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An Effective Stress Analysis of the Liquefaction at Kobe Port Island

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INTRODUCTION

In the January 17, 1995, Hyogoken-Nanbu Earthquake of magnitude 7.2, widespread liquefaction occurred in the seaside area of Kobe city causing severe damages to many modern engineering structures. The liquefaction was particularly extensive in the reclaimed lands of Port Island and Rokko Island. Motions induced by the main shock of this earthquake have been recorded at several sites that exhibited severe liquefaction of reclaimed soil. Among these records, particularly interesting are those obtained at the observation site of Port Island since they include accelerograms at four different depths of the soil profile ranging between the ground surface and 83 meters depth. These records, provided by the Committee of Earthquake Observation and Research in the Kansai Area, were used to evaluate the accuracy of an effective stress analysis with a recently developed elastic-plastic constitutive model for sandy soils, termed Stress-Density Model (S-D Model). In this paper the computed acceleration time histories are compared with those recorded at the ground surface and at depth of 16 meters, and the most salient features of the computed response are presented.

SOIL PROFILE AND MASADO PROPERTIES

The soil profile of the observation site including SPT N-values, measured shear wave velocities V_S and location of the accelerometers along the depth of the profile are shown in Fig. 1. The surface layer, which is thick about 19 meters, is reclaimed Masado. It overlies the original sea-bed layer of alluvial clay 8m thick, with a mixture of gravel and sand layer and diluvial clay layer underneath, up to depth of 80 meters.

To evaluate the liquefaction resistance of Masado, results from liquefaction tests on undisturbed samples of Port Island's Masado obtained by Nagase et al. (1995) are used. The tested soil has mean grain size of D_{50}=1.3 mm, specific gravity of G_S = 2.65 and less than 10% fines content. The empty symbols in Fig. 2 show the measured cyclic strength in the undrained triaxial tests on samples isotropically consolidated to mean effective stresses of 50 and 100 kPa. Relative density of the tested samples is about 40%.

It can be seen in Fig. 2 that most of the experimental data were obtained for cyclic stress ratios less than 0.2, with the number of cycles needed to induce DA strain of 5% being more than ten. On the other hand, the earthquake that caused the liquefaction on January 17 is characterized by small number of cycles with very large amplitudes. This indicated that the experimental data shown in Fig. 2 do not cover the response of Masado triggered by this earthquake. In order to better approximate the liquefaction resistance at higher cyclic stress ratios, the Energy Model (Igarashi, 1993) is employed. The approximated liquefaction resistance of Masado by the Energy Model is shown by the solid line in Fig. 2.

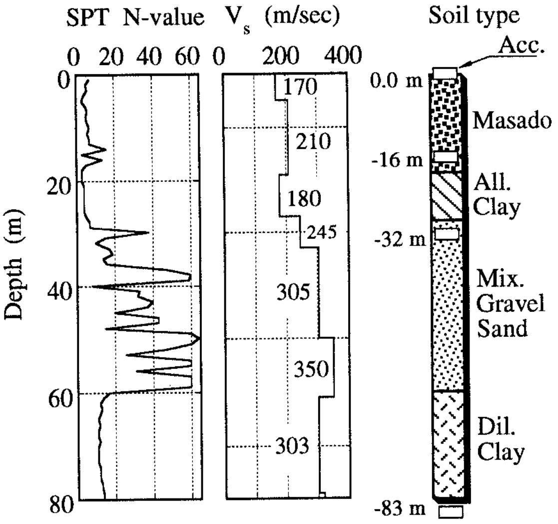

Fig. 1 Soil profile of the observation site at Port Island

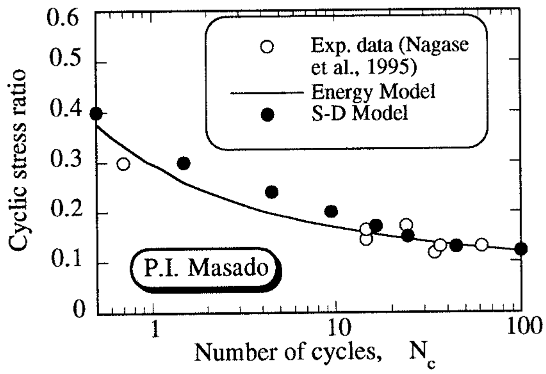

Fig. 2 Measured and computed liquefaction resistance of Masado

EFFECTIVE STRESS ANALYSIS

The Stress-Density Model (Cubrinovski, 1993) is used as a constitutive model within the finite element code DIANAJ-2 to conduct effective stress analysis of the Port Island soil profile. Drained analysis is performed on a 1-D soil-column model with height of 28 meters including the surface layer of Masado and the original sea-bed clay layer. The recorded N-S component of the motion at 32 meters depth is used as base input motion in the analysis.

