

Supporting Capability of Geogrid-Mattress Foundation

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ABSTRACT : Mattress foundations using geogrid are often used to improve the supporting capability of a soft soil foundation. It is known that the vertical load applied on the geogrid-mattress foundation is transmitted to the supporting foundation with a wider area, therefore providing the supporting foundation with greater supporting capability. In order to examine particularly the characteristics of the vertical stress distribution under the geogrid-mattress, a series of experiments was carried out, in which the geogrid-mattress thickness and the vertical stiffness of the supporting foundation are considered to have some influence on the stress distribution. It is shown that the choice of the geogrid-mattress thickness is important in improving the overall supporting capability and it is desirable to design a geogrid-mattress foundation in accordance with the degree of the vertical stiffness of the supporting foundation underneath.

1 INTRODUCTION

Among reinforcement practice for embankments and buildings constructed on soft soil ground, the use of a geogrid-mattress foundation is a unique method, in which the mattress is placed upon the soft soil foundation of insufficient bearing capacity so as to withstand the weight of the superstructure. A mattress foundation is made of sand/gravel enclosed by geogrids which are folded to create a mattress-like structure, and forms a plate structure possessing appropriate flexibility. As a consequence of the flexible interaction with the supporting soil foundation underneath, even locally or unevenly applied vertical load propagates within the mattress and is transmitted widely to the supporting soil foundation underneath. A conventional approach to the assessment of the improvement of the bearing capacity due to the placement of the mattress foundation may be seen in Fig.1, in which a vertical load applied on the mattress with the width of B and the vertical load intensity p is transmitted widely to the supporting foundation with the corresponding B_m and p_m . The ultimate bearing capacity q without the use of the mattress may be given by Terzaghi's equation as follows,

$$q = cN_c + \frac{1}{2}\gamma BN_\gamma, \quad (1)$$

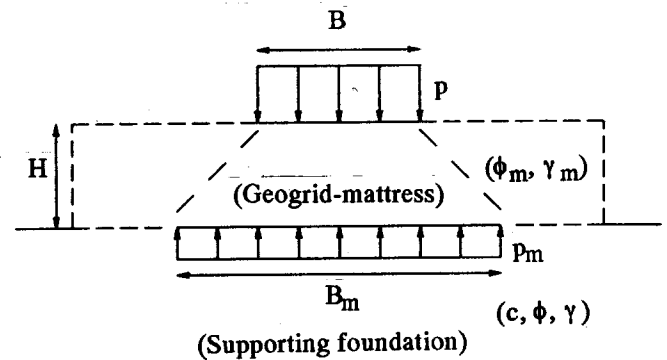


Fig.1 Effects of use of geogrid-mattress

where c is the cohesion and γ is the unit weight of the supporting foundation. On the other hand, the ultimate bearing capacity q_m with the use of the mattress may be given as follows, assuming that the placement of the mattress has a surcharge effect on the bearing capacity of the supporting foundation,

$$q_m = cN_c + \gamma_m H N_q + \frac{1}{2}\gamma B_m N_\gamma, \quad (2)$$

where γ_m is the unit weight of the mattress, and H is the thickness of the mattress. Therefore, the increase in the

bearing capacity Δq due to the placement of the mattress can be given as follows,

$$\Delta q = \gamma_m H N_q + \frac{1}{2} \gamma (B_m - B) N_\gamma \quad (3)$$

It is therefore found that the evaluation of the bearing capacity improvement requires the estimation of the width B_m .

In order to examine particularly the characteristics of the vertical stress distribution developed under the mattress foundation subjected to a vertical load, a series of experiments was carried out, in which the mattress model is made of fine gravel enclosed by geogrids and the supporting soil foundation model comprises lines of elastic springs.

