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# NUMERICAL SIMULATION ON THE EFFECT OF VERTICAL GROUND MOTION UPON LIQUEFACTION OF SATURATED SAND

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## 1. INTRDOCTION

It has been observed in some past earthquakes that there have been strong motion records where the vertical accelerations have been greater than the other two orthogonal horizontal acceleration components. These occurrences have stimulated the current studies to further an understanding of destruction of saturated ground induced by liquefaction during the earthquake right under the urban area in general. To simulate the effect of vertical ground motions upon liquefaction of saturated sand ground, the sand particles are treated as circular elements and the porosity being related with the potential of liquefaction is calculated by using nonlinear inelastic 2-D DEM under sinusoidal excitation.

## 2. SIMULATION OF POROSITY CHANGE UNDER MULTIDIRECTIONAL EXCITATIONS

### 2.1. Differential Equation of Motion of Each Sand Particle

Once we obtained the forces of contact $[f_n]_t$ and $[f_s]_t$ for all elements contacting with element $i$, we can then calculate the resultant forces in both directions $X$ and $Y$: $FX_i$, $FY_i$ and the resultant moment $M_i$ at the centre of $i$ (positive in counter-clockwise direction) by using the following equations:

$$[FX_i]_t = \sum_j (-[f_n]_t \cos\alpha_{ij} + [f_s]_t \sin\alpha_{ij}) + m_i(g - a_v)$$

$$[FY_i]_t = \sum_j (-[f_n]_t \sin\alpha_{ij} - [f_s]_t \cos\alpha_{ij}) + m_i a_h$$

$$[M_i]_t = -r_i \sum_j ([f_s]_t)$$

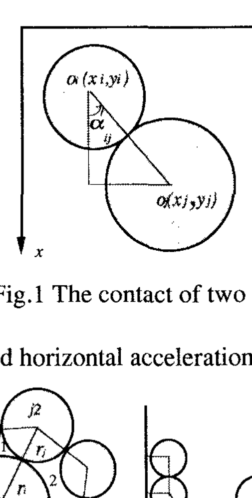



Fig.1 The contact of two particles

where $\sum_j$ represents the sum of all $j$ elements contacting with element $i$, $m_i$ is the mass of element $i$ and $g$, $a_v$ and $a_h$ are the gravity, vertical and horizontal accelerations.

### 2.2. Derivation of Pore Area

As the first step of our study on analyzing the liquefaction potential of saturated sand ground under both horizontal and vertical excitations, this paper developed the proposal[1] of calculating the porosity of sand. As shown in Fig.2, a particle $i$ is surrounded by other particles $j1$-$j4$, then four pores are formed. To calculate the pore area such as $1$, a searching approach should go from the route by making the angles (clockwise), between $i \to j1$ and $j1 \to j2$, $j1 \to j2$ and $j2 \to i$, be minimal. The area of pore $1$ is equal to the difference of triangular area and sector areas. By searching such kind of approach for all $i$, the pore areas formed by contacting particles can be calculated. As shown in Fig.3, the pores formed by the particles contacting with the sand box can be calculated in the same way as long as we

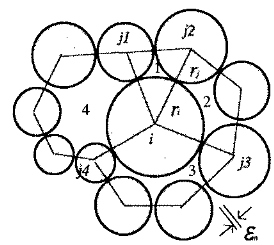



Fig.2 Diagram of pores surrounding a particle $i$

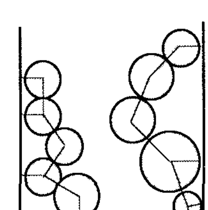
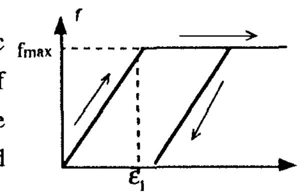


Fig.3 Diagram of pores surrounding the walls

treat the three walls as three special elements, *N+1*, *N+2*, *N+3*, where *N* is the number of sand Particles.

2.3. Modification of Spring Between Particles

Characteristics of spring between particles are usually treated as elastic relation. To simulate the characteristics of dilantancy and compressibility of loosen sand it is proposed[1] that inelastic spring should be adopted. We choose the nonlinear inelastic model shown in Fig.4 to simulate the sand porosity change under horizontal and vertical excitations.




Nonlinear inelastic

Fig.4 Characterics of spring between particles

3. APPLICATION TO THE POROSITY CHANGE OF SAND GROUND

3.1. Ground Model and Parameters

Ground model is as Fig.5 and the coefficients are shown in Table1.

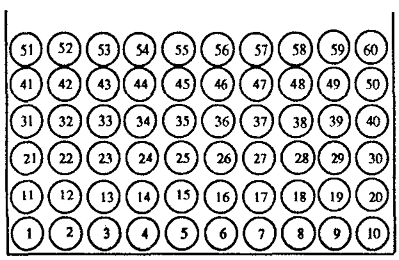



Fig.5 Particles position in initial condition

Table1 Coefficients data

| | |
|---|---|
| Spring constant (normal) $k_n$ | $1.4\times10^{6}$ $(N/m)$ |
| Dashpot (normal) $\eta_n$ | 5.2 $(N\,sec/m)$ |
| Spring constant (shear) $k_s$ | $3.5\times10^{5}$ $(N/m)$ |
| Dashpot (shear) $\eta_s$ | 1.3 $(N\,sec/m)$ |
| Sand density $\rho$ | $2.7\times10^{3}$ $(kg/m^{3})$ |
| Particle Radius $r$ | $2.15\times10^{-3}$ $(m)$ |
| Friction coefficient $\mu$ | 1.0 |
| $f_{max}$ | 3.0 $(N)$ |
| $\Delta t$ | $1.0\times10^{-6}$ (sec) |
| $\varepsilon_m$ | $8.6\times10^{-4}$ $(m)$ |

3.2. Calculated Results

Five cases of calculations have been performed to compare the porosity changes. Case 1: horizontal exciation only; case 2: both horizontal and vertical excitations; case 3: same as case 2, but with 30° phase difference; case 4: same as case 2, but with 60° phase difference; case 5: same as case 2, but with 90° phase difference. The calculated results are shown in Fig.6.

4. CONCLUSION

This paper tried to numerically simulate the effect of vertical ground motion upon liquefaction potential of saturated sand. It can be observed from Fig.6 that vertical excitation does affect the porosity change. Two directional excitation leads to much more reduction of porosity. It shows the trend that vertical ground motion can enlarge the pore pressure and result in the rise of excess pore water pressure. Effect of phase difference is not obvious to the porosity change in above calculation. Much more calculations in the future are needed to observed its effect.

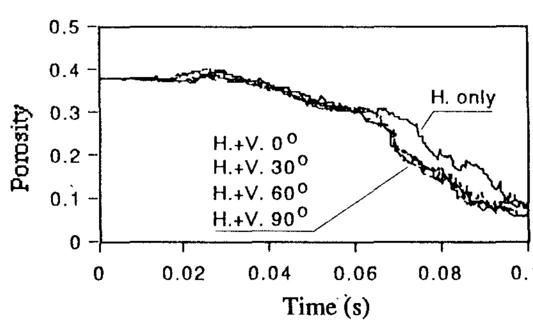



Fig.6 Sand porosity change under horizontal and vertical excitations

REFERENCE

1) Y.TARUMI and M.HAKUNO, Granular Assembly Simulation on Quick Sand and Liquefaction, Bull. Earthq. Res. Inst., Univ. Tokyo, Vol.62(1987) pp.535-577. (In Japanese)