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Deformation behavior of cohesive soil ground forced large displacement by the dip-slip reverse fault

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ABSTRACT

The large vertical displacement of the earth surface gives structures serious damage when the reverse fault of the bedrock is generated. Main focus of fault displacement in the civil engineering is the development of the mechanical behavior prediction and the measures technique near the active faults. In this study, we carried out the reverse fault experiments using the centrifugal loading device to examine the progressive deformation behavior in the clay surface layer caused by the large displacement of the bedrock reverse fault. As the results, we can observe in the case of the clay layer that the width of the shear zone is wider and the vertical displacement of ground surface is smaller than that in the case of sand layer.

1. INTRODUCTION

Discussion of structural damages caused by the earthquake has been performed on the ground motion mainly. However, the structure may suffer a serious damage also from the foundation displacement by the slip of a fault. Particularly, in the case of the dip-slip fault, the vertical displacement of the ground surface, which sometimes reaches several meters, leads to the collapse of the structures. For example, at the 1999 Chi-Chi earthquake, mach infrastructures suffered damage from displacement by dip-slip fault. In recent years, much information including the position of a fault, and the failure form and the probability of motion have come to be more acquired.

Against this background, the problem is that active fault is present under the existing important structures couter-measures are needed. However, as for the deformation behavior of the soil structures such as embankment, nothing definite has been understood about its deformation behavior due to the confining pressure, localization area of deformation by the forced displacement of several m order, or by a surface of discontinuity showing complicated behavior. Deformation behavior of reverse

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fault, the upper part of the soil structure in particular, is subject to a number of factors such as the structural properties, or fault of form and angle and scale, including material properties and boundary condition of the embankment. However, there are many unclear points about the differences about each factor. In this study, it is assumed that fill layer thickness of about 11~12m using a centrifugal test. We considered deformation of the ground forced large displacement by the dip-slip fault experimental. In this kind of experimental study, most studies have been carried out by using sand until now.

In this study, mostly the cohesive soil ground is targeted, localization area and the volumetric strain deformation is performed to examine the deformation of the surface layer portion.

