Liquefaction Susceptibility of Soils With Clay Particles from Earthquake-induced Landslides

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Abstract: The main reason for earthquake-induced landslides is liquefaction of soil, a process considered to occur mostly in sandy soils. Liquefaction which occurs in clayey soils has also been reported and proven in the recent literature, but liquefaction in clayey soils still remains unclear and there are many questions that need to be addressed. In order to address these questions, an depth study on the liquefaction potential of clayey soils was conducted on the basis of field investigation and a series of laboratory tests on the samples collected from the sliding surface of the landslides. The liquefaction potential of the soils was studied by means of undrained cyclic ring-shear tests. Research results show that the liquefaction potential of sandy soils is higher than that of clayey soils given the same void ratio; the soil resistance to liquefaction rises with an increase in plasticity for clayey soils; relation between plasticity index and the liquefaction potential of soil can be used in practical application to estimate the liquefaction potential of soil.

Key words: liquefaction; earthquake-induced landslides; undrained cyclic ring-shear tests; plasticity index; clay content

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1 Introduction

Earthquake-induced landslides in Japan have claimed a number of human lives and caused great economic loss in the last few decades. The main reason for such disasters is liquefaction of soil, a process said to occur mostly in sandy soils such as that of the infamous Niigata earthquake (1964) and the 1995 Hyogoken-Nambu earthquake in Kobe. The process of liquefaction in sandy soils in which the rise of pore water pressure causes a drastic reduction of shear strength, is a well understood phenomenon, and a procedure for its evaluation has been developed.

It has also been proven that liquefaction can occur in clayey soils. Despite the widely accepted supposition that clayey soils are not susceptible to liquefaction, a few notable cases of such a phenomenon have been reported in the literature. Ishihara[1] noted the occurrence of liquefaction in silty sand containing clay in the Tokyo Bay area, Japan, during the 1987 Chibaken-Toho-Oki earthquake. Tohno and Yasuda[2] reported liquefaction of soils with up to 18% of clay fraction due to 1968 Tokachi-Oki earthquake. More recently, Miura et al[3] noted liquefaction of soils with up to 48% of fines and 18% of clay fraction due to the 1993 Hokkaido Nansei-Oki earthquake. Compared to the liquefaction of sandy soils the mechanism of liquefaction in clayey soils still remains unclear and there are many questions that need to be addressed. For example, what effect can clay particles have on the structure of sand and its liquefaction potential? In addition, there is the pressing question of what criteria should be used to evaluate the liquefaction potential of clayey soils.

In order to address these questions, an in depth study on the liquefaction potential of clayey soils was conducted at Disaster Prevention Research Institute, Kyoto University, which included field investigation of several landslides triggered by the 2004 Mid-Niigata prefecture earthquake and a series of laboratory tests on the samples collected from the sliding surface of the landslides. The liquefaction potential of the soils was studied by means of undrained cyclic ring-shear tests.

2 The 2004 Mid-Niigata Prefecture Earthquake Event

The 2004 Mid-Niigata Prefecture earthquake (M6.8), which was said to be the greatest disaster after the 1995 Hyogoken Nambu earthquake (M7.2), triggered a great number of landslides with the total volume of all landmass involved estimated to be about one hundred million cubic meters, according to the Ministry of Land, Infrastructure and Transport, Japan. Forty-five landslide dams were formed after this earthquake, posing a potential threat to the local people. Several large landslides were investigated by Research Center on Landslides; Kyoto University [4] and two of them

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the Higashi-Takezawa landslide and the Terano landslide, will be discussed below.

The landslide that likely posed the greatest danger to the local people was the Higashi-Takezawa landslide (Fig. 1). Moving rapidly, and for about 100 meters, it plunged into the Imokawa River, forming an earth dam. To reinforce the dam, special constructions were hastily erected by the Japanese Self-Defense Force.

Fig. 1 Location of the Terano and Higashi-Takezawa landslides in Nigata prefecture Japan

Table 1 The properties of the studied soils

Name	landslide	Clay fraction (<2μm, %)	Liquid limit	Plasticity index
T1	Terano	10	—	—
T2	Terano	29	45.6	20.1
T3	Terano	11	51.4	19.1
T4	Terano	11	41.0	10.1
H1	Higashi-Takezawa	4	—	—

Although the building of a local school sustained great damage, fortunately no human lives were taken. The field investigation of the area revealed that the upper part of the landslide was not fully saturated and the movement occurred along the narrow sliding surface. To study the properties of soil from the sliding surface, a sample was collected for laboratory investigation (named H1). The soil characteristics are presented in Table 1.

The Terano landslide (Fig. 1) also formed a landslide dam. It occurred on a gentle slope and was a part of a big reactivated landslide which had a sliding surface that developed in tertiary mudstone. To study the liquefaction potential of soils from this landslide, 4 different samples were collected from the sliding surface as schematically shown in Fig. 1. The sample were: T1, H1-sandy material; T2-clayey silt; and T3, T4-clayey sand soils. The characteristics are summarized in Table 1.

3 Test Procedurces

3.1 Ring-shear apparatus

A ring-shear apparatus (DPRI24 see Fig. 2) was used in this study to carry out cyclic undrained stress-controlled tests. DPRI-4 is one of a series of intelligent ring shear apparatuses developed at Disaster Prevention Research Institute. Kyoto University [5]. The main features of this apparatus, distinguishing it from other types, are the structure of the undrained shear box and the servo-controlled dynamic loading system which enables cyclic shear and normal stress loading. In addition, this allows for very precise measurement of pore pressure generation near the sliding surface which is important for landslide risk evaluation.