2 EXPERIMENTAL SETUP AND PROCEDURE

Fig.2 shows the layout of the experimental setup. On the floor of a 1.08 m wide, 0.4 m deep, 0.8 m high tub, twenty-one aluminium blocks are lined up, and two elastic springs are placed under each block. By changing the elastic stiffness of the springs, supporting foundation models possessing different degrees of vertical stiffness are achieved. In this study, three kinds of elastic springs are used. The measurement of vertical loads acting on the blocks is provided by dial gages fixed under the blocks, which measure vertical displacements of the blocks. The tub walls are made of acrylic plates, on which rubber membranes are put with some lubricant so as to reduce the friction between the geogrid-mattress foundation model and the tub walls, and to produce an plane strain condition. The geogrid-mattress foundation model is made in the following manner. A sheet of geogrids is laid over the line of the aluminium blocks, and fine gravel is prepared by an air pluviation method. Then the fine gravel is wrapped in the sheet of geogrids, and both ends of the geogrid sheet are connected together using the sheet metals which are strain-gaged to measure the tensile force generated in the geogrids. The geogrid-mattress foundation model is then vertically loaded in a displacement-controlled manner, and the output data are collected into a personal computer through GPIB interface and are recorded into ASCII-coded data files every 10 seconds. The details of the test conditions are shown in Table 1.

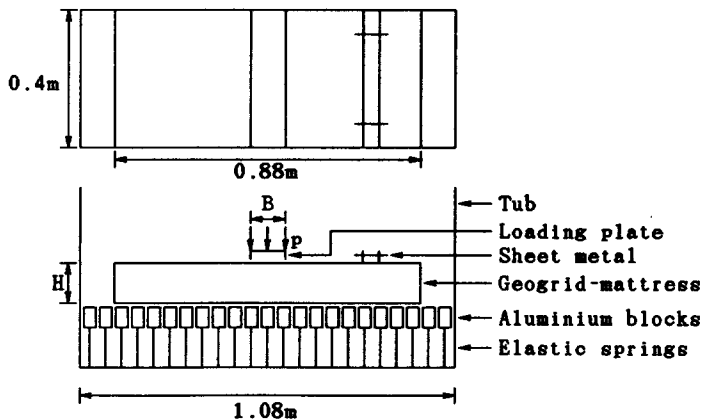


Fig.2 Experimental set-up

Table 1 Experimental details

geogrid-mattress		
geogrid	polymer grid	SR-1
	tensile strength	58.8 kN/m
soil	fine gravel	$G_s=2.613$
	dry density	16.4 kN/m ³
size	width	0.88 m
	length	0.4 m
	thickness H	0.05, 0.1, 0.15, 0.2, 0.25 m
supporting foundation		
elastic springs	vertical stiffness k_s	1098, 3077, 5018 kPa/m
loading conditions		
	width of loading plate B	0.1 m
	length of loading plate	0.4 m
	loading speed	1.67×10^{-5} m/s (1 mm/min)

3 EXPERIMENTAL RESULTS

The key factors of influencing the characteristics of the vertical stress distribution developed under the geogrid-mattress are considered to be :

- (1) the thickness of the geogrid-mattress; since the propagation of stresses takes place along the whole thickness of the geogrid-mattress,
- (2) the flexural rigidity of the geogrid-mattress and the stiffness of the supporting foundation; since the vertical load is distributed on the supporting foundation in accordance with the way of the interaction between the geogrid-mattress and the supporting foundation.

Herein, a series of tests was organized to investigate especially the effects of the vertical stiffness of the supporting foundation k_g and the thickness of the geogrid-mattress foundation H on the characteristics of the vertical stress distribution, as shown in Table 1. The experiments were carried out with 0.05, 0.1, 0.15, 0.2, 0.25 m thick geogrid-mattress models on the supporting foundation models of vertical elastic stiffness $k_g=1098$ kPa/m (using two elastic springs $k=1.12$ kgf/mm), $k_g=3077$ kPa/m ($k=3.14$ kgf/mm), and $k_g=5018$ kPa/m ($k=5.12$ kgf/mm). Fig.3 summarizes the notations of the values measured in the experiments.

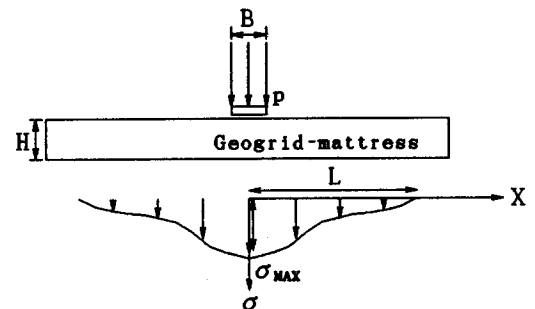


Fig.3 Vertical stress distribution

3.1 Vertical load intensity - maximum vertical stress curves

Fig.4 shows the behaviour of the maximum vertical stress σ_{MAX} generated beneath the centre of the mattress placed

