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Experimental study on localized deformation behavior of reinforced foundation ground

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ABSTRACT: In this paper, the behavior of real localized deformation of reinforced foundation ground was investigated based on the model loading test using the simulation of the ground by aluminum rods. A series of model loading tests with and without reinforcing materials was conducted. And not only the improved bearing capacity but also its localized deformation property were investigated using the picture processing analysis of the deformations on the photograph for every settlement steps. The results drawn from these investigations were 1) the mechanism of progressive failure for the reinforced foundation ground was clearly investigated as a result of localized deformation and this was totally different from that for unreinforced ground, and 2) the failure mechanism for different reinforcement condition such as the length and the stiffness of the reinforcement was compared in each other and these bearing capacities were also evaluated quantitatively.

1 INTRODUCTION

Earth reinforcement practice using geogrid type of reinforcing materials has been widely used around the world in this three decades, and the design method for these structures are mainly based on the limit equilibrium method which assumes the location and the shape of failure mechanism. Besides, in the current design method, it is assumed that the failure mechanism of the reinforced ground is same as that of non-reinforced ground such as the mechanism proposed by Terzaghi (1943) and the effect of reinforcing materials is added in the design calculation in terms of its tensile strength. Considering the future trend of this design method, the design method has to be optimized by economical point of view, and the feasibility for new applications in this technique should be considered. For these purposes, it is necessary to investigate the real failure mechanism of these structures. According to the reinforcing effect for this structure, it may be considered that this mechanism should be progressive and localized rather than total failure type of the mechanism.

The objective of this paper is to investigate the behavior of real localized deformation of reinforced foundation ground based on the model loading test using the simulation of the ground by aluminum rods. The failure mechanism as a result of this localized behavior is also discussed using picture processing analysis of the test results.

2 MODEL LOADING TEST

2.1 *Test apparatus*

Test apparatus used here is shown in Photo 1. The foundation ground was modeled by a large amount of aluminum rods, in which two different sizes of the rods(its radius: 1.6mm and 3.0mm) with the same 50 mm long were mixed for the model ground. Here, in order to simulate sandy soil on its particle size distribution curve, these two sizes of the rods were mixed with the ratio of 3:2 in its

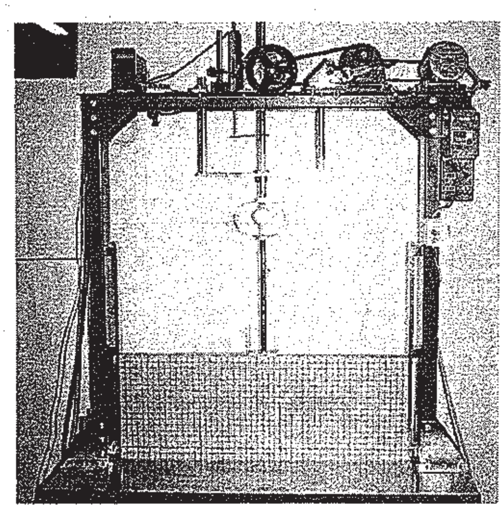


Photo.1 Test apparatus

weight. The model ground was 100cm in width and 40cm in height and the size of rigid loading plate, B was 10cm. The physical property of this model ground are listed as follows:

- unit weight, $\gamma = 2.23\ gf/m^3$
- strength parameter, $\phi = 25^o$(Murayama et al. 1969)

The reinforcing materials used here were paper whose tensile strength is $T_{max} = 2.4kgf/cm$ with no bending stiffness and plastic plate whose material property is considered to be rigid. The widths of these materials are same as that of model ground in order to satisfy plane strain condition.

