THE EFFECT OF SOIL PERMEABILITY ON THE LIQUFACATION BEHAVIOR OF SAND SUBJECTED TO CYCLIC LOADING

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ABSTRACT

Liquefaction is accompanied by large lateral displacement, increasing excess pore water pressure and noticeable strains in soils. Soil excitation due to external loading is as vital parameter as soil inherent characteristics in the liquefaction. In order to investigate the effect of soil permeability in conjunction with loading parameters on the liquefaction occurrence in sandy soils, a numerical parametric study has been done. It is shown that soil permeability and the amplitude of cyclic acceleration are main component on the liquefaction, while the number of cycles has no effect.

INTRODUCTION

Liquefaction is one of the most complicated issues that earthquake and soil parameters play key role in its occurrence and devastating consequences of this phenomenon. Peak ground acceleration and the numbers of cycles of an earthquake record are main parameters of proposed analytical approaches in the literature to investigate the probability of soil liquefaction, when the soil is in the range of liquefiable soils (Kramer and Elgamal, 2001). On the other hand, to study the liquefaction, soil permeability is one of the substantial characteristics that should be taken into consideration. Comprehensive previous numerical studies related to the effect of permeability on the soil liquefaction have been described by Rahmani et al. (2012). The ongoing challenge in numerical modelling of soil liquefaction numerically is adopting approprite soil model as asserted by Cheng et al. (2007).

In this paper, numerical procedures have been implemented to investigate the influence of soil permeability in conjunction with loading parameters such as number of cycles and load amplitude on the liquefaction potential of sandy soils using the Finite Element software OpenSees (Mazzoni et al., 2006).

NUMERICAL MODELLING

The numerical 2D-model has consisted of a 10 m column of sand that can be capable of moving horizontally and vertically . The sand column was restrained at the base in every direction that is subjected to cyclic load (Figure 1). Besides, to consider the effect of the amplitude and number of cycles of sinusoidal cyclic loads various cases were applied in diffrent models . The pore fluid-stress coupled analysis has been performed in three steps as follows:

Step 1: An elastic analysis was done to consider the soil weight

Step 2: This step contains a plastic analysis while the applied load is what was considered step 1.

Step 3: The plastic analysis is done in this step, however, another load in the form of sinusoidial cyclic accelaration is applied in the base of model.

The soil material in this analysis is “Pressure-Dependent Multi-Yeild” which is elastic-plastic that can consider dilatancy in the soil as well as non-flow liquefaction or cyclic mobility. The typical parameters considered in this study are presented in the table 1.

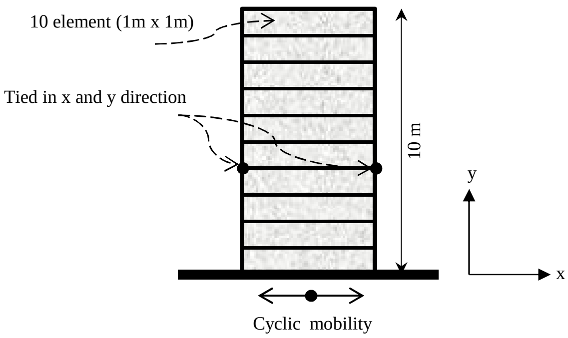


Figure 1. Soil column consists of 10 elements and relevant boundary conditions

Table 1. Typical soil properties

Density $(\frac{ton}{m^3})$	Friction angle (at peak shear strength)	Reference shear modulus (kPa)	Peak shear strain (at confining pressure = 80 kPa)	Phase transformation angle	Initial void ratio
2	31.4	6e4	0.1	26.5	0.6

