. Comparisons are made with experimental studies. More sophisticated finite element techniques are also being resorted to.

Parametric studies with isolated footings continue to be done. In addition, parametric studies and behaviour of multiple footings on reinforced foundations are also being looked into. Attempts have been made to study the application of soil reinforcement techniques to in-situ conditions and to improve the already existing footings. Newer soil reinforcement techniques and materials are being tried out. Some special features of the reinforced soil foundations, such as its resistance to impact loads are also being studied.

Quest for high strength reinforcing materials continues. The materials technology has advanced to such an extent that geotextile materials capable of withstanding loads of up to 100 tons per m. and above for long periods of time have been developed.

In most cases, when used as basal reinforcement beneath embankments, the geotextile support is required only in the initial stages. Once the foundation soils gain sufficient shear strength by way of consolidation, the geotextile support will not be required anymore. This decides the functional life of the geotextile required. However, in a few other cases, the geotextile is required to function effectively for the entire life period of the geotechnical element. Geotextile products are, therefore, put to rigorous quality control tests before being put to use in actual practice.

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