

Evaluation of the bearing capacity improvement of geogrid mattress foundations

N.Yasufuku, H.Ochiai, K.Omine, S.Ohno & K.Kawamata
Department of Civil Engineering, Kyushu University, Fukuoka, Japan

Y.Tsukamoto
Department of Civil Engineering, Science University of Tokyo, Japan

ABSTRACT: Mattress foundations using geogrids are often used to improve the supporting capability of a soft soil foundation. It is well known that the vertical load applied on a geogrid-mattress foundation is transmitted to the supporting soil over a wider area, thus, improving the soils ability to support the foundation load. In order to clarify the improvement in bearing capacity due to geogrid-mattress foundations, a series of model loading tests on a geogrid-mattresses were carried out, with particular reference to their thickness and stiffness. In addition, a method of evaluating bearing capacity improvement is presented based on the experimental and theoretical considerations. It was found that the bearing capacity improvement can be formulated as a function of width of loading normalized by the effective width in the supporting soil layer.

INTRODUCTION

Geogrid mattresses aim to improve the bearing capacity of foundations by spreading the load over a wider area. The functions affecting the spread of the load are firstly the thickness of the mattress, secondly the stiffness of the foundation soil and finally the stiffness of the geogrid. In this paper, we will present an empirical method for the estimation of the improvement in bearing capacity together with the experimental results of model loading tests on geogrid-mattress.

1 PROPAGATION OF VERTICAL STRESS

The effects of thickness of the mattress and the stiffness of the supporting foundation on the characteristics of the vertical stress distribution under the geogrid-mattress have been already investigated by Ochiai et. al.(1994). A practical approach to the problem of the propagation of the vertical load through a soil layer is illustrated in Fig.1. In this figure, the loading width increases from B to B_L under an applied stress q on the upper surface of the mattress. This stress reduces to q_m at the base of the mattress. The effect of load spreading is evaluated by modifying Terzaghi's basic bearing capacity equation. In the case of no spreading of the load:

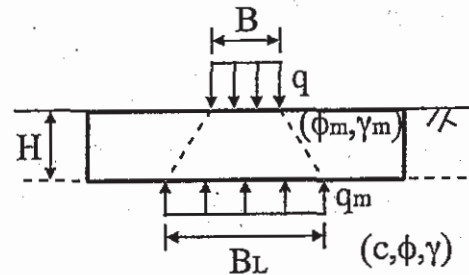


Fig. 1 Propagation of the vertical load through soil layer

$$q = cN_c + 0.5\gamma BN_q \quad (1)$$

On the other hand for a mattress foundation:

$$q_m = cN_c + 0.5\gamma B_L N_q + \gamma_m H N_q \quad (2)$$

where, γ_m is the unit weight of the mattress and H is the thickness of the mattress. Based on Eqs.(1) and (2), the increase in bearing capacity for a geogrid-mattress foundation is given by:

$$\Delta Q = q_m B_L - qB = cN_c B(B_L/B - 1) + 0.5\gamma B^2 \left\{ (B_L/B)^2 - 1 \right\} N_q + \gamma_m H B(B_L/B) N_q \quad (3)$$

This equation shows that the increase in bearing capacity due to the load spreading effect is a function of the ratio of the loading width B to the effective width B_L at the base of the mattress. In the following, an evaluation method for B_L/B values will be discussed in detail based on the experimental results of model tests on geogrid-mattress foundations of varying thickness and stiffness.