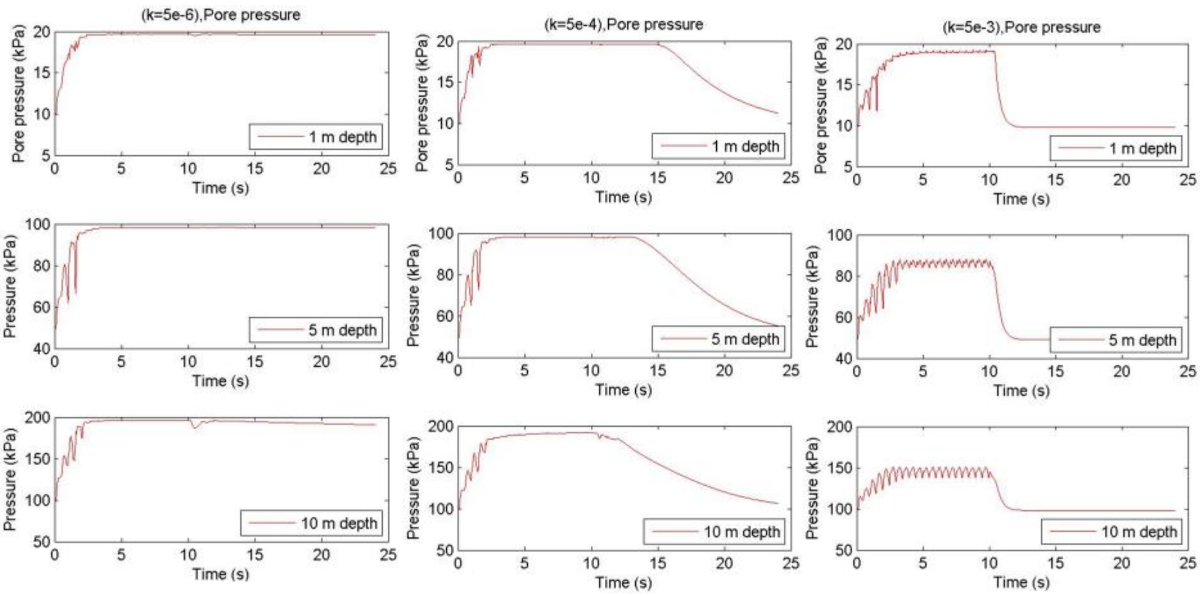
NUMERICAL RESULTS

In order to investigate the effect of soil permeability, cyclic acceleration amplitude and number of cycles on the stress-strain response of a soil column, a number of analyses have been performed. The main effect of high permeability in soils is dessipating of excess pore pressure in a shorter time when compared to that of the low permeability soils. Figure 2 shows that in the soil with k=5e-3 the excess pore pressure is less than soils with k=5e-4, k=5e-6, also, it will be dissipated in a shorter time.This issue cause the soil with higher permeability coefficent to be less susceptible to liquefaction.

Shear stress and strain changes through cyclic loading process were examined for various soil depths in different permeability features. As shown in Figure 3, in the soil subjected to an identical cyclic sinusoidal load liquefaction does not occur, although softening takes place in the soil. The main reason is that soil is not susceptible to liquefaction due to high permeability.

