Earth Reinforcement, Ochiai, Yasufuku & Omine (eds) © 1996 Balkema, Rotterdam. ISBN 90 5410 833 9

Foundation method combining clay-cement mixture with geogrid

K.Tanaka & Y.Kato
Mitani Sekisan Co., Ltd, Fukui, Japan

K. Kasahara & Y. Kadokawa
Maeda Kosen Co., Ltd, Fukui, Japan

K.Arai, H. Machihara, K. Funaya & A.Ohtani
Fukui University, Japan

ABSTRACT: The soil improvement method based on cement stabilization, which has been widely used as a shallow foundation method, has a shortcoming such as the insufficient reliability for strength and stiffness especially against tensile and bending forces. This shortcoming is mainly due to incomplete mixing of cement powder with cohesive soil and due to cracks caused by the shrinkage of clay-cement mixture. Geogrids have the reliable strength and stiffness for tensile force, while geogrids have little resistance against bending and compressive forces. The combination of geogrid with cement stabilization technique, enables to create a reliable foundation method in which the two kinds of soil improvement methods compensate for the shortcomings each other. In order to practice this idea, the following two schemes are considered. Type-1 spreads a sheet of geogrid at the lower part of clay-cement mixture. Type-2 wraps the whole clay-cement mixture by a sheet of geogrid. This paper reports the results of field model tests of these two schemes.

1 FIELD MODEL TEST FOR TYPE-1

1.1 Testing Procedure

Figure 1 illustrates the outline of field model test for Type 1. A sheet of geogrid is spread at the lower third position of clay-cement mixture. Figure 2 shows a brief description of subsoil properties where the field test is carried out. As seen in Fig. 2, the ground surface is covered with a thick alluvial clay deposit which is extremely soft and weak. The ground water table is almost of the same level as the ground surface. The construction and testing procedures are as follows. 1) Excavate the natural ground surface with the size of clay-cement mixture shown in Fig. 1, by using a drag shovel bucket. 2) Mix the excavated clay material with cement powder (SiO_2: 20.4%, Al_2O_3: 5.1%, CaO: 61.6%, SO_3: 7.2%) thoroughly by using a shovel bucket. The mixing ratio of cement powder to clay material is 1 kN/m^3. This means that 1 kN of cement powder is mixed with 1 m^3 of clay material. 3) Take the one third amount of clay-cement mixed into the hole excavated at step 1) and compact it by using a tamping roller. 4) Spread a sheet of geogrid at the surface of compacted clay-cement mixture. 5) Take the remaining clay-cement mixed into the excavated hole and compact it similarly. 6) Three weeks after the clay-cement mixture has been constructed, a plate loading test is practiced as shown in Fig. 1. The load increment is 4.9 kN, which is sustained for 10 minutes. The surface settlement is monitored both on the loading plate and on the mixture. During the

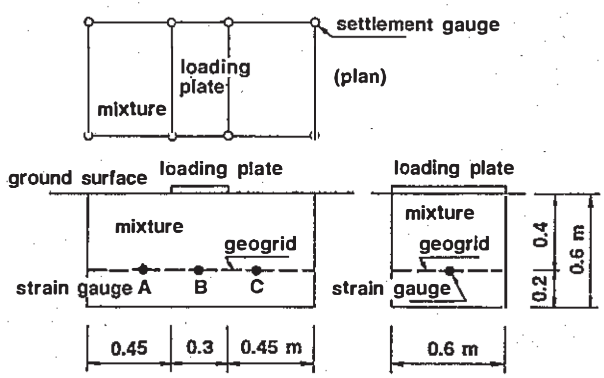


Fig. 1. Field model test (Type-1)