Dilatancy parameters of the S-D Model were determined in order to simulate the liquefaction resistance of Masado shown in Fig. 2. The filled symbols in this figure show the simulated liquefaction strength by the S-D Model. Due to the lack of complete laboratory test data for Masado, the stress-strain and the state index parameters of the S-D Model were approximated by those of Toyoura sand with relative density of D_r = 50 %. The clay was modeled in the analysis as linear material with a shear modulus degraded to 40% of the initial modulus.

RESULTS AND DISCUSSION

Figure 3 shows the comparison between the computed and the recorded acceleration time histories at the ground surface and at 16 meters depth. Apparently, excellent agreement between the computed and the recorded acceleration time histories at the ground surface can be seen. Remarkable similarity in the accelerations is also found for the motion at 16 meters depth except that the analysis failed to produce the largest observed peak at about 6 seconds.

Computed excess pore water pressures at 2.5, 5 and 10 meters depth are shown in Fig. 4. The build-up of the excess pore water pressure was faster in the lower part of the Masado layer than that in the top 3-4 meters of the layer. The excess pore water pressure reached 90 to 100 % of the initial effective overburden pressure up to depth of 15 meters, thus indicating that almost the whole Masado layer contributed to the observed liquefaction. In order to shorten the computational time but still compute the final settlement of the soil, large permeability (k = 0.5 cm/s) for Masado is used. As a result, the dissipation time of the excess pore water pressure shown in Fig. 4 is very short.

Finally, Fig. 5 shows the computed settlement and horizontal displacement at the ground surface. The settlement at the surface reached about 12.5 cm which is close to the observed 15-20 cm settlement in the vicinity of the observation site.

In order to further clarify the liquefaction of the Port Island additional laboratory tests on Masado which will enable consistent definition of the S-D Model parameters are needed. The present analysis, however, affirms the ability of the effective stress analysis with the S-D Model to very accurately simulate the most prominent features of the observed ground response during liquefaction.

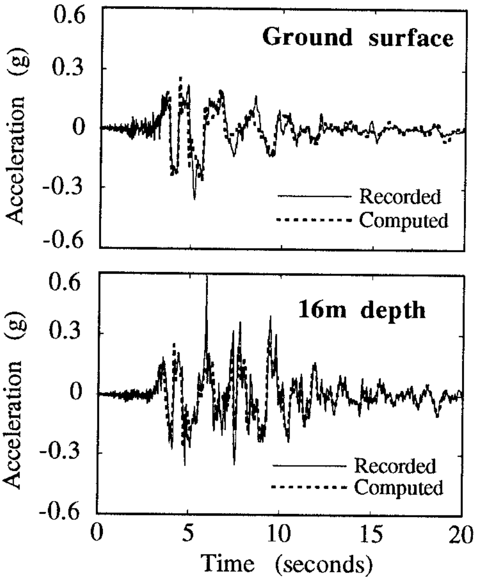

Fig. 3 Recorded and computed accelerations (N-S) at the ground surface and at 16m depth

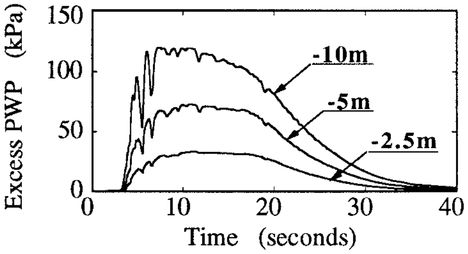

Fig. 4 Computed excess pore water pressures

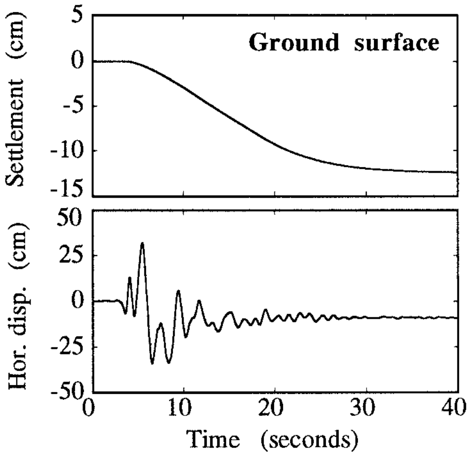

Fig. 5 Computed settlement and horizontal displacement at the ground surface

References: 1) Cubrinovski, M. 1993. A constitutive model for sandy soils based on a stress-dependent density parameter. D.Eng. Thesis, Univ. of Tokyo; 2) Igarashi, S. 1993. Dislocation energy of liquefaction. JSCE J. Geot. Eng. No.481/III-25; 3) Nagase, H., S.Rei, K. Kimura and S. Tsujino 1995. Liquefaction strength of overconsolidated undisturbed sandy soil samples. (sub. to 30th JSSM&FE).