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Finite element analysis of grid reinforcement

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ABSTRACT: Strip and grid reinforcements have often been used to strengthen various geotechnical structures such as retaining walls, embankments and foundations. Alternatively, geogrids and geocells can also be used for the same purpose. This paper describes the finite element analysis of soil reinforcement system which consists of geogrids used for two cases - one is an embankment on soft soil and the other is a footing foundation.

1 INTRODUCTION

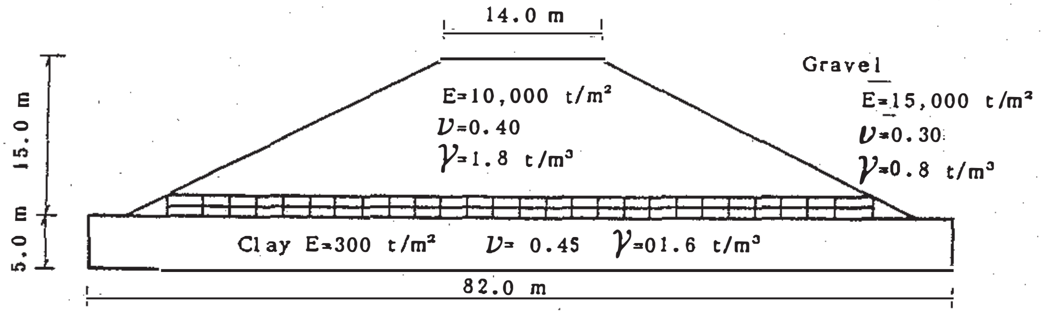
Earth reinforcements are widely used at present for various structures such as embankments, foundations in soft soils, pavements and earth dams. For the purpose of reinforcing the soil, materials such as steel strip, geotextiles and polymer geogrids have been used. Even though the reinforcements in soil structures have become popular, the success or effective use of such reinforcements depend on the efficient design and construction of the reinforced soil structures. To achieve this aim, a proper analysis has to be carried out to determine the stresses in the materials used and the settlement or deformation of the structures. This in turn, requires the determination of material properties by proper testing procedures.

This paper describes the finite element analysis of soil-reinforcement system of geogrids with particular reference to an embankment on soft soil and a footing foundation.

In Japan, it has been found that the use of geogrids throughout the embankment permits higher compaction to be achieved. This allows a reduction in the width of the embankment, thus resulting in an economic construction. Embankments constructed on very soft subsoils may experience large settlements and geogrid mattress may improve the stiffness of the system and possibly reduce the amount of settlement. Similarly, in the case of foundations of structures on soft soils, the total settlement may be large or there may be differential settlement due to uneven loads. In such cases, the provision of geogrids may increase the bearing capacity and settlement characteristics of the subsoil.

2 FINITE ELEMENT ANALYSIS

For designing the soil reinforcements, empirical, experimental and numerical approaches have been used. The design of structures such as retaining walls, embankments and foundations on homogeneous soil situations can probably be done using conventional analytical methods. However, if the soil conditions are nonhomogeneous and the soil is of soft or weak type, then in order to arrive at efficient design, computer oriented analysis such as the finite element technique has to be adopted. The advantage of such an analysis is that displacement distribution and stress distribution can be obtained both in the subsoil as well as the soil reinforcement system. Nevertheless,it should be realized that the accuracy of the finite element results depends on the appropriate material properties used and the type of modeling adopted for the analysis. In the finite element analysis, the complete soil reinforcement system can be modelled using individual elements such as bar elements for reinforcements. continuum elements for soil and joint elements for interface behaviour or by using composite elements which comprise of the soil-reinforcement system as a whole. In the latter case, the properties of the composite element have to be evaluated either experimentally or by a separate numerical analysis.