on the supporting foundation models with different degrees of vertical stiffness, against the vertical load intensity p applied on the mattress. It can be seen that the larger the geogrid-mattress thickness H is, the smaller the vertical stress σ_{MAX} becomes, and almost linear relationships may be found between the applied vertical load intensity p and the generated maximum vertical stress σ_{MAX} . Therefore, the ratio of σ_{MAX}/p can be approximated to be constant throughout the application of the vertical load on the mattress. The σ_{MAX}/p values are plotted against H/B , in Fig.5. It can clearly be seen that the larger H/B value and the smaller k_g value reduce the stress ratio of σ_{MAX}/p greatly. It should be noted in Fig.5 that the conditions of $H/B = 0$ should correspond to the situations where no layer of the mattress soil foundation but the two sheets of geogrids are placed on the supporting foundation. It is interesting to see that three

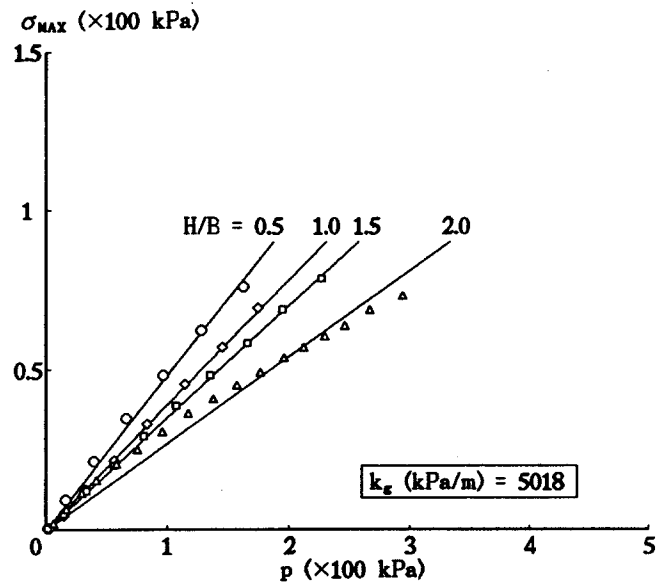


Fig.4(c) $p - \sigma_{MAX}$ relations ($k_g=5018$ kPa/m)

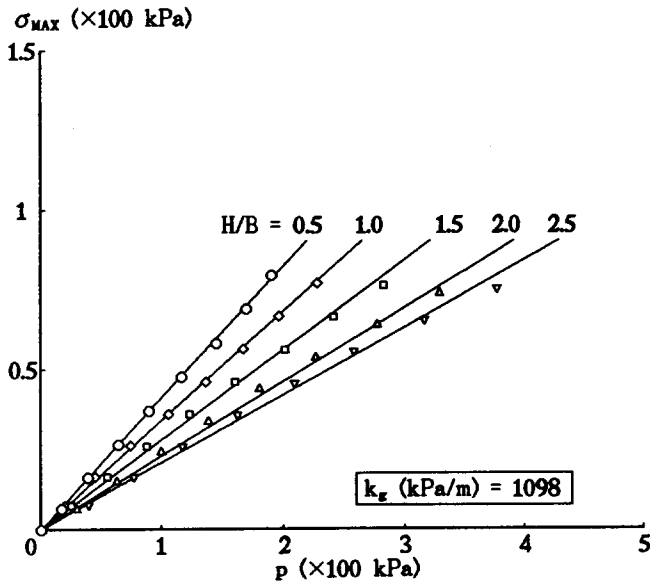


Fig.4(a) $p - \sigma_{MAX}$ relations ($k_g=1098$ kPa/m)