2.2 *Testing method*

The testing method in this paper was summarized as follows:

a) The ground condition was selected from following cases:
   <u>CASE 1:</u> unreinforced case
   <u>CASE 2:</u> reinforced case by paper with the length of the reinforcement, b/B = 1.0 with its depth, z/B = 0.4.
   <u>CASE 3:</u> reinforced case by paper with the length of the reinforcement, b/B = 2.0 with its depth, z/B = 0.4.
   <u>CASE 4:</u> reinforced case by plastic plate with the length of reinforcement, b/B=1.0 with its depth, z/B=0.4.

b) In order to observe the rigid motion of each aluminum rod in the area of the ground close to the loading plate, the colored rods were placed every 1cm distance for both vertical and horizontal directions with total number of 8x11rods as shown in Photo.2. Here each colored rod was scratched on the surface of the rods in order to observe the rotation activity.

c) The load was applied under displacement control in which the velocity is 1cm/min. The frictional condition between the loading plate and the ground was assumed to be perfectly rough. The load was measured in every 1mm settlement of the plate and at the same time, the picture of the deformation in each step was taken. This was continued until the total settlement of 50mm.

d) The photograph taken in each step was transferred to photo CD and then, the rigid motion such as the change of gravity center of the rod and its individual angle of rotation was analyzed using computer picture processing integration software.

Thus, the results of localized deformation from above picture processing analysis are obtained for unreinforced case and different reinforcement cases, and based on these results, not only the failure mechanism of the reinforcement foundation ground but also its improved bearing capacity are discussed.

3 TEST RESULTS AND DISCUSSION

The relation between the loading pressure and the settlement of the loading plate for all cases are shown in Fig.1. It is realized that this relation for all the cases is fairly close in each other at small settlement range, but the reinforcing effect appears obviously as the value of settlement increases and the bearing capacity itself of the reinforced cases is also gradually increased. These behavior are also unstable with local up and down changes.

