An investigation on the liquefaction behavior of sandy sloped ground during the 1964 Niigata Earthquake

Chiaro, G., Koseki, J. and Kiyota, T.
Institute of Industrial Science, University of Tokyo, Japan
email: chiaroga@iis.u-tokyo.ac.jp

INTRODUCTION

Liquefaction of sloped ground is a major natural phenomenon of geotechnical significance associated with damage during earthquakes, which is not fully understood yet. To address this issue, in this paper, a simplified procedure for predicting earthquake-induced sloped ground failure, namely liquefaction and shear failure, is proposed and validated by predicting the liquefaction-induced large-deformation slope failure that occurred in Ebigase area (Niigata City, Japan) during the 1964 Niigata earthquake.

A SEMPLIFIED PROCEDURE FOR SEISMIC SLOPE FAILURE ASSESSMENT

The proposed simplified procedure for seismic sloped ground failure analysis consists of a framework where cyclic stress ratio (CSR), static stress ratio (SSR) and undrained shear strength (USS) are formulated considering simple shear conditions, which simulate field stress during earthquakes more realistically. In this procedure, the occurrence or not of ground failure is assessed by means of a plot η_{max} (= [SSR+CSR]/USS) vs. η_{min} (= [SSR-CSR]/USS), where a liquefaction zone, a shear failure zone and a safe zone (i.e. no-liquefaction and no-failure) are defined.

The earthquake–induced CSR at a depth z below the ground is formulated by adjusting the well-known simplified procedure for evaluating the CSR [1] to the case of simple shear conditions:

$$(1)\ \mathrm{CSR}_{7.5} = \frac{\tau_{\mathrm{cyclic}}}{p_0'} = \frac{0.65\,(a_{\max}/a_{\mathrm{g}})\,r_{\mathrm{d}}}{\mathrm{MSF}\,[(1+2\,K_0)/3]\,[1-0.5\,(z_{\mathrm{w}}/z)]}$$

where $\mathrm{MSF} = [6.9\ \exp(-\mathrm{M_w}/4) - 0.058] \le 1.8$; $r_{\mathrm{d}} = (1-0.015\,z)$; a_{max} = peak ground acceleration (g); a_g = gravity acceleration (=1 g); M_w = earthquake moment magnitude; K_0 = coefficient of earth pressure at rest; z = depth below the ground surface (m); z_w = depth below water level (m).

Assuming infinite slope state and simple shear conditions, the SSR induced by gravity on a soil element of sloped ground is calculated as follows:

$$(2)\ \mathrm{SSR} = \frac{\tau_{\mathrm{static}}}{p_0'} = \frac{i/100}{[(1+2\,K_0)/3]\,[1-0.5\,(z_{\mathrm{w}}/z)]}$$

where i = gradient of slope (%).

Based on laboratory monotonic torsional shear test results on Toyoura sand (clean sand) an empirical formulation is suggested for USS:

$$(3)\ \mathrm{USS} = 0.1015 + 0.0046\,D_{\mathrm{r}} + 0.180\,\mathrm{SSR}$$

where D_r =relative density (%)

PREDICTION OF SLOPE FAILURE OBSERVED DURING1964 NIIGATA EARTHQUAKE

On June 1964, an M_w=7.5 earthquake hit Niigata City (Japan) and its neighbouring area. According to [2] the peak ground acceleration (a_{max}) in those areas was approximately 0.16 g. Large permanent horizontal displacement, subsidence and rising zones, a number of ground fissures and various sand boiling, observed in the Ebigase area (Niigata City), were the evidence that the gentle slope was extensively damaged by liquefaction. A post-seismic field survey revealed that the soil consisted mostly of sandy soils (i.e. sand dune (TS), alluvial sandy soils (As-1 and As-2)) and alluvial clayey soils (Ac), as shown in Fig. 1(a). The sandy soil layer was very loose to loose since its SPT N values were typically below 10. The range of estimated (by authors) liquefaction-induced shear strains was on the order of 90-200%.

The $(CSR)_{7.5}$, SSR and USS were evaluated for various soil elements, located at different depths beneath sloped ground level, by referring to a typical soil profile (Fig. 1(a)). In Fig. 1(b), the predictions of failure mode of gentle slope at Ebigase are reported in the plot η_{max} vs. η_{min}. Due to the severe seismic loading conditions (i.e. a_{max} = 0.16 g and M_w = 7.5), soil was likely to experience extremely large deformation (γs > 50%) triggered by liquefaction, except for the case of dense soil (N-2). These predictions are well in accordance with the field observation results [2].

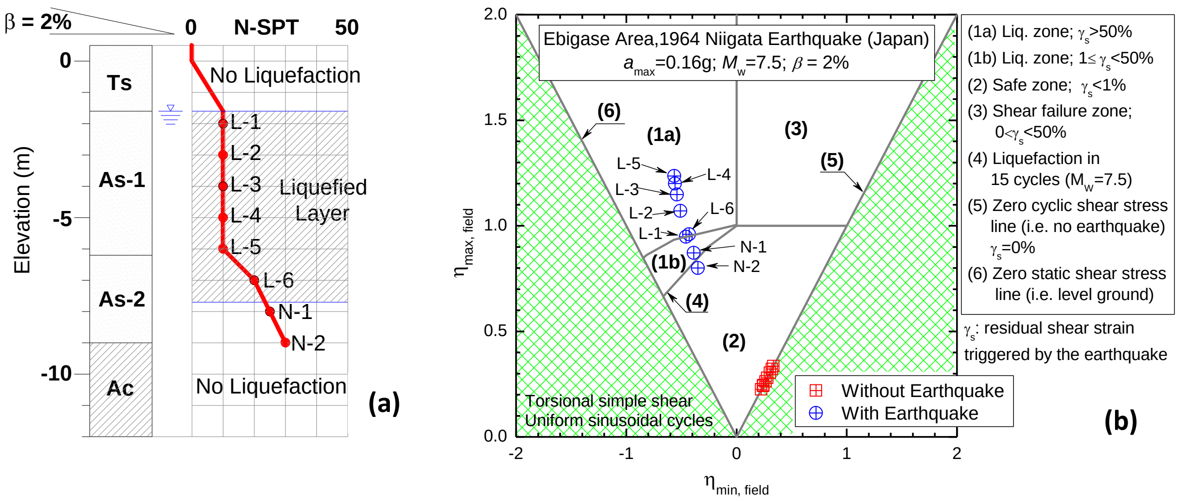

Fig. 1. (a) Typical soil column; and (b) Predictions of slope failure mode

CONCLUSIONS

In this paper, an attempt is made to identify key factors that govern failure of sandy sloped ground during earthquakes and a simplified procedure to assess whenever liquefaction or shear failure occurs within a saturated sandy sloped deposit is presented. It is shown that the proposed procedure is capable of predicting the liquefaction-induced large-deformation slope failure observed in the field in Ebigase area during the 1964 Niigata Earthquake.

REFERENCES

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