Numerical Modeling of Seismic Site Response of Liquefiable Soils Based on Cumulative Strain Energy

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Introduction

Liquefaction phenomena may cause two major concerns: 1- Ground deformation or ground failure due to the excess pore water pressure, and 2- Changing in ground site response caused by softening of liquefiable soil [1]. Liquefaction assessment and its consequences have been investigated by many researchers [2]. Although, there are not enough studies to determine the effect of soil softening and liquefaction on the seismic ground response. The main purpose of this study is to evaluate the ground response for liquefiable sites. Hence, Specific Cumulative Strain Energy (SCSE) parameter is defined to consider the effects of earthquake duration and thickness of liquefiable layer. The results of amplification pattern were presented in both of the effective and total stress analyses.

Numerical modeling

Numerical prediction of the liquefiable soil response requires a nonlinear, effective stress analysis with a relatively sophisticated constitutive model. In order to use compatible constitutive model in numerical analysis, multi-yield surfaces models applied in CYCLIC1D software [3]. The centrifuge model of VELACS project (model number 1) is examined for the verification of numerical modeling, Figure (1). Note that, this program models the nonlinear, inelastic behavior of soils and can represent phase transformation behavior of the potentially liquefiable soils.

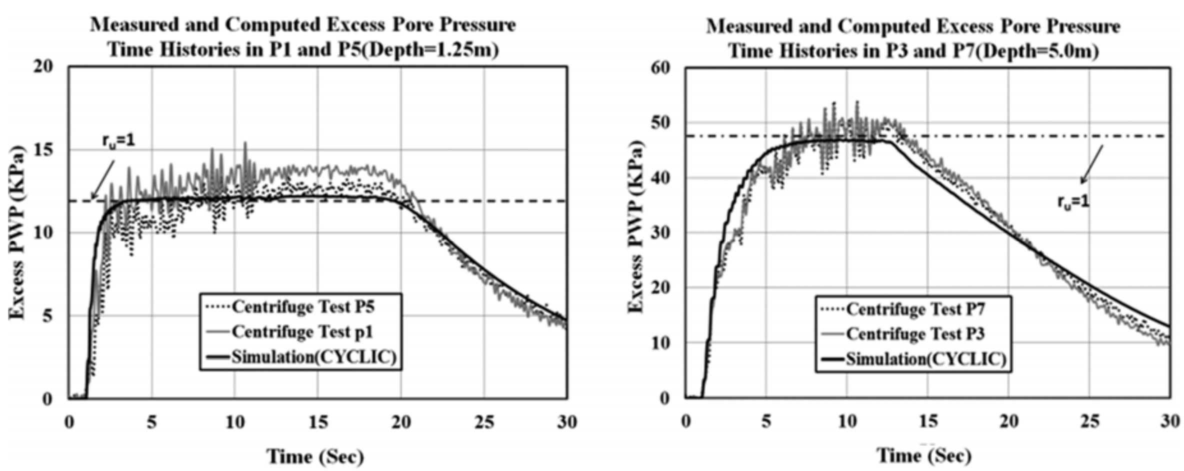

Figure 1. Comparison of predicted and measured pore water pressures at points P5–P7 from VELACS centrifuge tests No.1.

Results and Discussion

The cumulative enclosed area of the earthquake-induced shear stress–strain loops is referred to as dissipated strain energy density (or unit energy). Cumulative strain energy is an internal response of soil body to the external loading, and thus, it can be employed as a useful measure for the analysis of soil behavior. Hence, Specific Cumulative Strain Energy (SCSE) parameter was defined to consider the effects of earthquake duration and thickness of liquefiable layer.

In order to study the effect of excess pore pressure and strong motion characteristics on the seismic response of ground surface, the following equation was presented:

$$RSR(T) = S_a^{eff}(T) / S_a^{tot}(T) \quad (1)$$

where, S_a^{eff} and S_a^{tot} are the response of effective and total analyses, and RSR is response spectra ratio, respectively. The earthquakes were classified as strong (SCSE≥0.66), moderate (0.34≤SCSE<0.66), and weak (SCSE<0.34) motions in this study. The response spectra ratio (*RSR*) of these different ground motions (strong, moderate and weak motion) were depicted in Figure (2).

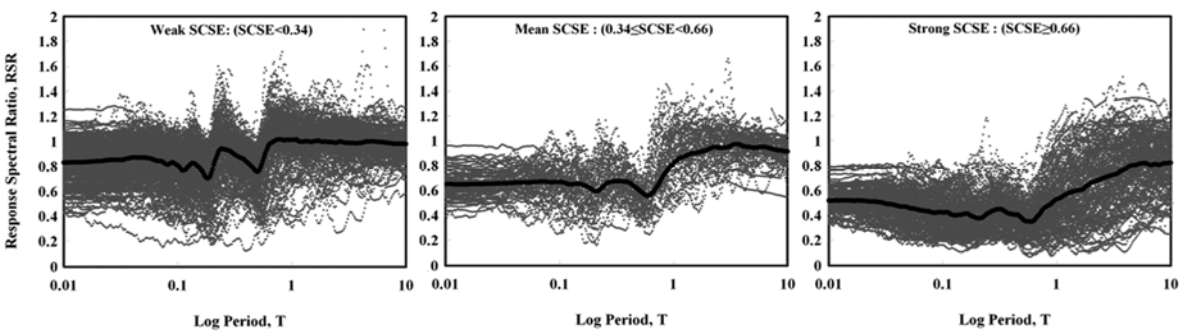

Figure 2. RSR of total and effective stress analysis of these different ground motions (strong, moderate and weak motion)

Summary and Conclusion

In this paper, the effects of strain energy and excess pore pressure on the seismic response amplification of liquefiable soil were studied based on the effective and total stress nonlinear analyses approaches. The main important conclusions drawn from present study are as follows:

1. Regarding the liquefaction potential throughout the soil profile, the results of total and effective stress analyses are in compliance with each other for weak ground motions. However, for stronger motions, effective stress analyses method is essentially recommended.
2. Strong ground motions that generated the excess pore water pressure and consequent increasing of the cumulative strain energy in depth of soil, reduce ground response spectra.
3. The value of RSR for earthquake with weak and mediocre strain energy variety from 0.8 to 1.1, that indicate the similarity of effective and total stress methods results for weak and mediocre strain energies.
4. The average values of spectra ratio (*RSR*) for high strain energy for all periods of input ground motions are lower than one. In other words, by growing strain energy, the soil nonlinear behavior and absorption of strain energy increases. Thus, the response that calculated by effective stress method (S_a^{eff}) reduces compared to the result of the total stress method (S_a^{tot}).

References

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