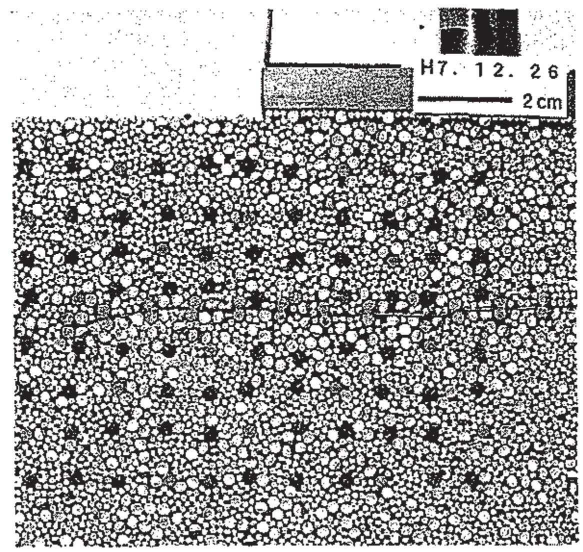


Photo.2 Initial condition of the ground in model test

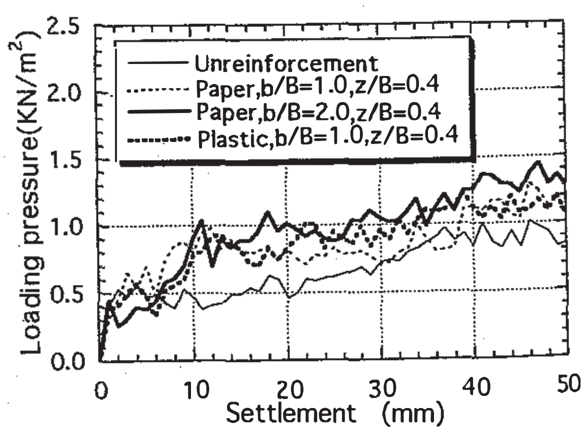


Fig.1 Loading pressure - settlement curve

It is considered that this behavior is caused by the change of interlocking between two contacted aluminum rods. It is noted here that this behavior was quantitatively checked by conducting the same trial in each test case. In order to investigate more precise deformation in the ground, the picture processing analysis was conducted using the test results on photo CD. One of the photograph after deformation is shown in Photo.3 and this picture was obtained by transferring the picture to photo CD. First of all, the movement of aluminum rods after this processing analysis for CASE 1 is plotted in Fig.2. This is the result of consecutive deformation with 21 steps from the beginning to the final settlement of the loading plate, S = 40mm. The colored rods were numbered from 1 to 88. This result shows that the deformation property of the ground may be divided into three zones which is divided with dotted lines. These are 1) active zone, 2) radial shear zone, and 3) passive zone spreaded laterally from the center of the loading plate. This is exactly the same as the assumption proposed by Terzaghi (1943), thus it can be said that the results of the processing analysis is verified. Meanwhile, the same results for CASE 2 are shown in Fig.3. Here, in order to show the deformation more clearly, the total deformation is divided into two parts and these are shown in Fig.3 separately. For the first half of the deformation shown in Fig.3(a), the movement of the ground spreads laterally only above the reinforcement (CASE 1). For the last half of the results shown in Fig.3(b), the dominant deformation is concentrated right below the loading plate with the area even under the reinforcement.

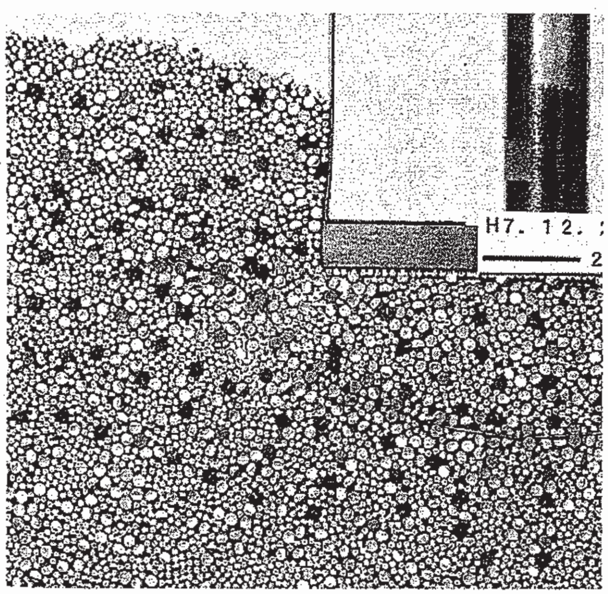


Photo.3 Picture of deformed ground(CASE 3)

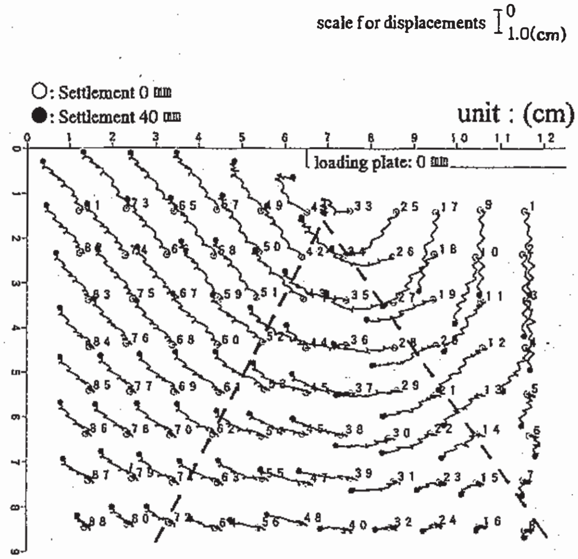


Fig.2 Movement of aluminum rods(CASE 1)

