27 May 2010, 4:30 pm - 6:20 pm

Effect of Density on Critical Depth of Liquefaction in a Soil Deposit Containing Double Loose Sand Lenses

S. M. Mir Mohammad Hosseini
Amirkabir University of Technology, Iran

Y. Pashang Pisheh
Amirkabir University of Technology, Iran

K. Shakiba Nia
K. N. Toosi University of Technology, Iran

N. Ganjian
University of Tehran, Iran

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

EFFECT OF DENSITY ON CRITICAL DEPTH OF LIQUFACTION IN A SOIL DEPOSIT CONTAINING DOUBLE LOOSE SAND LENSES

S. M. Mir Mohammad Hesseini
Professor, Amirkabir university of Technology
Tehran, Iran, email: mirh53@yahoo.com

Y. Pashang Pisheh
Ph.D. Candidate of Geotechnical Engineering, Amirkabir University of Technology, Tehran, Iran, email: yadolah_p@yahoo.com

K. Shakiba Nia
Senior Geotechnical Engineer, K.N.Toosi University of Technology, email:k.nia@live.com

N. Ganjian
Ph.D. Candidate of Geotechnical Engineering, University of Tehran
Civil Engineering Department, email: nganjian@ut.ac.ir

ABSTRACT

Large surface deformations due to liquefaction have been observed in many soil deposits which seem to feature good geotechnical characteristics. These deformations are often caused by the liquefaction of sand layers surrounded by clayey or silty soils called “sand lenses”. Liquefaction potential often decreases with increasing of depth. Hence, a specific depth of embedment of the lenses can be defined below which liquefaction would unlikely happen or the consequential surface deformation would be negligible. This depth is called critical depth. This research aims at studying the effects of the relative density of the sand within the lenses on the critical depth of liquefaction in a soil deposit containing double sand lenses. The soil deposit is simulated in plane strain condition using the computer code, FLAC (Version 4), which is based on finite difference method. Soil deformation, hysteresis loops, shear strain, shear stress, pore water pressure and effective stress in the sand lenses have been plotted during seismic loading. Results indicate that critical depth is strongly dependent on the relative density of the sand. The rate of change of the critical depth versus the standard penetration test number decreases with increasing relative density.

INTRODUCTION

Liquefaction occasionally takes place when loose saturated cohesionless materials at or near the ground surface lose their shear strength during dynamic loading. If drainage does not occur during seismic loading, the tendency for volume reduction in each cycle of loading results in a corresponding progressive decrease in the effective stress. If the effective stress reaches zero, liquefaction takes place causing the soil to lose its shear strength. Sand boils, lateral spreads and settlement are the common results of liquefaction (Martin et al., 1975). Liquefaction can cause a large drop in stiffness and strength (Mir Mohammad Hosseini and Nateghi, 2001). Large surface deformations due to liquefaction have been observed in many soil deposits which seem to feature good geotechnical characteristics. These deposits often contain some sedimentary layers of loose and comparatively uniform fine sand surrounded by clayey or silty soils. The surface deformations of these areas during ground shaking are sometimes due to the liquefaction of these sand layers, named “sand lenses” (Holchin and Vallejo, 1995).

In this context, the seismic behavior of a saturated soil deposit containing double sand lenses has been studied in order to investigate the effects of the relative density of the sand within the lenses on the critical depth. The sand lenses and the surrounding fine soils have been simulated using the computer code, FLAC (Version 4) which is based on a finite difference framework. This software is a 2-D explicit finite difference program for engineering mechanics computation (Cundall, 1976).

MODELING

The simulated soil deposit is 20m thick and 100m long, containing two sand lenses. The model consists of 2000 square zones 1 meter a side. There is a 4m free space between the elliptical sand lenses which are embedded at the depth of 7m. The lenses are surrounded by a clayey soil. Horizontal movement is prevented at the sides of the model and the water table is at the ground surface elevation. Hence, the sand lenses and surrounding fine soil are completely saturated. The configuration is shown in Fig.1.

Constitutive models should be able to realistically simulate the behavior the soils within the model. Here, Mohr-Coulomb model has been used to simulate the behavior of the surrounding clayey soil. This constitutive model is the common model used to represent stress-strain behavior and corresponding shear failure in soils and rocks (Byrne, 1991). The characteristics of the surrounding clay are shown in Table 1. The saturated sand lenses are assumed to satisfy Finn model during dynamic loading. The maximum shear and bulk modulus of the sand have been computed based on the method of Seed and Idriss (1969). These parameters are shown in Table 2.