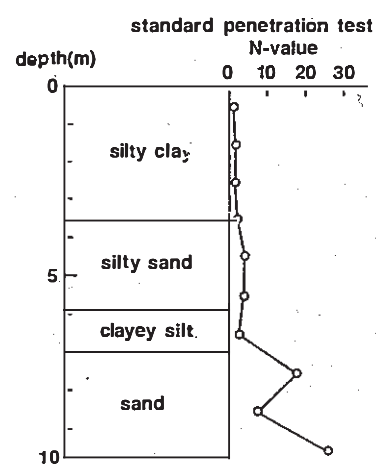


Fig. 2. Subsoil properties

loading test, the tensile strain on the geogrid is monitored at the three points shown in Fig. 1. Table 1 specifies the geogrid used for each case of field test, and shows the properties of clay-cement mixture which was obtained by the unconfined compression test performed at the time stage of plate loading test or three weeks after the construction work. Case 0 in Table 1 means the plate loading test on the natural soil deposit, and Case 1 represents the test on the clay-cement mixture without geogrid. Table 2 shows the mechanical properties of geogrids used in Table 1. The main purposes of the field test are to evaluate the ultimate bearing capacity of this foundation method and to compare the effect of stiffness and mesh size of geogrid.

1.2 Results of Field Model Test

Figures 3 and 4 show the load-settlement curves for each case defined in Table 1. Figure 3 represents the average settlement monitored on the loading plate, and Fig. 4 gives the average settlement observed at the position of clay-cement mixture as shown in Fig. 1. As seen in Table 1, the compressive strength and stiffness of clay-cement mixture varies quite widely for each case. This is the point of cement stabilization method when applied to soft clay. Thus it is difficult to compare the effect of stiffness of geogrid directly from the result shown in Figs. 3 and 4. In order to make the fair comparison, we introduce the 'normalized bearing capacity' which is defined as the ratio of a bearing capacity of clay-cement mixture foundation to the compressive strength of clay-cement mixture. The bearing capacity of mixture foundation is defined by the turning point on the load-settlement curve, at which the settlement increases rapidly (see Fig 3). Figure 5 shows the relationship between the normalized bearing capacity and the compressive strength of clay-cement mixture, which may represent the effect of geogrid by eliminating the difference or scatter of compressive strength. Cases 2 through 5 defined in Table 1 seem to give greater bearing capacity than Case 1 which applies no

Table 1. Test cases for Type-1 and properties of mixture

case	mixture			geogrid
	compressive strength (kPa)	water content (%)	deformation modulus E_{50} (kPa)	
0	20.1	62.1	388	natural
1	191.9	53.5	28880	-
2	37.6	69.4	3310	G5
3	54.0	69.0	3020	G10
4	78.9	61.3	10070	F10
5	107.6	57.1	12140	P

Table 2. Properties of geogrid

geogrid	tensile strength (kN/m)	strain at failure (%)	deformation modulus (MPa)	mesh
G5	50	5	2000	26x28
G10	100	10	4000	26x28
F10	100	10	3800	18x16
P	150	15	1110	90x90

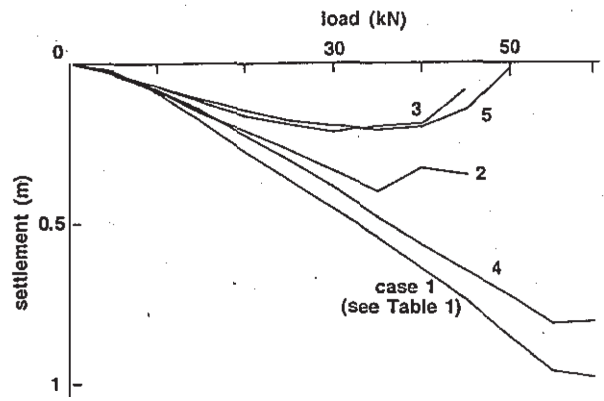


Fig. 4. Load-settlement curves (Type-1, on mixture)

