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Experimental evaluation of reinforcement in geogrid-soil structure

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ABSTRACT : Geogrids are usually inserted horizontally in geogrid-soil structure. A potential sliding surface, however, intersects geogrid at an angle which varies with the position of geogrid. There are satisfactory ways of investigating the interaction between the soils and geogrids in the current routine test techniques. A new prototype shear apparatus has been developed for this purpose. The shear surface is inclined and the geogrid is inserted horizontally, in which the tensile force can keep a constant level in this apparatus. The tests were carried out to evaluate the influence of the tensile force of the geogrids on the effects of soil reinforcement. The test results were compared with the idea of the mechanism in the current design method.

1 INTRODUCTION

The internal stability criteria for geogrid-soil structures require an evaluation of adequate stability against tensile rupture failure and pullout failure. For this purpose, various testing techniques have been developed. These include the testing of materials, interaction properties, laboratory models, field scale test, and the monitoring of working structures (Jewell,1993). The interaction behavior of soil–geogrid is routinely investigated by conducting the direct shear or pullout tests. The former determines an available shear resistance (Fig.1(a)), while the latter determines the bond capacity of geogrid against pullout (Fig.1(b)). When a potential sliding surface generally intersects the geogrids at an angle, there are no good means of investigating the response between the soils and geogrids. Jewell (1980), Bauer and Zhao (1992) have done some shear experiments in direct shear box, in which the geogrids were placed in inclined position instead of being horizontal (Fig.1(c-1)). However, the strain or the tensile force of geogrids was not able to be controlled in their tests.

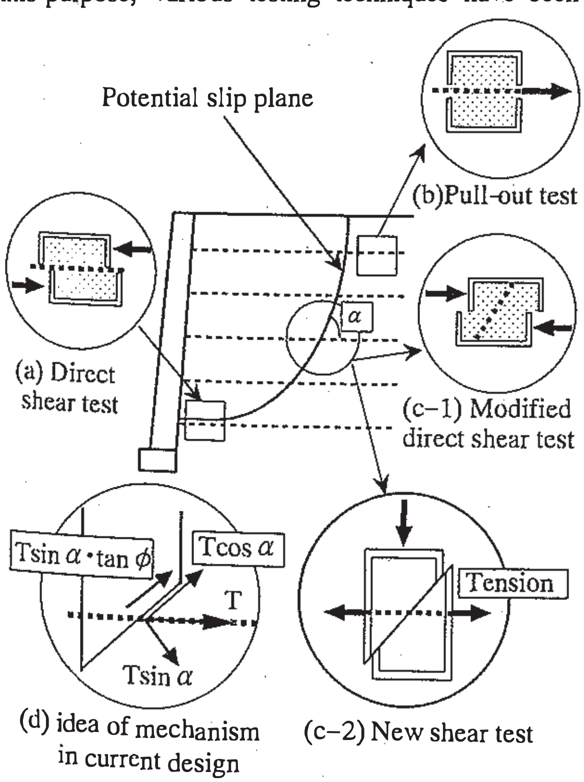


Fig.1 Tests to determine interaction coefficient for geogrid-soil structure

For the purpose of understanding the effects of soil reinforcement, a new small prototype shear test apparatus (Fig.1(c-2)) has been developed here. Experiment results were analyzed, and compared with the idea of the reinforced mechanism in current design methods.

2 APPARATUS AND TEST PROCEDURE

2.1 Test apparatus

On the working load condition shown in Fig.1, as the angles between the potential sliding surface and the geogrids vary with the positions which geogrids are placed, a series of tests needs to be carried out under the condition that the angles can be varied in order to study the influence of the angles on the effects of soil reinforcement. Further, in order to study the influence of the tensile force on the effects of soil reinforcement, a series of tests needs to be carried out under the condition that the tensile force of geogrid is set up. So, a new prototype shear apparatus shown in Fig.2 was developed at Kyushu University in 1995. The characteristics of the apparatus are as follows:

(1) it can imitate the working load conditions in most geogrid-soil structures,

(2) the angles between the potential sliding surface and the geogrid can be changed,

(3) a test can be carried out under the condition that the tensile forces which works at the geogrid is kept at a constant level.

