Liquefaction Analysis of River Dike with Discrete Element Method

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ABSTRACT

It is well known that the major cause of Yodo-gawa river dike damaged by the 1995 Hyogoken-Numbu earthquake in Osaka, Japan was the liquefaction of the ground where the loose sand layer existed. For these reasons, an earthquake-proof project of embankment is carried out by Tokyo Metropolitan Government. In this study, we have developed a liquefaction analysis method by using DEM, in which the pore water pressure is taken into account to estimate the large permanent ground displacement due to liquefaction at the microscope level.

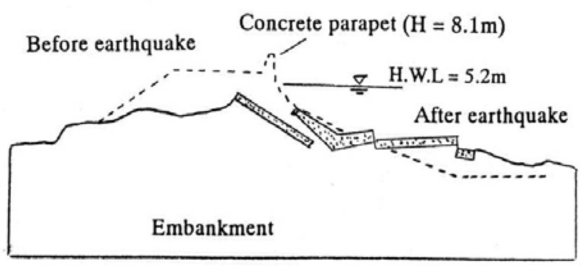

Fig.1 Damaged cross section of Torishima area

Fig.1 shows the severely damaged cross section of Torishima area (Damaged model) located near the Yodo-gawa river mouth within about 40km from the epicenter. The concrete parapet wall at the top of embankment slipped into the riverbed and the maximum permanent displacement was about 3m. On the other hand, the major damage in Takami area (Non-damaged model) with the high-water channel located in the upper river side from Torishima area was not observed.

In this analysis, the parameters of DEM are determined as shown in **Fig.2**. According to consider the primary wave velocity, the stiffness K_n of spring contact for calculation of contact force between discs in the direction of the disc center, is determined finally based on the simulation results of the simple shear test and cyclic simple shear test. The accumulative pore water pressure caused by shear force plus the effective normal force is equal to the initial effective normal force. The constitute model (Iwan model) proposed by Iwan is introduced to the shear spring system at each contact point. This model composes of springs and sliders representing stress-strain relationships following Masing's rule. Development of pore water pressure caused by shear force is simulated based on the dissipative energy and stored elastic energy of the model. The dissipative energy is calculated from dislocations of sliders and the stored elastic energy is done from compression and expansion of springs. Also, the effective shear force of the shear spring system is reduced according as the effective normal force.

At the first, **Fig.3** shows the DEM simulation model for simple shear test in conditions of the different radius (R=30, 15, 7.5cm) to estimate the influence of radius of disc. In spite of the different radius, G, K and τ obtained by DEM are identical with the experimental results done by real specimen test. **Fig.4** shows the distributions of excess pore water pressure ratio (0.25～1.0) by cyclic simple shear test in 2.0Hz frequency. In the case of R=7.5cm, the zone that tented to coincide with σ_1 direction inclining to $\pi/4-\phi/2$ from horizontal appeared.

Fig.5 shows the damaged and non-damaged model of Yodo-gawa river dike by DEM (R=30cm). The deposits at Torishima area consist of sandy layers shown by an oblique line (No.2, No.3, No.5), a clay layer (No.4) and a bearing stratum (No.6). Also, the deposits at Takamai area consist of sandy layers (No.2, No.4, No.6), a clay layer (No.5) and a bearing stratum (No.7), and the clay layer (No.3) of about 2m in thickness is sandwiched between No.2 and No.4. The input wave for 25 second obtained from an accelerometer attached to the bottom of bearing pile located at G.L.-30m near the Takami area, has the predominant frequency of around 0.5Hz and the maximum acceleration of 137.63gal. **Fig.6(a)(b)** show the deformations of damaged and non-damaged model of Yodo-gawa river dike at 25 second. The vertical displacements of embankment crest in damaged model are larger than those of non-damaged model, and the former has good agreement with the actual measured maximum vertical permanent displacement (about 3m). Furthermore, the vertical displacement of embankment crest in the direction of riverbed with effect of high-water channel does not appear at all. It shows that this analysis is possible to indicate the movement of slope moved in the direction of riverbed due to liquefaction flow realistically. **Fig.7(a)(b)** show the distributions of excess pore water pressure ratio (0.2～0.8) at 25 second. The excess pore water pressure ratios obtained at upper sandy layer of damaged dike are high, and larger slightly than that of non-damaged dike.