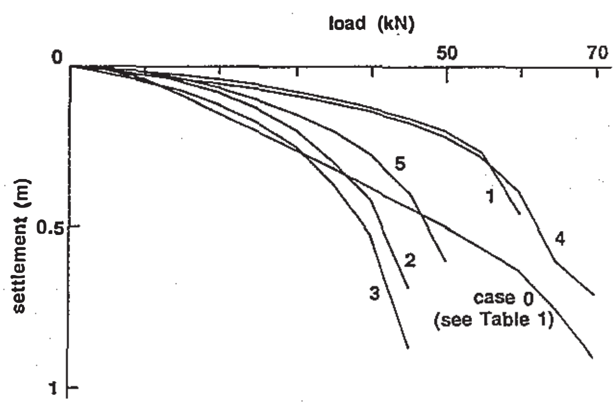


Fig. 3. Load-settlement curves (Type-1, on plate)

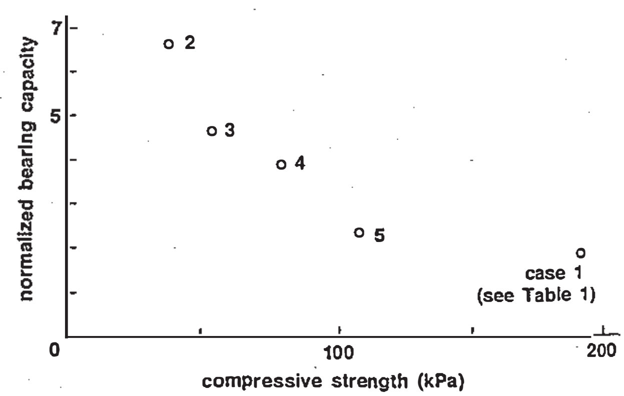
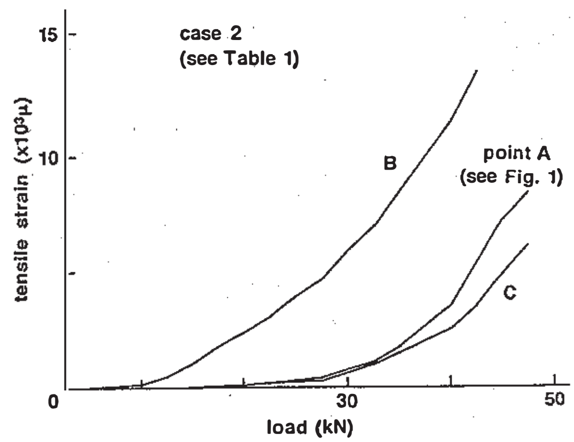
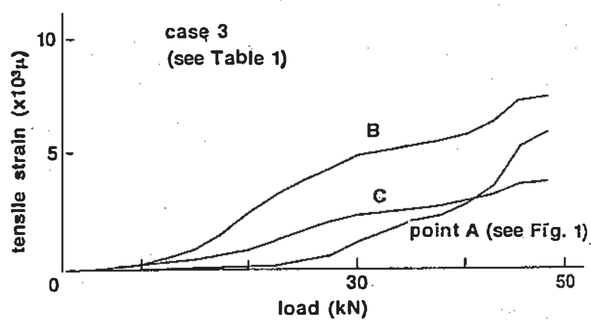


Fig. 5. Normalized bearing capacity

geogrid. Refering to Table 2, Fig. 5 suggests that the stiffer geogrid may give the greater bearing capacity. Figure 6 shows the relationship between the tensile strain induced on geogrid and the load during the plate loading test. Figure 6 proves that the geogrid bears a lot of tensile force with the increase in applied force. Estimating from Fig. 6 and Table 2, for instance, the geogrid applied in Case 2 may sustain about 15 kN/m of tensile force at the final state. It should be noted that by the effect of mesh size of geogrid, some kinds of geogrid happen to separate the lower part of mixture from the upper part and to reduce the bearing capacity. When applying Type-1, it is important to select geogrids which have a suitable mesh size.



