SIMULATION OF LIQUEFACTION PHENOMENON AT MICROSCOPIC LEVEL USING 3-D DISTINCT ELEMENT METHOD

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1. INTRODUCTION

Liquefaction is one of the most important, and complex topics in geotechnical earthquake engineering. Since Niigata earthquake, it has been popularly recognized that the liquefaction induced ground failures caused severe damage to the built environment. Since then, understanding the mechanism of liquefaction phenomenon at microscopic level became very important to take measures against the liquefaction induced ground failures. Mechanism of liquefaction at microscopic level can be effectively modeled by Distinct Element Method (DEM).

Our primary objective is to simulate the hollow cylindrical torsion test under undrained condition using 3-D Distinct Element Method[1]. A vertical strip is extracted from the hollow cylindrical specimen as shown in the **Fig. 1(a)** and it is modeled by the proposed three-dimensional DEM. Spherical particles are used in the simulation. Slipping of particles at the contact obeys Coulomb friction limit. The stresses acting on the specimen are modeled approximately as will be explained in the following section. There are some researches that have been done on the numerical simulation of liquefaction phenomenon using two-dimensional DEM[2]. We extended this problem to three-dimension. Also, we have adapted a method to consider the effects of pore water directly to improve the micro mechanical behavior of the particles.

In the simulation of liquefaction phenomena at microscopic level using DEM, special attention has to be paid to the calculation of exact pore volume change, calculation of excessive pore pressure and the dissipation of excessive pore pressure in a cell. To facilitate the above calculations, the specimen for numerical simulation is divided into number of cells. **Figure 1(b)** shows the two-dimensional views of the specimen and the total calculation region. Element volume and excessive pore pressure are calculated within the cell. The pore water pressure is assumed constant within a cell and it is calculated at the center of the cell. Excess pore water pressure in the cell (j,k,l) is calculated as follows,

$$\Delta P_t = \left(\frac{PV_{t-1}(j,k,l) - PV_t(j,k,l)}{PV_{t-1}(j,k,l)} \right) bmw \qquad (1)$$

where ΔP_t increase in pore water pressure at time t, $PV_t(j,k,l)$ the pore volume at the present step, $PV_{t-1}(j,k,l)$ the pore volume at the previous step and bmw bulk modulus of pore water. Pressure difference between adjacent cells develops a hydraulic gradient and exerts a force, F_s, on the element. F_s is calculated as,

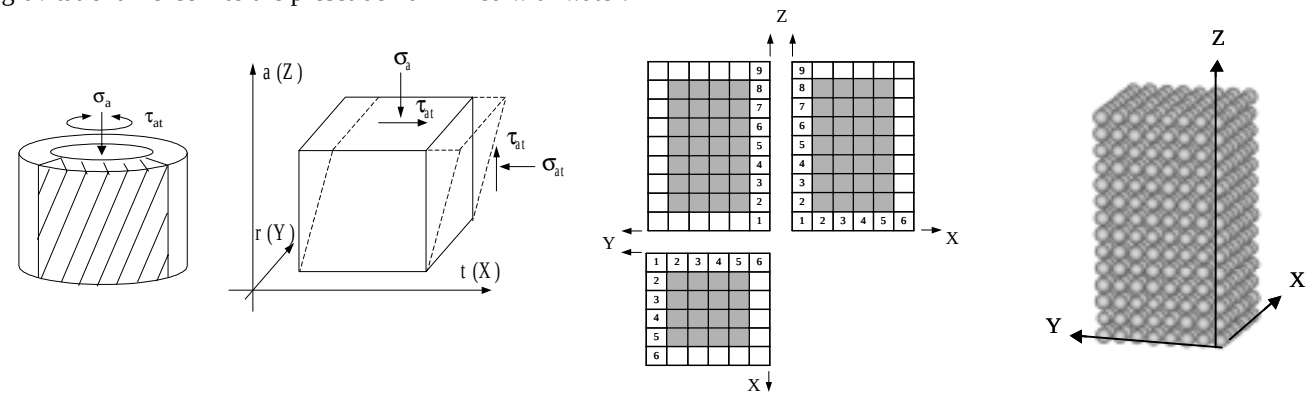
$$F_s = i \times \gamma_w \times V \qquad (2)$$

where i is hydraulic gradient, γ_w unit weight of water and V volume of an element. Between adjacent two cells, one-dimensional Darcy's law is applied to calculate the amount of water flow from one cell to another.

2. DESCRIPTION OF THE MODEL

Relatively larger size elements are used in the simulation to reduce the CPU time. Elements, whose radii following the log normal distribution, are set at the corners of the three-dimensional grid that was set with the spacing of maximum element diameter as shown in **Fig. 1(c).** In the initial setting, there are eight elements located in a cell.

X planes are numerically connected to form a so-called cyclic boundary (Circumferential direction). Rigid walls are set in the y direction (inner and outer cylinder walls) during packing and these walls are removed during numerical simulation after applying confining pressure. The elements, which were set at the corners of the grid, were allowed to fall freely under the gravitational force into the preset domain filled with water.