Bar element $E=0.18x10$ t/m² $A=0.13x10^{-2}$ m²

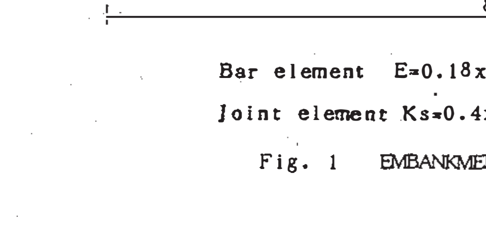
Joint element $Ks=0.4x10^3$ $Kn=0.4x10^5$ t/m²

Fig. 1 EMBANKMENT

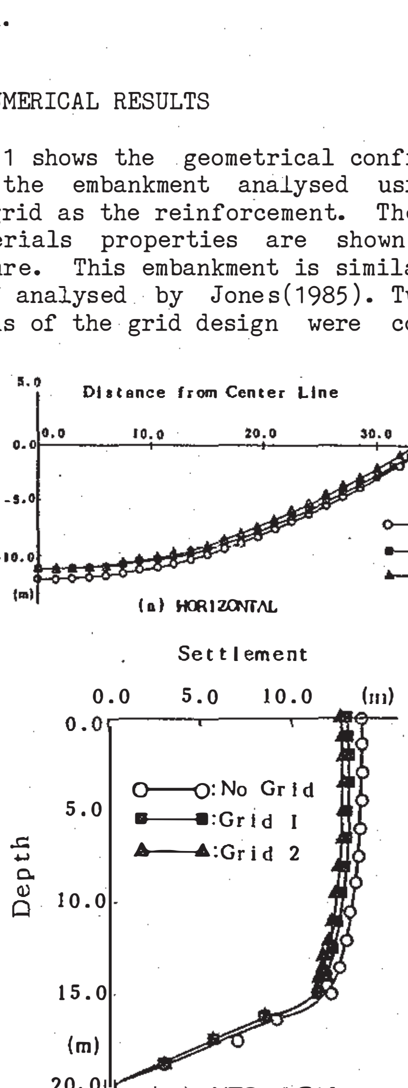
In this paper, the former approach, that is, individual elements for soil, reinforcement and interface behaviour has been used.

3 NUMERICAL RESULTS

Fig.1 shows the geometrical configuration of the embankment analysed using the geogrid as the reinforcement. The assumed materials properties are shown in the figure. This embankment is similar to the one analysed by Jones(1985). Two variations of the grid design were considered in the analysis - one with a single layer of 1m grid depth and the other two layers of each 1m depth. The settlement profile along a horizontal section in the subsoil just below the grid reinforcement, is shown in Fig.2(a) whereas Fig.2(b) shows the settlement profile along vertical section at the center line of the embankment. It can be noted that there is some minor advantage in using the geogrid regarding the reduction of settlement. However, there is practically no difference between the alternative designs. Fig.3 shows the stress distribution in the reinforcement for the two designs and the distribution is as would be expected.



(a) HORIZONTAL



(b) VERTICAL

Fig. 2 SETTLEMENT PROFILE

Fig.4(a) shows the vertical stress (σ_y) distribution along the horizontal section in clay layer, just below the reinforcement. It can be observed that for all the three cases - no grid and two alternative grid designs - the distribution is almost the same. The maximum principal stress along the same horizontal section for the three cases considered has been plotted in Fig.4(b). As can be noted that using the geogrid reduces the maximum tensile stress by nearly 50 %.

Thus, it can be stated that in the case of embankment, providing the geogrid as

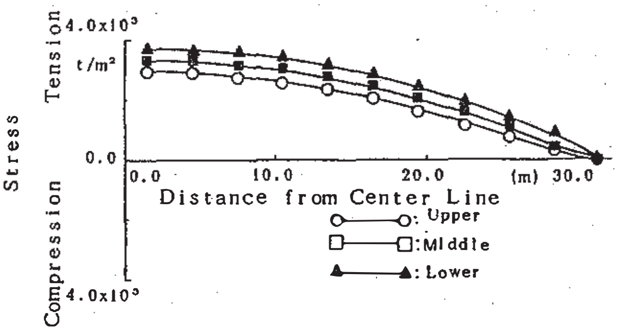
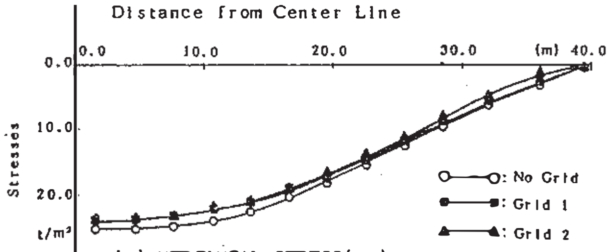
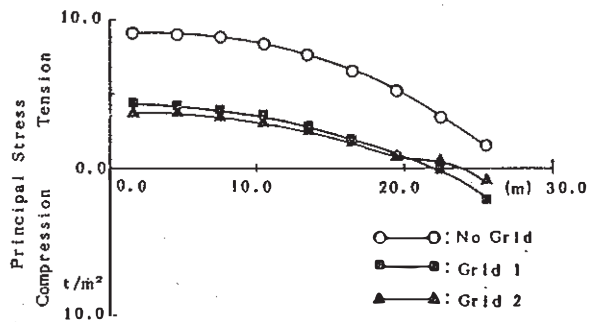