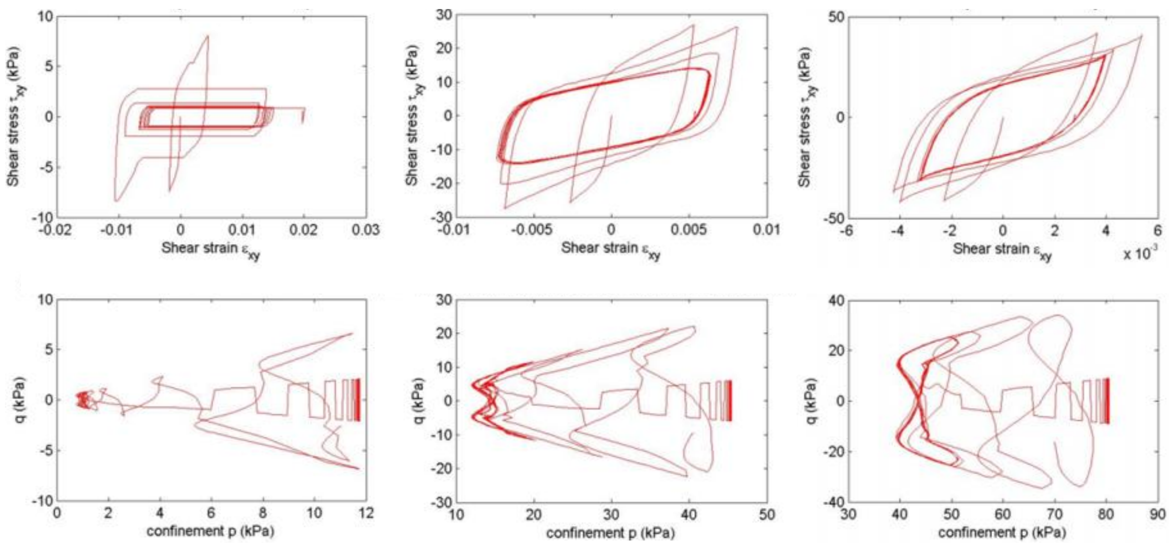
As shown in Figures 4-7, an increase in the number of cycles leads to decrease in the lateral displacement of the soil column. It seems unrealistic because it is in contrary to the basic principles of liquefaction issue. On the other hand a decline in the acceleration amplitude from 3 to 2 cause to decrease in the lateral displacement in the soil column. In addition, the effect of increasing in the number of cycles on the soil stiffness reduction maybe manifested at the end of analysis, as shown in Figures 4-7.

In Figures 8 and 9, the dissipation of excess pore water pressure and stress-strain response of the soil column is depicted. Because of high amplitude of the acceleration, the amount of excess pore pressure reached to the confined pressure, i.e. $r_u = 100$. Furthermore, in the soil with K=5e-3 m/s, the permeability is so high that excess pore pressure dissipation is considerable thorough the soil, after 10 second of the loading. It is worth mentioning that in soils with low permeability, there would be dilatancy issue that is associated with a decrease in the pore pressure or even negative pressure (Figure 8). The effect of such pressures was depicted in the stress situation at p-q space by rising confined pressure during every cycle (Figure 9). However, at the end of analysis, soil softening was obvious thoroughly.



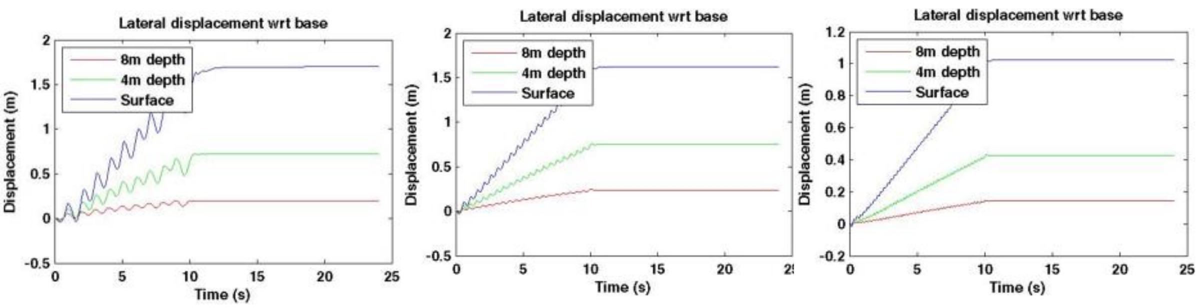
(a) (b) (c)

Figure 2. Excess pore pressure dissipation for (a) k = 5e-6 **m/s**, (b) k = 5e-4 **m/s**, (c) k = 5e-3 **m/s**, (10 cycle, acceleration amplitude = 2)