The outline of the apparatus is briefly mentioned as follows.

① Shear box: The shear box is a rectangular shape of 200×200×380mm. It consists of an upper box and a lower box. The interface between the two halves of box, that is, the shear surface, is inclined. Two boxes are connected and guided by two linear motion bearings, which have little resistance. Three kinds of boxes with angles of 30°, 40° and 50° were prepared in order to change the angle between the potential sliding surface and the geogrid. The friction between soil and inside wall of the shear box is lubricated by using the greased rubber membranes.

② Pressure bag: By means of air pressure through the pressure bag fitted on the upper part of the shear box, the confining pressure which represents the overburden pressure is loaded.

③ Surcharge load system: It consists of a load cell, a motor, and a linear motion bearing. Through this system, the surcharge load is loaded vertically. Then, as the sliding angle is inclined, the shear box moves along the shear surface.

④ Bellofram cylinder: Through this, the tensile force is transmitted to the geogrid which is placed horizontally through the shear box. The tensile force can keep a constant level while shearing. In this paper, geogrid on one side is fixed on the upper box (refer to Fig.2).

In this test, Dry Toyoura sand which is a standard sand in Japan was used as specimen, and four kinds of geogrids with varied the shape properties were used as reinforcement materials, as shown in Table.1.

Fig.3 gives the summary of explanation of terms used in this paper. The surcharge load is measured using a load cell. The shear force S along the inclined surface is provided by the surcharge load. The component of the surcharge load perpendicular to the shear plane is canceled out by the linear motion bearings. The vertical displacement of the shear box is measured using a dial gauge and the shear displacement D along the inclined surface is provided by the vertical displacement of the shear box.

2.2 Test procedure

Sand is poured into the lower half of the shear box through multiple sieves in order to make a homogeneous specimen. The relative density of specimen D_r is about 70% .

After placing the geogrid on poured sand and fixing it on the box, the specified tensile force is provided by the bellofram cylinder. Additional sand is then filled in the upper half of the shear box in the same

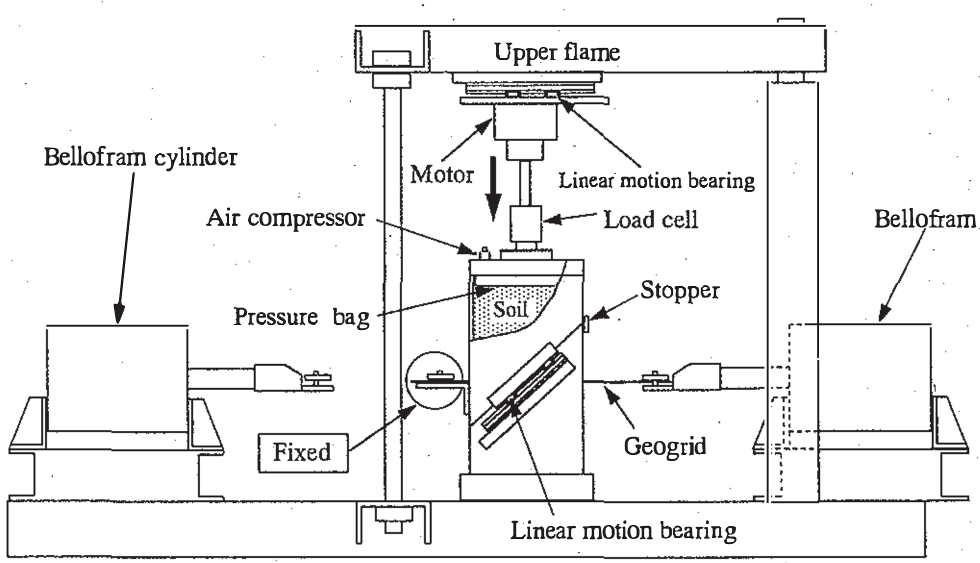


Fig.2 Sketch of the new prototype shear apparatus
(In this paper, geogrid on one side is fixed on the box.)

manner. The confining pressure is loaded by means of the air pressure through a pressure bag.

