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ABSTRACT

Liquefaction of saturated sands during earthquakes is known to be the cause of significant earthquake related damages, including loss of bearing capacity, lateral flow and spreading, slope failures. In recent earthquakes including the1999 Marmara Earthquake in Turkey, field observations have indicated that silt inclusions or silt layers in the sandy deposits can have significant effects on development of liquefaction. The objective of this work is to analytically study the behavior of saturated sand deposits with silt layers. For this purpose, a hypothetical soil profile in which silt layers exist has been selected. The selected profile was then modeled and analyzed using the LASS-IV code that has nonlinear effective stress analysis capability. As base motion, rock site recordings of the mentioned earthquakes were utilized. Furthermore, as part of this study, a parametric study has been conducted to further understand the effects of silt layers within sand deposits on the onset of liquefaction. The results of the analyses of various parameters such as depth of silt layer, the relative density of sand layer and maximum base acceleration were tabulated to summarize the effect of silt layers on the onset of liquefaction.

INTRODUCTION

It is well known and well documented that loose and medium dense sand deposits are susceptible to liquefaction under seismic motion. As a result of the liquefaction, significant damages, including loss of bearing capacity, lateral flow and spreading, slope failures take place. For a long time, it was believed that the liquefaction was purely a behavior of the saturated sand deposits. But, observations from the recent earthquakes have shown that silt inclusions or silt layers within the sand deposits can have significant effects on the development of earthquake induced liquefaction.

However it is known that silt inclusions or silt layers in the sandy deposits can have significant effects on development of liquefaction. For example, the silty sand layers were subjected to liquefaction at the Wildlife Liquefaction Site, causing sand boils, ground fissures and lateral ground displacements (Youd and Bartlett,1989; Youd and Holzer, 1994) when it was struck by a strong ground motion, Superstition Hills Earthquake in 1987.Similarly, after the 1999 Kocaeli Earthquake, Bray et al. (2004) observed that many structures in Adapazarı were tilted, damaged and collapsed due to the problems caused by slow plasticity silt seams.

Experimental research have shown that sands mixed with silts of high plasticity increase the resistance against liquefaction, whereas silts of low plasticity can cause reduction in liquefaction resistance (Erken and Ansal,1994). Kokusho (1999) conducted 1 dimensional and 2 dimensional shaking table tests and showed that the water film developed beneath a silt layer has a key role in the time of occurrence and extent of lateral deformations in sloping surfaces. Ozener et al (2006) also demonstrated through experimental study that a thin water film might develop due to the accumulation of water underneath the silt seam. Hence, the presence of a silt layer of lower hydraulic conductivity within the soil of higher hydraulic conductivity is thought to decrease the flow of pore water under the influence of cyclic loading, causing increased excess pore pressure build-up and so having an important role towards liquefaction.

The objective of this work is to study analytically the behavior of saturated sand deposits with silt layers. A parametric study has been conducted using different depths for the silt layer.

METHOD OF ANALYSIS

To investigate the effects of silt layers on the formation of liquefaction of saturated sand deposits, a 30 m thick sand deposit with a silt interlayer has been modeled. Then this deposit has been analyzed using software named LASS IV (Dikmen and Ghaboussi, 1984) which utilizes an effective stress soil analysis method and can take into account multi-directional cyclic motion.

The reason of using LASS-IV is its capability of performing fully nonlinear effective stress analysis of sands under seismic conditions in time domain. The method models the horizontally layered ground by a number of "layer elements". Thus the response of the system is described in terms of the nodal plane displacement degrees of freedom. Each nodal plane has three degrees of freedom, namely two components of the solid displacement and a third component for the displacement of the pore water relative to solid. The nodal planes are assumed to remain horizontal and undergo parallel displacements. Thus, the corresponding stresses considered are, the vertical normal stress, σ, the horizontal shear stress τ, and the pore water pressure π. The method uses a plasticity based material model for analyzing the behavior of sands under cyclic loading. A modified Masing type material model is used to define the stress-strain relationship. The method inherently comprises two damping mechanisms, namely hysteretic damping and dissipative damping of the pore water. Hence, no additional viscous damping is used (Ghaboussi and Dikmen (1978, 1981, 1984), Dikmen and Ghaboussi (1984)).