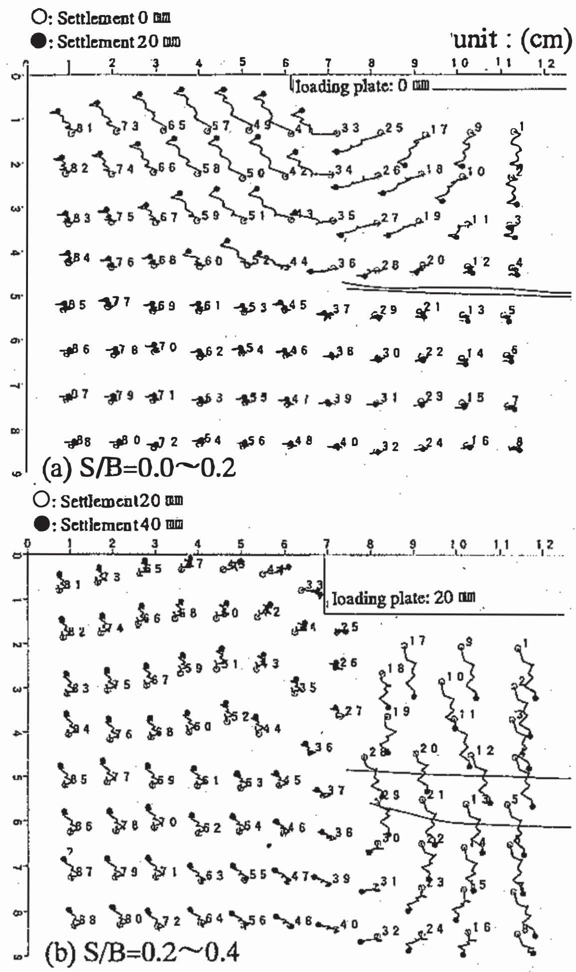


Fig.3 Movement of aluminum rods(CASE 2)

Figure 4 shows the same result as Fig.3 for the case of the reinforcement length as twice as that of CASE 2, which is the results of CASE 3. According to these figures, the tendency of the deformation property for each first half and last one is very close to those for CASE 2, but the deformation for the last half shown in Fig.4(b) is widely spread beneath the reinforcing material compared to CASE 2. The results for the case of large bending stiffness of the reinforcing material are shown in Fig.5(CASE 4) in which the length of the reinforcement is the same as CASE 2. For this case, the tendency of the deformation is not much changed between two settlement ranges shown in Fig.5(a) and (b). This is because the bending stiffness is very large and the deformation mode of the reinforcement is not changed between these two results. This is totally different from that for flexible reinforcement case such as CASE 2 and 3.

Next, the results of total accumulation of the rotation in each aluminum rod for all the cases are shown in Fig.6. For the case of unreinforced ground, the rotation of the rods around the corner of the loading plate excels others in which the number of these rods are 25, 33 and 41. For the cases of reinforced foundation ground (CASE 2, CASE 3 and CASE 4), this remarkable difference does not appear and it may be said that the rotational activity is deeply depend on the location of the reinforcing materials. This is also realized from Figs. 7 and 8 which are the contour of the rotation angle in each rod for CASE 1, CASE 2 and CASE 3. Figure 7 shows the results at relatively small settlement of the loading plate(S/B=1.2~1.6) while Fig.8 shows those at large settlement range(S/B=3.2~3.6). The location of the reinforcement is also shown in each figure with its deformation. These figures convince the results of discussion on Fig.6.