After taking off the stopper to prevent the upper shear box from sliding, the tests are carried out by vertically loading with a constant speed of 0.35mm/min. using a motor fitted with load cell.

In this study, all tests were carried out under the condition that the geogrid on one side is fixed on the box and the sliding angle α=40°. Table.2 shows the type of geogrids and the conditions of the confining pressure σ_0 and tensile forces T of geogrids.

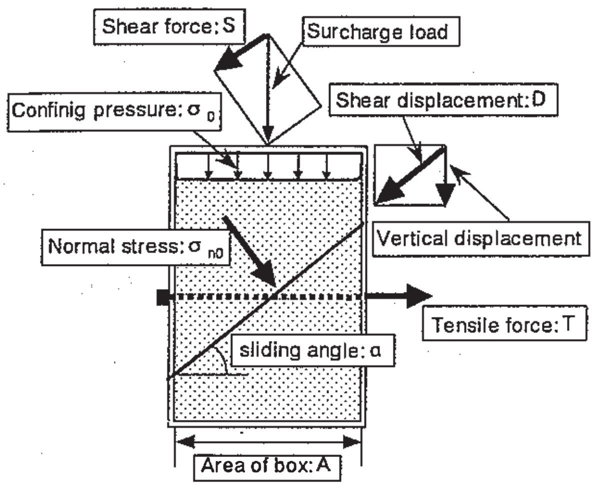


Fig.3 Summery of terms used in this paper

Table. 1 The geometry of dimensions of geogrids

	Tensile force (kN/m)	Spacing L(cm)	Width B(cm)	Thickness t (cm)
Geogrid A	76.6	0.89	0.94	0.13
Geogrid B	37.2	5.42	2.79	0.10
Geogrid C	28.4	2.97	0.83	0.06
Geogrid D	76.6	1.78	0.94	0.13

Table.2 The type of geogrids and the conditions of the confining pressure and the tensile force

	σ_0=24.5, 49.0, 73.5, 100kPa
	Non -reinforcement
T=1.87kN/m	Geogrid A, B, C, D
T=4.90kN/m	Geogrid A
T=9.80kN/m	Geogrid A

3 TEST RESULTS AND DISCUSSION

3.1 Idea of current design method

Current design method is generally based on the limit equilibrium analysis. The typical equation for safety factor F_S along the sliding surface in Fig.1 is as follows:

$$F_S = \frac{E + \Delta E}{S_D} \tag{1}$$

where, E is the mobilized shear resistance of soils and ΔE is the increment of shear resistance due to reinforcement, and S_D is an applied shear force on the sliding surface.

Considering the effects of the tensile force T of geogrids, ΔE in Eq.(1) is generally evaluated as the sum of two components (refer to Fig.1(d));

$$\Delta E = T\cos\alpha + T\sin\alpha \cdot \tan\phi \tag{2}$$

The first term (Tcosα) is the component of the tensile force T which is parallel to the sliding surface. The other (Tsinα· tanϕ) is the incremental component of the friction resistance of soils ,which is caused by the component of the tensile force T perpendicular to the sliding surface.

3.2 Effects of tensile force T and normal stress σ_{n0}

Here, the experimental results at the sliding angle α=40° are reported as a typical ones in this study.

