International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:14, No:1, 2020

Effect of Plastic Fines on Liquefaction Resistance of Sandy Soil Using Resonant Column Test

S. A. Naeini, M. Ghorbani Tochaee

Abstract**—**The aim of this study is to assess the influence of plastic fines content on sand-clay mixtures on maximum shear modulus and liquefaction resistance using a series of resonant column tests. A high plasticity clay called bentonite was added to 161 Firoozkooh sand at the percentages of 10, 15, 20, 25, 30 and 35 by dry weight. The resonant column tests were performed on the remolded specimens at constant confining pressure of 100 KPa and then the values of G_{max} and liquefaction resistance were investigated. The maximum shear modulus and cyclic resistance ratio (CRR) are examined in terms of fines content. Based on the results, the maximum shear modulus and liquefaction resistance tend to decrease within the increment of fine contents.

Keywords**—**G_{max}, liquefaction, plastic fines, resonant column, sand-clay mixtures, bentonite.

I. Introduction

INVESTIGATION of liquefaction resistance is an important step in understanding the dynamic behavior of soils. There are several methods to assess the liquefaction resistance. The method proposed by Seed and Idriss [1], called Simplified Procedure, is the most widely used method for evaluating soil liquefaction potential. Many researchers have suggested new methods based on other techniques, including standard penetration test (SPT), cone penetration test (CPT), Becker penetration test, and shear wave velocity (V_s) for the liquefaction phenomenon [2]-[5]. Recently, the use of V_s for the evaluation of liquefaction resistance becomes common because, according to the researchers, both V_s and CRR are affected by same parameters, including void ratio, confining pressure, soil fabric and etc. [6]-[9].

Liquefaction was first observed in sandy soils through sand boils and tilting of the buildings (1964 Niigata earthquake), further observations and research demonstrated that silts and silty and clayey sands may also show low liquefaction resistance. After Kocaeli and Chi-Chi Taiwan earthquakes, the liquefaction phenomenon was observed in silty and clayey sands. Therefore, the influence of plastic and non-plastic fines on sand behavior has become an important issue for geotechnical researchers. Many researchers have reported significant decrease in cyclic resistance in samples with up to a threshold silt content of 15-40% based on a constant void ratio, relative density, and intergranular void ratio [10]-[16].

S.A. Naeini is Professor of Geotechnical Engineering at Department of Civil Engineering at Imam Khomeini International University, Qazvin, Iran (corresponding author: e-mail:Naeini.hasan@yahoo.com).

M. Ghorbani Tochaee is Student in Master of Science of Geotechnical Engineering, Department of Civil Engineering at Imam Khomeini International University, Qazvin, Iran (e-mail: Mo.ghorbani@edu.ikiu.ac.).

Only a few researchers have investigated the effect of plastic fine content sand behavior. The effect of clay content on the liquefaction resistance of sandy soils has also been clearly established in field studies. Seed et al. [17] concluded that if a soil has a clay content greater than 20% it will not liquefy. A study of worldwide earthquakes by Tokimatsu and Yoshimi [18] came to the same conclusion. Ishihara and Koseki [19] found that while there was no clear correlation between either clay content or fines content and liquefaction resistance, increasing plasticity index consistently increased liquefaction resistance. As reported by Marcuson et al. [20], soils with greater than 15% material finer than 0.005 mm, liquid limits greater than 35%, and water contents less than 90% of the liquid limit should be safe from liquefaction. Koester [21] indicated that soil plasticity is not a controlling factor in liquefaction resistance in soils with plastic fines. He found that while at a given void ratio, fine type and plasticity play a minor role in liquefaction resistance; they exert far less influence than the percentage of fines in the soil. Polito [22] investigated the effects of plastic fines content by testing a series of specimens prepared to a constant soil specific relative density with various fines content and composition. He found that the cyclic resistance of sands with plastic fines appears to be relatively independent of fines content, clay content, water content, and liquidity index and the cyclic resistance of sands with plastic fines increases with increases in liquid limit, plasticity index and activity. Ghahremani and Ghalandarzadeh [23] found that for clay content increasing from 10% to 30% the liquefaction resistance of mixtures with constant void ratio decreased, whereas this trend was reversed for value of clay content greater than 30%. Gratchev et al. [24] reported that clayey sands with $PI \leq 4$ rapidly liquefied in undrained cyclic ring shear tests, while an increase in PI toward 15 increased the liquefaction resistance of specimens, and finally the specimens became non-liquefiable when $PI \geq 15$. Park and Kim [25] mixed clean sand with 10% plastic fines having different plasticity indexes and they studied the effect of plastic fines on liquefaction resistance in terms of cyclic stress ratio. They concluded that the liquefaction resistance tended to decrease as the plasticity index of 10% fines in the specimens increased. Eseller-Bayat et al. [26] used sand specimens with 10% clay contents. Their result showed clean sand specimens demonstrated highest liquefaction strength compared with that of sands with fines up to 10% fine contents. Cabalar et al. [27] added low plasticity clay to clean sand. They found that, in most of cases up to 20% fines CRR values decreased and then increased with an increase in fines content.

