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Liquefaction damage expansion caused by the generation of surface waves from base end section

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The 2011 off the Pacific coast of Tohoku Earthquake caused liquefaction to occur in reclaimed lands in Urayasu City and in other wide areas of reclaimed land along Tokyo Bay. One of the important characteristic of the observed liquefaction damage is that the level of liquefaction damage was nonuniform spatially, and the variation in the damage levels was large. The difference in damage levels in various parts has often been explained by the presence/absence of past ground improvement and by the difference in the dates of reclamation work. From the boring survey at Urayasu, thin layer of soft alluvial clay is located directly under the liquefiable layer on the inland side where liquefaction damage was small. However, the basement layer is inclining towards coast side and alluvial clay layer is increasing in thickness as approaching to the coast where liquefaction damage was severe. This paper examines the cause of extensive and nonuniform liquefaction damage observed in Urayasu City by focusing attention on the stratum inclination at the deeper part of the liquefiable layer with the use of 2D elasto-plastic seismic response analysis of the multi-layer ground. The analysis code employed in this report was the soil-water coupled finite deformation analysis code GEOASIA (Noda et al. 2008), which incorporates an elasto-plastic constitutive model (SYS Cam-clay model; Asaoka et al. 2002) that allows description of the behavior of soils ranging from sand through intermediate soils to clay under the same theoretical framework.

Fig.1 (a) illustrates the velocity vector distribution 50 sec after earthquake occurrence. Only the area around the sloped part is shown in this figure, and the scale in the vertical direction has been magnified by 2 times. Surface waves generate at the base end section of the inclination which shows orbit in a counterclockwise direction with ongoing wave propagation to the right-hand side. Excess pore water pressure ratio at the liquefiable layer is shown, superimposing the result of 1D analysis with same stratigraphic composition at the point. 2D analysis result shows liquefaction (excess pore water pressure ratio is greater than 0.95), even 1D analysis did not liquefy (Fig.1 (b)). In the case of 2D analysis, in addition to the magnitude, duration time of the oscillation increases in subsurface layer accompanied by the generation of surface waves (Fig.1 (c)). Excess pore water pressure ratio of 2D analysis continues to increase for a long period even after the primary earthquake motion. Fig.1 (d) illustrates the shear strain distribution 200 sec after earthquake occurrence. Although shear strains are small in the non-inclined horizontal strata, large strains are produced in the subsurface liquefiable layer. Furthermore, this strain distribution is nonuniform and localized even assuming homogeneous initial conditions for subsurface layer. The nonuniform, localized shear strain are due to the existence of the sloped boundary. In other words, in addition to the vertical component of seismic movement being generated by the stratum slope, multi-dimensional propagation is also exhibited because of complex reflection behavior in the diluvial layer. Moreover, in sloped layers such, the danger of liquefaction is increased compared with the one-dimensional model. The actual liquefaction damage observed in Urayasu City was heavy in the sloped stratum locations where midterm reclamation work had been executed. This behavior resembles the results of the analysis carried out here. The current analysis shows that even in the case of homogeneous geomaterials, stratigraphic nonhomogeneity results in large variations in ground deformation behavior and that such deformation becomes particularly large in sloped strata locations. These things cannot be taken into consideration in one-dimensional analysis and highlight the necessity of performing multi-dimensional effective stress analysis.

Keywords: liquefaction, stratum inclination, surface wave, effective stress analysis

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