Fig.4 shows the relationships between shear force S which works on the sliding surface and shear displacement D to the sliding direction (refer to Fig.3), under the conditions of confining pressure σ_0=49.0kPa and three kinds of tensile forces T. The reinforced cases yield both higher peak and residual

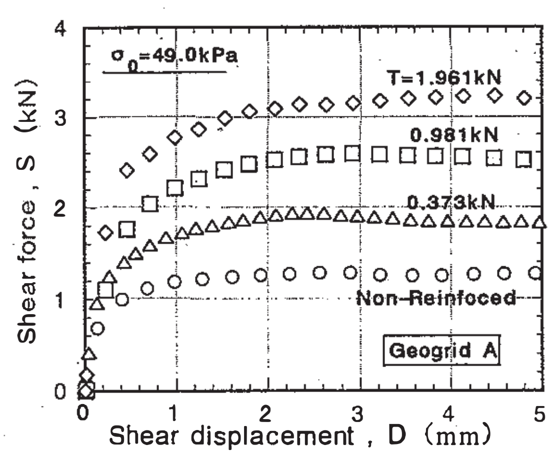


Fig.4 Relationships between shear force and shear displacement

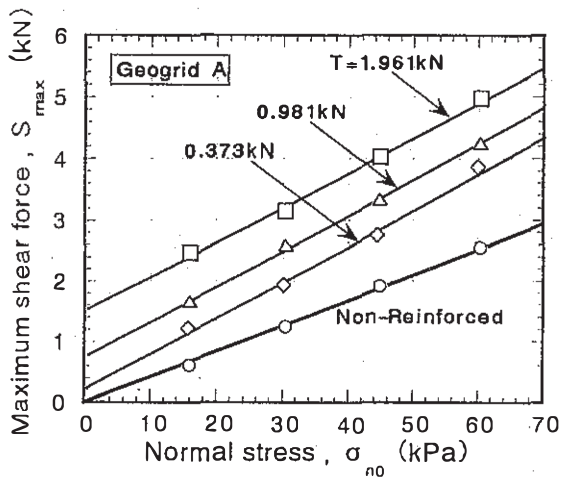


Fig.5 Relationships between maximum shear force and normal stress

shear resistance than the non-reinforced case. However, the force-displacement relationships of reinforced cases are similar to that of non-reinforced cases. As can be seen in Fig.4, no distinct peak value was observed for all the cases and the shear resistance mobilized in reinforced cases increases with the tensile force T.

Fig.5 shows the relationships between maximum shear force S_{max} of non-reinforced and reinforced cases and normal stress σ_{n0} on the sliding surface (refer to Fig.3). As is clearly shown, the reinforced cases exhibit an intercept with the longitudinal axis when a straight line extrapolation is made, while non-reinforced cases pass through the origin. This implies that the reinforced cases have an "apparent cohesion", depending on the tensile force and the reinforcement materials.

3.3 Effects of soil reinforcement

The focus here will be on the shear strength increment in reinforced cases compared with non-reinforced cases. The effects of soil reinforcement are presented by the shear strength increment $\Delta\tau$ which is defined by,

$$\Delta\tau = \frac{S_R - S_0}{A'} \qquad (3)$$

S_R: the maximum shear force in reinforced case
S_0: the maximum shear force in non-reinforced case
A': the area of sliding surface, $A'=A/\cos\alpha$
A: the area of cross section of shear box

When the test results give the same ones as the idea in current design in Eq.(2), the shear strength increment $\Delta\tau_{design}$ in current design is expressed in the form of a function of the tensile force T as follows:

$$\Delta\tau_{design} = \frac{\Delta E}{A'} = \frac{\cos\alpha}{A'}T + \frac{\sin\alpha\cdot\tan\phi}{A'}T \qquad (4)$$

In the following, the effects of soil reinforcement are discussed through the experimental results, comparing with the current idea in Eq.(4). Fig.6 shows the relationships between the shear strength increment $\Delta\tau$ and the normal stress σ_{n0} with the different kinds of the tensile forces T. It is clear that $\Delta\tau$ increases with the tensile force T and the normal stress σ_{n0}. Further, the gradients of three lines in Fig.6 are almost same, independent of the tensile force T. Based on the results, $\Delta\tau$ can be expressed as

$$\Delta\tau = \Delta\tau_1 + \Delta\tau_2 \qquad (5)$$
$$= \Delta\tau_1 + k_2\sigma_{n0} \qquad (6)$$

where $\Delta\tau_1$ is the intercept with the longitudinal axis ($\Delta\tau$), $\Delta\tau_2$ is given as $\Delta\tau - \Delta\tau_1$, and also the coefficient k_2 is a constant which is defined by the gradient of $\Delta\tau$–σ_{n0} linear relationships in Fig.6.