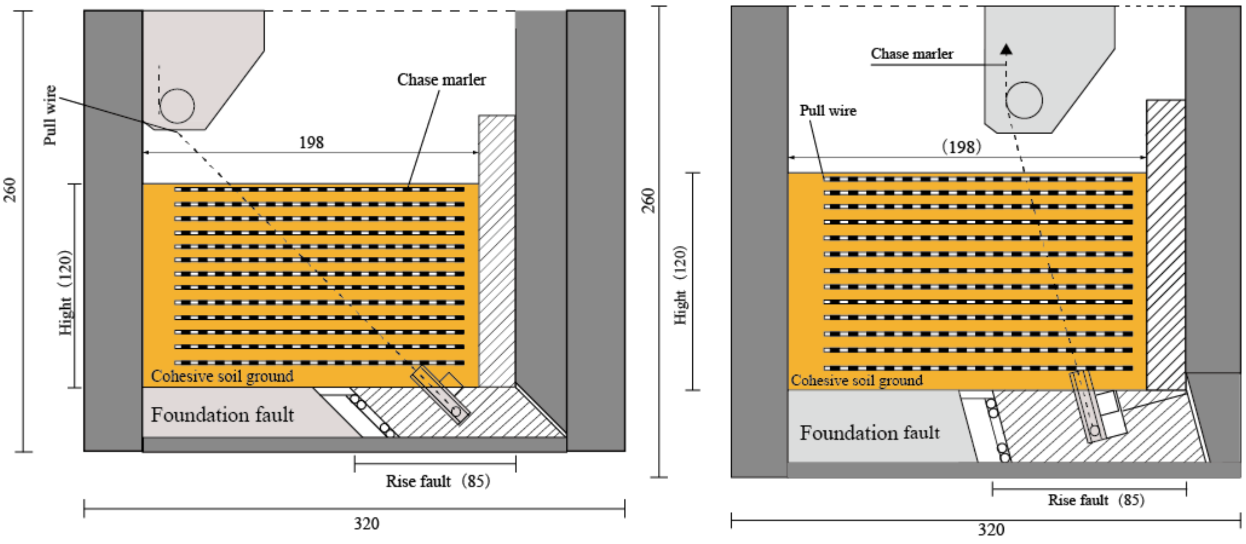


Fig. 1 45° and 75° schematic diagram of test device

2. EXPERIMENTAL OUTLINE

In this study, confining pressure of conditions at 1G field can-not be reproduced. Dip-slip fault against the horizontal ground by using a centrifugal loading device was subjected to a centrifugal load model experiment that assumes that it occurred. A diagram of the developed experimental device is illustrated in Fig.1. We represent the dip-slip fault by giving the displacement to the part of about 60mm from the right side. In paper, we set the angle of fault to 45 and 75 degree. The test box is made with steel, but only the front is made by a transparent acrylic plate to observe the deformation of soil layer. In the case of cohesive soil, we install colored to black that dried noodles to chase the displacements inside the soil layer. In the case of silica sand, we installed black point targets to chase the displacements inside the soil layer.

The ground materials used in an experiment are LOAM A (Aomori), LOAM B (Kanagawa), embankment material and silica sand No.4. We used adjusting the materials in the vicinity of the liquid limit. This was followed by centrifugal compaction in 100G ground for 12 hours. We have confirmed that consolidation settlement amount becomes approximately constant in around 12 hours. After consolidation each becomes a horizontal ground model of 11~12cm, it is to be assumed the layer thickness of 11~12m to scale. Fig.2 shows the grain size distribution curve used in the experiment. Table.1 shows the Fundamental soil material. In the case of silica sand No. 4 to set the model layer thickness to 12cm in fact the layer thickness was estimated to be 12m.

The experiment case is shown in Table.2. In addition, it was performed experimentally by Cole et al (1980). We compared it with the predictive position that estimated the position of the surface of theoretically discontinuity for a function of the dilatancy angle.

Table.1 Fundamental nature of the soil material

soil material	LOAM A (Aomori)	LOAM B (Kanagawa)	Embankment material	Silica sand No.4
ρ_t(g/cm³)	1.776	1.403	1.796	1.452
w (%)	44.1	104.4	42.3	0
ρ_s (g/cm³)	1.232	0.686	1.262	452
ρ_d (g/cm³)	2.677	2.820	2.661	2.648
e	1.173	3.111	1.109	0.824
S_r (%)	100.6	94.6	101.5	0
q_u (kN/m²)	28.42	16.96	37.44	—
E_{50} (MN/m²)	0.270	0.249	0.520	—
c_{cu} (kN/m²)	48	29	43	513
Φ_{cu} (°)	30.2	20.8	26.5	64.8

Table.2 Experiment case

Grand material	Angle(°)
LOAM A （Aomori）	45
LOAM B （Kanagawa）	
Embankment material	
LOAM A （Aomori）	75
LOAM B （Kanagawa）	
Embankment material	
Silica sand No.4	