2 EXPERIMENTAL PROCEDURE

Fig.2 shows the layout of the experiment. On the floor of a 1.08 m wide, 0.4 m deep, 0.8 m high container, twenty-one aluminium blocks (0.05 m wide, 0.40 m long) were lined up. Two elastic springs were fixed under each aluminium block and the vertical deformation of each spring was measured by a dial gage attached alongside. The elastic springs with an elastic stiffness of $k=3.14 \text{ kgf/mm}$ were used to represent the supporting soil, possessing an elastic

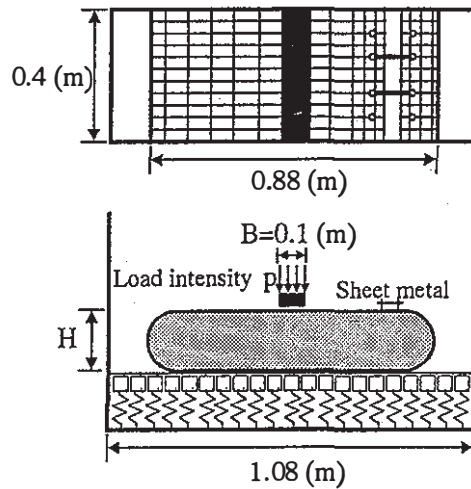


Fig.2 Experimental setup

modulus of subgrade reaction $k_g=3077 \text{ kPa/m}$. The model geogrid-mattresses were made of fine gravel enclosed by geogrids. The average dry density was 16.4 kN/m^3 and the internal friction angle was 41° (Ochiai et. al., 1994).

In this study, three different tensile stiffnesses of geogrid (2.9, 3.9 and 10.8 kN/m) were used to estimate the effect of mattress stiffness on the propagation of the vertical stresses. The details of each geogrid are shown in table 1. The size of each geogrid-mattress model was 0.88 m wide, 0.40 m long and 0.05 , 0.10 , 0.15 or 0.20 m thick. The loading plate (0.1 m wide, 0.4 m long) was placed on the model geogrid-mattress, which was then vertically loaded under displacement control. The rate of displacement was about 1 mm/min . The experimental details are summarized in table 2.

Table 1 Details of geogrids used

	Geogrid	Strength (kN/m)	Young's modulus (kPa)	Stiffness (kN/m)
G-1	WB	25.5	2.5×10^6	2.9
G-2	SS2	14.7	4.7×10^6	3.9
G-3	SR1	58.8	—	10.8

Table 2 Experimental details of geogrid-mattress model

geogrid-mattress		
geogrid	polymer grid	WB, SS2, SR1
	tensile strength	25.5, 14.7, 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 m
supporting foundation		
elastic springs	vertical stiffness k_g	3077 kPa/m
loading conditions		
	width of loading plate B	0.1 m
	length of loading plate	0.4 m
	loading speed	$1.67 \times 10^{-6} \text{ m/s}$

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Definition of Effective Width B_L

The mechanism of improvement of bearing capacity due to a mattress foundation lies in the fact that the mattress foundation placed on a given supporting subgrade produces a wider distribution of vertical stress than in the case of the directly applied vertical load, leading to a larger effective base width B_L . The proper evaluation of B_L/B is therefore important. When loading is applied to a mattress foundation the resulting stress distribution is convex with a maximum vertical stress at the center of the base as shown schematically in Fig.3, (Ochiai et.al., 1994). Based on the results and considering equilibrium of forces acting on foundation depicted in Fig.3, the

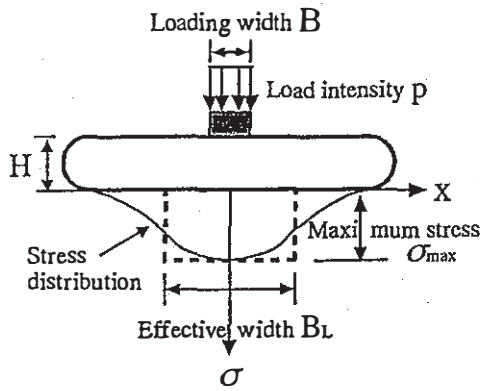


Fig.3 Definition of effective width B_L

definition of the effective width B_L can be given as follows:

$$pB = \sigma_{\max} B_L, \text{ hence } \frac{B_L}{B} = \frac{1}{\sigma_{\max}/p} \quad (4)$$

in which σ_{\max} is the maximum vertical stress generated at the center of the supported foundation (Ochiai and Tsukamoto, 1995). Based on Eq.(4), the effective width B_L can be easily determined by the measured values of σ_{\max}/p and B

