I -614 ONE DIMENSIONAL RESPONSE ANALYSIS BY EFFECTIVE STRESS METHOD AT A LIQUIFIED SITE DURING THE GREAT HANSHIN EARTHQUAKE, 1995

University of Tokyo Student Member Mehedi A. Ansary
University of Tokyo Member Fumio Yamazaki
University of Tokyo Member Tsuneo Katayama
University of Tokyo Member Ikuo Towhata

INTRODUCTION: The recent Great Hanshin earthquake in the vicinity of Kobe liquified many sites. Most of the liquefaction occurred under the level ground condition [1]. In this study the authors used multi-spring model [2,3] for effective stress dynamic response analysis of a liquefied site at the Kobe port area.

LOCATION AND SITE CONDTION: A one-dimensional vertical array is situated at the Kobe Port Island area, which is located 34.670° N and 135.208° E. The array is situated in a reclaimed land and consists of 4 three-component accelerographs. Figure 1 shows soil condition at the site and soil model used for the analysis. The water table is situated approximately at a depth of 4 m from the ground surface.

In this array site, orientation errors were detected from particle orbit plots of two horizontal components and were estimated by applying maximum coherence method [4]. The ground surface at this site was liquefied, so accelerograph at GL-32 m was used as a reference point (pivot) instead of accelerograph at GL 0 m. The rotation angles are shown in Table 1. For further analysis for this study, corrected records were used.

SOIL PARAMETERS: Initial shear modulus for different soil layers were obtained from PS-logging and ϕ'values from SPT N-ϕ'relation. It was assumed that for clay layers there would be no pore pressure rise. For sand and gravel layers pore pressure parameters a and r were determined by using the relations between shear strain energy (W_s) and pore water pressure at zero shear stress (u_0) for different relative densities [5]. The values of W_s and u_0 obtained for a particular relative density were normalized by initial effective stress (σ'_{z0}) and put in the empirical relations (Eqs. 1 and 2) to obtain parameters a and r [2].

$$\frac{u_o}{\sigma'_{zo}} = \frac{1}{1+\left(\dfrac{r}{(W_s/\sigma'_{zo})}\right)^a}; \text{ if } \frac{u_o}{\sigma'_{zo}} \le 0.5 \qquad (1)$$

$$\frac{u_o}{\sigma'_{zo}} = \frac{a}{4}\left(\ln(W_s/\sigma'_{zo}) - \ln r\right) + 0.5; \text{ if } 0.5 < \frac{u_o}{\sigma'_{zo}} \le 1.0 \qquad (2)$$

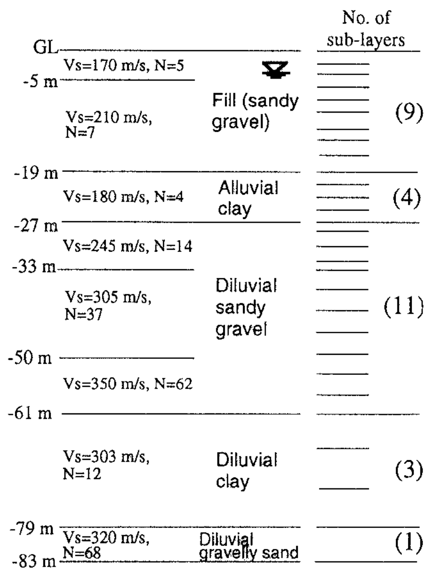

Fig. 1 Soil condition at the site (left) and layering used for the analysis (right)

Table 1. Measured orientation errors for the downhole instruments with the instrument at GL-32m as pivot

Seismometer locations	α (deg.)	β (deg.)	γ (deg.)
GL 0 m	-11.5	-3.0	12.0
GL-16 m	-3.5	0.5	-2.0
GL-83 m	18.0	1.5	-0.5

ANALYSIS OF THE SITE AND RESULTS: The detailed description of the model used in this analysis is given by Yamazaki et. al [2]. The acceleration records obtained in the GL-83 m in the vertical array was used as the incident waves. The maximum amplitudes are 572.3 gal in NS-direction and 448.4 gal in EW-direction. The dynamic effective stress analyses in two-directional motion and in uni-directional motion were conducted. The results are shown in Figures 2 and 3.

In general, the agreement between computed and observed results is good. The discrepancy between recorded and computed motions may have arisen due to the nature of the ground motions and the assumptions used in the 1D-analysis.

Liquefaction may occur in more than one layer and at different times. In case of two-directional analysis, liquefaction occurred in the loose layer at GL-10m to -16m (i.e., layer #6 to #8) and also at GL-27m to -33m (layer #14 to #17). The liquefaction occurred first in the lower level and later in the upper level. The liquefaction in the lower level which occurred first can be explained by Finn et al's parametric study [6]. According to that study, if a saturated sand stratum is sealed on both sides by impermeable surfaces there will be no external drainage but an internal redistribution of pore-water pressure will take place. This will ultimately raise the the level of initial liquefaction and decrease the time to liquefaction within the sand layer. On the other hand, liquefaction in the upper layers which occur later can be explained by the fact that liquefaction may also occur after an earthquake ceases due to the seepage forces exerted by the upward flow of water as the pore-water pressures remaining in the soil will try to dissipate in the vertical direction. Generally, this type of liquefaction occurs near the ground surface.