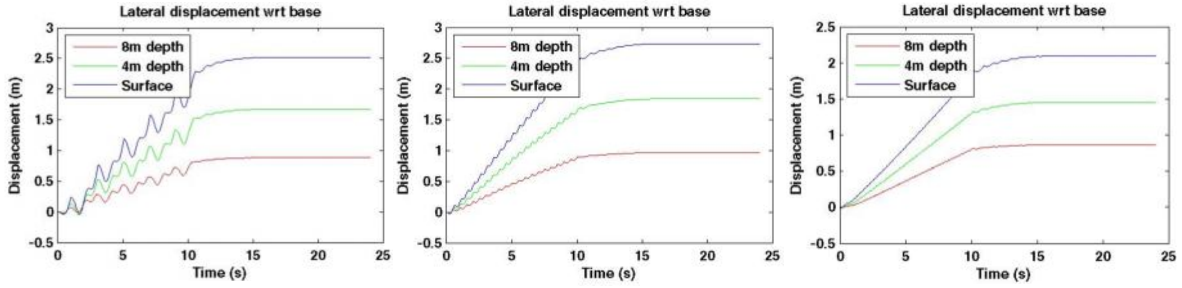
(a) (b) (c)

Figure 3. Shear stress $^{2}{}_{xy}$ VS. shear strain £$_{xy}$ and confinement p VS. deviatoric stress q for (a) 2m depth, (b) 6m depth, (c) 10m depth, (k = 5e-3 **m/s**, acceleration amplitude = 2, and 10 cycle)



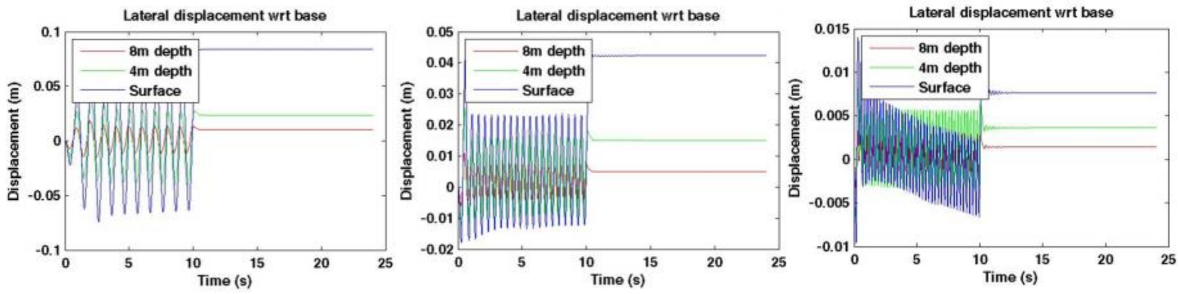
(a) (b) (c)

Figure 4. Lateral displacement: (a) 10 cycle, (b) 20 cycle, (c) 40 cycle, (k = 5e-3 **m/s**, acceleration amplitude = 3)



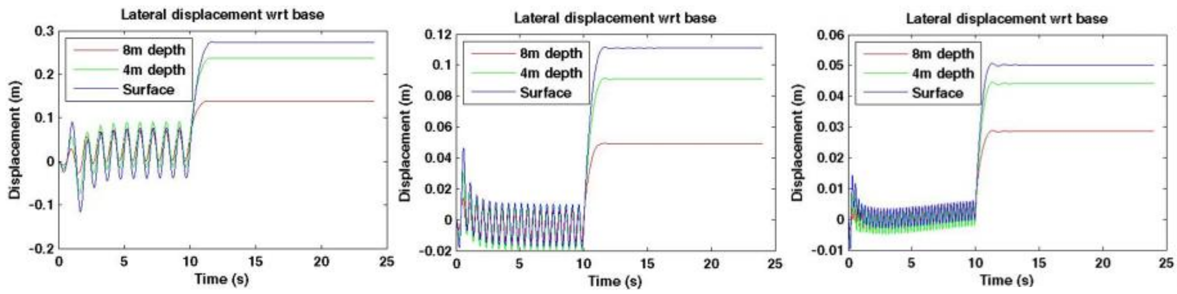
(a) (b) (c)

Figure 5. Lateral displacement: (a) 10 cycle, (b) 20 cycle, (c) 40 cycle, (k = 5e-4 $\mathbf{m/s}$, acceleration amplitude = 3)