Figs.4(a) to (c) shows the vertical stress distribution developed under the geogrid-mattress model with the G-1, G-2 and G-3 geogrids in the case of $H/B=1.0$, respectively. It can be seen that these agree with previous results in that the shape of the vertical stress distribution was convex with a maximum vertical stress at the center. Figs.5(a) to (c) show the relationship between σ_{\max} and load intensity p under each mattress with normalized thicknesses $H/B=0.5, 1.0, 1.5$ and 2.0 . It is obvious that the ratio σ_{\max}/p becomes constant irrespective of H/B and the geogrid stiffness. This means that B_L/B in Eq.(4) is always constant and is independent of the magnitude of the load intensity p . The comparison of σ_{\max}/p - H/B relationships for three kinds of geogrid-mattresses and fine gravel layers is shown in Fig.6. It is found that the values of σ_{\max}/p decrease with increasing H/B and geogrid stiffness. It is important to note that as the stiffness of a geogrid-mattress becomes higher, the spreading of the vertical stress is much larger.

3.2 Determination of B_L/B

When a loading plate of width B is placed on a geogrid-mattress foundation, the applied vertical load

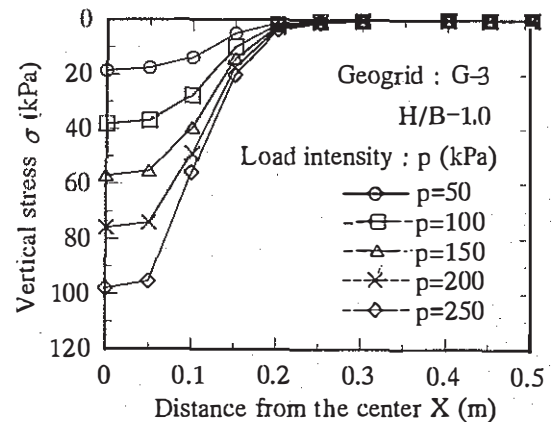
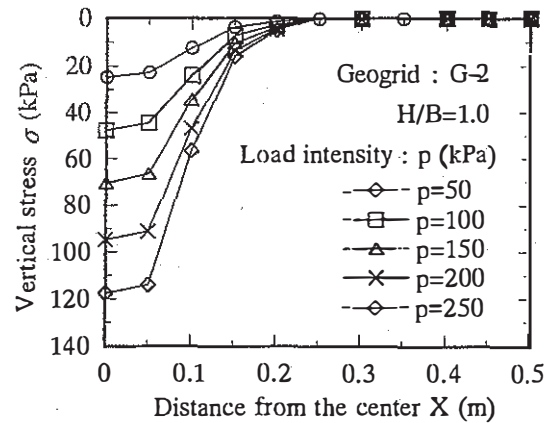
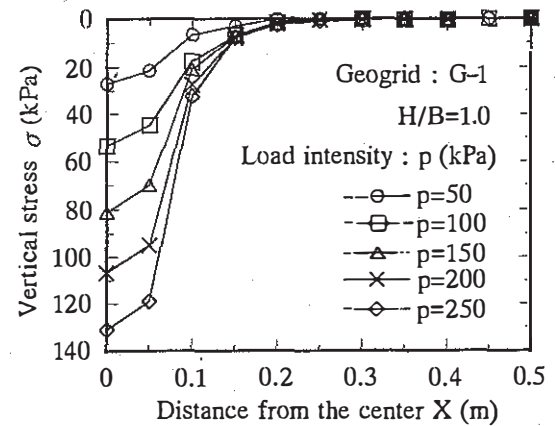