In the present study, a series of resonant column tests were carried out on 161 Firoozkooh sand mixtures with different percentages of bentonite (0, 10, 15, 20, 25, 30, and 35%) at a constant void ratio and confining pressure. The main purpose of this study is to determine the effect of plastic fines content on CRR of saturated clayey sand under cyclic loading.

II. Material Properties

In this study, 161 Firoozkooh sand and bentonite were used make samples. This sand has a golden-yellow color and it is subangular according to [28] and predominant minerals are silica. The sand is classified as poorly graded sand (SP) according to the unified soil classification system. Fig. 1 shows the microscopic image of 161 Firoozkooh sand. The fines used in this study were a bentonite that is a high plastic clay (CH) according to the unified soil classification system. The particle size distribution curves of tested sand and bentonite material are obtained from the sieve and the hydrometric test on this soil is shown in Fig. 2.

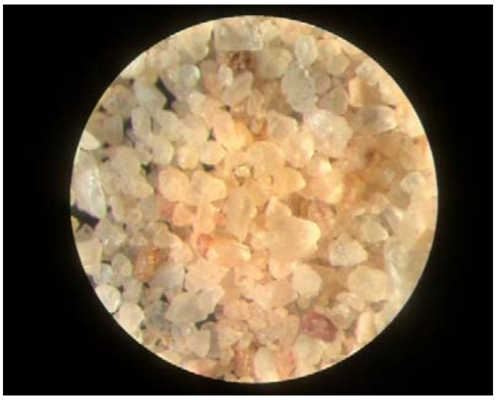

Fig. 1 Microscopic image of tested Firoozkooh sand

III. Test Procedure and Apparatus

A. Sample Preparation

All specimens in this study were constructed by the moist tamping method, which is performed by compacting moist soil in layers to a selected percentage of the required dry unit density of the specimen. The specimens were prepared in the approximately same void ratio equal to 0.61. The water content of the soil during specimen preparation was 15% by weight. All the specimens were compacted in seven layers. The specimens were 50 mm in diameter and 100 mm in height, and they were prepared with seven values of fines content (FC = 0%, 10%, 15%, 20%, 25%, 30% and 35%) in each group. The properties of the mixtures used in this study are shown in Table I. The first letter refers to sandy soil and its number indicates the plastic fines content percentage of specimen. For example, S20 means a sample containing 80% sand and 20% bentonite.

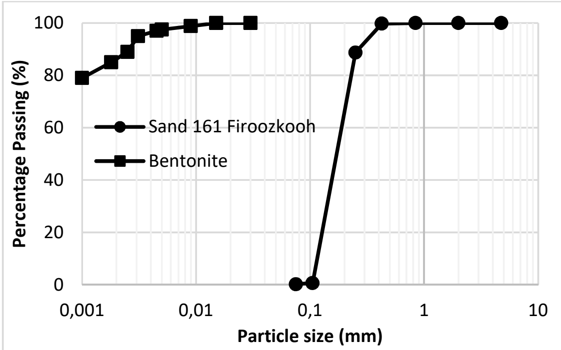

Fig. 2 Particle size distribution curves of tested materials

B. Resonant Column Test

Resonant column tests were performed using the ASTM D4015 [29] available in the geotechnical laboratory at IKIU university. The test essentially involves a soil column in fixed-free end conditions that is excited to vibrate in one of its natural modes. Saturation was performed by purring the specimens with carbon dioxide before adding de-aired water. Back pressure was applied to ensure complete saturation of the specimens. A minimum B-parameter of 0.96 was obtained for all the specimens. After saturation, the specimens were isotropically consolidated to a confining pressure of 100 KPa.