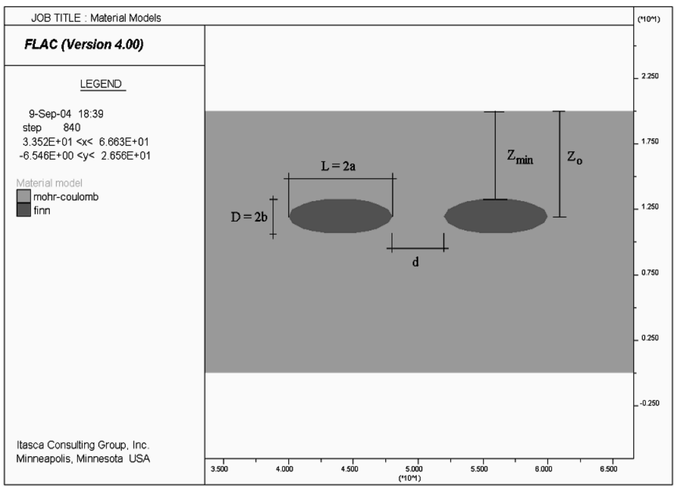

Fig. 1. Geometric parameters of sand lenses and surrounding soil (L=2a=8m; D=2b=2.66m; d=4m; Z_o=8m; Z_{min}=6.66m).

STATIC ANALYSIS

We computed the initial in situ stresses and pore water pressure in the model. The model subjected to self weight was analyzed statically.

Table 1. Characteristics of the Clay

E(Mpa)	30
ν	0.3
Φ (Deg.)	10
C (Kpa)	10
γ_{dry} (KN/m^3)	15
γ_{sat} (KN/m^3)	18
Porosity	0.3
K (m/sec)	1E-6

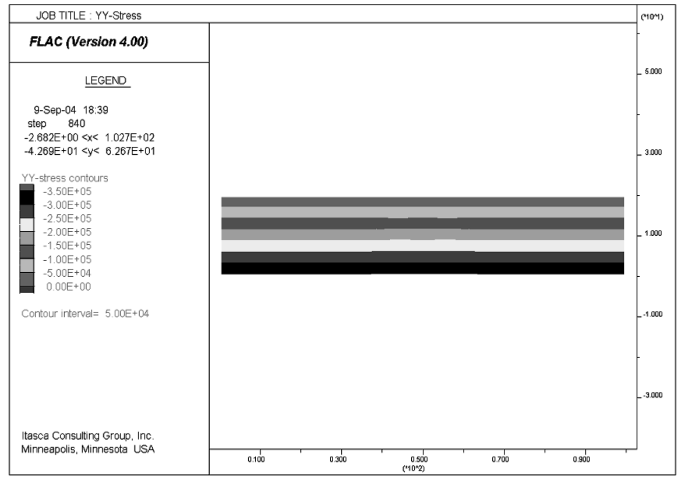

Fig. 2. Initial total stress contours.

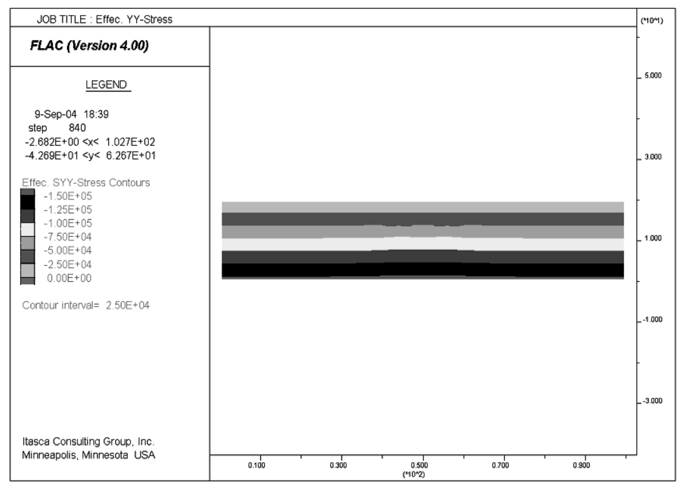

Fig. 3. Initial effective stress contours.

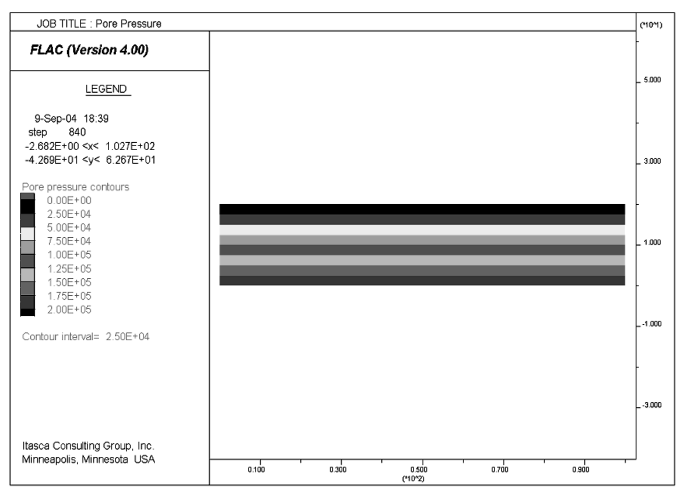

Fig. 4. Initial pore pressure contours.