(a) case 2



(b) case 3

Fig. 6. Tensile strain acting on geogrid (Type-1)

1.3 Design Policy

Photograph 1 shows the failure behavior of clay-cement mixture which was observed after finishing the plate loading test described above. Photograph 2 shows the failure behavior of the mixture observed in the laboratory test carried out separately. From Photos. 1 and 2, it is concluded that at first a few cracks develop at the bottom of mixture, and that just after the creation of cracks the settlement due to loading increases rapidly. That is, the creation of cracks corresponds to the bearing capacity defined previously by using the load-settlement curve. The relationship between the tensile strength of mixture and the tensile stress induced at the bottom of mixture seems to be a criterion for designing this foundation method. Stiffer geogrid tends to sustain a lot of tensile force instead of mixture as shown in Fig. 6, and it may reduce the tensile stress induced at the bottom of mixture. For instance, the elastic finite element analysis enables to estimate the tensile stress at the bottom of mixture considering the stiffness of geogrid. When the tensile stress calculated does not exceed the tensile strength of mixture, it is concluded that the foundation is stable. For practicing this design technique, it is necessary to know the deformation moduli of geogrid and mixture, and the tensile strength of mixture. It is our future subject to evaluate the tensile strength of mixture correctly and easily.

Photo. 1. Failure behavior of mixture (Type-1)

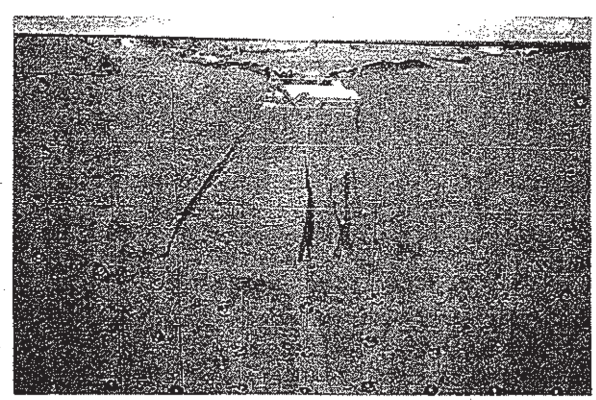


Photo. 2. Creation of cracks (Type-1)

2 FIELD MODEL TEST FOR TYPE-2

2.1 Testing Procedure

Figure 7 illustrates the outline of field model test for Type-2. The whole of clay-cement mixture is wrapped by a sheet of continuous geogrid. Two kinds of height of mixture are used as shown in Fig. 7. The field test for Type-2 was performed at the same site as the test for Type-1. The construction and testing procedures are fundamentally the same as those described for Type-1, except that a sheet of geogrid was spread just after excavation of soil deposit. Based on the experience of the test for Type-1, the construction procedure was practiced more carefully as follows. 1) Excavation is carried out by using a hand shovel, so that the excavation may not disturb the surrounding natural ground. 2) Especially the mixing of excavated clay with cement powder is practiced more thoroughly by using a special mixing equipment. This operation seems to produce a more homogeneous clay-cement mixture which has a small difference in compressive strength as shown later. 3) The clay-cement mixture is compacted sufficiently by dividing the mixture into three layers. 4) The geotextile is overlapped at the upper surface of mixture and is connected closely by wires. As the same as the test for Type-1, three weeks after the clay-cement mixture has been constructed, a plate loading test is practiced. The load increment is 4.9 kN, which is sustained for 5 minutes. As well as the test for Type-1, the surface settlement and the tensile strain on geogrid are monitored as shown in Fig. 7. Table 3 shows the specification of field test for each case, where two kinds of height and two kinds of mixing ratio are applied. The main purposes of the field test are to evaluate the bearing capacity of Type-2 and to estimate the necessary strength and height of mixture. Based on the result of test for Type-1, a kind of geogrid G-5 shown in Table 2 is employed. Table 4 shows the properties of clay-cement mixture at the time stage three weeks after mixing. As seen in Table 4, the difference of compressive strength among the cases becomes considerably small compaiing with the result of Type-1.