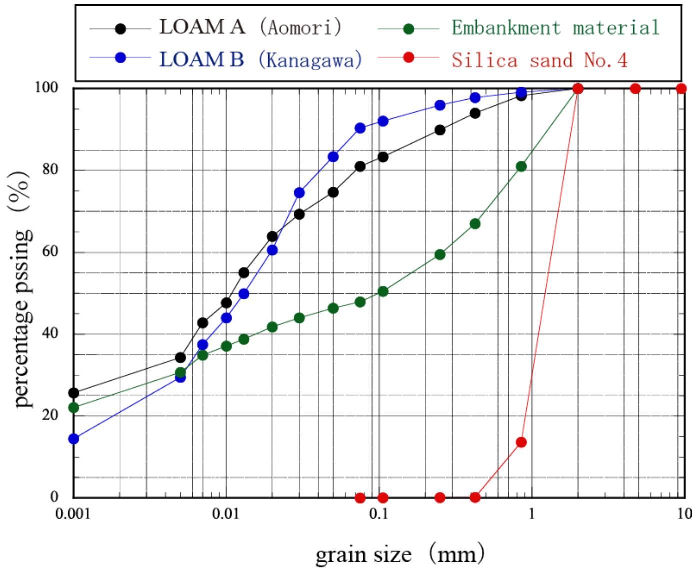
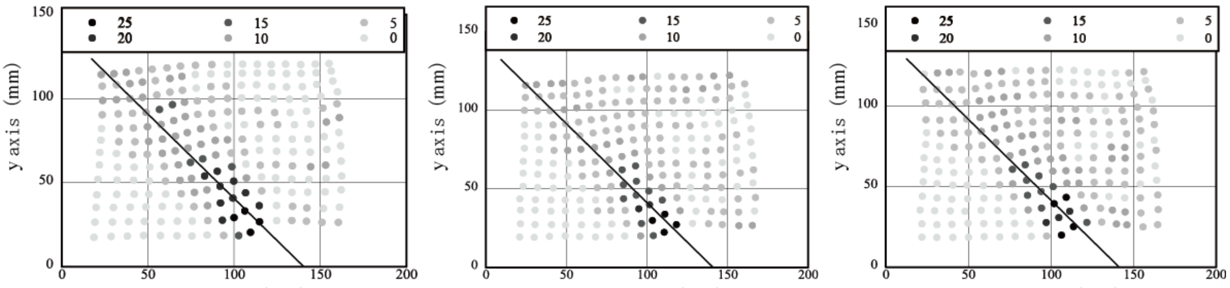


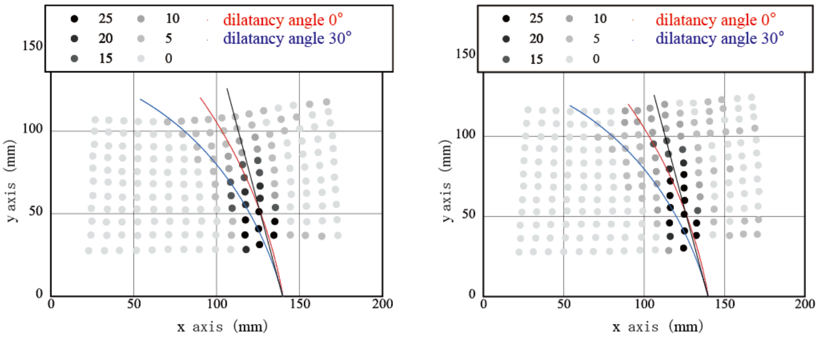
Fig. 2 Grain size distribution curve

3. EXPERIMENTAL RESULT

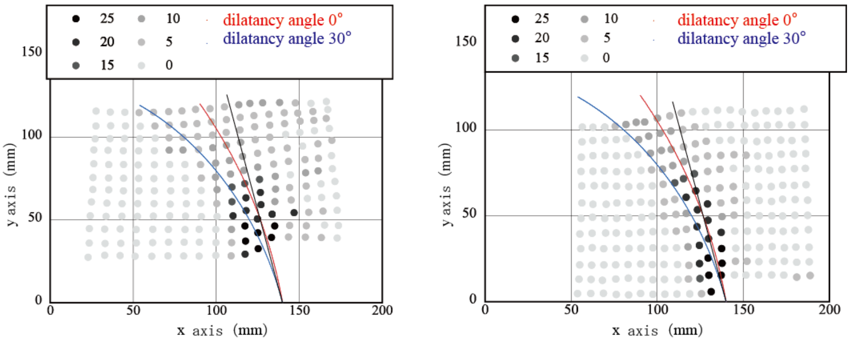


a LOAM A (Aomori) b LOAM B (Kanagawa) c Embankment material

Fig. 3 Position of the marker and relative displacement distribution(45°)