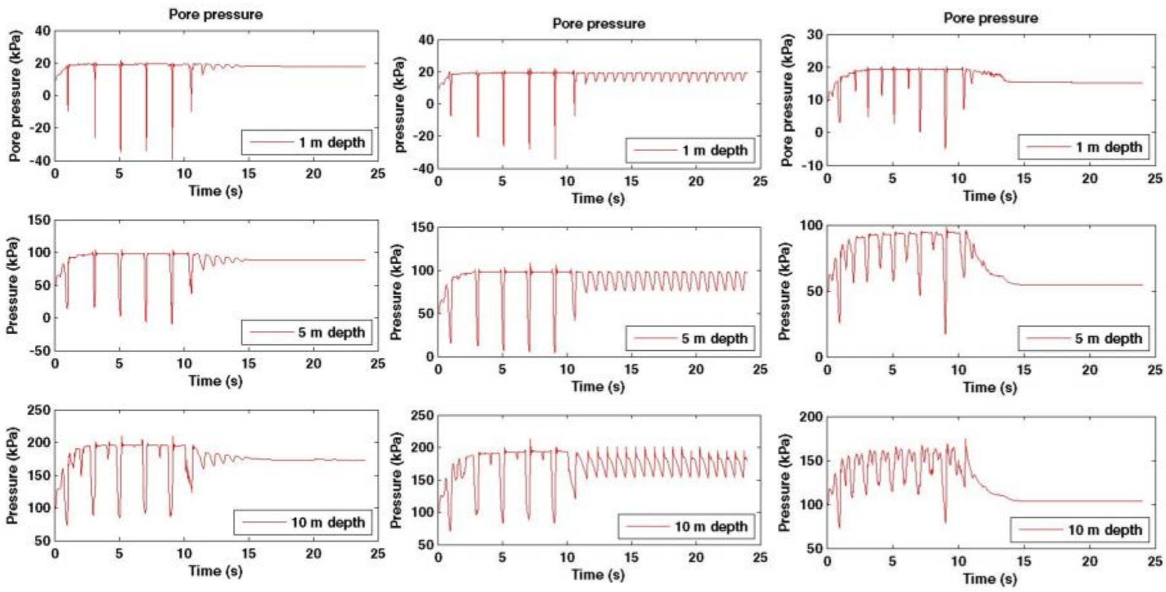
(a) (b) (c)

Figure 6. Lateral displacement: (a) 10 cycle, (b) 20 cycle, (c) 40 cycle, (k = 5e-3 $\mathbf{m/s}$, acceleration amplitude = 2)



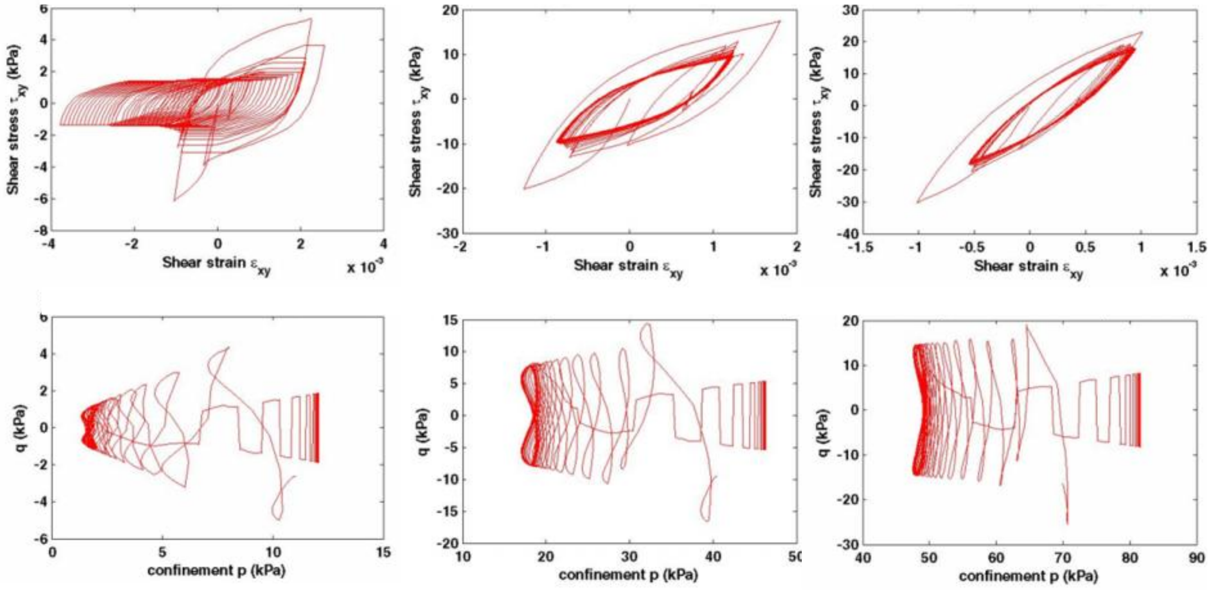
(a) (b) (c)