According to Schlosser and Long(1974), $\Delta\tau_1$ can be called a pseudo-cohesion or an apparent cohesion. It can be understood that $\Delta\tau_1$ is a function of the tensile force T. $\Delta\tau_1$ is, therefore, considered to be a shear strength increment due to the tensile force T. Fig.7 shows the relationships between $\Delta\tau_1$ and the tensile forces T. $\Delta\tau_1$ increases linearly with the increasing tensile force T. The relationship is given by

$$\Delta\tau_1 = k_1 T \qquad (7)$$

where, k_1 is a constant, which is given as 14.7 ($1/m^2$) based on the results in Fig.7.

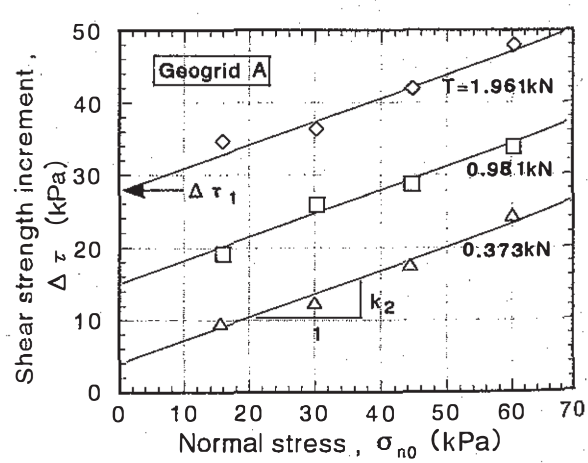


Fig.6 Relationships between shear strength increment and normal stress

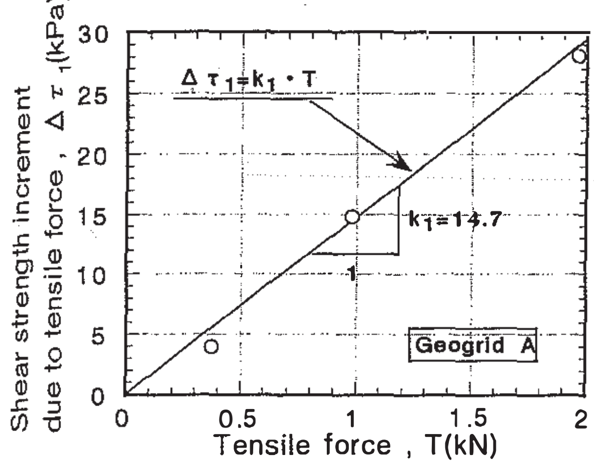


Fig.7 Relationships between shear strength increment and tensile force

Considering $\Delta\tau_1$ in Eq.(7) to be equivalent to the first term in Eq.(4), the coefficient k_1 becomes,

$$k_1 = \frac{\cos\alpha}{A'} \qquad (8)$$

Substituting α=40(°) and A'=0.052(m²) into Eq.(8), the value of k_1 is calculated as 14.7 (1/m²). It is obvious that this value is almost same as the gradient of $\Delta\tau_1$-T relationship in Fig.7.

Next, the second term $\Delta\tau_2$ in Eq.(5) is considered. As mentioned above, $\Delta\tau_2$ is independent of the tensile force T, which is given by

$$\Delta\tau_2 = k_2\sigma_{n0} \qquad (9)$$

Here, comparing $\Delta\tau_2$ with the second term in Eq.(4), the form of Eq.(9) is clearly different from that of the second term in Eq.(4). Eq.(9) means that when σ_{n0} becomes higher, $\Delta\tau_2$ becomes larger.