Fig.4 Typical vertical stress distribution under each geogrid-mattress model in the case of $H/B=1.0$

is transmitted to the supporting subgrade through the sheets of geogrids. As shown in Fig.7, the spreading effect can be divided into a spreading by the mattress alone, ΔB_g , and a further spreading by the fine gravel material in the mattress to an effective width B_L . ΔB_g is dependant on the stiffness of the geogrid-mattress. The following equation describes the geometry of the spreading:

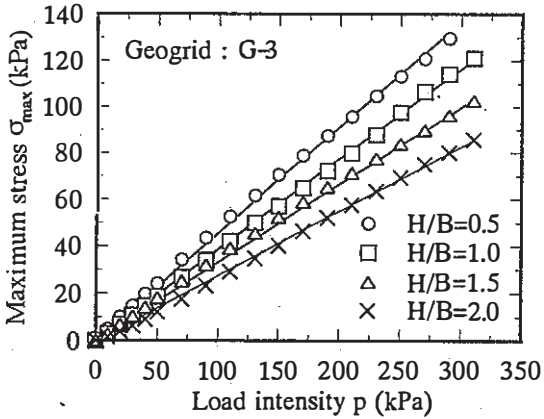
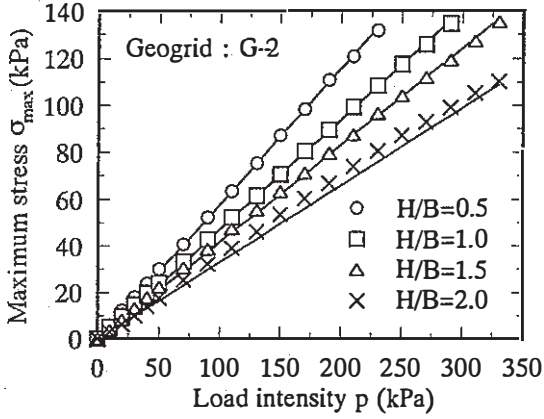
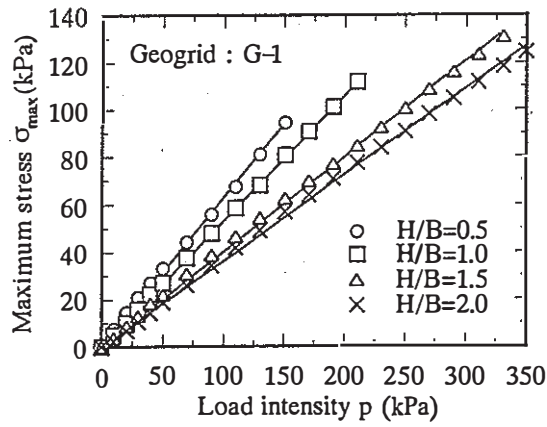


Fig.5 Relationship between σ_{\max} and load intensity p for each geogrid-matress

$$\frac{B_L}{B} = \left\{ \frac{\Delta B_g}{B} + 1 \right\} + 2 \frac{H}{B} \tan \beta \quad (5)$$

The geogrid spreading effect ΔB_g depends on the stiffness of the geogrid and further spreading to B_L depends on the stiffness of the granular materials in the mattress as well as the reaction of the subgrade.

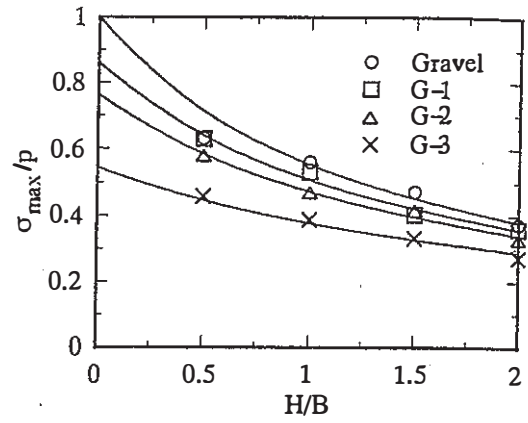


Fig.6 Comparison of σ_{\max}/p - H/B relationships for three kinds of geogrid-mattresses and gravel layer foundation