.

Results of static analysis are shown in Figs. 2 to 4, as total stress, effective stress and pore pressure contours.

Table 2. Characteristics of the Sand

D_r (%)	33	40	47	58	65
$(N_1)_{60}$ (SPT)	5	7	10	15	20
γ_{dry} (KN/m^3)	14	14	14.5	15	15.5
γ_{sat} (KN/m^3)	20	20	20.5	20.5	20.5
E (Mpa)	12	15	23	35	45
ν	0.3	0.3	0.3	0.3	0.3
Φ'(Deg)	26	28	29	31	33
K_{2max}	35	40	44	50	55
G_{max} (Mpa)	50	58	63	72	79
B_{max} (Mpa)	108	125	136	156	171

DYNAMIC ANALYSIS

The boundary conditions are perhaps the most important factors influencing numerical analyses. In static analyses, fixed or elastic boundaries can be placed at sufficient distance from the region of interest. But in dynamic problems, such boundary conditions lead the reflection of upward propagating waves back into the model and do not allow the necessary energy radiation. Hence; here, free-field boundaries have been assigned to the model. These conditions lead to absorption of most of the energy in the wave reflected from the side boundaries, avoiding distortion of propagating waves. The dynamic loads were applied to the base as a sine acceleration wave in x-direction. Assuming the amplitude of this wave, a_{max}= 0.2g, the frequency, f=5 Hz, and duration, t_d=10 sec, the mechanism of liquefaction in the double sand lenses and soil deformation due to seismic loading were studied. The relative density of the sand is assumed to be 40% (See Table 2).

As shown in Fig. 5, the effective stress in sand lenses reaches zero after 12 cycles of loading (t=2.4 sec) and then liquefaction takes place. Also, the changes of the pore water pressure during cyclic loading are shown in Fig. 6. This Figure shows two pore pressure curves versus time, at the depths of 7m and 8m. It can be inferred that, the pore water pressure in the sand lenses increases during cyclic loading up to a maximum value at t =2.4 Sec and then, stays relatively constant.

The residual pore water pressure at the end of each cycle increases progressively with increasing of the number of the cycles. The vertical effective stress contours at the end of loading are shown in Fig. 8.

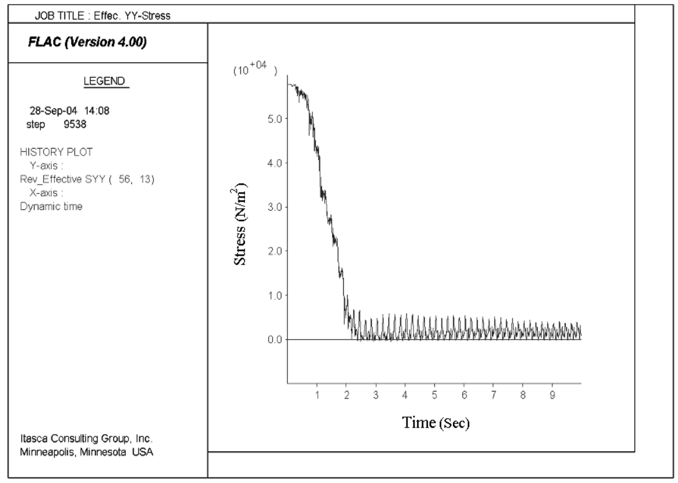

Fig. 5. Vertical effective stress versus time.

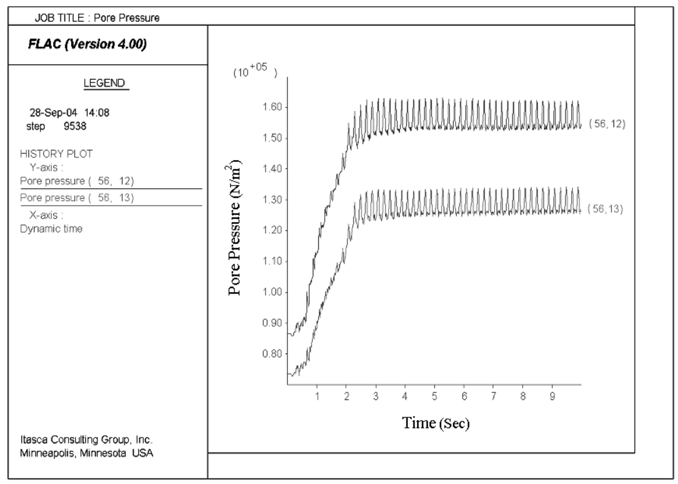

Fig. 6. Pore water pressure versus time.