When it is considered that an increment of the normal stress $\Delta\sigma_n$ exists in reinforced cases, the actual normal stress σ_n on the sliding surface is given by,

$$\sigma_n = \sigma_{n0} + \Delta\sigma_n \qquad (10)$$

where, σ_{n0} is the normal stress which is applied by a confining pressure σ_0 (refer to Fig.3). Based on this idea, $\Delta\tau_2$ is considered to be mobilized by $\Delta\sigma_n$, and is expressed as

$$\Delta\tau_2 = \Delta\sigma_n \tan\phi \qquad (11)$$

where, ϕ is the friction angle of soil (ϕ=36°).

Fig.8 shows the relationship between the increment of the normal stress $\Delta\sigma_n$ and normal stress σ_{n0}. Here, $\Delta\sigma_n$ is calculated by substituting $\Delta\tau_2$ and ϕ into $\Delta\sigma_n = \Delta\tau_2/\tan\phi$. It is shown that the $\Delta\sigma_n$ increases linearly with increasing σ_{n0}. $\Delta\sigma_n$ can be expressed as

$$\Delta\sigma_n = k_n\sigma_{n0} \qquad (12)$$

where based on the result of Fig.8, the coefficient k_n is a constant value which is equal to 0.44. It is found that $\Delta\sigma_n$ is about 40 percent of normal stress σ_{n0}. According to the results, Eq.(9) can be rewritten as

$$\Delta\tau_2 = k_n\sigma_{n0}\tan\phi \qquad (13)$$

Eq.(13) means that the effects of soil reinforcement due to the increment of normal stress exist in the reinforced mechanism. The effect of $\Delta\tau_2$ is considered to be mainly dependent on the friction angle ϕ and dilatancy property of soils.

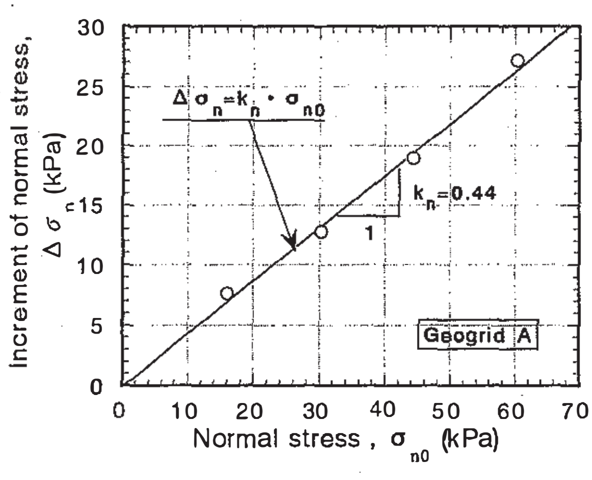


Fig.8 Relationships between the increment of normal stress and normal stress

3.4 Effects of the shape of geogrid

Fig.9 shows the relationships between the shear strength increment $\Delta\tau$ obtained by Eq.(3) and the normal stress σ_{n0}. Based on these results, the effects of geogrid shown by the coefficients k_1 and k_n in Eqs.(7) and (13) are discussed in the following ways. It is, firstly, concluded that because $\Delta\tau_1$ is constant as shown in Fig.9, the coefficient k_1 is regarded as a constant value which is independent of the shape of geogrids. It is, secondly, clear that because the gradients of the lines vary as shown in Fig.9, the coefficient k_n varies with the shape of geogrids, that is, the increment of the normal stress depends on the shape of geogrids. Fig.10 shows the relationships between the k_n and the shape coefficient R of geogrid, which is defined as R=2t (1/L+1/B) (refer to Fig.11 and Table.1). It can be seen that the R-k_n relationship is unique, at least in the geogrids used in this study.