In the case of uni-directional analyses the maximum pore water pressures developed in the layer #6 were 98% of the initial effective vertical stress by both NS and EW-motions. For layer #14, maximum pore water pressures developed were 93% and 98% of the initial effective vertical stress by NS and EW-motions, respectively.

Maximum acceleration in each layer changes with the variation of pore-water pressure in each layer. In the liquified layers, maximum accelerations by two-directional analysis were smaller than those by uni-directional analyses due to the intensification of non-linearities of the loose layers by the combined motion [2] as shown in Figure 2. Such effects were also observed in the acceleration response spectra (Figure 3). From maximum pore-water pressure and maximum shear strain variation with depth (Figure 2), it can be clearly seen that at the liquified layers pore-water pressure equals the initial effective vertical stress of the layer and shear strain exceeds the failure strain of the layer. Figure 4 shows particle traces of shear stress and shear strain in the horizontal plane of a liquified layer.

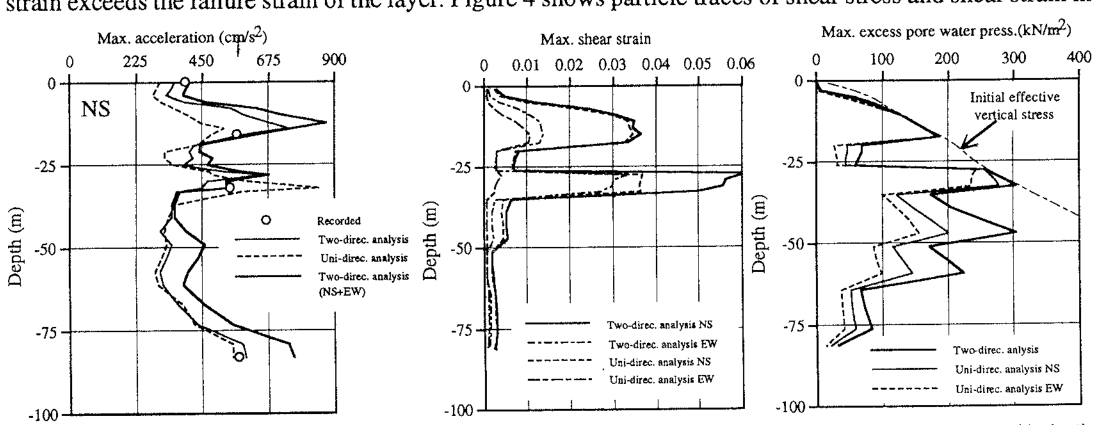

Fig.2 Distribution of the computed maximum acceleration, maximum shear strain and maximum pore-water pressure with depth

CONCLUSION: Nonlinear dynamic effective stress analysis using multi-directional shearing model can predict the occurrence of liquefaction at the Kobe Port Island array site quite well. The results of this analysis also showed that combined two-directional input motion is more liable to cause liquefaction but induces smaller acceleration response spectrum than uni-directional input motion as observed by Yamazaki et al [2].

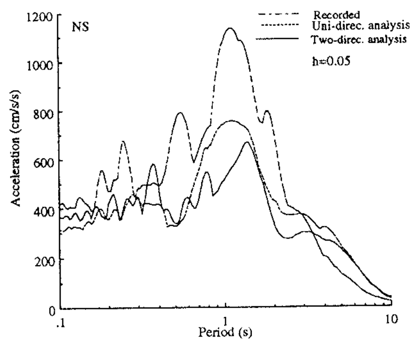

Fig.3 Computed and recorded acceleration response spectra of the ground surface for NS component

REFERENCES:

1. K. Ishihara,'Liqefaction and flow failure during earthquakes', *Geotechnique*, **43(3)**, 351-415 (1993).
2. F. Yamazaki, I. Towhata and K.Ishihara,'Numerical model for liquefaction problem under multi-directional shearing on horizontal plane', *Fifth Int. conf. on Numerical Methods in Geomechanics*, Nagoya, 399-406 (1985).
3. I. Towhata and K.Ishihara,'Modelling soil behavior under principal stress axes rotation', *Fifth Int. conf. on Numerical Methods in Geomechanics*, Nagoya, 523-530 (1985).
4. F. Yamazaki, L. Lu, and T. Katayama'Orientation error estimation of buried seismographs in array obserevation', *Earthquake eng. struct. dyn.*, **21**, 679-694 (1992).
5. I. Towhata,'Effect of principal stress axes rotation on shear deformation charcteristic of sand due to cyclic loading', *Dr. Thesis, University of Tokyo* (1981).
6 W. D. Liam Finn, K. W Lee and G. R. Martin,' An effective stress model for liquefaction', *J. Geotech. Engg. Div., ASCE*, **103(GT6)**, 517-533 (1977).

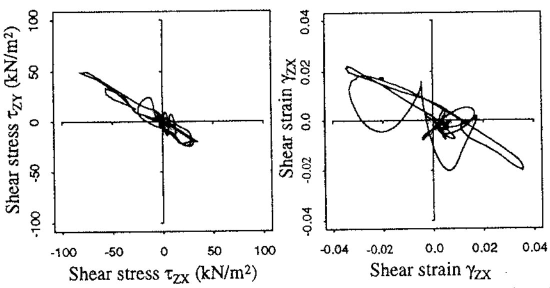

Fig. 4 Traces of shear stress and shear strain by two-directional analysis in the liquified layer at GL-10 m