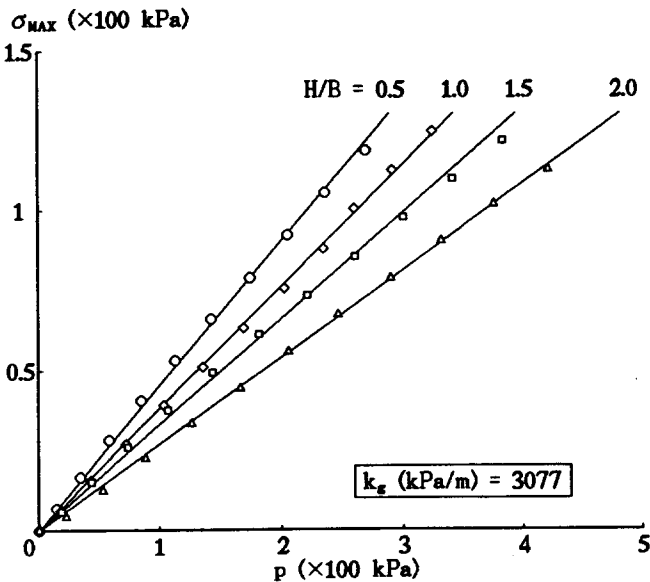


Fig.4(b) $p - \sigma_{MAX}$ relations ($k_g=3077$ kPa/m)

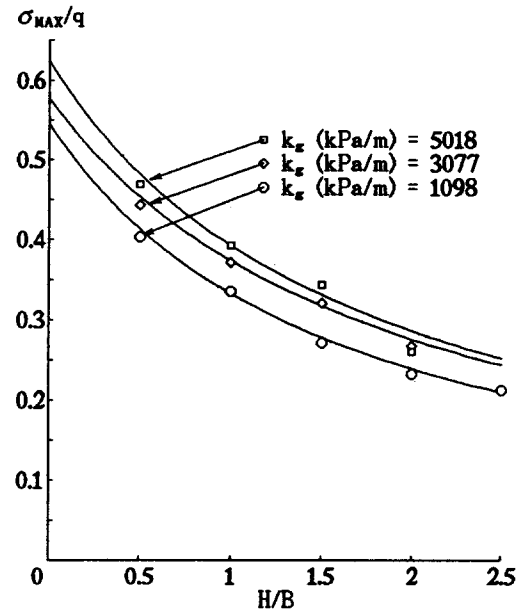


Fig.5 $\sigma_{MAX}/p - H/B$ relationship

curves in Fig.5 have different intersections with the σ_{MAX}/p axis.

3.2 Vertical stress distribution under the geogrid-mattress foundation model

It was examined above that the vertical load applied on the mattress is transmitted to the centre of the supporting foundation with a smaller magnitude of the vertical stress σ_{MAX} . In this section, the distribution of the vertical stress developed on the supporting foundation is examined. Fig.6 ~ 8 show the vertical stress distributions developed with the increasing applied vertical load intensity p , for the supporting foundation models with different degrees of vertical stiffness, respectively, in which σ is the vertical stress developed on the supporting foundation and X is the distance from the centre of the geogrid-mattress foundation models. It can be seen that the vertical stress

distribution has a convex curvature with the maximum stress σ_{MAX} at its centre, and hardly changes its width with the increasing applied vertical load. It can also be seen that the width of the supporting foundation on which the vertical stress is developed varies with the mattress thickness H as well as the vertical stiffness of the supporting foundation k_g . It may be suggested, from the design point of view, that the width of the geogrid-mattress should be large enough to accommodate the development of the vertical stress distribution on the supporting foundation, depending on the mattress thickness H as well as the vertical stiffness of the supporting foundation k_g as described above.

3.3 Normalized vertical stress distribution under the geogrid-mattress foundation model

The observation of the vertical stress distribution developed under the geogrid-mattress clearly showed that the area on the supporting foundation closer to the centre of the geogrid-mattress is subjected to greater vertical stress, however, it is not known whether the shape of the vertical stress distribution would change as the applied vertical load increases. Fig.9 ~ 11 show the distributions of the vertical stress σ normalized by the maximum vertical stress σ_{MAX} observed at each step of the applied vertical load p , on the supporting foundation with different degrees of vertical stiffness, respectively, which examine the shape of the vertical stress distribution developed on the supporting foundation. It can be seen that the vertical stress distribution hardly changes its shape