Therefore, the coefficient k_n is determined from the shape coefficient R. In addition, it is noted that the value of R represents the effects that soil is confined into the aperture of geogrid, and is pressed by the surface of geogrid.

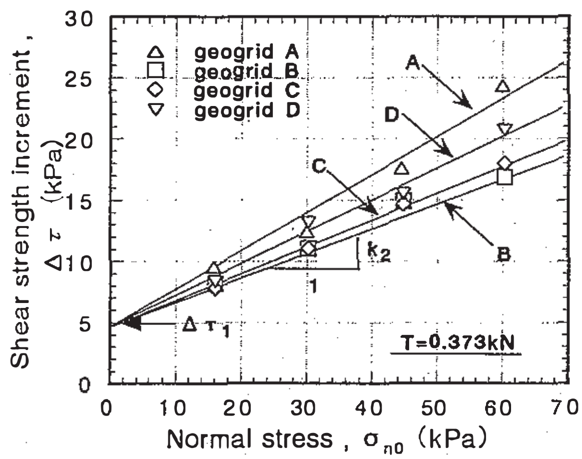


Fig.9 Relationships between shear strength increment and normal stress

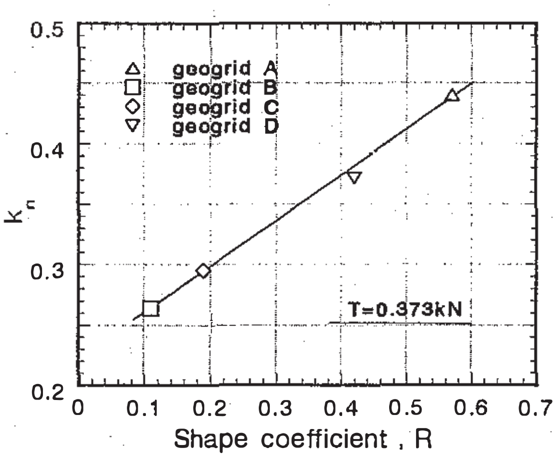
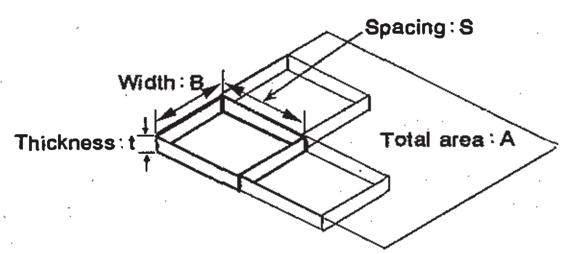


Fig.10 Relationships between k_n and shape coefficient



$$\text{Shape coefficient}: R = \frac{(\text{Side area of one box}) \times (\text{number of box})}{(\text{Total area})}$$

$$= \frac{2t\,(B+L)\cdot\frac{A}{BL}}{A}$$

$$= 2t\left(\frac{1}{B}+\frac{1}{L}\right)$$

Fig.11 Explanation of the shape coefficient

4 CONCLUSIONS

A new small shear prototype apparatus has been developed at Kyushu University. A series of tests using four kinds of geogrids in the apparatus has been performed to clarify the effect of the tensile force of geogrid in the reinforced mechanism. Test results were focused on the shear strength increment of reinforced cases related to non-reinforced cases. It is concluded from this study that:

1) the effects of soil reinforcement on geogrid-soil structure are expressed as the sum of the shear strength increment due to tensile force of geogrid $\Delta\tau_1$ and the shear strength increment due to the increment of a normal stress $\Delta\tau_2$, such that;

$$\Delta\tau = \Delta\tau_1 + \Delta\tau_2$$

2) $\Delta\tau_1$ is expressed as

$$\Delta\tau_1 = k_t T = \frac{\cos\alpha}{A'} T$$

In addition, $\Delta\tau_2$ is expressed as

$$\Delta\tau_2 = k_n \sigma_{n0} \tan\phi$$

in which the coefficient k_n is determined from the shape of geogrid.

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