Fig. 3 STRESS DISTRIBUTION OF REINFORCEMENT



(a) VERTIVCAL STRESS(σy)



(b) PRINCIPAL STRESS

Fig. 4 STRESS DISTRIBUTION

the reinforcement did not influence the settlement profile. This result is similar to the observation made by Symes(1985). For this case, the important thing is that the tensile stress in the soft layer has been reduced by nearly 50 % with the use of geogrid which would assist in preventing the failure of the subsoil.

Fig.5 shows the strip footing on cohesive soil containing horizontal layers of reinforcement, with two alternatives - one with strips and the other with geogrids. The material properties adopted for the analysis are also given in the figure. This problem is similar to the one analysed by Binquet and Lee(1975). Two cases of strip footings - surface footing and embedded footing were considered.

The vertical displacement(settlement) along the horizontal surface has been plotted in Fig.6(a) for the surface footing and in Fig.6(b) for the embedded footing. The maximum settlement of the surface footing for the case without any reinforcement is 8.44cm compared with the theoretical solution of 8.76cm. By providing only strip reinforcement the maximum deflection was reduced only very little (8.18cm) whereas the provision of grid reinforcement reduced the maximum deflection to 6.82cm. For the case of embedded footing the maximum displacement for the unreinforced soil medium is 4.28cm whereas for the strip reinforcement it is 4.11cm and for the grid reinforcement, it was reduced to 2.78cm.

Fig.7 shows the distribution of vertical stress(σ_y) for the case of surface footing, along horizontal sections between the four layers of reinforcement. As can be seen, the distribution for the three cases considered is similar. The stress distribution for the case of embedded footing is plotted in Fig.8. Again, it can be noted that practically there is no difference in results among the three cases.

It was observed that in the case of surface footing, the maximum tensile stress was not reduced by the use of reinforcement whereas in the case of embedded footing, it was reduced considerably, for example by about 30% with the use of grid reinforcement.

The maximum tie forces for both cases of reinforcements are given in Table 1. It can be noted that for both surface and embedded footing, the maximum tie force in the case of strip reinforcement is greater than that for grid reinforcement.

The bearing capacity ratio(BCR) calculated according to Binquet and Lee(1975) is 1.24 for surface footing and 1.54 for embedded footing. Binquet and Lee stated

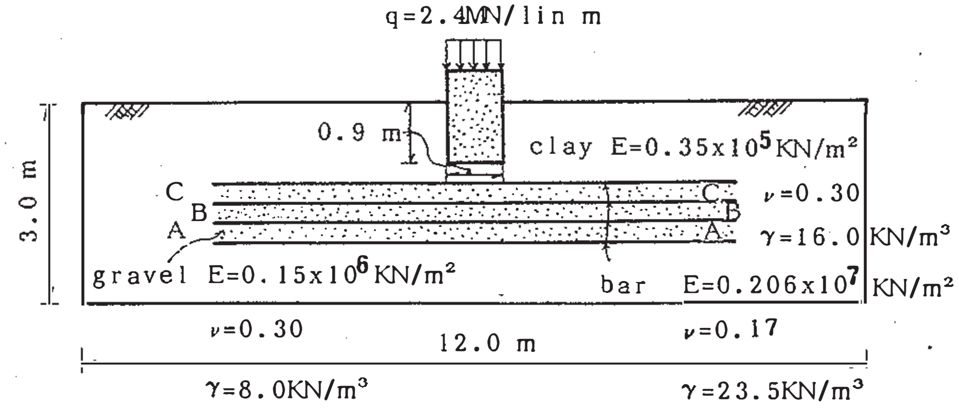


Fig. 5 FOOTING

that the experimental data showed that the BCR values are between 1.5 and 4.0.

4 CONCLUSIONS

From the foregoing discussion of the numerical results related to the two examples - embankment and footing - it can be stated the use of geogrids as soil reinforcements

(1) Reduce the tensile stresses in the weak subsoil for the case of embankments.