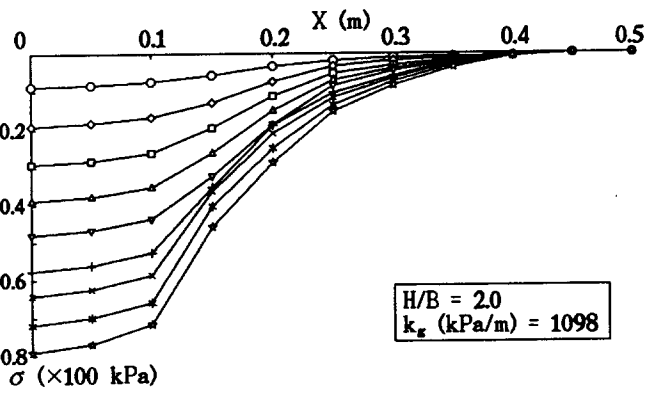
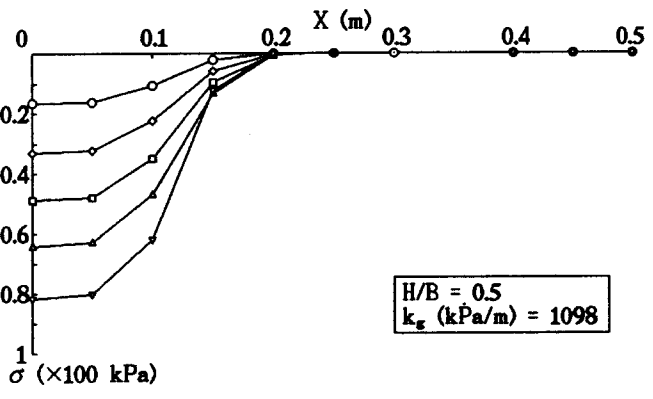


Fig.6 Vertical stress distribution ($k_g=1098$ kPa/m)

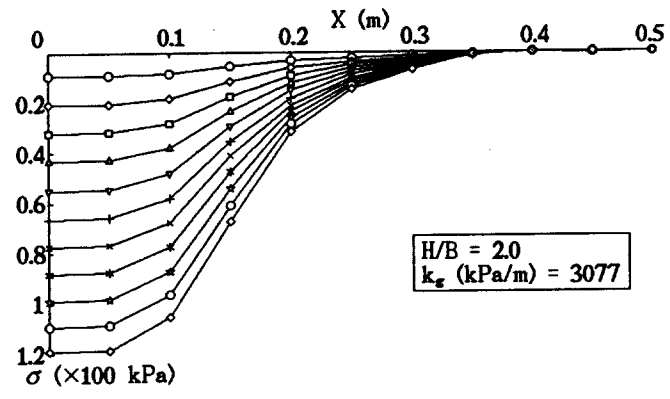
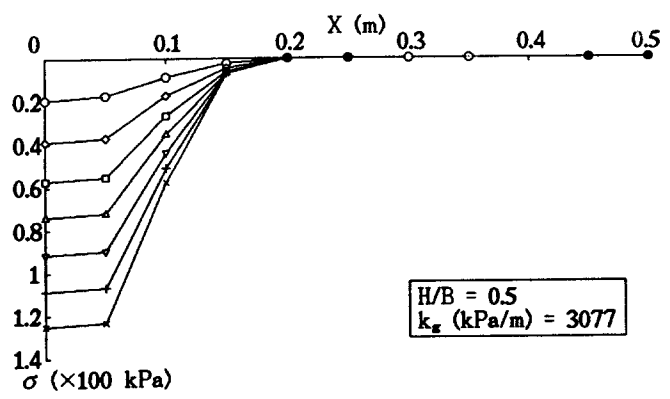


Fig.7 Vertical stress distribution ($k_g=3077$ kPa/m)

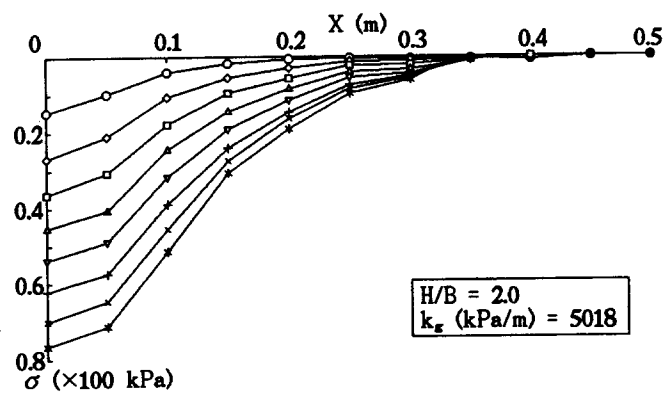
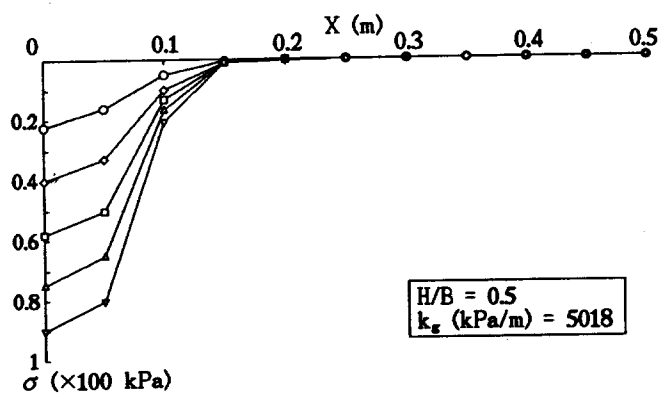