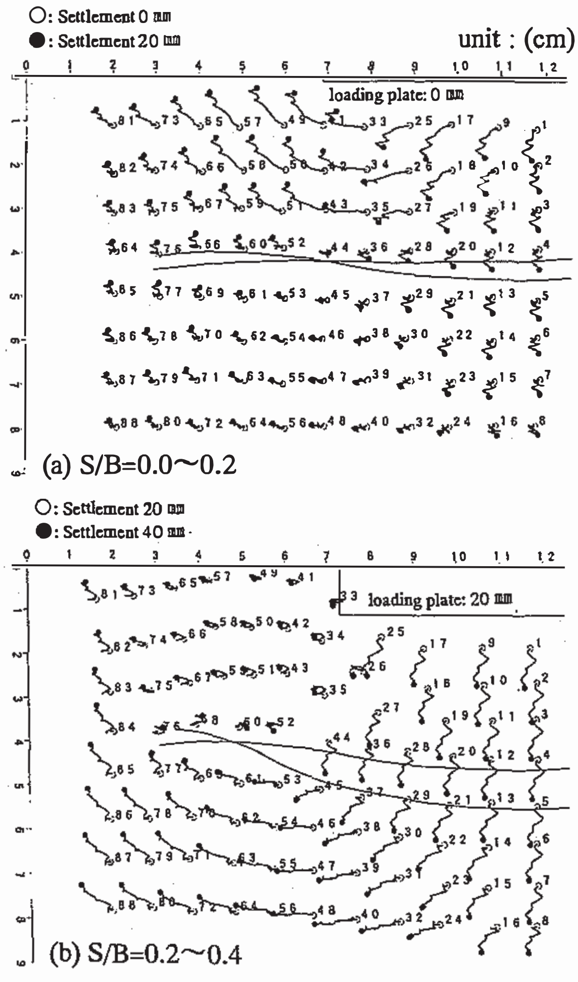


Fig.4 Movement of aluminum rods(CASE 3)

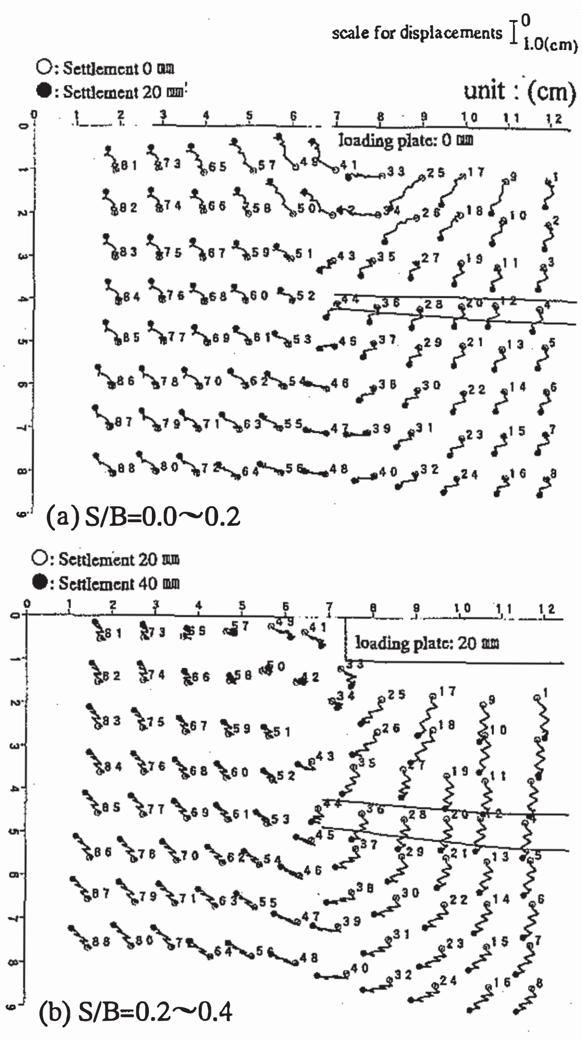
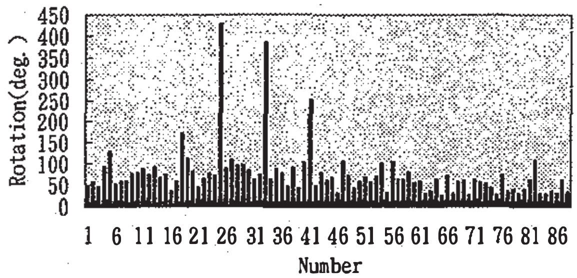
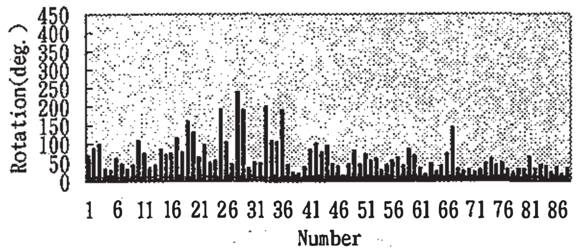