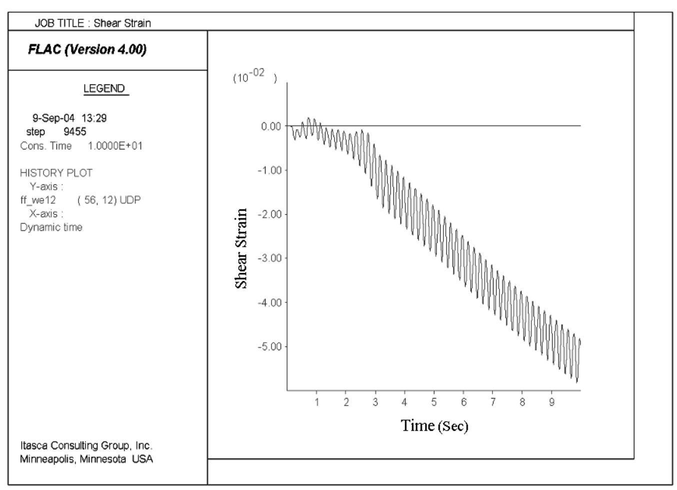

Fig. 7. Shear strain versus time.

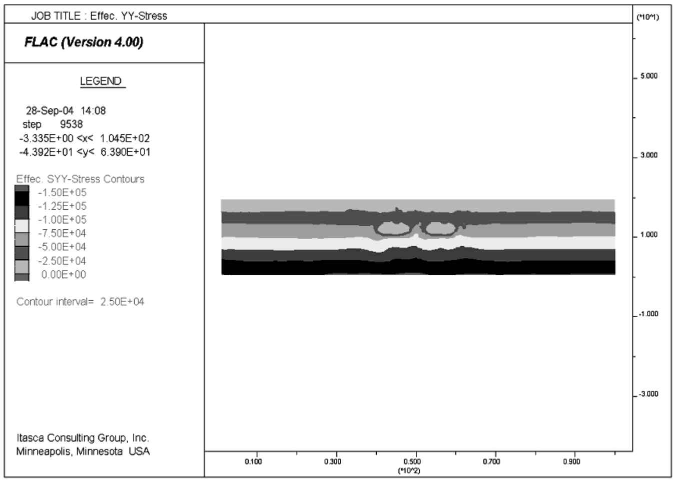

Fig. 8. Effective stress contours at the end of loading.

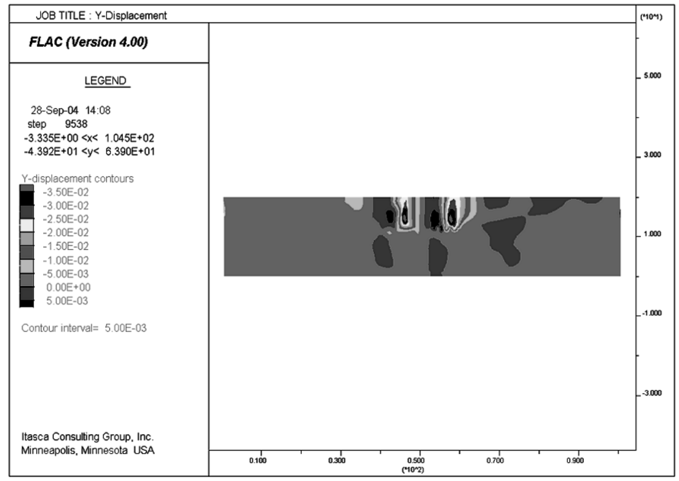

Fig. 10. Vertical deformation contours.

In order to simulate the stress-strain behavior of the sand during dynamic loading, a program was written in C^{++} to generate hysteresis loops through using the developed Masing model rules. These loops were modelled during the increase in shear strain in the sand lenses as shown in Fig. 9. It can be inferred from Fig. 9 that, the shear modulus decreases with increasing of shear strain and at the end of loading the magnitude of the shear modulus decreases to approximately 5 percent of its initial value. Vertical displacement of the soil after liquefaction of the sand lenses is shown as contours in Fig. 10. It is observed that, due to liquefaction in the double sand lenses and settlement formation, a bowled settled media is established in the middle of the sand lenses. Also, the maximum magnitude of soil settlement occurs near the liquefied lenses while this deformation decreases with increasing of the distance from the lenses horizontally and vertically. Hence, at distances of approximately 3 to 4 times the length of the lenses, the settlements are negligible.