Fig.8 Vertical stress distribution ($k_g=5018$ kPa/m)

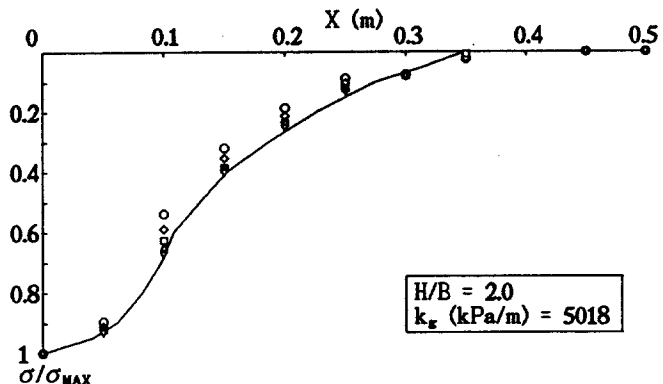
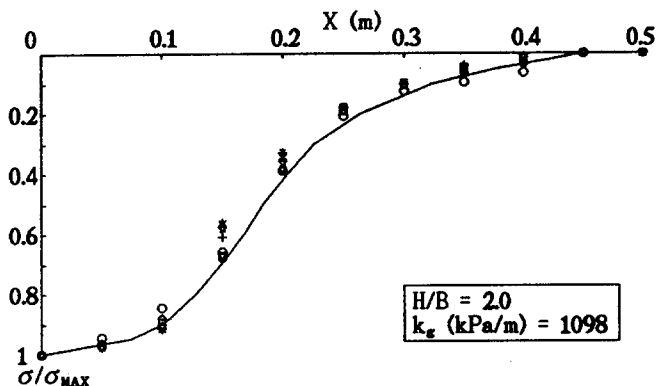
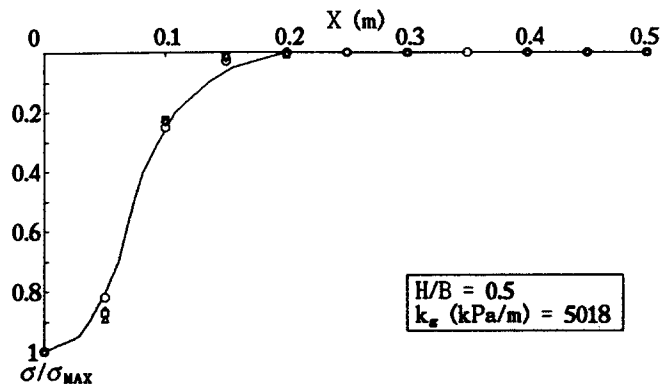
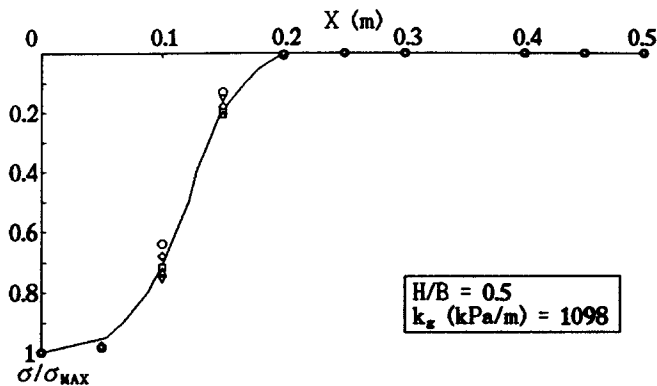


