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学 位 論 文 要 旨
Dissertation Summary

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論　文　名:
(Dissertation Title) Investigation of Soil Liquefaction in Kathmandu Valley and Remediation on Existing Structures Using Desaturation By Air-injection Technique.

Case histories from strong earthquakes and laboratory studies show clearly that fines content, soil particle gradation, particle morphology and mineralogy content have significant influence on liquefaction behaviors of soils. Because of the uniqueness of soil deposit in Kathmandu, which are rich in Mica, and very heterogeneously distributed, liquefaction assessment methods established based on the experiences in Japan and the US need to be verified. In order to refine and reestablish liquefaction assessment methods, identification of field evidence of liquefaction including sand volcanos and lateral spreading are necessary and the 2015 April earthquake provided a valuable opportunity to do this.

In this study, an extensive survey was conducted after the Gorkha earthquake 2015 and marked 12 liquefied spots. The liquefactions were spread throughout the valley, mostly in the vicinity of the rivers passing through it. The main features of ground failures in liquefied area were fissuring towards the downwards slope with sand boils ejected through the fissuring's in slope area and sand boils in the plain low land area. The sand erupted at liquefaction sites were collected and conducted the X-ray diffraction analyses

and it was found that quartz (60-80%), feldspar (10-20%), mica (10-20%) and calcite (5-10 %) are the dominant minerals in Kathmandu soil.

In-situ field test, including boring, standard penetration tests (SPT), undisturbed soil sampling and PS-logging were conducted at five representative locations. The relation between the normalized N-value or S-wave velocity with CSR obtained from this study were plotted on the curves proposed based on the Japan and US experiences to separate the liquefied and non-liquefied sites. The plotted point's showed that the proposed curves based on the Japan and US experiences do not well satisfied the Kathmandu soil.

The reconstituted triaxial specimens by the wet tamping method at different relative density were tested under undrained cyclic loading. The liquefaction strength curve obtained from these tests indicate that the Kathmandu soil is very crushable and easily failed under the cyclic loading. Finally, both the laboratory test results and field in-situ test results were combined and proposed a new boundary curve based on the normalized S-wave velocity (Vs1) and CSR to separate the liquefiable and non-liquefiable sites for Kathmandu soil. This proposed boundary line satisfied all the liquefied and non-liquefied locations included in this study and data from the JICA study (2002).

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During large earthquakes, soil liquefaction has repeatedly damaged many buildings with shallow foundations. Many researchers have continuously worked to develop more reliable countermeasure techniques apposite to the foundation soils of existing buildings. However, most countermeasure techniques available in the current practice are either too expensive or applicable only to new construction sites. Lowering the degree of saturation by artificially injecting air is a newly developed, innovative technique that significantly improves the liquefaction strength of soil. In this study, the effectiveness of desaturation by air injection technique as liquefaction remedial on the foundation soil under light structures were evaluated through the series of centrifuge tests. Four centrifuge model tests were performed in the laboratory to evaluate the effectiveness of desaturation by the air injection technique as a liquefaction countermeasure technique for shallow foundation soil under light structures. The effectiveness of the air injection technique was evaluated in terms of pore pressure generation, vertical settlements and factor of safety against liquefaction in saturated and desaturated centrifuge model. All the results of centrifuge modeling conducted in this study demonstrated the effectiveness of the air injection technique to strengthen the liquefiable soil below light structures. Thus far, the test results have indicated that desaturation by the air injection technique is a useful solution for increasing the liquefaction resistance of soil at shallow foundations upon which lightweight structures rest.

An attempt was also made to simulate the centrifuge models with numerical analysis by changing the compressibility of the pore. Four centrifuge models tested in the laboratory were simulated by using the Coupled Analysis of Liquefaction (LIQCA-2D), a finite-element method (FEM) based effective stress analysis. The computed results were compared with the test results in terms of excess pore pressure (EPP) generation, volumetric strain distribution and settlements and deformations. Excess pore pressures as well as structural settlement and deformation mechanisms of foundation soils observed in the centrifuge tests were mostly accurately duplicated by the simulations. This study confirmed that the seismic behavior of desaturated soil can successfully modeled by reducing the bulk modulus of pore fluid.

One of the concerns on the desaturation by air injection technique is the durability of the injected air because the soil desaturated by air injection regain its degree of saturation once it was lowered by artificial air injection. In this study, the laboratory experiment and in-situ field test conducted to observe the saturation process in unsaturated soil were numerically simulated by using the multiphase flow simulator (TOUGH2). The observed pattern of degree of saturation changes in laboratory experiments at continue seepage flow in the different hydraulic head, considering the advection and diffusion process of mass transfer are well comparable with simulated results.

The predicted degree of saturation from the numerical simulation in the field, where the soil was desaturated by air injection, showed that the injected air exists in the soil pores will not dissipate easily. Even after the 10 years of desaturation the soil did not regain its saturation level, 100%, even though the simulation was performed in extreme condition by flowing the water with zero air content. These results further confirmed the longevity of the injected air in the soil pore which is also mentioned by Okamura et al. (2006).