Analysis model

In case of loose and medium dense saturated sands, increasing pore water pressure will cause a decrease in the effective stress which in turn will cause a decrease of the effective shear modulus apart from the decrease due to the nonlinear material behavior of sands. On the other hand when the relative density of sand deposits decrease their susceptibility to liquefaction or seismic mobility increases.

Turkish Earthquake Code, TEC-2007 (2007), subdivides the subsoil conditions into 4 different types from Z1 thru Z4. Type Z1 being solid rock with a shear wave velocity of above 1000 m/sec or very dense sand or very stiff clay deposits with a shear wave velocity above 700 m/sec. Whereas, type Z4 representing loose sand or soft clay deposits having a shear wave velocity of less than 200 m/sec. According to TEC-2007, in case of a sand deposit to qualify for Z3 type condition, the deposit should have a shear wave velocity 200-400 m/sec and a thickness ranging between 15 to 50 m. the code also specifies that Z3 type soil will have a relative density of 35 to 65 percent.

Similarly EUROCODE-8 subdivides the subsoil conditions into 5 different types from A thru E and 2 special soil conditions S_1 and S_2. Type A being a rock or rock-like formation with a shear wave velocity of above 800 m/s. Type B represents deposits of very dense sand, gravel or very stiff clay having a shear wave velocity of 360 – 800 m/s. Type C represents deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters and a shear wave velocity of 180 – 360 m/s and SPT values of 15 to 50. Type D soils have SPT values below 15 and a shear wave velocity below 180 m/s. Type E represents a soil profile of a surface alluvium layer with shear wave velocity, $V_{s,}$ values of Type C and Type D and thickness varying between about 5 m and 20 m, underlain by stiffer material with V_s>800 m/s. types S1 and S2 represent soft clays/silts and deposits of liquefiable soils respectively.

Considering these facts, since especially the Z4 per TEC-2007 and D type per EUROCODE-8 soils might have a high potential to liquefy under seismic conditions, it is decided to choose a sand deposit with the properties of Z3 type subsoil per TEC-2007. This selected type is also similar to C type in EUROCODE-8. Two different sand profiles with different average shear wave velocities were developed, one representing the lower bound of Z3 soils and the other representing the average Z3 soils. Namely, these are profiles with approximately 200 and 300 m/sec shear wave velocities. The shear wave velocity is calculated by averaging across the 30 m depth as specified by EUROCODE-8. For practical purposes, they are designated as S1 and S2 respectively.

The initial shear modulus values with depth were calculated first using the equation proposed by Kokusho (1980) for sands.

$$G_0 = 8400\frac{(2.17-e)^2}{1+e}(\sigma_0')^{0.5} \qquad (1)$$

Where G is the initial shear modulus and σ' is the effective stress. Then the values obtained were linearized to account for possible over consolidation near the ground surface and also for simplicity. The values of shear modulus obtained with depth have been presented in Figure 1.

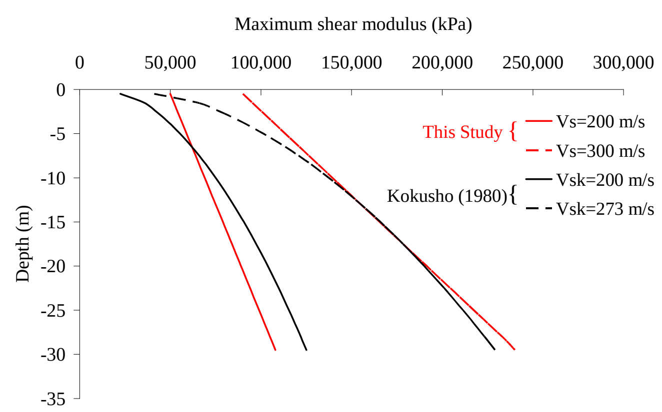

Fig. 1. Shear modulus values per equation proposed by Kokusho (1980) and values used in this study

A summary of the properties of sand deposits used in analyses are presented Table 1 below.