Fig.9 Shape of vertical stress distribution ($k_g=1098$ kPa/m)

Fig.11 Shape of vertical stress distribution ($k_g=5018$ kPa/m)

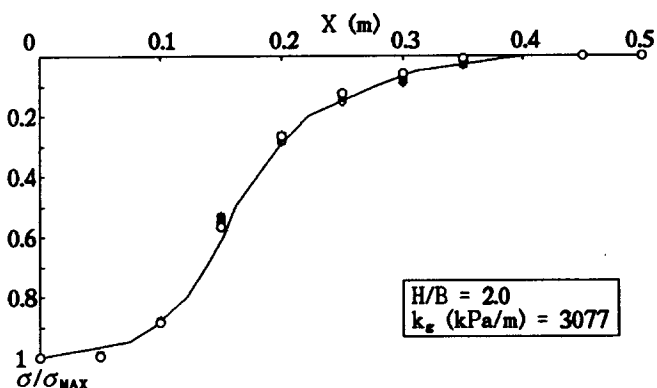
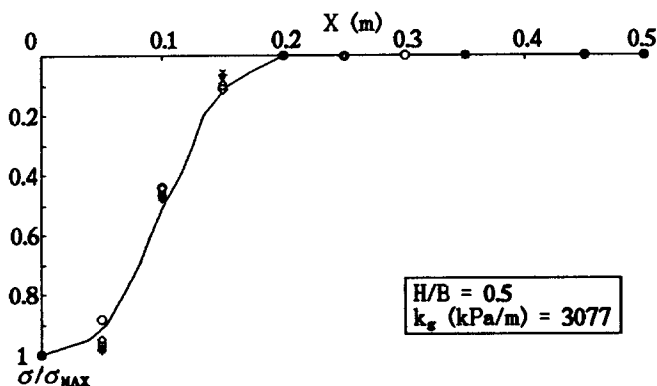


Fig.10 Shape of vertical stress distribution ($k_g=3077$ kPa/m)

with the increasing applied vertical load, when the normalized values σ/σ_{MAX} are examined. This experimental evidence implies that the same proportions of the vertical load are always transmitted to certain positions of the supporting foundation underneath.

3.4 Comparison of the shapes of the vertical stress distribution under the geogrid-mattress foundation model

It was experimentally confirmed above that the vertical stress distribution developed on the supporting foundation hardly changes its shape, therefore it may be possible to compare the shapes of the vertical stress distribution for different values of the mattress thickness H and the vertical stiffness k_g . Three diagrams in Fig.12 compare the shapes of the vertical distribution for different values of the mattress thickness H , on the supporting foundation models of $k_g=1098, 3077, 5018$ kPa/m, respectively. The comparisons made in Fig.12 are for the normalized distribution of the vertical stress, with σ/σ_{MAX} at the centre of the geogrid-mattress ($X = 0$) fixed to be unity. Therefore, it is appropriate to discuss the characteristics of the vertical stress distribution towards the X axis in Fig.12. Fig.13 shows the width of the vertical stress distribution L over B , against the H/B values. It is clearly seen that the width over which the vertical stress is distributed increases as the thickness of the geogrid-mattress H becomes greater, and the supporting foundation with lower vertical stiffness tends to offer a

