EFFECTS OF UNDERGROUND CAVITY LOCATION ON PROPERTIES OF ASSICIATED LOOSED GROUND IN UNIFORM SAND

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1. INTRODUCTION

Sinkholes are mostly associated with ground loosening around the initial cavity and by knowing the variation of mechanical properties of loose soil; it will be able to confirm the availability of existing cavities. Main objective of this research is to analyze the variation of mechanical properties of loosened sand which is accompanied with underground cavities. Furthermore, significance of the location of initial cavity is also observed. Small scale triaxial apparatus was used here with forming a cavity inside the specimen.

2. METHODOLOGY

2.1. Materials and testing apparatus

Toyoura sand is uniformly graded fine sand which, was taken from Toyoura beach in Japan. The soil grains are mostly sub angular quartz shape and having specific gravity, G_s = 2.656; mean diameter, D_{50} = 0.19mm; fine content, F_c =0.1%; maximum and minimum dry density, γ_{max} and $\gamma_{min =}$ 16.33 and 1.35 kN/m^3 respectively. The underground cavity was simulated by introducing water soluble material ($C_6H_{12}O_6$) in to sand as in required size, shape and location. Cylindrical shape glucose blocks were used here and dimensions are given in Table 1. Ground loosening which is accompanied with cavities was formed by dissolving the glucose block by passing water through the specimen with representing fluctuations of ground water level.

Small size, gear driven, strain controlled triaxial machine was used. Minor principal stress (σ_3) was directly measured by a High Capacity Differential Pressure Transducer. Furthermore, small and larger axial strains were separately measured by Local Deformation Transducers (LDT) manufactured in the lab and External Displacement Transducers respectively. Radial strain was measured by Clip Gauges (CG) and the arrangement of LDTs and CGs is shown in Fig 1.

2.2. Testing procedure

The specimens of 75mm in diameter, 150mm in height and 60% relative density were tested. Three cases were considered with one as control specimen (NC) and other two with cavities located at depth of 10(CB-10) and 7(CB-7) times of cavity height. Which means cavity of CB-10 was located at very base of the specimen and for CB-9 it was at 45mm above the base. Sand was placed by air pluviation while inserting the glucose block simultaneously and specimens were erected at isotropic state of 25kPa.

Applied stress path is shown in Fig. 2 where, steps 1, 2, 3 and 4 are key stages of water movement path. In step 1, water was passed from bottom and drained out from top which is connected to the lower water tank. The flow rate was controlled at 14-16 ml/minute and 1500 ml of water was passed through. The step 2 was to close both valves for approximately 10 minutes for stabilizing of water and in step 3, drainage was allowed from bottom for 24-27 hours before starting of shearing in step 4. Small strain (0.001%) cyclic loading was applied just before step 1 and 4. Finally shearing was conducted up to 20% of axial strain by controlled strain rate of 0.1% per minute. Specially, both clip gages and LDTs was detached from the specimen, before applying of shear.

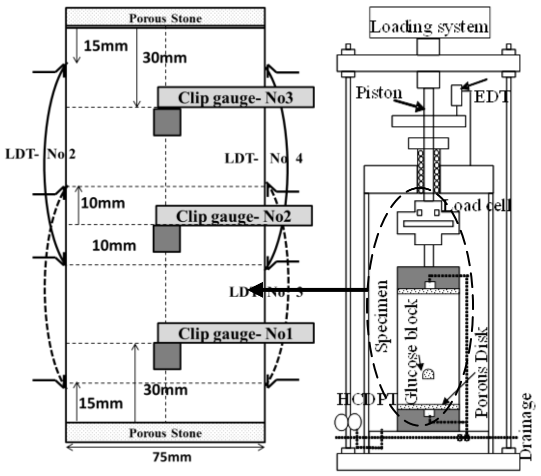

Fig 1.Arrangement of fixing sensors in specimen

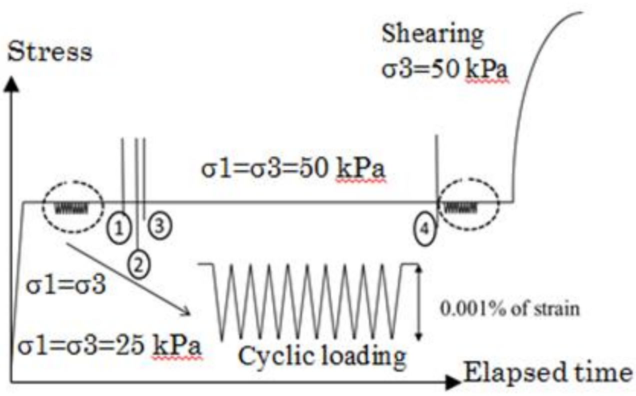

Fig 2.Stress path for triaxial loading

Keywords: underground cavity, cave-ins, ground loosening
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3. RESULTS AND DISCUSSION

Axial strain for all three cases just after the isotopic stress increment from 25 to 50 kPa, was about 0.02%. However after inserting and draining water, ground settlements were changed significantly and recorded as shown in Table 1. The final axial deformation, ε_a of case-CB-7 is nearly two times larger than case-CB10 while radial strain, ε_r was recorded four times larger than CB-10. Specially, controlled specimen shows radial expansion while others are compressive at the end. As a fact of that, volumetric strain is finally expansive in case-NC when, CB-7 shows nearly three times larger volume reduction than case-CB10. (Table1 and Fig 3)