a LOAM A (Aomori) b LOAM B (Kanagawa)



c Embankment material c Silica sand No.4

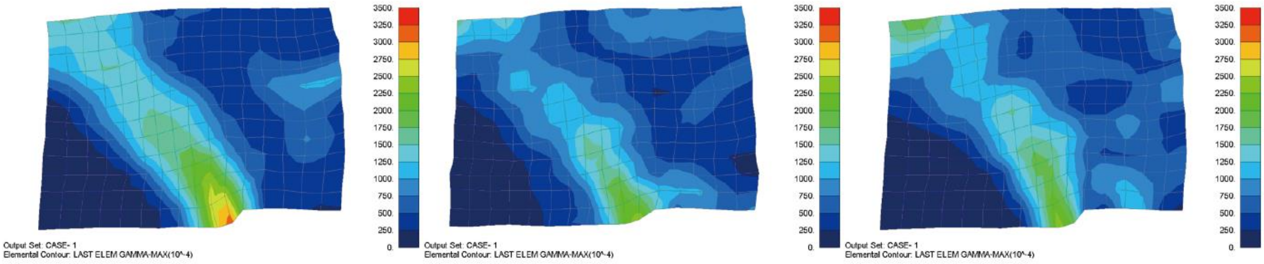
Fig. 4 Position of the marker and relative displacement distribution(75°)

3.1 Progress of the shear cross-section in the ground, the amount of displacement

In the centrifugal loading model tests, in order to extract the shear zone of the ground caused by the fault displacement, we calculated the position as followsing the below procedure:

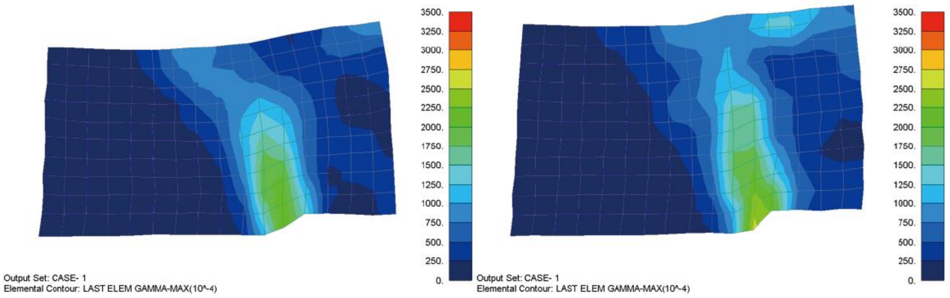
- Perform image analysis of images taken during the experiment, and we obtained position coordinates (xi, yi) of all markers before and after the occurrence of the fault. In order to calculate the displacement vector ui. (Note that I is a marker number)

- Calculate the relative displacement vector (uij=ui-uj) between adjacent marker j the horizontal direction, and this is followed by the calculation of the magnitude of ||uij||.
- Normalizes the ||uij|| by the size of the foundation fault of relative displacement.

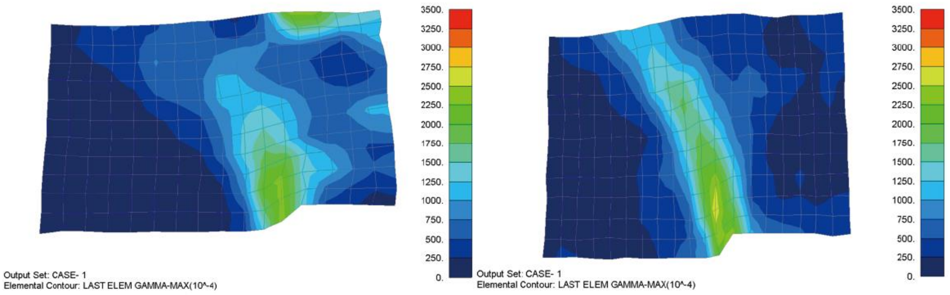


a LOAM A (Aomori) b LOAM B (Kanagawa) c Embankment material

Fig. 5 Maximum shear strain distribution(45°)



a LOAM A (Aomori) b LOAM B (Kanagawa)