Table 1. Properties of soils used in this study

	S1	S2
Initial shear modulus, (kPa)	50,000	90,000
Shear modulus increase by depth, (kPa)	2000	5200
Total unit weight, (kN/m^3)	20.4	20.4
Coefficient of permeability, (m/s)	$0.3*10^{-5}$	$0.3*10^{-5}$
Initial void ratio	0.80	0.65
Relative density, %	33	58
Average shear wave velocity, m/sec	200	300

It is assumed that there exists a rock layer beneath the sand deposit with a shear wave velocity of 750.0 m/sec. This rock layer can also be classified as NEHRP class B. For both profiles, the ground water table is assumed to be located 1 m below the ground surface.

Base Motion

As base motion, a real life strong motion record from the August 17, 1999 Marmara Earthquake has been selected. The recording is made at TUBITAK Research Center at Gebze located approximately 40 km distance from the epicenter. The subsurface condition at the recording site is designated as rock or alternatively as Class B per NEHRP and Z1 type per TEC-2007. The duration of the record is 47.62 sec and digitized at intervals of 0.005 s. NS component of the recording was used in the analyses. The peak acceleration of this component is 2.3339 m/s^2. The time history of record used is shown graphically in Figure 2.

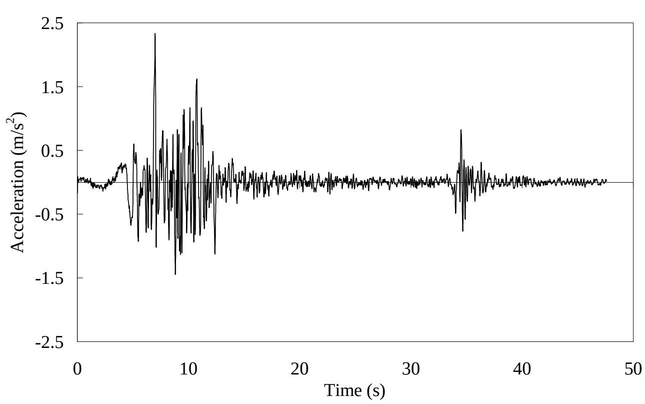

Fig. 2. NS component of 1999 Kocaeli Earthquake recorded at TUBITAK Gebze

Acceleration response spectrum for 5% damping of this record is also calculated and plotted together with the design spectrum proposed by TEC-2007 for Z1 type subsurface conditions and scaled to the same peak acceleration as the selected record. Both spectra are presented in Figure 3. As can be seen from the figure the spectrum of the selected record is reasonably framed by the code spectrum.

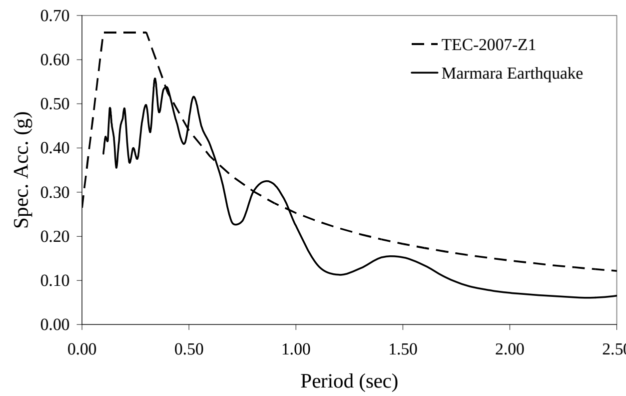

Fig. 3. Comparison of TEC-2007 specified spectrum and spectrum of the selected strong motion component

ANALYSES AND DISCUSSION OF RESULTS

As mentioned above, a parametric study has been conducted to investigate the effect of silt layers within sand deposits on the onset of liquefaction.