3.2 Test procedure

The specimens were first prepared from a slurry, and then set into the shear box. The degree of saturation was examined by measuring BD Value, which was defined as the ratio between the increments of generated pore water pressure (Δu) and normal stress ($\Delta\sigma$) ($BD=\Delta u/\Delta\sigma$)[6]. The ratio for each test was ensured to be more than 0.95, a value that approximates full saturation. All samples were normally consolidated under a confining stress of 105 kPa. Then a reversal shear stress with a constant amplitude of about 45 kPa and a loading frequency of 0.5 Hz was applied to the samples during 50 cycles of loading. After each test, a cyclic stress ratio defined as the ratio between the maximum cyclic shear strength and the normal stress was measured for the last (50th) cycle of loading.

4 Test Results and Discussion

To compare the cyclic behavior of different soils, the obtained results were summarized in Fig. 3 in terms of void ratio against cyclic stress ratio for the 50th cycle. It is clear that the sandy samples (H1 and T1) were very vulnerable to cyclic loading; that is, the loss of cyclic shear strength was significant due to the process of liquefaction. For the soils T2, T3 and T4, the values of cyclic shear stress after the 50th cycle were found to be higher than those of H1 and T1.

Fig. 3b plotted as plasticity index against cyclic stress ratio normalized to a void ratio of 0.963 (see Fig. 3a) indicated that the soil potential to liquefy was related to the soil plasticity. Increase in plasticity leads to higher values of cyclic stress ratio and thus higher resistance to liquefaction. This finding (the relation between plasticity index and cyclic stress ratio) has practical application and can be used for evaluation of the liquefaction potential of clayey soils.

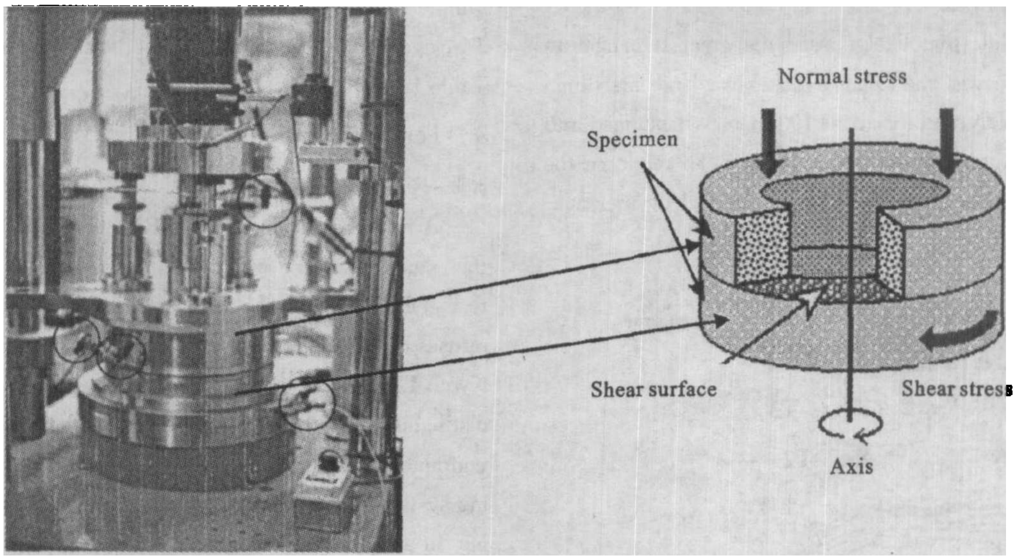

Fig. 2 Photo and conceptual figure of the IDPRI-4 ring-shear apparatus

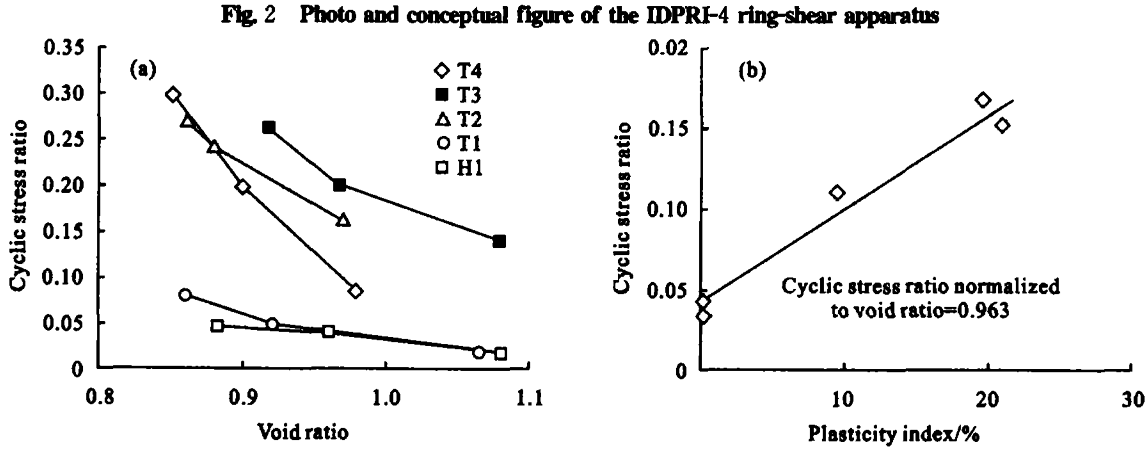

Fig. 3 Results of cyclic undrained st ress-controlled tests

5 Conclusions

On the basis of field and laboratory investigations the following conclusions can be drawn:

(1) The liquefaction potential of sandy soils is higher than that of clayey soils given the same void ratio.

(2) For clayey soils, an increase in plasticity raises the soil resistance to liquefaction.

(3) The observed relation between plasticity index and the liquefaction potential of soil can be used in practical application to estimate the liquefaction potential of soil, provided its PI is known.

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