Figure 7. Lateral displacement: (a) 10 cycle, (b) 20 cycle, (c) 40 cycle, (k = 5e-6 $\mathbf{m/s}$, acceleration amplitude = 2)



(a) (b) (c)

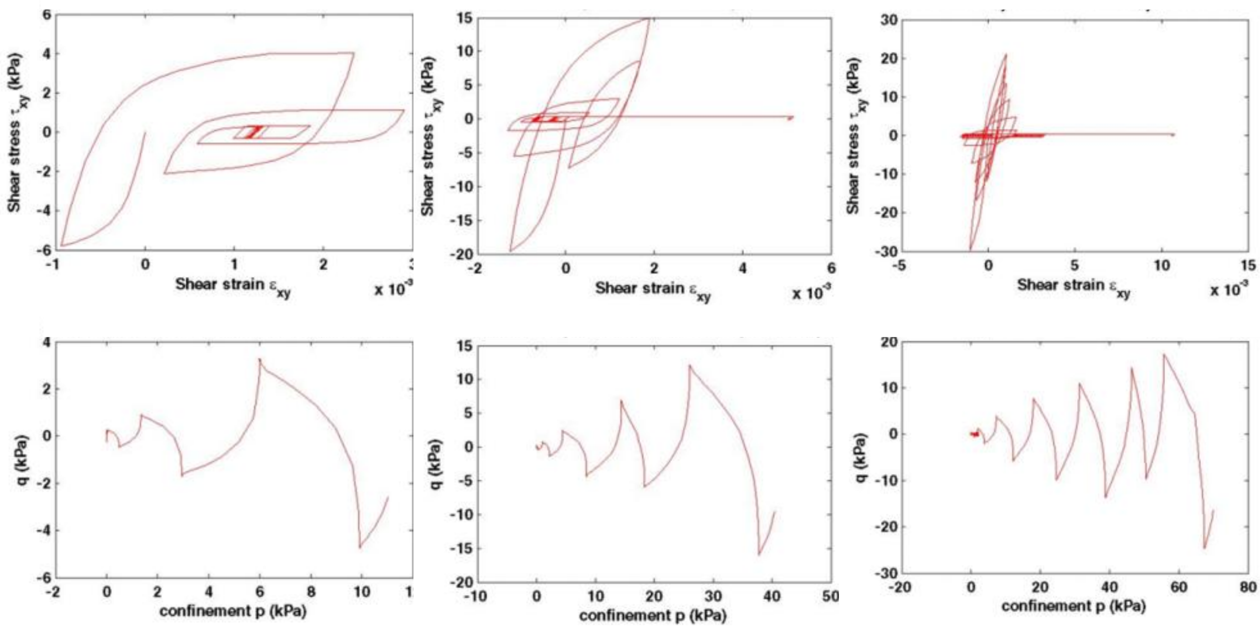
Figure 8. Excess pore pressure dissipation for (a) k = 5e-6 $\mathbf{m/s}$, (b) k = 5e-4 $\mathbf{m/s}$, (c) k = 5e-3 $\mathbf{m/s}$, (10 cycle, acceleration amplitude = 3)



(a) (b) (c)