(a) Hollow cylindrical torsion test specimen　(b) Two-dimensional views of the numerical model　(c) Model before packing

Fig.1 Hollow cylindrical torsion test specimen and numerical model

Key words: Distinct Element Method, DEM, Liquefaction, Hollow cylindrical torsion test, Cyclic loading,
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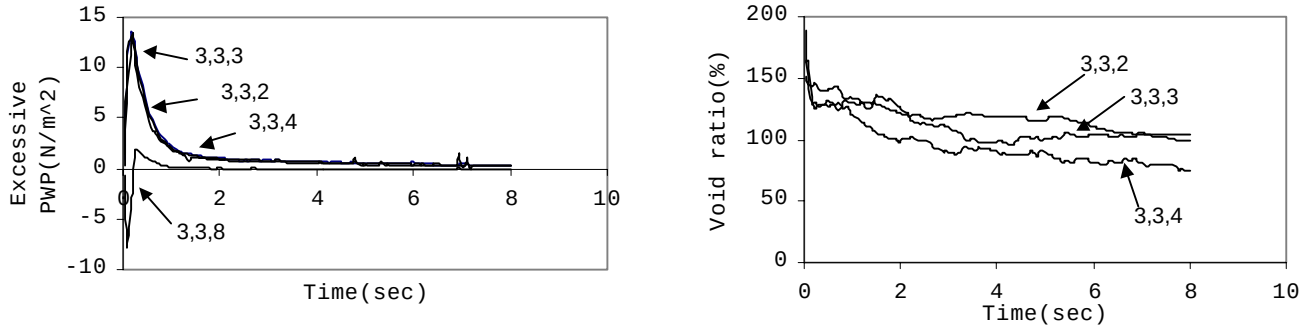
During packing, relatively smaller value for bulk modulus of water and lager value for coefficient of permeability are used to bring the model stable within a short time. The time histories of pore water pressure and void ratio during packing for some particular cells are shown in the **Figs. 2(a)** and **2(b)**.



(a) Time history of pore water pressure　　(b) Time history of void ratio

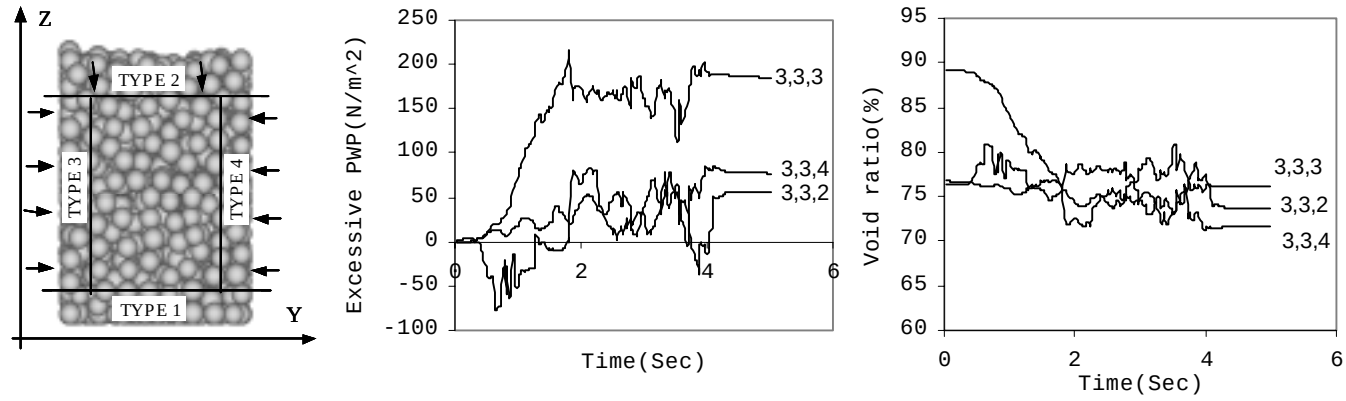
Fig. 2 Time histories of pore water pressure and void ratio during packing

3. NUMERICAL SIMULATION

For the shake of simple identification of certain elements, whole elements are classified into different types as shown in Fig. 3(a). Type 1: Elements touching the base wall. This type of elements is called as base plate hereafter. Type 2: Elements whose centers located above a certain level decided by the total specimen height after the packing. This type of elements is referred as loading plate. Type 3: Elements whose y coordinates satisfy $y(i) < y_{0l} + y_c$, and it is referred as interior wall and Type 4: Elements satisfy $y(i) > y_{0r} - y_c$ and it is referred as exterior wall. y(i) is the y coordinate of i th particle and y_{0l} and y_{0r} are the minimum and maximum position of the walls in Y direction, respectively. Confining pressure, P_c, on the inner and outer boundaries is applied through type 3 and the type 4 elements, respectively. Force on an element due to confining pressure is calculated as follows.

$$F_c = P_c \times \pi \times r^2 \tag{3}$$

Vertical pressure, P_a, is applied to the model in the form of gravitational force by controlling the unit weight of the elements in the loading plate. The bottom layer is kept immovable and shear displacement is applied to the model through type 2 elements. The time histories of excessive pore water pressure and void ratio are shown in **Figs. 3(b) and (c)**.



(a) Application of confining pressure　(b) Time history of excessive pore water pressure　(c) Time history of void ratio

Fig. 3 Simulation results

4. CONCLUSION

The general characteristics of saturated sand under undrained and cyclic loading condition is studied using the proposed 3-D Distinct Element Method. In the model, direct effect of pore water has been considered with simple algorithm. Using the model, liquefaction and its associated phenomena, such as increase in excessive pore water pressure, change of void ratio could be simulated

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