FLOW DEFORMATION BEHAVIOR OF CLEAN SAND CAUSED BY WATER INFLOW UNDER CONSTANT SHEAR STRESS

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1. INTRODUCTION

The catastrophic long-distance flow-slide that occurred in several places in Palu city due to the 7.5 Mw Sulawesi Earthquake has grasped much attention from the researchers. This flow disaster took more than a thousand people's lives and significant economic losses as this flow hit densely populated residential areas. This flow could devastate large areas, even though the ground inclination was very gentle (1-5%). Hidayat et al. (2020) revealed that sand ejecta, as the evidence of soil liquefaction, has been found in several places around the affected areas as well as the spring freshwater pond even two weeks after the disaster occurred. Okamura et al. (2020) conducted several trench surveys in the Sibalaya area. They reported that the water-interlayer concept solely could not explained the mechanism of this flow-slide. In addition, Kiyota et al. (2020) reported that the shallow groundwater in the affected areas was under-pressure, based on the interview with the residents. They considered that the possibility of this long-distance flow-slide was because the effective stress and the shear strength of the surface ground significantly reduced by a large amount of groundwater supplied from the confined aquifer and unlikely to occur at the gently sloped ground under the undrained condition. Therefore, it is vital to examine the possibility of flow slides occur at the gently sloping ground in drained conditions by the experimental approach. This paper describes the shearing behavior of clean sand subjected to volume change due to pore water in/outflow to explain the progressive flow failure mechanism due to confined aquifer.

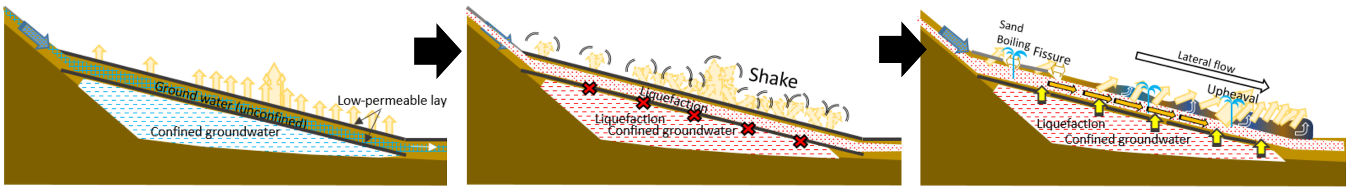

Figure 1. Schematic illustration of long-distance flow slides induced by the confined aquifer (Hidayat et al., 2020)

2. TESTING PROCEDURES

The static liquefaction with constant deviatoric stress was conducted in strain-controlled Triaxial Apparatus to study the shearing behavior of Toyoura sand due to the volume expansion. The specimen sizes were 75-mm diameter and 150-mm height, with the maximum measured axial strain rate was 9.6%/min. The properties of Toyoura sand used for all the tests were G_s=2.648, D_{50}=0.22 mm, e_{max}=0.948, and e_{min}=0.619. The specimen was prepared by the air pluviation method to achieve the desired densities. After making the specimen, the double vacuum method for 12 hours to remove the air inside the specimen. The specimen was saturated with de-aired water for 3 hours. All the specimens were confirmed to have Skempton's B-value of more than 0.96. At first, the saturated specimen was consolidated under isotropic effective confining stress to p'_{ini}=100 kPa. This step was followed by increasing the deviatoric stress (q) to induce the initial static shear stress under the drained condition with constant back-pressure 200 kPa. The static liquefaction test was preceded by increasing the back-pressure manually to reduce the effective stress, with the rate of reduction was 5 kPa/min. This step was directly followed by a creep for 3 minutes to ensure that the deformation was not continuous. At the same time, the deviator stress was controlled to be constant. Both effective stress reduction and creep were repeatedly continued until the failure point where the axial strain and the volumetric strain were continuously increased, even though all the stresses were kept constant. The tests were terminated when the axial strain achieved 20%.

3. DISCUSSION OF THE TEST RESULTS

As shown in Figure 2a, for the q range from 5 kPa to 15 kPa with p'_{ini}=100 kPa, the start of flow failure point could be observed when the stress path approached the Phase Transformation Line (PTL), while for q=40 kPa and q=80 kPa stopped at USSL. Figure 2b also showed that even at the low initial static shear stress (q=15 kPa), the continuous deformation under constant shear stress in drained conditions could be identified. Figure 3a shows the dilation behavior of sand is promoted by the initial density. The denser the sand, the more volumetric strain developed. These results confirmed a good agreement as to the previous researches by Sento et al. (2004) and Yoshimine et al. (2006). This result led to a hypothesis that the dense sand is more resistant to the flow behavior under the drained condition as the fact that dense sand needs more water to produce flow behavior. However, at the start of the flow failure point, it is found that the shear strain rate of a specimen is higher when the initial density is higher. Figure 3b shows that once the flow failure induced continuously, the higher the density of the sand, the faster the rate of flow was developed. This result implies that the dense sand produces faster flow slides compared to the loose sand in drained condition, in particular when the amount of infiltrated water is abundant, such as there is a supply from the seepage of a deep liquefied soil layer or a confined aquifer. Once the presence of this factor could be confirmed in the field, the hypothesis stating that dense

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sand has more resistance than the loose sand to the flow slides could be misleading. The faster flow rate of flow slides could be more harmful and might promote more casualties.