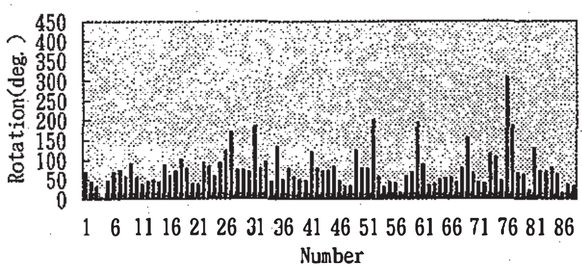
Fig.5 Movement of aluminum rods(CASE 4)



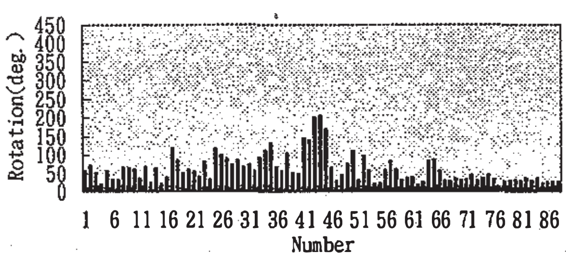
(a) CASE 1



(b) CASE 2

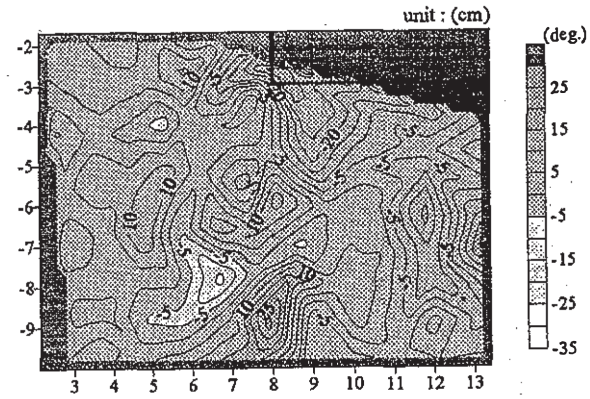


(c) CASE 3

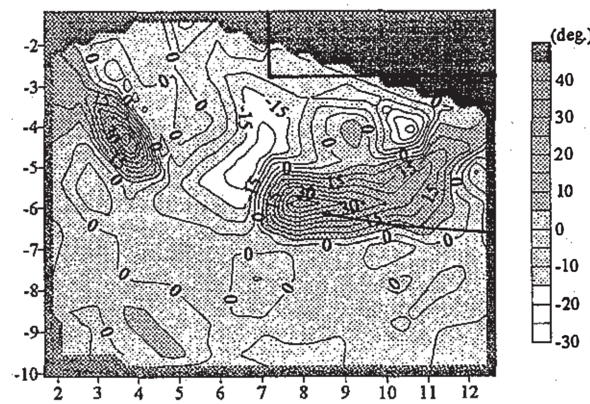


(d) CASE 4

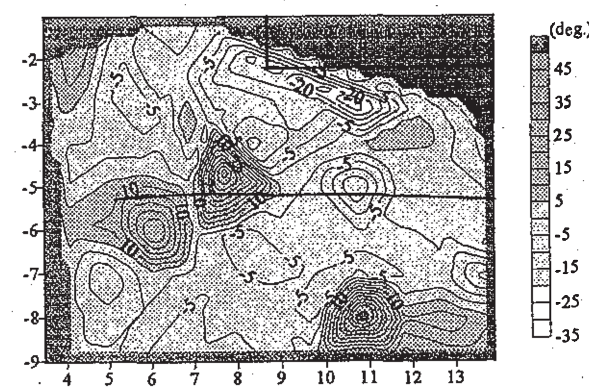
Fig.6 Accumulation of the rotation in each aluminum rods due to deformations