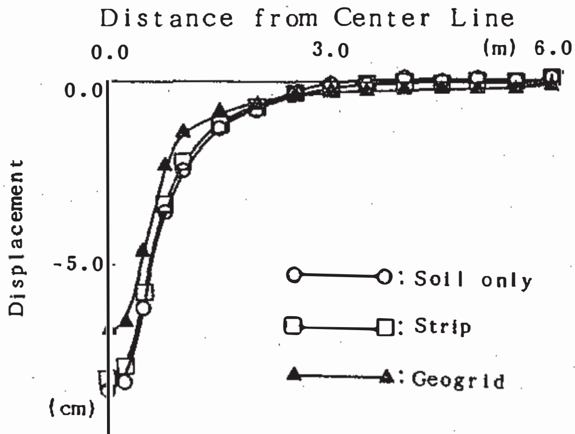
(2) Does not influence the settlement characteristics of the embankment.

(3) Reduce the maximum settlement considerably both in the case of surface and embedded footings.

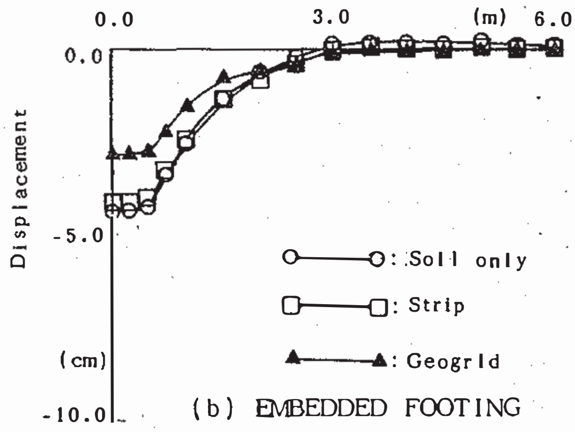
(4) Does not influence the tensile stress distribution in the case of surface footing

(5) Considerably reduces the maximum tensile stress for the case of embedded footing.

It was also noted that geogrids are better than strips as soil reinforcements.