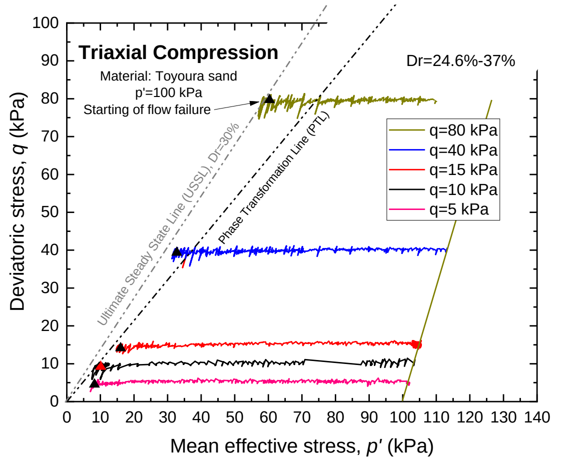

Figure 2a. The stress path of static liquefaction test with constant deviatoric stress

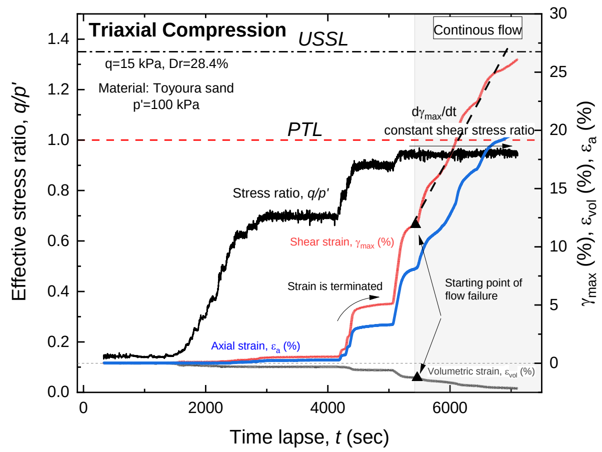

Figure 2b. The relationship between strain development and time for q=15 kPa, Dr=28.4%

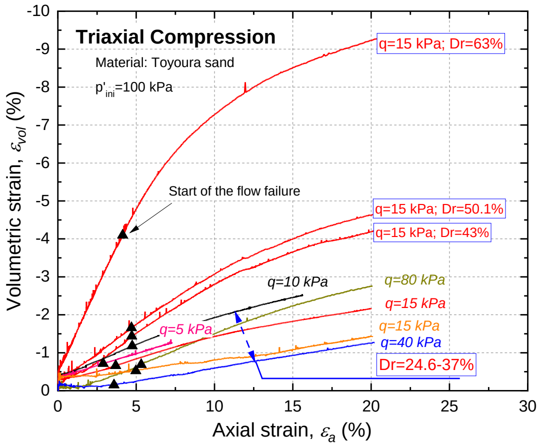

Figure 3a. Relationship between volumetric strain and axial strain for various densities

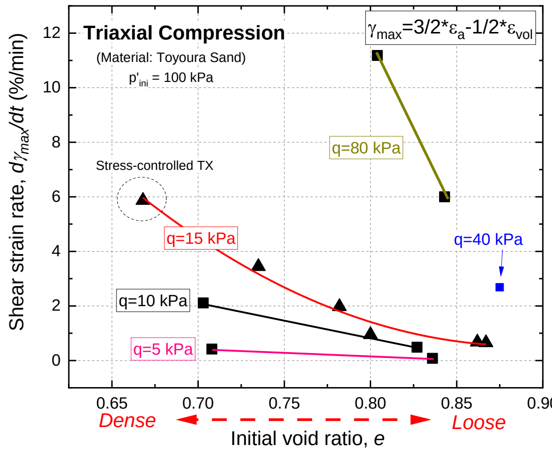

Figure 3b. Relationship between shear strain rate and initial void ratio

4. CONCLUSION

The static liquefaction with constant shear stress under the drained condition could produce flow behavior even at the low initial static shear stress. In addition, the amount of water needed to produce the flow behavior on clean sand could be identified in this test. It is found that the dilation behavior of sand is defined by the initial density. The denser the initial density, the more volumetric expansion developed. It is also found that at the start of flow failure, the flow rate of initially denser sand would be faster than that of the looser one. This result shows a contrast conception that the dense sand might be more resistant to the flow slides.

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REFERENCES

Hidayat, R. F. et al., 2020. Reconnaissance on Liquefaction-induced flow failure caused by the 2018 Mw 7.5 Sulawesi Earthquake, Palu, Indonesia. *Journal of Engineering and Technological Sciences*, 52(No. 1).

Kiyota, T. et al., 2020. Overview of long-distance flow-slide caused by the 2018 Sulawesi earthquake, Indonesia. *Soils and Foundations (accepted).*

Okamura, M. et al., 2020. Large-scale flow-slide in Sibalaya caused by the 2018 Sulawesi Earthquake. *Soils and Foundations (accepted).*

Sento, N. et al., 2004. Possibility of post-liquefaction flow failure due to seepage. *Journal of Geotechnical and Geoenvironmental Engineering*, pp. Vol. 130, No. 7, 707-716.

Yoshimine, M., Nishizaki, H., Amano, K. & Hosono, Y., 2006. Flow deformation of liquefied soil under constant shear load and its application to analysis of flow slide of infinite slope. *Soil Dynamics and Earthquake Engineering*, pp. Vol. 26, Issues 2-4, 253-264.