IV. Result and Discussion

Resonant column tests were conducted to investigate the effect of different plastic fines content on behavior of shear modulus and liquefaction resistance of sand. Maximum shear modulus and CRR of specimens were calculated. Fig. 3 shows the maximum shear modulus (G_{max}) variations with different percentages of plastic fines content in a constant confining pressure of 100 kPa.

TABLE I
Physical Properties of Soil Samples Used for Resonant Column Tests

Name of Sample	FC (%)	$\gamma_{d\,max}$ (KN/m^3)	LL (%)	PL (%)	PI	e_0	e_f
S0	0	16.52	-	-	-	0.621	0.604
S10	10	18.2	22	-	-	0.641	0.606
S15	15	18.7	28	26	2	0.644	0.605
S20	20	19.1	32	25	7	0.656	0.611
S25	25	18.6	37	24	13	0.669	0.590
S30	30	18.1	42	22	20	0.702	0.601
S35	35	17.8	47	21	26	0.731	0.614

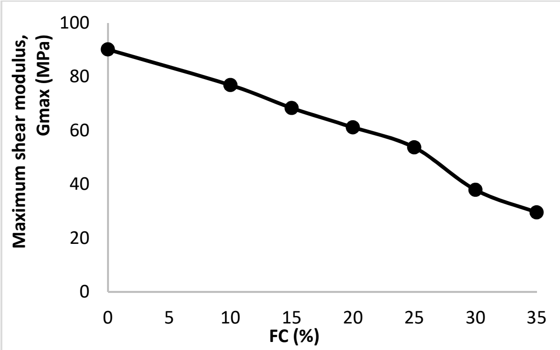

Fig. 3 Variation of G_{max} with FC for different mixtures

According to Fig. 3, the shear modulus of the sand-clay mixtures is decreased by increasing the percentage of plastic fines contents to the clean sand. It is observed that the results are influenced by fine content and plasticity. For sand-clay mixtures, the initial shear modulus increases with the increase in sand content. The results are in agreement with the general trend of increasing maximum shear modulus for soils of low plasticity at constant confining pressure. According to the authors' interpretation, when fine content is low, the shear modulus of sand-clay mixtures is high and the behavior of it is similar to clean sand reported by other researchers [30]-[32].

De Alba et al. [33] suggested that there exists a satisfying correlation between elastic-wave velocity and liquefaction resistance under the identical confining stress. This conclusion implies that the field measurements of elastic-wave velocities may be used to reconstitute laboratory specimens to find out their liquefaction resistance [34]. Tokimastu [34] showed that a reasonable correlation would exist between liquefaction characteristics and elastic shear modulus for a given soil under given confining stresses. Based on this conclusion, many researchers have obtained the liquefaction resistance of soils through shear wave velocity [7], [9], [35]-[37]. In this study CRR is investigated according to the equation presented by Yunmin et al. [5]:

$$CRR = \frac{K^2 G_{max}^2}{F^2(e_{min})\,\sigma_0'} \tag{1}$$

where K is a constant value of 1.22×10-4 kPa$^{-0.5}$, F(e) is obtained for angular graines from the equation given by Hardin and Richart [38], σ_0' is confining pressure.

$$F_e = \frac{(2.97-e)^2}{1+e} \tag{2}$$

Fig. 4 shows the CRR variations with different percentages of plastic fines content in a constant confining pressure of 100 kPa. As can be seen from this figure, the CRR values of the sand clay mixtures decrease for all percentages. A review of the literature has enabled to the authors to identify similar outcomes from numerous studies. Gharemani and Ghalandarzadeh [23] found that adding clay from 10% to 30% to the sand by dry weight increased liquefaction resistance of the specimens. Other researchers report same result [25], [26], [37].