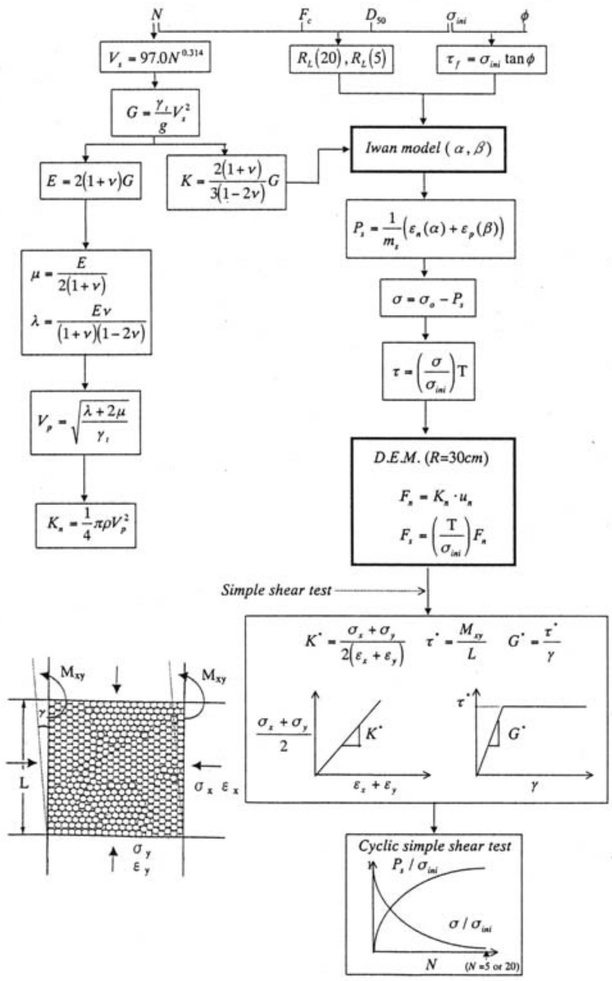

Fig.2 Flowchart for determination of parameters

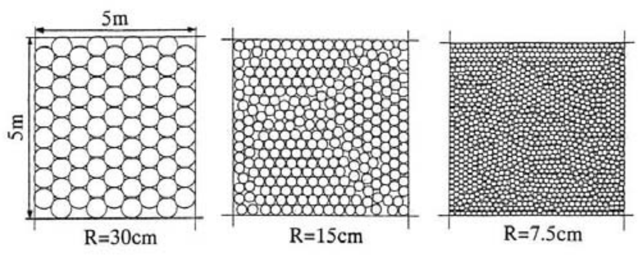

Fig.3 DEM model for simple shear test

DEM analysis can be applied to the liquefaction analysis by using Iwan model and it satisfactorily provided enough data to correlate the results of experiment or real disaster. Now, further study on estimation of the influence of radius (R=15cm, 7.5cm) based on analysis of

Yodo-gawa river dike is carried out.