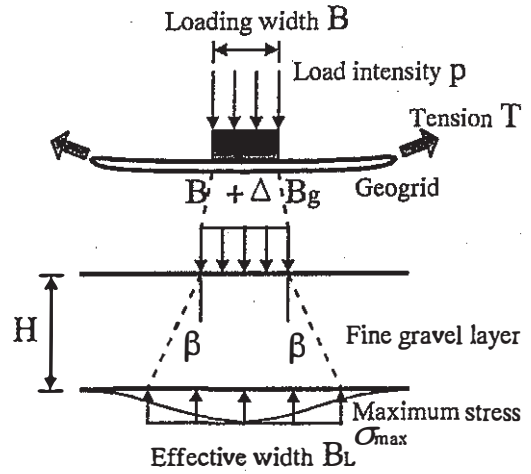


Fig.7 Spreading mechanism of geogrid-matress

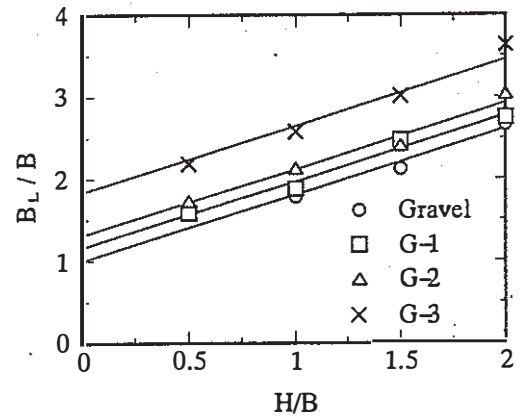


Fig.8 Relationships between B_L/B and H/B for three kinds of geogrid-mattresses and gravel layer foundation

Fig.8 compares the relationship between H/B and B_L/B for both experimental and computed data. Here, the experimental values of B_L/B were estimated using Eq.(4) together with the observed values of σ_{\max}/p as shown in Fig.5. On the other hand, the computed values are calculated by Eq.5, in which the spreading angle β in Fig.7 is estimated to be 23 degrees. This value was simply determined from the slope of the $B_L/B-H/B$ relationship in the gravel layered foundation, which was assumed to be $B_L/B=1+2(H/B)\tan\beta$. It can be seen from Fig.7 that the spreading effect of the geogrid, ΔB_g , which is defined as the value of B_L/B at $H/B=0$, increases with increasing geogrid stiffness and also that the calculated results in Eq.5 agree well with the experimental results. In addition, it is important to emphasize that the spreading effect of geogrid is always constant, irrespective of H/B .

3.3 Evaluation of Mattress Spreading Effect $\Delta B_g/B$

Fig.9 shows the relationship between $\Delta B_g/B$ and E/E_0 , in which the value of E is the geogrid stiffness defined as the slope of the tensile stress-strain relationship when the strain level is 3% and also E_0 is a reference stiffness. Here, $E_0=1.0\text{kN/m}$. As a result from this figure, the following liner relationship can be written:

$$\frac{\Delta B_g}{B} = \alpha \frac{E}{E_0} \quad (6)$$

in which α is an experimental parameter, and for the data shown in Fig.9, α was estimated as 0.076. Substituting Eq.(6) into Eq.(5), it is found that B_L/B can be easily calculated by the parameters E/E_0 , H/B and β .