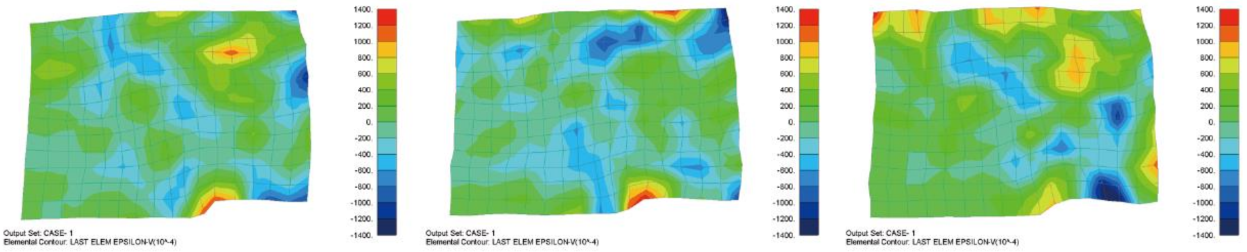


c Embankment material c Silica sand No. 4

Fig. 6 Maximum shear strain distribution(75°)

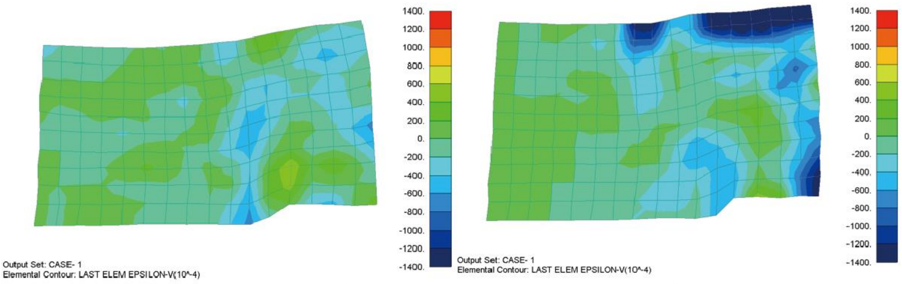
Fig. 3 and Fig. 4 plotted on the position coordinates of the color experiment the normalized displacement. The same figure has shown the extension line of the fault angle from the foundation fault boundary. In addition, we show the predictive position of the surface of discontinuity by the logarithm spiral which Cole et al suggested in Fig.5 at the same time. Since dilatancy angle is difficult to accurately determine by experiment. Here, it shows the case of a 0 ° and 30 °.

With Fig.3, the cohesive soil ground of Fig.4, the part which relative displacement has a big is from the foundation neighborhood to the central neighborhood of the layer thickness, it is not also seen a large step to the ground surface. Moreover, a large part of the relative displacement, understood that it is progressing linearly in a direction substantially coincident with the direction of the concentrated foundation faults near the extension of the foundation fault angle. A faults progress has been observed like the logarithmic spiral when Cole et al’s dilatancy angle set to 0 °. In the case of silica sand, the part of which relative displacement is large has reached closer to the vicinity of the Earth's surface than the cohesive soil has. Shear plane is understood to be that lying on down to the left side in comparison with cohesive soil from the extension line of the foundation fault angle and progresses. Silica sand compared to Cole et al’s logarithmic spiral is distributed in the center of the 0 ° and 30 °.