(a) CASE 1



(b) CASE 2



(c) CASE 3

Fig.7 Contour of the rotation in each aluminum rods (Settlement: 12 - 16 mm)

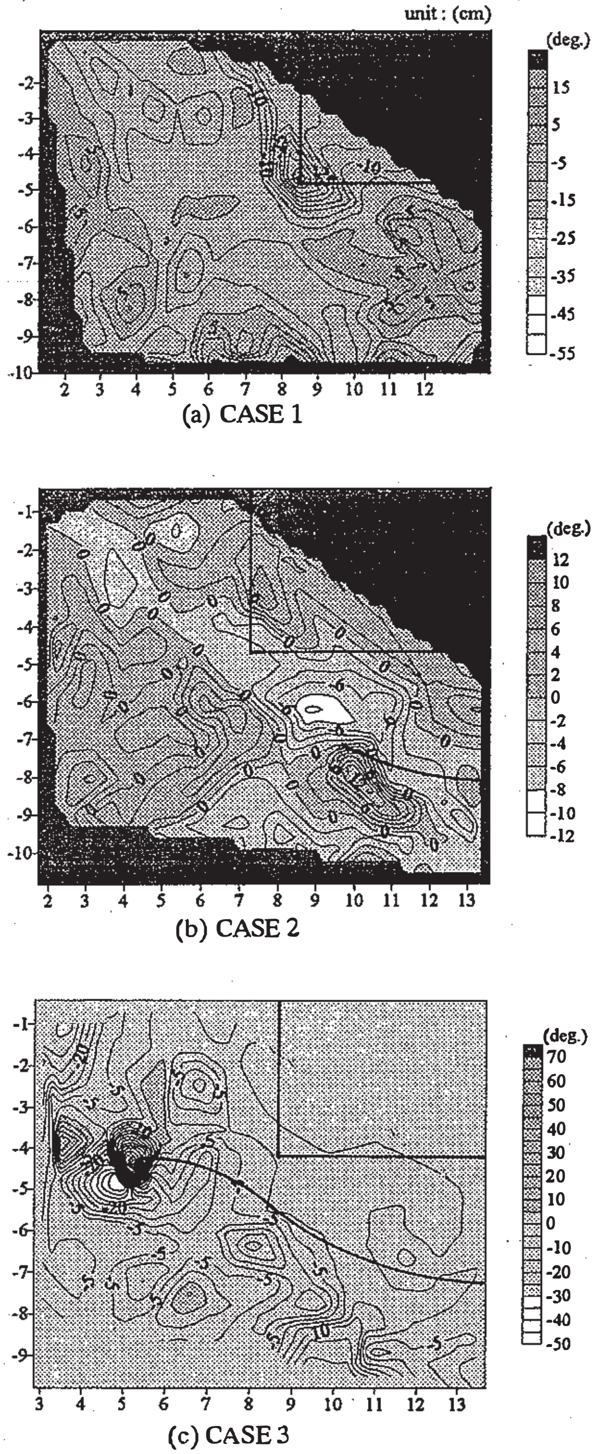


Fig.8 Contour of the rotation in each aluminum rods (Settlement: 32 - 36 mm)

CONCLUSIONS

The behavior of real localized deformation for reinforced foundation ground was investigated based on the results from model loading test using aluminum rods. In order to evaluate the local movement and rotation of these rods, the picture processing analysis was conducted on the picture of each deformation of model ground by aluminum rods. The following conclusions may be drawn:

(1) The deformation property of the reinforced foundation ground is totally different from that of unreinforced ground and this is also depend on the condition of the reinforcement, such as the length and bending stiffness of the reinforcing materials.

(2) The micro rotation which is not related with its deformation also depends on the reinforcement condition and this behavior should be included in the bearing capacity analysis of reinforced foundation ground.

Although the results discussed here are the fundamental data of localized behavior of the reinforced foundation ground, these will be promised to be indispensable information for the future trend of the design method.

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