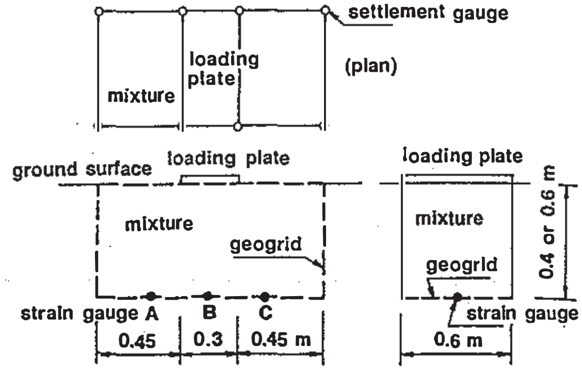


Fig. 7. Field model test (Type-2)

Table 3. Test cases for Type-2

case	mixing ratio (kN/m^3)	height (m)	geogrid
0	natural ground		
1	1.0	0.6	-
2	1.0	0.4	-
3	0.7	0.6	-
4	0.7	0.4	-
5	1.0	0.6	G5
6	1.0	0.4	G5
7	0.7	0.6	G5
8	0.7	0.4	G5

Table 4. Properties of mixture

case	compressive strength (kPa)	strain at failure (%)	water content (%)	deformation modulus E_{50} (kPa)
0	44.9	15.0	59.3	437 (natural)
1	73.3	1.9	52.2	6771
2	134.4	2.9	48.3	11893
3	98.9	3.7	49.6	4582
4	105.0	3.5	48.4	5551
5	78.0	4.2	48.7	2609
6	82.3	3.9	50.8	4186
7	64.2	4.4	47.0	2629
8	72.2	3.0	44.3	4468

2.2 Results of Field Model Test

Figures 8 and 9 show the load-settlement curves for each case defined in Table 3. Figure 8 represents the average settlement monitored on the loading plate, and Fig. 9 gives the average settlement observed at the position of clay-cement mixture as shown in Fig. 7. Since the difference of compressive strength of mixture is not large as seen in Table 4, it may be possible to compare directly the load-settlement curves without modification. Both in Figs. 8 and 9, the load-settlement curves appear to be clearly classified into two groups according to the existence of geogrid. Refering to Table 3, when using no geogrid, in Fig. 8 the load settlement curves seem to have a definite failure state, and in Fig. 9 the curves have an upward tendency. These tendencies indicates that the clay-cement mixture has broken in the cases without geogrid. When applying geogrid, in Fig. 8 the curves may not show a definite failure state, and in Fig. 9 the relationships describe a downward curves. Figure 10 shows the tensile strain induced on geogrid at the points illustrated in Fig. 7. All the curves in Fig. 10 reach the ceiling after the load has exceeded a certain value. This means that the geogrid is not bearing when the load exceeds a certain value. And that the turning point in Fig. 10 seems to correspond to that in Fig. 8. Considering these results shown in Figs. 8 through 10, the turning point in Figs. 8 and 10 corresponds to the failure of natural subsoil below the clay-cement mixtute. After the subsoil has reached the failure state, the clay-cement mixture wrapped by geogrid appears to sink without its failure. This estimation was supported also by observing the state of mixture after completing the plate loading test (for instance, see Photo. 3). Note that for Type-1 the failure of mixture due to tensile force leads to the limit state of foundation, while for Type-2 the failure of natural subsoil gives the bearing capacity of foundation on this particular test site. This result suggests that Type-2 gives the bearing capacity greater than Type-1, though it is difficult to directly compare Fig. 3 with Fig. 8 due to the large scatter of compressive strength of mixture constructed for Type-1. Comparing Fig. 10 with Fig. 6, the geogrid in Type-2 sustains larger tensile force than that in Type-1. Refering to Fig. 10, the smaller is the height of mixture, the more tensile force the geogrid tends to bear. However the difference of height and mixing ratio may not largely affect the load- settlement relationships as shown in Fig. 8.