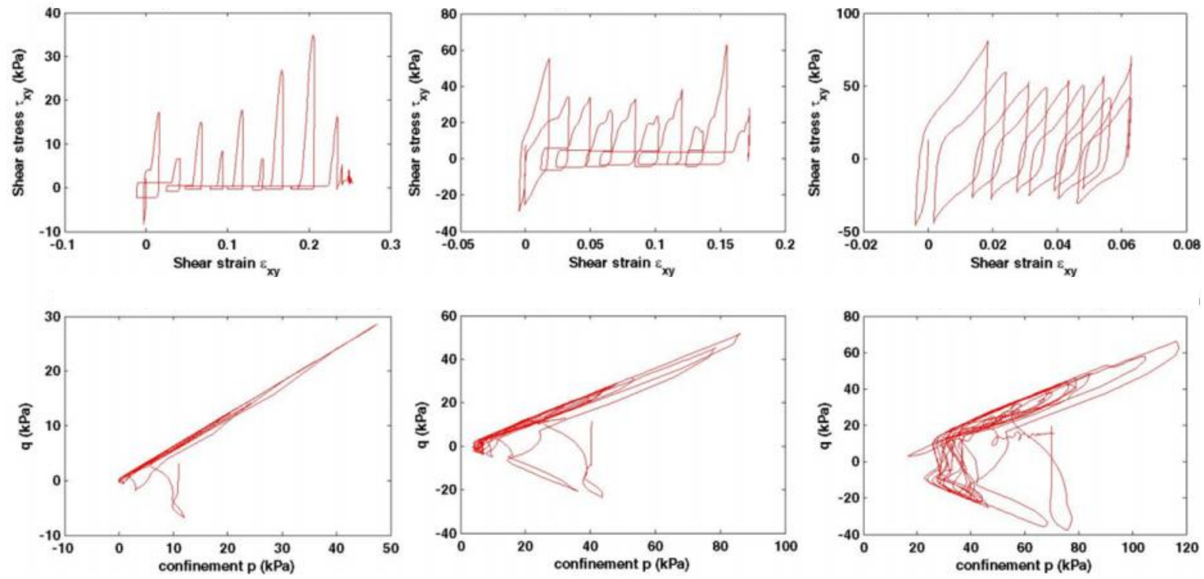
Figure 9. Shear stress ²$_{xy}$ VS. shear strain £$_{xy}$ and confinement p VS. deviatoric stress q for (a) 2m depth, (b) 6m depth, (c) 10m depth, (k = 5e-3 **m/s**, acceleration amplitude = 2, and 40 cycle)

Figures 10-12 show the stress-strain response of soils with various permeability (5e-3 m/s and 5e-6 m/s) when the applied load is different in that they have varied number of cycle or amplitude of loading. As shown in Figure 10, although the soil is in the range of low permeability (k = 5e-6 m/s) and the number of cycles are 40, liquefaction does not occur because the loading amplitude is not enough to make soil disturbed. This phenomenon is corresponding to the liquefaction occurrence principles. In this case, liquefaction has compression effect on the soil. On the other hand in the highly permeable soil (k = 5e-3 m/s) liquefaction can be occurred owing to higher loading amplitude (Figure 11). Furthermore, if the soil is lowly permeable (k = 5e-6 m/s) and the acceleration amplitude is enough high liquefaction occurs in the primary cycles, as shown in Figure 12.



