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TS 4b: Earthquake related problems Panelist report “Some research front on post-liquefaction phenomena”

ST 4b: Problèmes relatifs aux tremblements de terre Rapport de spécialiste : "Recherches sur le phénomène de post-liquéfaction"

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Despite the great advance in liquefaction research since the 1964 Niigata earthquake, there still remain unsolved problems vital to proper design methodology. One of them is post-liquefaction soil behavior, which plays an important role in soil-structure interactions in making performance-based designs of various buildings and civil structures.

1 POST-LIQUEFACTION SHEAR BEHAVIOR

It is generally accepted that some residual shear stiffness or strength still remains in liquefied deposits. Time-delay effect in post-liquefaction displacement or flow is also recognized. Quite a few mechanical models for the degraded shear stiffness or the rheological effect have been proposed to deal with such post-liquefaction phenomena. However, how to understand and evaluate them from the viewpoint of soil mechanics are quite controversial, still. Several different views have been proposed so far on the residual strength and the flow mechanism in liquefied ground as indicated below, which are classified as the undrained mechanism, and the partially drained mechanism. The latter will be focused here.

The partially drained mechanism was explicitly explained in a committee report in US (National Research Council, 1985) though this concept had been intuitively shared among researchers. By using a special terminology, water interlayer, Seed (1987) pointed out, why the steady-state strength of uniform sand in the undrained mechanism (a) leads significantly higher values of residual strength than those estimated by the case studies in the field. In this view, fine soil sublayers or seams sandwiched in sand deposits are considered to play a key role in flow failure. The formation of water interlayers or water films between liquefied sand and overlying lower-permeability seams was observed under level ground conditions in a number of model tests (Scott and Zuckerman 1972, Fiegel and Kutter 1994, Kokusho et al. 1998). Kokusho et al. (1998), Kokusho (1999, 2000, 2003), through in situ soil investigations, 1-D liquefaction tests in a tube, 1G shake table tests, laboratory soil tests, numerical analyses etc., demonstrated that the water film or void-redistribution effect plays an important role in delayed large lateral flow in liquefied ground. They pointed out that various parameters; such as relative density, slope angle, magnitude of shaking, etc., have strong effect of lateral flow involving void water films. Kabasawa and Kokusho (2004) found that the post-shaking flow tends to be much larger than that during shaking and quantified the residual strength exhibited during the delayed flow along the water film as 20% of that of the uniform sand. Theoretical bases on post-liquefaction behavior of infinite slopes to the inflow of pore water beneath a silt seam from adjoining zones was discussed based on laboratory tests by Boulanger and Truman (1996). Kulasingam et al. (2004) and Malvick et al. (2005) demonstrated that the strain concentration along a low-permeable seam and delayed slip occurs also in

centrifuge model tests and the potential importance of various factors (e.g., shaking intensity and duration, layer thickness, permeability contrasts).

Thus void redistribution mechanism has drawn increasing attention recently. More research efforts are needed to integrate such research findings into actual design methodologies, though it may not be so easy due to complex in situ soil conditions.

2 BASE ISOLATION EFFECT ON LIQUEFIED GROUND

As another aspect of post-liquefaction behavior, the seismic isolation effect of liquefied ground should be focused. This effect was first demonstrated in the seismic records during the 1964 Niigata earthquake obtained in the basement of a 4 stories RC apartment house (Kanai 1966). The S-wave motion suddenly subsided in a short time from the start of large shaking, after that only a long period low-amplitude motion, presumably surface waves, sustained. It was also noticed during quite a few previous earthquakes that structural damage by seismic shaking effect is less pronounced in liquefied sites. During the 1995 Kobe earthquake, the same tendency was again observed in that structural damage in highway viaducts or buildings was severe in inland areas of competent soil than in coastal areas of soft and liquefied sites (e.g. Matsui et al. 1996). In the Port Island of Kobe where the reclaimed surface soil extensively liquefied during the Kobe earthquake, horizontal acceleration was the smallest at the ground surface compared to deeper levels according to the vertical array records, which clearly demonstrated the seismic isolation effect (e.g. Kokusho and Matsu-moto 1998). The energy evaluation in the same site indicates that about 70% of the incident wave energy at the base layer there was dissipated in the surface soil layers primarily by liquefaction (Kokusho and Motoyama 2002). Thus, the seismic isolation effect of liquefied ground has been clearly demonstrated during recent earthquakes, which may not be neglected in considering structural design resting on liquefiable soils.

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