Silt interlayer's thickness in the sandy soil was assumed to be 1.0 m. The silt layer is also assumed to have a shear wave velocity of 125 m/s and a coefficient of permeability of $0.3*10^{-7}$ m/s.

Initially both profiles were studied without silt interlayer. Then the top of silt layer is assumed to be at depths 1.0, 2.0, 3.0, 6.0 and 10.0 m from ground surface. The selected base motion is scaled to 0.20 g and 0.25 g peak acceleration. For both soil profiles where no silt layer existed, no liquefaction has been observed when subjected to both of the scaled base motions.

In Figures 4 through 6, the maximum absolute acceleration profiles obtained have been presented. As shown in these figures, the presence of silt seams has changed the trend of curves at depths just below silt interlayers with a sharp increase in computed maximum accelerations. This can be attributed to the drop in the shear modulus of the layer because of the drop in the effective stress due to increasing pore pressure. The effect of the silt interlayers in the sand soil on the change in effective stresses has been plotted in figures 7-9.

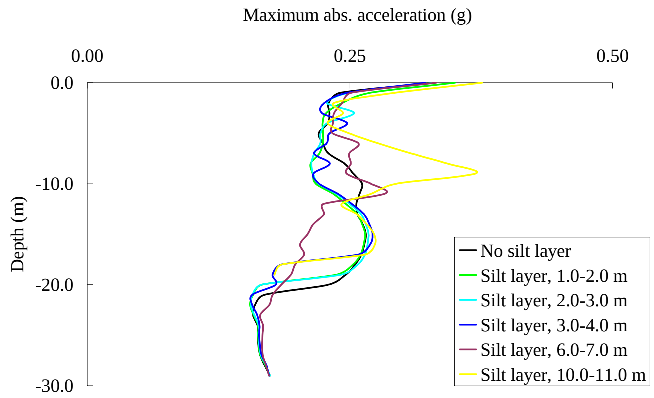

Fig. 4. The maximum acceleration profiles for soil deposit S1 subject to base motion with 0.20 g peak acceleration

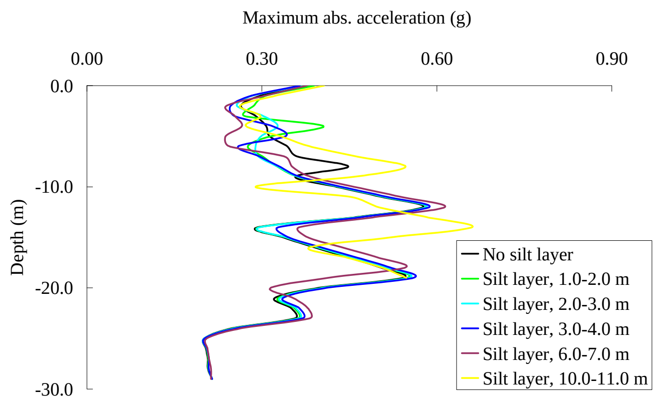

Fig. 5. The maximum acceleration profiles for soil deposit S1 subject to base motion with 0.25 g peak acceleration

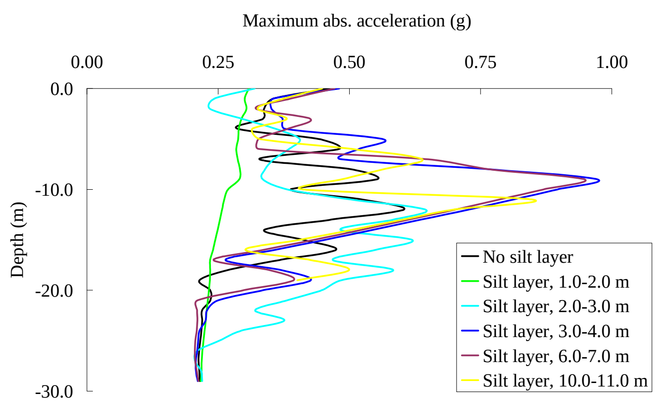

Fig. 6. The maximum acceleration profiles for soil deposit S2 subject to base motion with 0.25 g peak acceleration