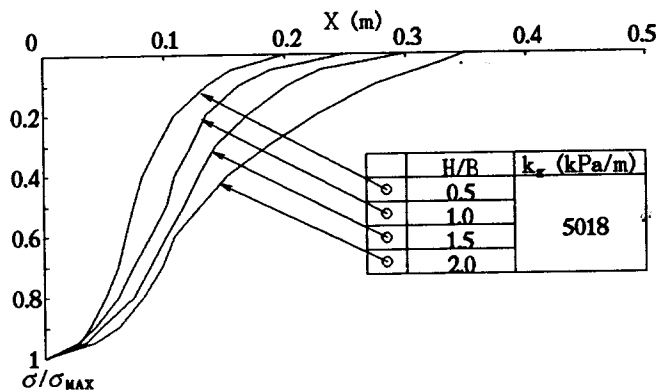
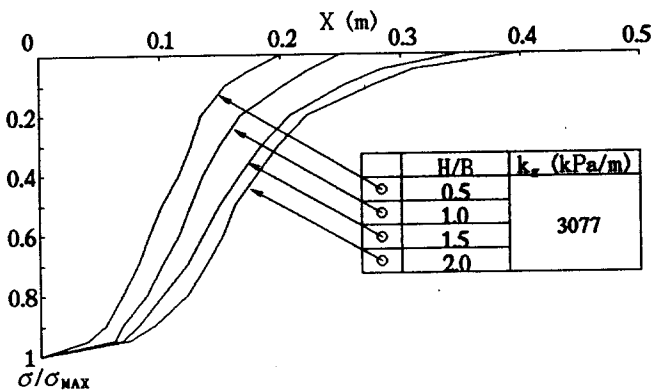
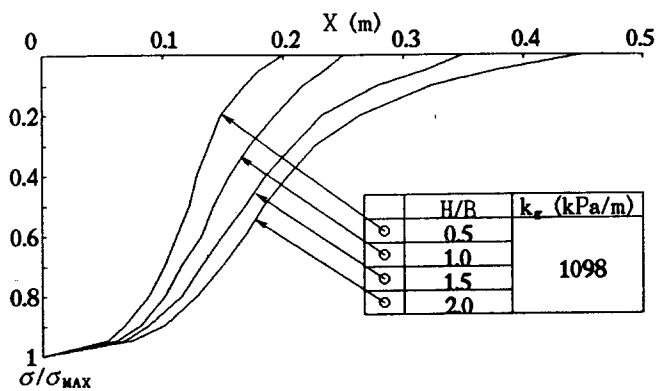


Fig.12 Comparison of shape of vertical stress distribution

wider vertical stress distribution, although no discussion is made on the settlement of the mattress-soil foundation system.

4 CONCLUSION

A series of experiments was carried out to investigate the geogrid-mattress foundation performance when subjected to vertical load. The advantage of using a geogrid-mattress foundation was considered to be due to the fact that the vertical load applied on the mattress propagates within the mattress and is transmitted to the supporting foundation, with the vertical load intensity reducing and with the width over which the vertical load acts increasing. Herein, the geogrid-mattress thickness and the vertical stiffness of the supporting foundation are considered to have some influence on the characteristics of the vertical stress distribution developed under the geogrid-mattress foundation. The experimental evidence suggested that the ratio of the maximum vertical stress developed at the centre of the geogrid-mattress σ_{MAX} to the applied vertical

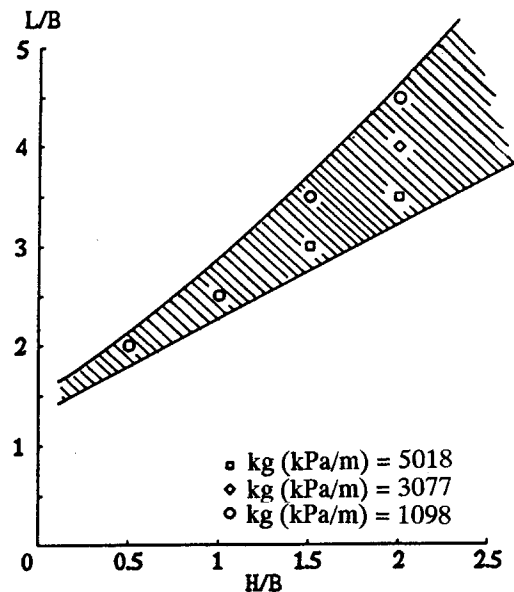


Fig.13 L/B - H/B relationship

load intensity p takes a constant value throughout the vertical load application. These stress ratios of σ_{MAX}/p depend on the mattress thickness as well as the vertical stiffness of the supporting foundation, and reduce with the greater mattress thickness and with the lower vertical stiffness of the supporting foundation. Then, the shape of the vertical stress distribution was examined. It was experimentally confirmed that the vertical stress distribution hardly changes its shape with the increasing applied vertical load, allowing the normalized shapes of the vertical stress distribution (σ/σ_{MAX}) for different values of the mattress thickness and the vertical stiffness of the supporting foundation to be compared with each other. It was found that the width of the supporting foundation over which the vertical stress is distributed becomes larger as the geogrid-mattress thickness becomes greater, and as the vertical stiffness of the supporting foundation becomes lower. It was noted from the design point of view, that the width of the geogrid-mattress should be at least large enough to accommodate the vertical stress distribution which takes place under the mattress.

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