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Liquefaction-induced water-film mechanism in submarine slide

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As one of possible mechanisms of seismically triggered submarine slides in cohesionless sandy & gravelly deposits, void redistribution or water film effect seems to be deeply involved (Kokusho, 1999, 2000). In this view, fine soil sublayers sandwiched in coarse grain deposits are considered to play a key role in flow failure. The formation of water films between liquefied sand and overlying lower-permeability seams has been observed under level ground conditions in a number of model tests. Fig. 1 shows a typical example of water film formed beneath a thin silt seam sandwiched in a uniform horizontal sand layer. It has also demonstrated that water film can be generated not only in sands beneath silt seam but also in gravels beneath smaller permeability sands (Kokusho & Kojima 2002). Visit http//:www.civil.chuo-u.ac.jp/lab/doshitu/index.html for video images of the model tests.

For sloping ground conditions it has been demonstrated, based on model shake table tests, that the water film plays an important role in post-earthquake large lateral flow in liquefied ground. Fig.2 shows typical test results where clean fine sand was rained in water to make saturated sand slope shown in (d) in a transparent soil box (Kokusho 2003). Fig.2(a) indicates a case of a uniform sand model where small flow deformation occurs mostly during shaking. The locations of markers in the model are shown in (d) with the same symbols. If a silt seam shown with chain-dotted arc is sandwiched in the uniform sand, a larger flow deformation above the arc occurs not only during but also after shaking as indicated in (b). These results in (a) and (b) are for the input acceleration of 0.31 G. Interestingly, for weaker input acceleration of 0.18G given to the same model in (c), much larger post-shaking flow than (b) occurs, while only minimal deformation takes place during shaking. In these tests, very thin water film can be observed beneath the silt arc.

A basic question may arise that sand which can be so dilative if sheared under a low confining stress may absorb ambient excess pore water and hence block the water film development. It can be pointed out, however, based on the comparative observation of the cases with and without a silt seam that a water film formed beneath the seam serves as a shear stress isolator which prevents deeper soils developing shear strain and positive dilatancy (Kokusho, 2000). Consequently, sand can experience large shear strain beneath the silt seam without suffering from the dilatancy effect, whereas it stops moving after the end of shaking if the sand is uniform.

Another shaking table tests has shown that a soil mass slides even on a very gently inclined water film, which breaks at weak points of the overlying sublayer, triggering the boiling failure in the sand above and a mud avalanche of the upper layer (Kokusho 1999, 2000). For video images of these model tests, visit http//:www.civil.chuo-u.ac.jp/lab/doshitu/index.html.

If water films are formed continuously, they will tremendously reduce the residual strength down to zero if sliding occurs all the way through a continuous water film. Kabasawa and Kokusho (2003) quantified the residual shear resistance exerted during the delayed flow along a water film in the model tests. The result shown in Fig.3 indicates that the residual strength along the water film is almost independent of sand density and other test parameters and remains around 20% that of the uniform sand. Considering that soil deposits are naturally stratified with sandwiched low permeability seams, it seems quite reasonable to identify the water film effect as a major mechanism for seismically induced submarine slides in gently sloped sandy or gravelly sea-bed near coastal areas.

Thus, liquefaction may be highly responsible in earthquake-induced submarine slides, particularly in near-shore sites where the seabed is composed of liquefiable loose sand or gravel.

Keywords: seismic liquefaction, water film, time delay, permeability