Young's modulus, E was evaluated for upper and lower halves separately, before and after formation of ground loosening. The results show in latter part of Table 1. In all three cases, E has been reduced after drainage. However, the scale of reduction is larger at the CB-10 and CB-7 compare to NC case. Finally, E value of CB-10 and CB-7, compare to NC case was recorded as 92%, 80% for lower half while 89% and 82% for the upper. It can be revealed that larger strength reduction has been caused in CB-7 which is 87% and 92% of CB-10 for lower and upper halves respectively. Furthermore, the stiffness reduction is not only in the lower half, but significantly in the upper part too.

During shearing CB-10 and NC cases follow the same path up to residual and sudden failure by 26MPa was recorded at ε_a =19% in CB-10. That might be due to sudden settlement in loosed area and not the complete failure of cavity ceiling. The evidence was a cavity, almost similar to the initial shape and size was observed even after shearing up to 25%. CB-7 has 92% of maximum strength of NC, which is almost not changed. However, ground seems to be much softer than other two conditions. (Figure 4)

Table 1. Conditions of experiments and results

Property	No cavity (NC)		Cavity at 150mm depth from surface top.(CB-10)		Cavity at 105mm depth from surface top (CB-7)	
Relative density, Void ratio	60%, 0.73		59%, 0.73		58%, 0.73	
Cavity height, diameter(mm)	No cavity		15,12		15,12	
Volume of cavity/volume of specimen	No cavity		0.25%		0.25%	
$\frac{\text{Depth to cavity from surface}}{\text{Height of initial cavity}}$	No cavity		$\frac{150}{15} = 10$		$\frac{105}{15} = 7$	
Axial strain (before/after) loosening (ε_a)	0.022/0.016		0.019/0.025		0.021/0.053	
Radial strain (before/after) loosening (ε_r)	0.027/-0.017		0.015/0.019		0.028/0.082	
Volumetric strain (ε_v)	0.076/-0.013		0.050/0.068		0.079/0.217	
	Bottom	Top	Bottom	Top	Bottom	Top
Young's Modules before loosening (MPa) -E_{dry}	170	151	171	152	146	137
Young's Modules after loosening (MPa) – E_{wet}	160	143	148	128	129	118
Reduction of E_{wet} as a % of E_{dry}	5.8%	5.3%	13.5%	15.8%	11.6%	13.8%

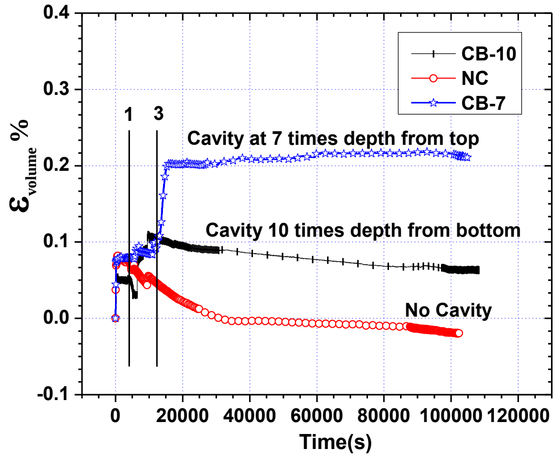

Fig 3. Volumetric strain vs. time

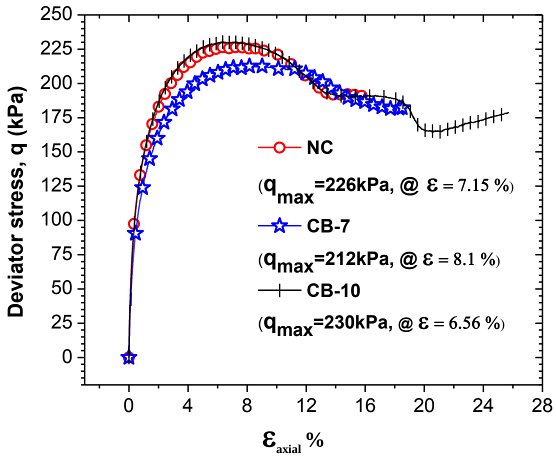

Fig 4. Deviator stress vs. axial strain

4. CONCLUSION

It can be concluded under conditions when the specimen width/ cavity width is 6 and the depth to cavity/cavity height is greater than 10, the effect from cavity to the shear strength is negligible though it was slightly reduced (nearly 8%) when the ratio is 7, which means the cavity moved up by 3 times of the cavity height. Furthermore, when the cavity is closer to surface, soil shows strain sensitive behaviour after the peak shear strength which is not seen in the normal ground. This location difference has increased ε_a by two times, ε_r by four times and ε_v by three times which can be significant in some designs. The volumetric strain after water drainage is expansive in the normal specimen while other's behaviour is contractive. In terms of Young's modulus, a cavity having 0.25% in volume of ground has formed loose soil above the cavity and the stiffness has reduced by 6-10 % relative to the controlled condition even closer to the ground surface.