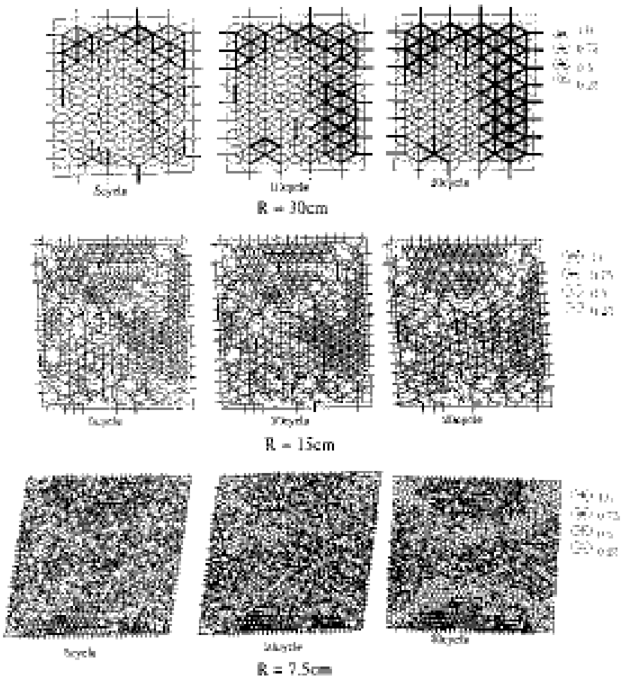

Fig.4 Distributions of excess pore water pressure ratio

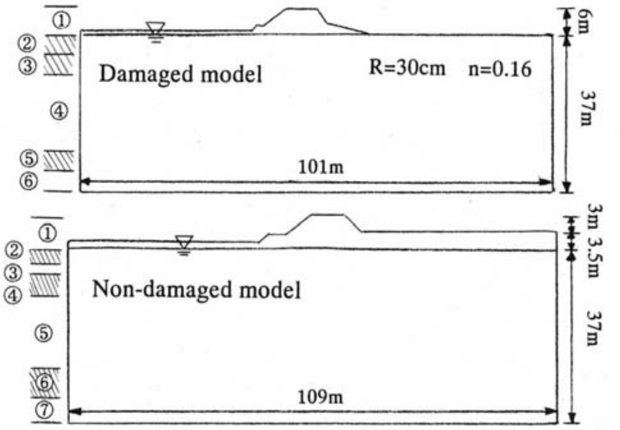

Fig.5 Damaged and non-damaged model of Yodo-gawa river dike

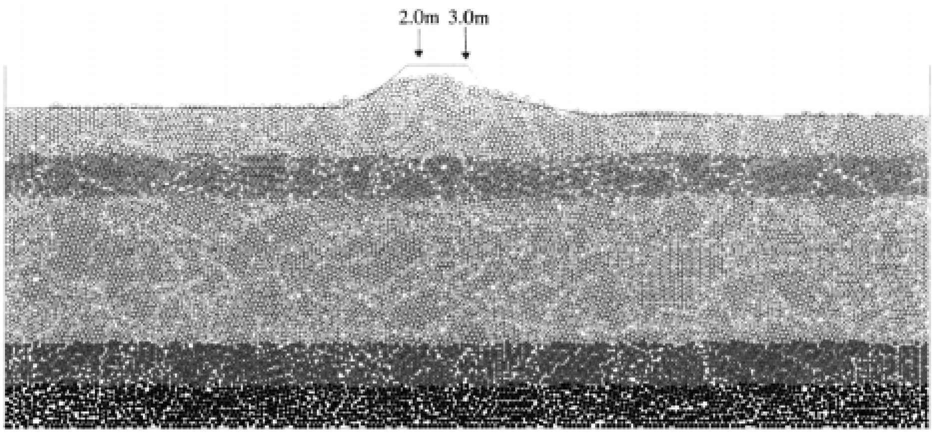

Fig.6(a) Deformations of damaged model at 25s

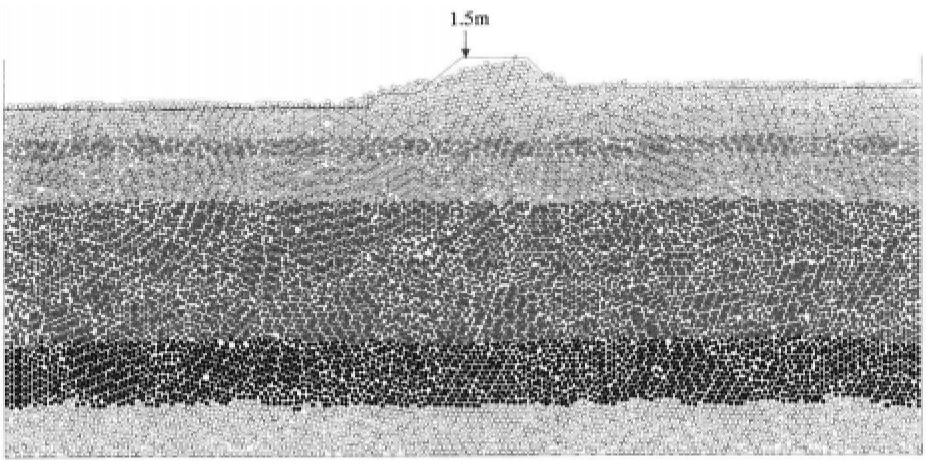