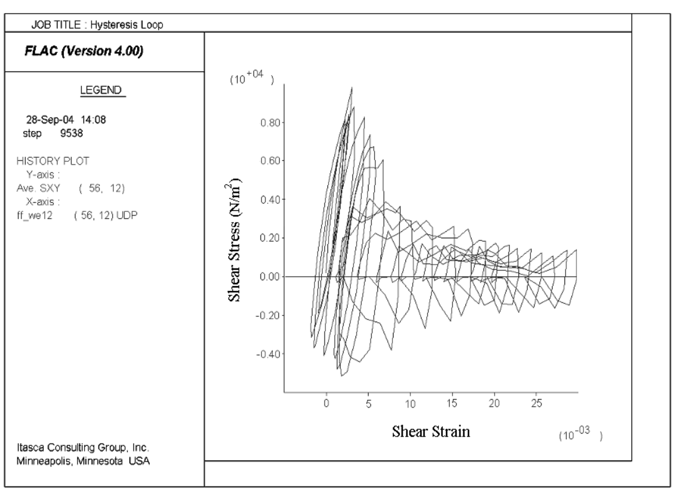

Fig. 9. Hysteresis loops in sand lenses during cyclic loading.

POST LIQUEFACTION ANALYSIS

At the end of dynamic loading, the loose sand lenses are liquefied and the effective stress reaches approximately zero. As consolidation and excess pore pressure dissipation begins, the effective stresses increase gradually. Hence, a post-liquefaction analysis was performed to illustrate the mechanism of excess pore pressure dissipation. The excess pore water pressure dissipation after 1, 10 and 60 minutes of cyclic loading are shown in Figs. 11 to 13. It can be inferred from these figures that, the reduction of pore water pressure has a high rate at the beginning and then its rate becomes lower. Hence, quite a long period of time is needed for complete pore pressure dissipation. Figs. 14 to 16 illustrate the increasing of vertical deformation of soil after 1, 10 and 60 minutes of loading. According to these figures, soil deformation develops slowly after loading, so that; just 4 mm of settlement is added to the existing deformation after 60 minutes of loading.

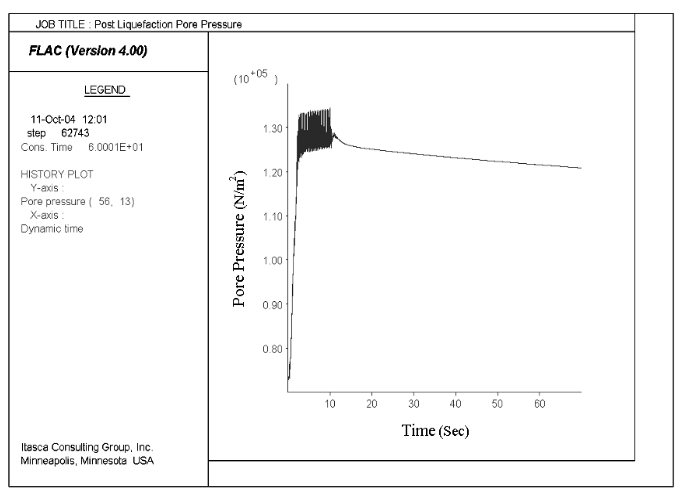

Fig. 11. Excess pore water pressure versus time.

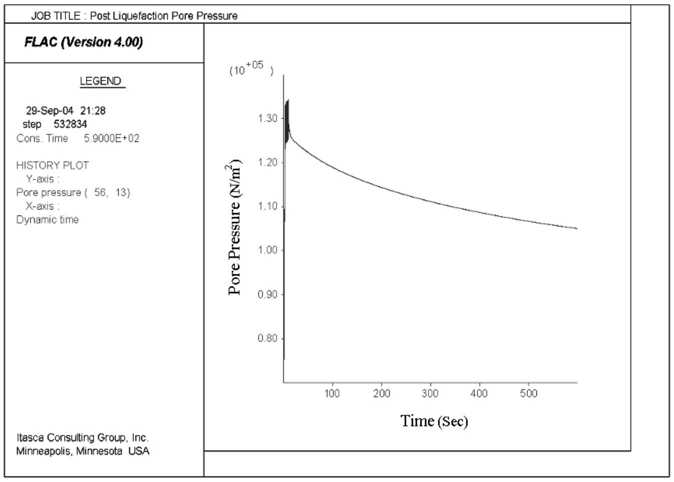

Fig. 12. Excess pore water pressure dissipation after 10 minutes of loading.

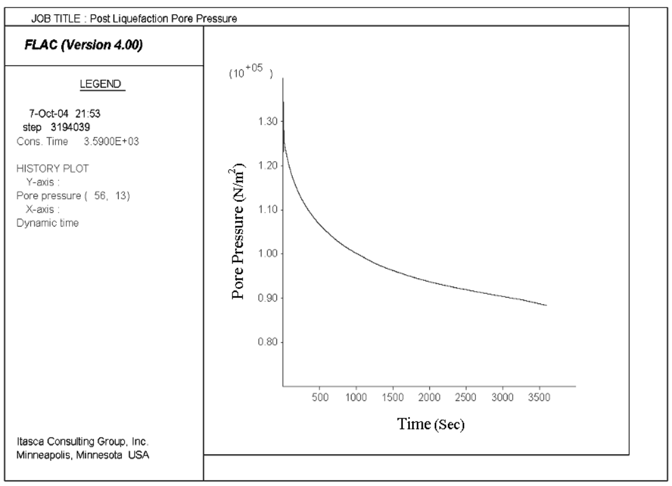

Fig. 13. Excess pore water pressure dissipation (60 minutes).