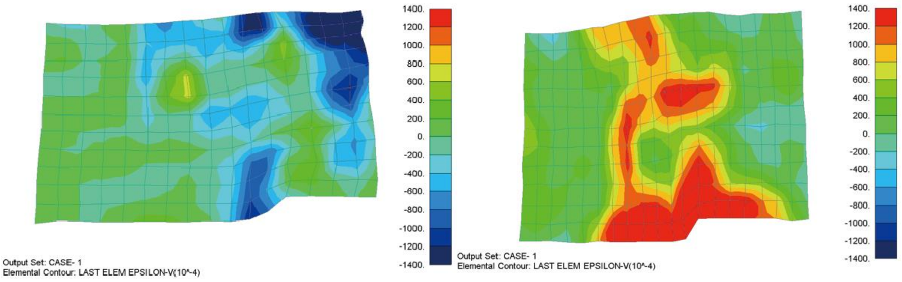


a LOAM A (Aomori) b LOAM B (Kanagawa) c Embankment material

Fig. 7 Volumetric strain distribution(45°)



a LOAM A (Aomori) b LOAM B (Kanagawa)



c Embankment material c Silica sand No.4

Fig. 8 Volumetric strain distribution(75°)

3.2 Maximum shear strain and volumetric strain in the ground

As in Fig.4 and Fig.5, we calculated strains inside the soil layer by considering the targets, which was obtained in the experiments, as the nodal point of a finite element. We reconfigured the elements at each step because there is a possibility that the element rendered an improperly large deformation due to the large displacement of bedrock. Then, we computed the incremental strain in each image step and added them. By distributing the strain increment to the nodal point was determined by accumulating strain in the nodal point. Shown in Fig.6 and Fig.7 are maximum shear strain distributions. In Fig.6 and Fig.7, if looked at the maximum shear strain distribution of cohesive soil, as in the case of 45 °, it has reached the ground surface. However, maximum shear strain becomes small as it reaches to the ground surface while spreading.

In the case of 75°, the width of the shear zone of cohesive soil is relatively wide. Together with the maximum shear, strain is rapidly decreased as it approaches the ground surface. It is understood that it spread over a wide range. Meanwhile, discerned about silica sand is that the maximum shear strain reached the concentrated ground surface in a relatively small range. These results, it is thought that a difference appears fault angle, cohesion, internal friction angle. In particular, in the case of large displacement by foundation reverse fault, it is thought that while absorbing force going to be deform in a large range. Because the cohesive soil is more soft and has a smaller strength than silica sand.

Fig.8 and Fig.9 show that volumetric strain is, in the case of fault angle 45°, the fault occurrence location and the neighborhood of ground surface are large, and an area of the volume expansion is seen. In the case of fault angle 75°, although a large volume expansion has not been observed, the state that an expansion mainly on shear zone has been noticed. However, it can be seen that the silica sand is in the difference compression side. Meanwhile, silica sand has a large volume expansion, located on the tension side. It is considered necessary to be careful for the volume expansion due to the large displacement in the ground surface. It is thought that differences in maximum shear strain and volumetric strain are produced in relation to the, fault angle, the internal friction angle of ground material property, and its cohesion. In the actual fault displacement, the volume expansion causes the eruption of soil and gives damage to the ground structures. Therefore, it is considered necessary to be careful for the volume expansion.

4. CONCLUSIONS

This study performed a basic examination in order to predict the deformation behavior of the cohesive soil ground forced large displacement by the dip-slip fault. In so doing, we conducted a centrifugal load model experiment on the effects of the ground material properties and confining pressure. In the case of a layer of cohesive soil, relative to the sandy soil, its deformation localized area appears smaller since it hardly reaches the ground surface. The width of the shear zone becomes relatively wide, deformation spreads as it approaches the ground surface. Moreover, it was understood that its volume expansion is lesser in size and it tends to be located on the compression side. Amidst the heated discussions of the active fault with the existing structures in particular, the development of methods to prevent serious damages caused by fault movement are much needed.

Towards the establishment of ground deformation prediction methods, in our future studies, we shall perform an experiment and a numeric calculation in greater detail. Also, we need to examine the factors, the impact, and so forth leading to the shear plane progress.

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