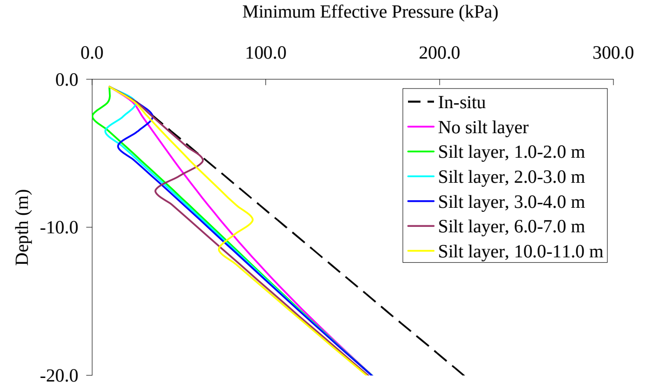

Fig. 7. The minimum effective stress profile for soil deposit S1 subject to base motion with 0.20 g peak acceleration

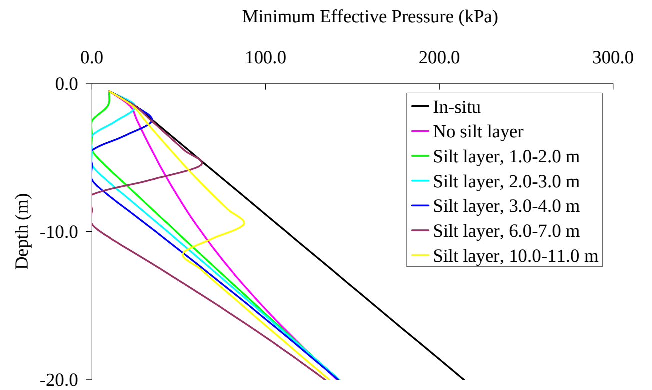

Fig. 8. The minimum effective stress profile for soil deposit S1 subject to base motion with 0.25 g peak acceleration

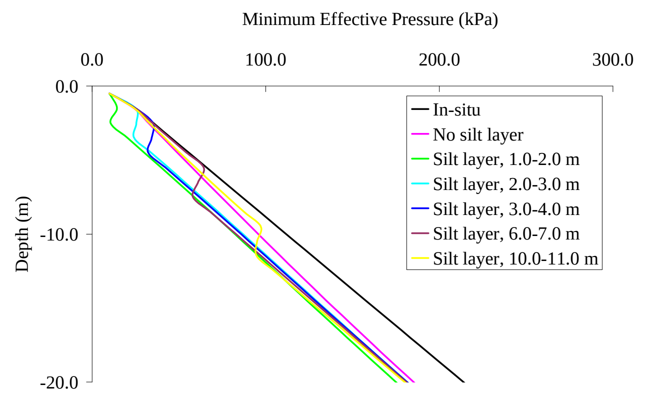

Fig. 9. The minimum effective stress profile for soil deposit S2 subject to base motion with 0.25 g peak acceleration

The decrease in effective stresses with depth due to seismic motion can clearly be seen from the figures above. As observed in Figure 8, liquefaction down to 10 m depth can be developed depending on the depth of silt seam. Similarly, effective stress values at depths just below silt interlayers sharply decrease due to the drastic increase in pore water pressures resulting from the existence of silt seams, as shown in Figures 10-12.

