Liquefaction Assessment of Sand in Sequenced Seismic Motions

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Liquefaction assessment of sand in sequenced earthquake motions was studied based on two series of stress-controlled, undrained hollow cylinder cyclic torsional shear tests. A high risk of liquefaction is expected under such conditions because of the accumulation of excess pore pressure by multiple seismic motions. The specimen with the residual excess pore pressure was exposed to various aftershocks that are (i) staged wave loading and (ii) irregular wave loadings with various waveforms and durations. The results of two loading tests are combined to draw a chart that tells the possibility of liquefaction depending on the level of the excess pore pressure remaining in the ground.

INTRODUCTION

The 2011 Tohoku Earthquake (EQ) caused severe damage to coastal structures due to ground liquefaction. Apart from the huge peak acceleration and the long duration, the seismic motion was particularly notable for the frequent aftershocks. In the hour following, aftershocks of magnitude of more than 7 occurred 3 times. More recently, in the 2016 Kumamoto EQ, the first shock of 6.2 magnitude was unexpectedly followed by a larger seismic shock after a day. In such conditions, latter seismic motions possibly cause further liquefaction by generating additional excess water pressure. However, the conventional liquefaction assessment methods do not account for this effect. The two recent seismic events have told us that a sequence of strong earthquake motions could happen in both trench-type and inland-type earthquakes. The impact of sequenced earthquake motions needs to be estimated for a better prediction of liquefaction.

Aftershock-induced liquefaction has been studied by several researchers in recent years. The field investigation by Quigley et al. (2013) reported recurrent liquefaction during the Canterbury EQ sequence. One of the early works is the physical modeling of lateral spreading by Okamura et al. (2001), who demonstrated that even a small aftershock could double the flow distance of the liquefied ground. Moreover, a series of centrifuge modeling tests on earthen embankments by Maharjan and Takahashi (2013 and 2014) concluded that the existence of an impermeable layer under the embankment caused larger settlement especially under the sequenced earthquake motions. Furthermore, the authors have performed shaking table tests to observe the liquefaction induced by aftershocks with various peak accelerations and quiet periods (Kobayashi et al., 2015). The effects of ground improvement methods, sand compaction piles, and compaction grouting were also evaluated in stratified ground (Kobayashi et al., 2016).

This study investigates the liquefaction of sand under sequenced earthquake motions by two series of stress-controlled, hollow cylinder cyclic torsional shear tests. First, some of the fundamental features of liquefaction assessment, such as characterizations of liquefaction resistance and seismic loading, are reviewed.

The concept known as “the effective number of waves” is also explained. After describing our test procedures, we examine the test results and discuss the liquefaction assessment in sequenced earthquake motions. Finally, our liquefaction assessment approach is examined against the foreshock and main shock of the 2016 Kumamoto EQ sequence.

BACKGROUND

Characterization of Liquefaction Resistance

The liquefaction resistance of soil is determined either by in-situ testing, such as standard penetration test and cone penetration test, or by laboratory testing, such as simple shear test, triaxial test, and hollow cylinder torsional shear test. Here, only laboratory testing is discussed. Figure 1 illustrates a typical result of an undrained hollow cylinder cyclic torsional shear test. In this case, liquefaction is reached after 62 cycles of sinusoidal waves of shear wave.