Fig.6(b) Deformations of non-damaged model at 25s

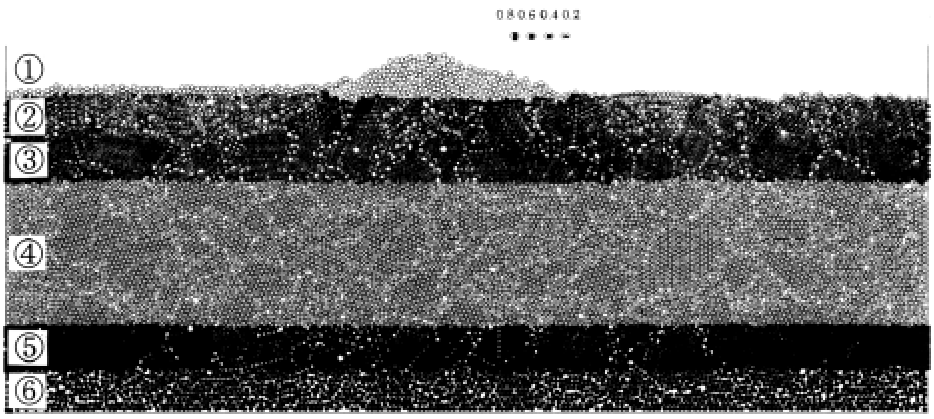

Fig.7 (a) Distributions of excess pore water pressure ratio of damaged model at 25s

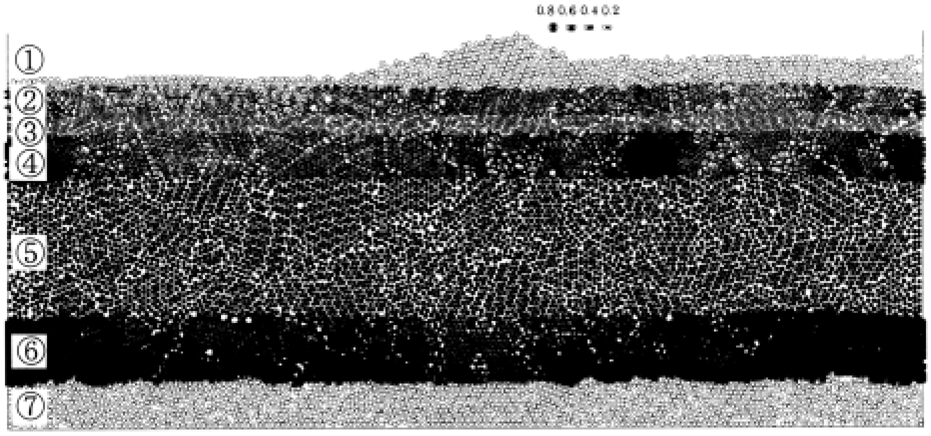

Fig.7 (b) Distributions of excess pore water pressure ratio of non-damaged model at 25s