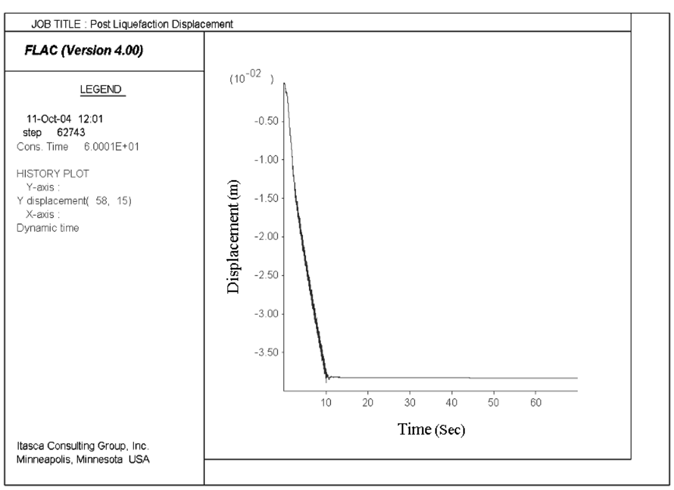

Fig. 14. Maximum vertical displacement after 1 minute.

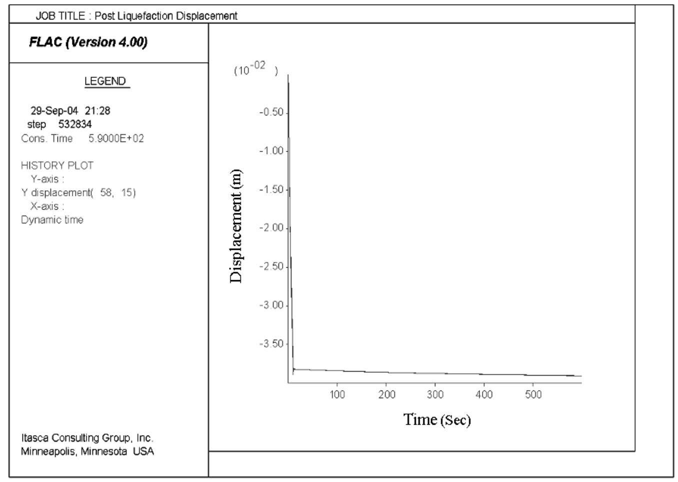

Fig. 15. Maximum vertical displacement after 10 minutes of loading.

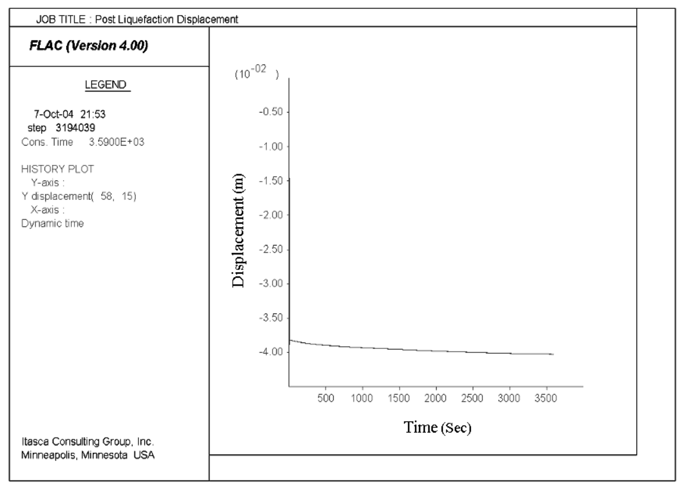

Fig. 16. Maximum vertical displacement after 60 minutes of loading.

CRITICAL DEPTH

As the embedment depth of the sand lenses increases within the soil deposit, liquefaction potential decreases. Therefore, a specific depth of embedment can be defined, below which the liquefaction of the sand lenses would unlikely happen or the consequential surface deformation would be negligible. These small deformations would be so small that they would not be able to damage surface structures seriously. This depth is called critical depth.

Since the critical depth depends on the characteristics of materials, we studied the effects of characteristics of the sand lenses on the critical depth of liquefaction. In order to investigate the effects of the dimensions of the sand lenses on the critical depth, different dimensions of elliptical sand lenses were investigated. As a logical criterion, we have considered the surface displacement of 5 millimetres as that corresponding to the critical depth. This amount of deformation in the upper layers could not damage common surface structures such as buildings and bridges significantly.