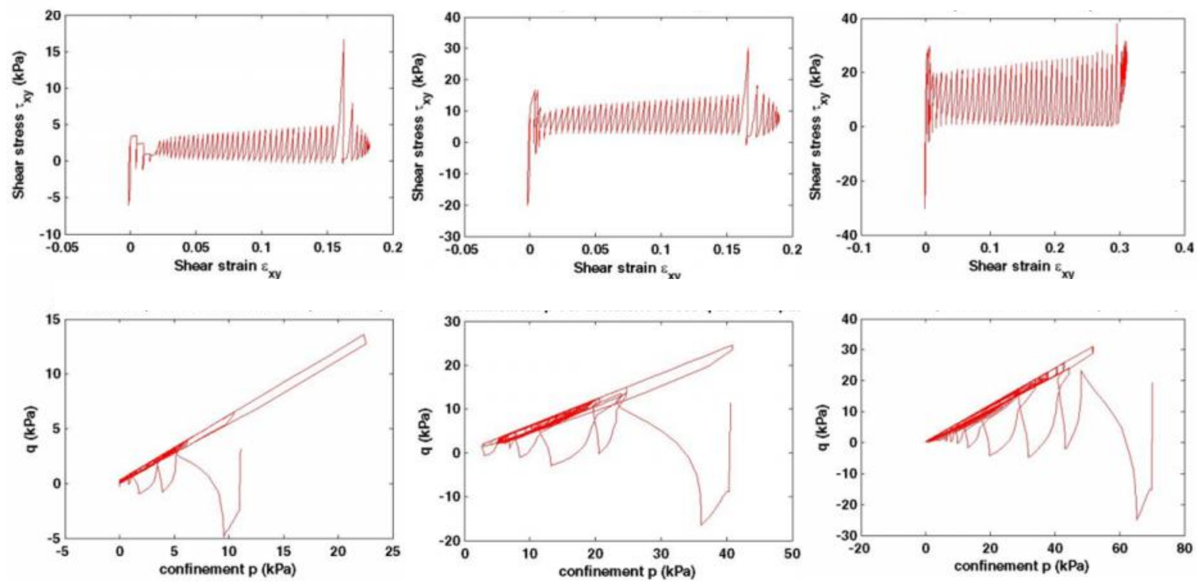
(a) (b) (c)

Figure 10. Shear stress ²$_{xy}$ VS. shear strain £$_{xy}$ and confinement p VS. deviatoric stress q for (a) 2m depth, (b) 6m depth, (c) 10m depth, (k = 5e-6 **m/s**, acceleration amplitude = 2, and 40 cycle)



(a) (b) (c)

Figure 11. Shear stress τ_{xy} VS. shear strain ε_{xy} and confinement p VS. deviatoric stress q for (a) 2m depth, (b) 6m depth, (c) 10m depth, (k = 5e-3 $\mathbf{m/s}$, acceleration amplitude = 3, and 10 cycle)



(a) (b) (c)

Figure 12. Shear stress τ_{xy} VS. shear strain ε_{xy} and confinement p VS. deviatoric stress q for (a) 2m depth, (b) 6m depth, (c) 10m depth, (k = 5e-6 $\mathbf{m/s}$, acceleration amplitude = 3, and 40 cycle)

CONCLUSION

The effect of soil permeability in conjunction with the loading amplitude and the number of cycles on the liquefaction occurrence were examined. It was concluded, in order that liquefaction occurs not only should soil be a low permeable (k = 5e-6 m/s), but also the loading amplitude should be enough high. Additionally, it was shown that when the loading amplitude is high, the liquefaction can occur in some parts of the soil even though it is highly permeable (k = 5e-3 m/s). On the other hand, regardless of the fact that the large number of loading cycles should enhance the possibility of liquefaction in a susceptible soil, the conclusion drawn from the results is in contrary to it.

REFERENCES

Cheng Z et al. (2007) Issues in modeling and simulations of soil liquefaction, *Proceedings of the 4th International Conference on Earthquake Geotechnical Engineering*, Thessaloniki, Greece, Paper ID

Kramer SL and Elgamal AWM (2001) Modeling soil liquefaction hazards for performance-based earthquake engineering, Pacific Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley

Mazzoni S, McKenna F and Fenves GL (2006) Open System for Earthquake Engineering Simulation User Manual, Pacific Earthquake Engineering Research Center, University of California, Berkeley, (http://opensees.berkeley.edu/OpenSees/manuals/usermanual/)

Rahmani A et al. (2012) Investigation of the influence of permeability coefficient on the numerical modeling of the liquefaction phenomenon, *Scientia Iranica*, **19**(2): 179-187