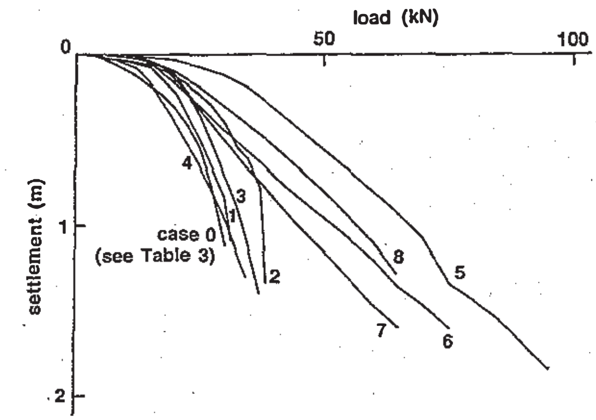


Fig. 8. Load-settlement curves (Type-2, on plate)

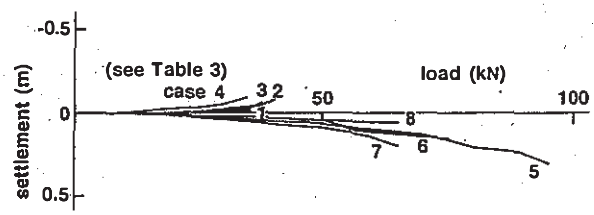


Fig. 9. Load-settlement curves (Type-2, on mixture)