EFFECT OF DENSITY ON CRITICAL DEPTH

Figures 17 to 21 show the changes of surface displacement versus the embedment depth of the sand lenses for different standard penetration test numbers (SPT) and the corresponding values of relative density (See table 2). In order to study the effect of the dimensions of the sand lenses, three double lenses with different dimensions were simulated. As illustrated in the following figures, surface displacement increases with the increasing of the dimension of the lenses. The rate of change of surface displacement versus the embedment depth of the sand lenses often decreases with increasing of the embedment depth.

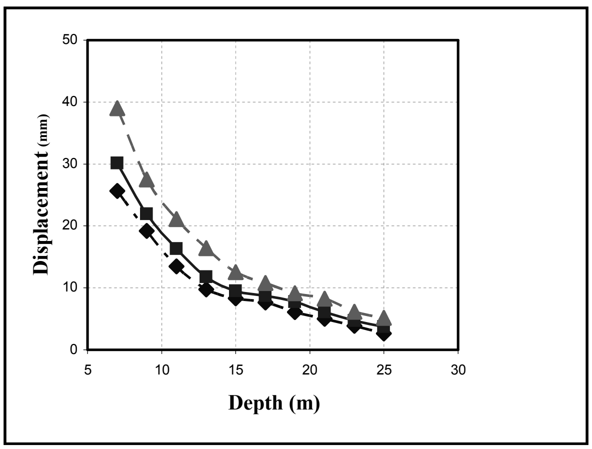

Fig. 17. Maximum surface displacement versus the embedment depth of the lenses (N_1=5).

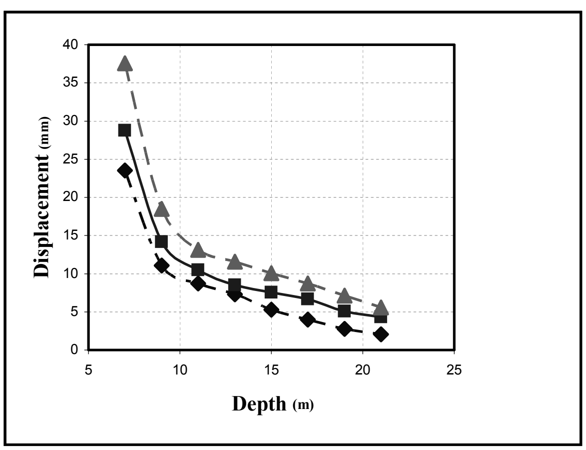

Fig. 18. Maximum surface displacement versus the embedment depth of the lenses (N_1=7).

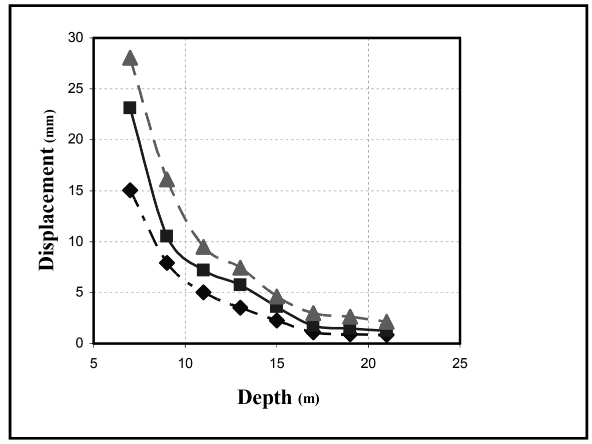

Fig. 19. Maximum surface displacement versus the embedment depth of the lenses (N_1=10).

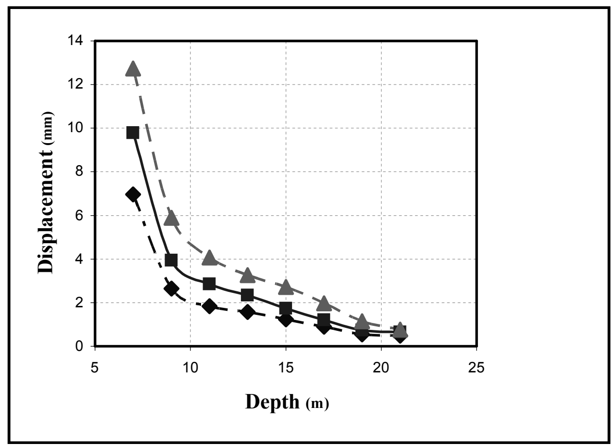

Fig. 20. Maximum surface displacement versus the embedment depth of the lenses (N_1=15).