4 SIMPLE MANNER DETERMINING MATTRESS THICKNESS FOR DESIGN

In a practical design, it is necessary to properly evaluate mattress thickness H against an allowable bearing capacity $\sigma_{\max(d)}/p$ in the supporting layer. Substituting Eq.(5) into Eq.(4) and rewriting Eq.(4), the following equation is obtained;

$$pB = \sigma_{\max}(B + 2H\tan\beta) + \sigma_{\max}\Delta B_g \quad (7)$$

where, $\sigma_{\max}\Delta B_g$ represents the mattress spreading

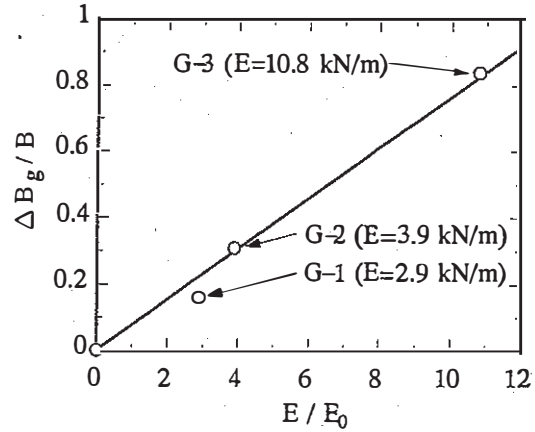


Fig.9 Relationships between $\Delta B_g/B$ and geogrid stiffness E/E_0

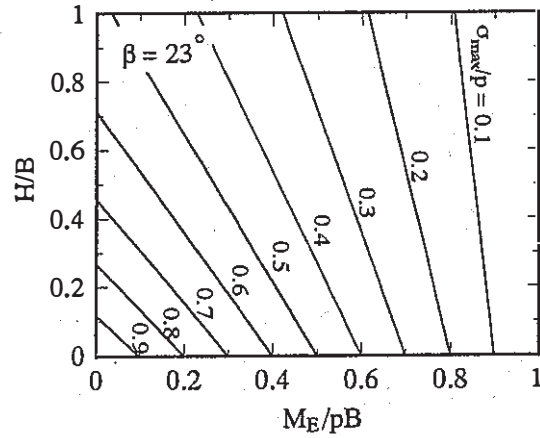


Fig.10 Chart of determining mattress thickness based on the mattress spreading effect

effect. Here, as discussed by Ochial et. al.(1986), taking the spreading effect as M_E and comparing with Eq.(7), M_E is given by

$$\begin{aligned} M_E &= \sigma_{\max}\Delta B_g \\ &= pB - \sigma_{\max}(B + 2H\tan\beta) \end{aligned} \quad (8)$$

Further, Eq.(8) is rewritten as follows:

$$\frac{M_E}{pB} = 1 - \frac{\sigma_{\max}}{p} \left(1 + 2 \frac{H}{B} \tan\beta \right) \quad (9)$$

Fig. 10 shows the $H/B-M_E/pB$ relationship for various values of σ_{\max}/p calculated from Eq.(9), when $\beta=23$ degrees. When the value of B , the loading intensity p ,

the allowable bearing capacity $\sigma_{\max(d)}$ and the geogrid stiffness E are given as design conditions, the mattress thickness H in the geogrid-mattress can be obtained using Fig.10. The spreading effect M_E ($=\Delta B_g \sigma_{\max(d)}$) is calculated by using Eq.(6), and then, based on the evaluated M_E/pB and the $\sigma_{\max(d)}/p$ design conditions, H/B can be easily determined from Fig.10.

5 CONCLUSIONS

The evaluation of bearing capacity improvement due to the load spreading effect of a mattress foundation is shown to be a function of the load normalized spreading width B_L/B . This ratio B_L/B can be represented by two parameters ΔB_g , dependent on the geogrid stiffness and β dependent on the stiffness of the materials in the mattress. In particular, based on a series of model loading tests on geogrid-mattress foundations, it was found that there is a simple linear relationship between the parameter ΔB_g and the geogrid stiffness E .

A practical design chart is given, which for a given subgrade bearing capacity allows the evaluation of the mattress thickness.

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