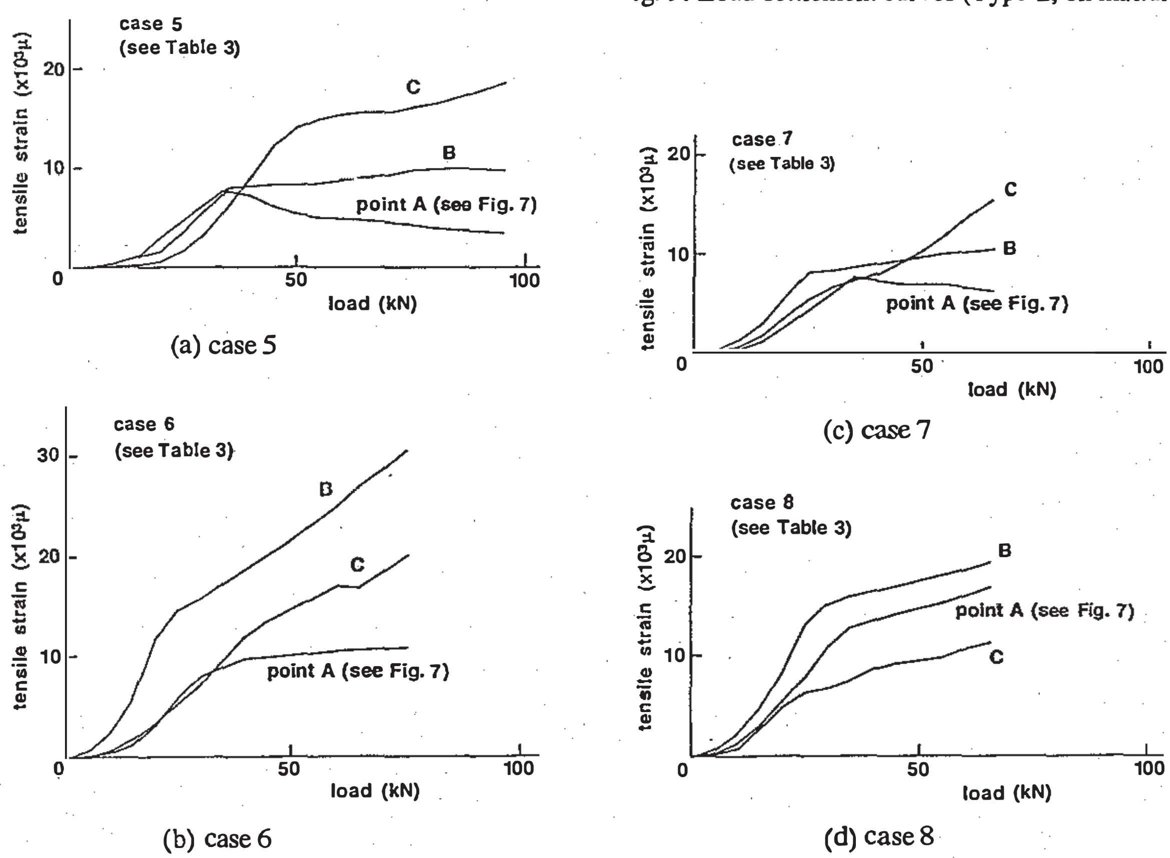


Fig. 10. Tensile strain acting on geogrid (Type-2)

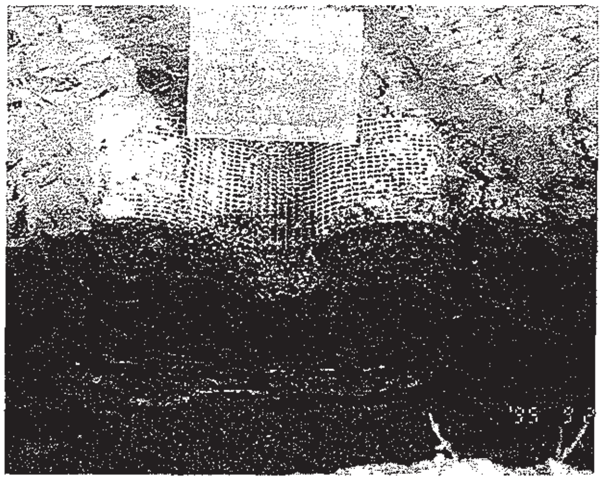


Photo. 3. Failure behavior of mixture (Type-2)

2.3 Design Policy

For the field model test for Type-2 described above, the natural subsoil below the mixture happens to specify the bearing capacity of the foundation method. Note that this result is given by the loading test on a extremely soft and weak clay deposit. For more general places of actual practice, we must investigate the following three criteria; 1) failure of mixture due to compressive or tensile force, 2) failure of geogrid due to tensile force, and 3) failure of natural soil deposit below the mixture. Items 1) and 2) are examined as follows. As being similar to Type-1, the elastic finite element analysis provides the tensile and compressive forces acting in mixture and the tensile force on geogrid. These calculated forces are compared with the strength of two materials. Item 3) should be considered by the traditional bearing capacity equation based on the limit equilibrium method, by regarding the clay-cement mixture as a rigid footing. For instance, Terzaghi's equation which considers the local failure of foundation ground, may give a fairly good approximation of the bearing capacity observed in Fig. 8.

3 CONCLUSIONS

This paper reports the field model tests for two types of shallow foundation methods, which combine the cement stabilization technique with the reinforcement technique by geogrid. Type-1 sets a sheet of geogrid at the lower third position of soil-cement mixture. Type-2 wraps soil-cement mixture by a sheet of geogrid. For Type-1 the tensile failure of mixture at the bottom tends to give the bearing capacity of the foundation method. For Type-2 the failure of natural subsoil below the mixture, seems to specify the bearing capacity, because the soil-cement mixture wrapped by geogrid has a sufficient strength in many cases. Generally Type-2 seems to provide greater and more reliable bearing capacity than Type-1. Based on the results of field model test, this paper gives the design policy for applying these foundation methods to actual engineering practice.