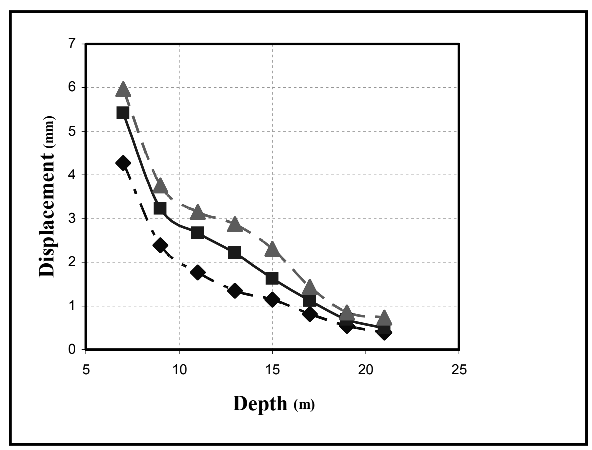

Fig. 21. Maximum surface displacement versus the embedment depth of the lenses (N_1=20).

It is also, observed that from surface to a specific embedment depth, the rate of change of displacement is rapid. Then, as the embedment depth of the sand lenses increases, the rate of change of displacement versus the embedment depth decreases significantly. As the density of the sand increases, the drop in the rate of change of displacement at this depth becomes more obvious. As the embedment depth of the sand lenses increases, the effect of their dimensions on surface displacement decreases and the curves get closer to each other. The acceleration applied to the model is 0.2g.

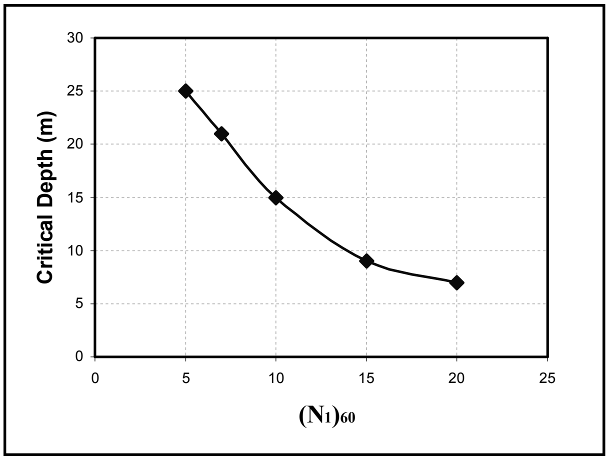

Fig. 22. Critical depth versus the standard penetration test number (a_{max}=0.2g).

Figure 22 illustrates how relative density affects the critical depth. The critical depth depends on the relative density of the sand within the lenses. As the relative density of the sand increases, the critical depth decreases. It can be inferred from Fig. 22 that the rate of change of the critical depth versus the standard penetration test number decreases with increasing of relative density.

CONCLUSION

In soil deposits containing loose sand lenses a specific depth of embedment of the lenses can be defined below which liquefaction would unlikely happen or the consequential surface deformation would be negligible. This depth is called critical depth. In this paper, the effects of the relative density of the sand on the critical depth of liquefaction in a soil deposit containing double sand lenses have been studied.

Results from finite difference analysis in plane-strain condition show that the critical depth strongly depends on the relative density of the sand within the lenses. As the relative density of the sand increases, the critical depth decreases. The rate of change of the critical depth versus the standard penetration test number decreases with increasing of relative density. The rate of change of maximum surface displacement versus the embedment depth of the sand lenses often decreases with increasing of the embedment depth.

REFERENCES

Byrne, P. [1991]. "A Cyclic Shear-Volume Coupling and Pore Pressure Model for Sand", Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Paper No. 1.24, pp.47-55.

Cundall, P. [1976]. "Explicit Finite Difference Methods in Geomechanics in Numerical Methods in Engineering", Proceedings of the EF Conference on Numerical Methods in Geomechanics, Blacksburg, Virginia, Vol. 1, pp. 132-150.

Holchin, J.D. and Vallejo, L. [1995]. "The Liquefaction of Sand Lenses Due to Cyclic Loading", 3rd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Dynamics, Missouri, Vol. 1, pp. 253-259.

Martin, G.R., Finn, W.D. and Seed, H.B. [1975]. "Fundamentals of Liquefaction under Cyclic Loading", Journal of the Geotechnical Engineering Division, ASCE, 101(GT5), pp. 423-438.

Mir Mohammad Hosseini, S.M. and Nateghi, F. [2001]. "The Crack Development Due to Liquefaction of Sand Lenses During Earthquake Loading", Fourth International Conf. on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, San Diego, California, pp. 407-413.

Seed, H.B. and Idriss, I. [1969]. "Influence of Soil Conditions on Ground Motion during Earthquakes", Journal of the Soil Mechanics and Foundation Division, ASCE, pp. 99-137.