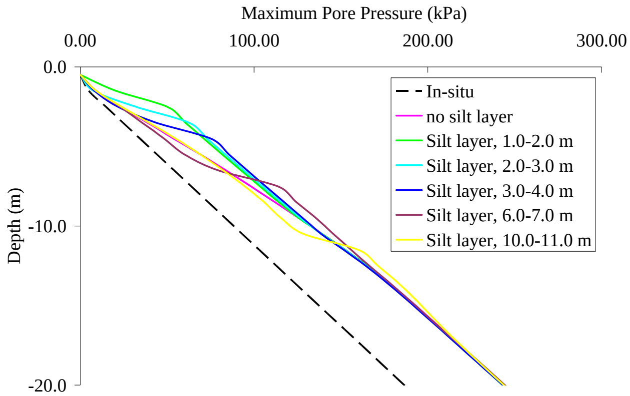

Fig. 10. The maximum pore pressure profile for soil deposit S1 subject to base motion with 0.20 g peak acceleration

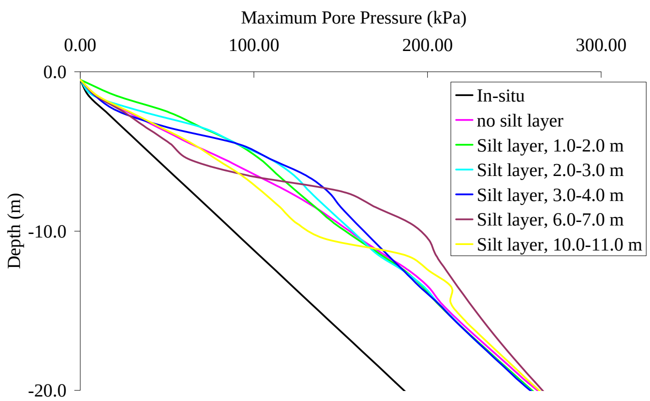

Fig. 11. The maximum pore pressure profile for soil deposit S1 subject to base motion with 0.25 g peak acceleration

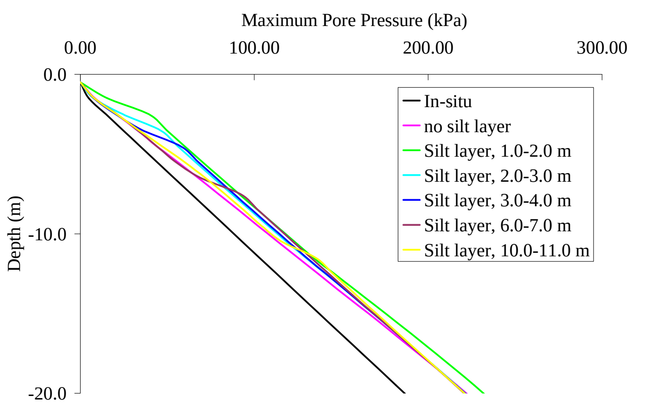

Fig. 12. The maximum pore pressure profile for soil deposit S2 subject to base motion with 0.25 g peak acceleration

The computed maximum shear strains with depth are plotted in Figures 13-15. A sharp increase in shear strain is noticed underneath the silt seam.

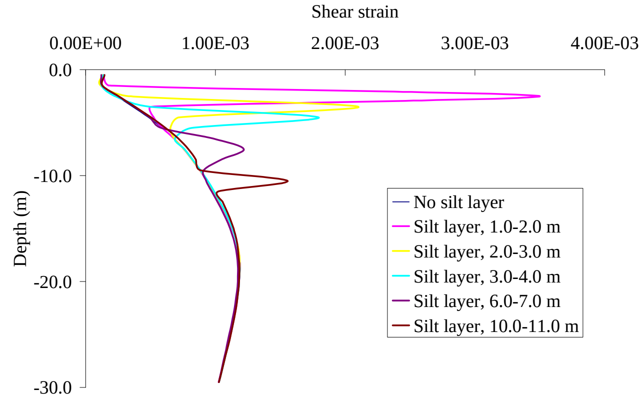

Fig. 13. The maximum shear strain values for soil deposit S1 subject to base motion with 0.20 g peak acceleration