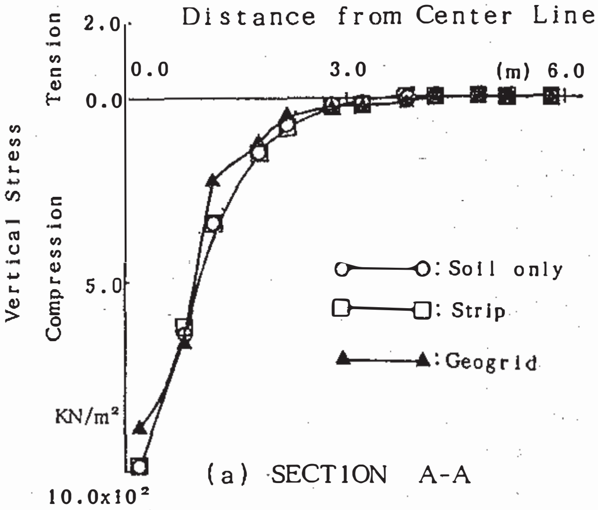


(a) SURFACE FOOTING

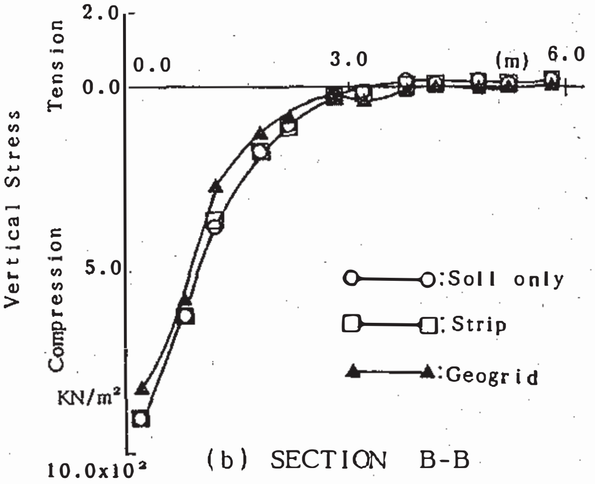


(b) EMBEDDED FOOTING

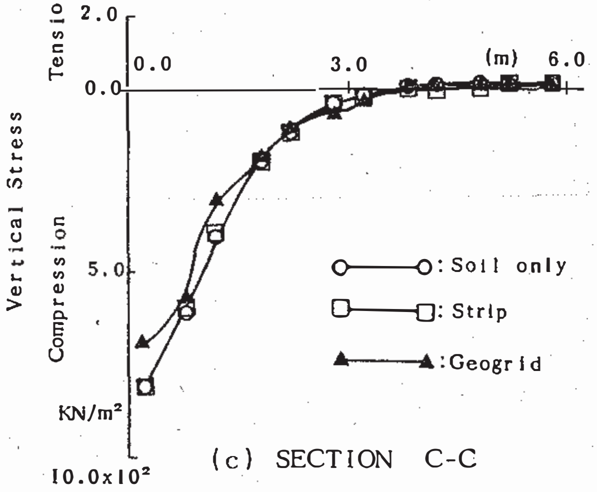
Fig. 6 VERTICAL DISPLACEMENT



(a) SECTION A-A

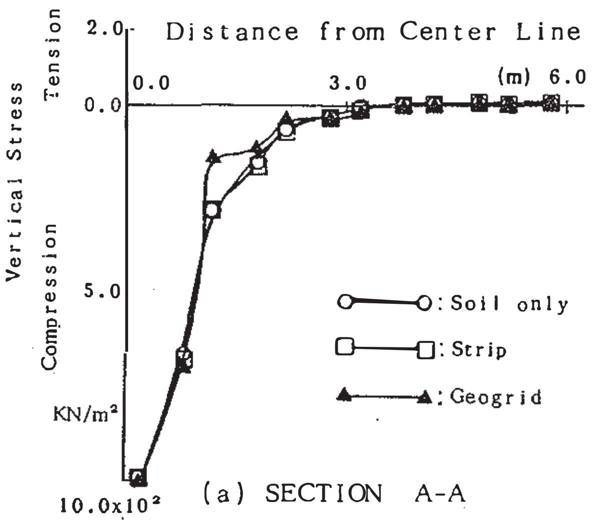


(b) SECTION B-B



(c) SECTION C-C

Fig. 7 VERTICAL STRESS - SURFACE FOOTING



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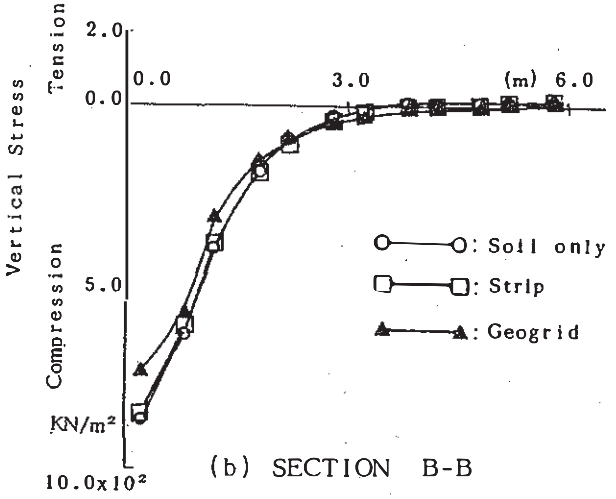
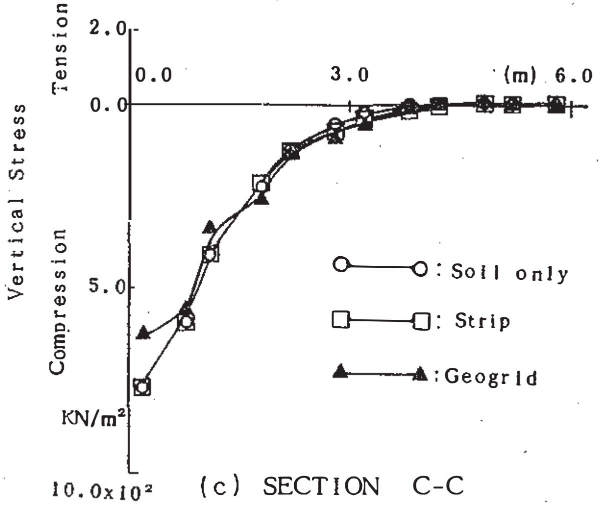


(b) SECTION B-B



(c) SECTION C-C

Fig. 8 VERTICAL STRESS - EMBEDDED FOOTING

Table-1 Maximum Tensile Forces (unit KN)

	strip	geogrid
surface footing	1580	936
embedded footing	1050	998

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