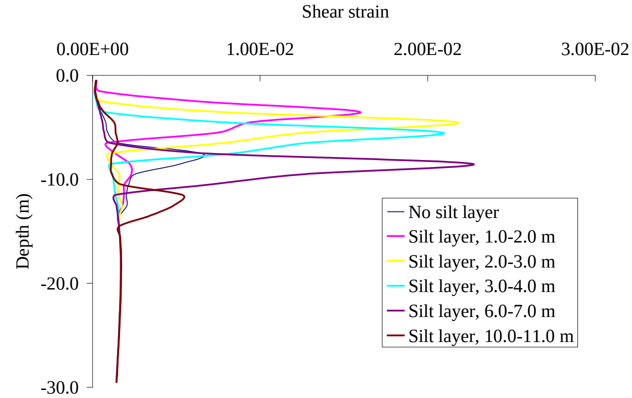

Fig. 14. The maximum shear strain values for soil deposit S1 subject to base motion with 0.25 g peak acceleration

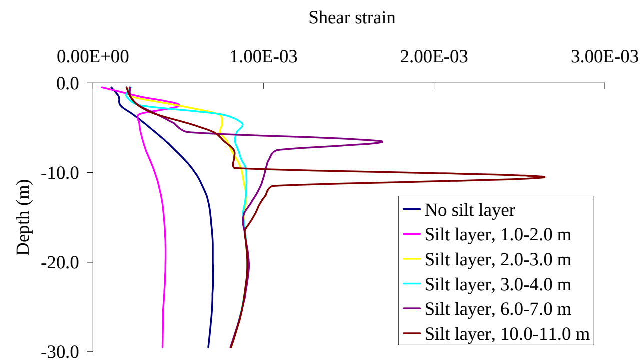

Fig. 15. The maximum shear strain values for soil deposit S2 subject to base motion with 0.25 g peak

CONCLUSIONS

In this study, an analytical study has been made to study the potential effects of silt interlayer on the onset of liquefaction of saturated sand deposits subject to seismic base motion. A 30 m thick sand deposit has been selected for analyses and a 1 m thick silt interlayer has been placed at different depths. The results obtained from numerical analyses have shown that the presence of silt seam increase the potential of liquefaction for sand soils. Particularly, this condition can be clearly seen at the depths just below silt interlayer, based on the changes of pore water pressures, effective stresses and shear strains.

REFERENCES

Dikmen, S.U., Ghaboussi, J., (1984) "Effective Stress Analysis of Seismic Response and Liquefaction: Theory", *Journal of Geotechnical Engineering*, ASCE 110(5), 628-644

Erken, A. and Ansal.A. [1994], "Liquefaction Characteristics of Undisturbed Sands, Performance of Ground and Soil Structures", *Thirteenth Int. Conf. On Soil Mechanics and Foundation Engineering*, pp. 165-170.

EUROCODE-8, [2004]. "Design of Structures for Earthquake Resistance", 1998-1:2004

Ghaboussi, J., Dikmen, S.U., [1978] "Liquefaction Analysis of Horizontally Layered Sands", *Journal of Geotechnical Engineering*, ASCE 104(3)

Ghaboussi, J., Dikmen, S.U., [1981] "Liquefaction Analysis for Multi-Directional Shaking", *Journal of Geotechnical Engineering*, ASCE 107(5)

Ghaboussi, J., Dikmen, S.U., [1984] "Effective Stress Analysis of Seismic Response and Liquefaction: Theory", *Journal of Geotechnical Engineering*, ASCE, Vol.110, No.5, pp.645-658.

Kokusho, T. [1980], "Cyclic Triaxial Test of Dynamic Soil Proporties for Wide Strain Range", *Soils and Foundations*, 20, pp. 45-60.

Kokusho, T. [1999], "Formation of Water Film in Liqufied Sand and Its Effect on Lateral Spread", *Journal of Geotechnical and Geoenviromental Engineering*, ASCE, Vol, 125. No.10, pp. 817-826.

Tohumcu, P.O, Berilgen, M. and Ozaydın, K. [2006]. "Investigation of Liquefaction in Layered Sands By Means of Shaking Table Tests", *The 6th International Conference on Physical Modelling in Geotechnics*, Vol., 1,pp.475-480.

TEC-2007, [2007] "Turkish Earthquake Resistant Design Code", Ministry of Public Works, Turkey