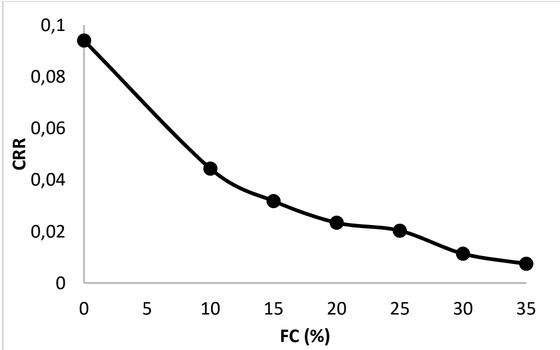

Fig. 4 Variation of CRR with FC for different mixtures

V. Conclusion

The focus of this research was to assess the influence of plastic fines content on shear modulus and CRR of clean sand. The resonant column tests were performed on the remolded specimens at constant void ratio and confining pressure of 100 KPa. Bentonite was added to 161 Firoozkooh sand at the percentages of 10, 15, 20, 25, 30 and 35 by dry weight. The following results were obtained:

- As an overall view, by increasing the plastic fines content to the sandy soil, its maximum shear modulus decreases.
- The testing results indicated that the specimens with more plastic fines content had less liquefaction resistance.
- Both the optimum water content (ω_{opt}) and maximum dry unit weight (γ_{dmax}) values were significantly affected by the clay addition in mixtures. The γ_{dmax} values increased up to about 20 % clay content (FC) then decreased with an increase in FC.

References

[1] H. B. Seed and I. M. Idriss, "Simplified Procedure for Evaluating Soil Liquefaction Potential," *J. Soil Mech. Found. Div.*, vol. Vol 97, No, p. PP 1249-1273.

[2] H. B. Seed, K. Tokimatsu, L. F. Harder, and R. M. Chung, "The influence of SPT procedures in soil liquefaction resistance evaluations: Berkeley, University of California," vol. I, no. 12, p. 15, 1984.

[3] P. Robertson and C. Wride, "Evaluating cyclic liquefaction potential using the cone penetration test," *Can. Geotech. J.*, vol. 35, no. 3, pp. 442--459, 1998.

[4] B. T. L. Youd *et al.*, "L Iquefaction R Esistance of S Oils : S Ummary R Eport From the 1996 Nceer and 1998 Nceer / Nsf W Orkshops on E Valuation," *J. Geotech. Geoenvironmental Eng.*, vol. 127, no. 10, pp. 817–833, 2002.

[5] J. T. Dejong *et al.*, "Instrumented Becker Penetration Test. I : Equipment, Operation, and Performance," vol. 143, no. 9, pp. 1–12, 2017.

[6] K. Ishihara, *Soil behaviour in earthquake geotechnics*, vol. 34, no. 09. 1997.

[7] B. R. D. Andrus, A. Member, and K. H. S. Ii, "Liquefaction Resistance of Soils from Shear-Wave Velocity," no. November, pp. 1015–1025, 2000.

[8] G. Cai, S. Liu, and A. J. Puppala, "Liquefaction assessments using seismic piezocone penetration (SCPTU) test investigations in Tangshan region in China," *Soil Dyn. Earthq. Eng.*, vol. 41, pp. 141–150, 2012.

[9] C. Yunmin, K. Han, and C. Ren-Peng, "Correlation of shear wave velocity with liquefaction resistance based on laboratory tests," *Soil Dyn. Earthq. Eng.*, vol. 25, no. 6, pp. 461–469, 2005.

[10] K. Law and YH Ling, "Liquefaction of granular soils with non-cohesive

and cohesive fines," in *Proceedings of the tenth world conference on earthquake engineering, Rotterdam*, 1992, pp. 1491–1496.
[11] Y. P. Vaid, "Liquefaction of silty soils," *Gr. Fail. under Seism. Cond. ASCE*, pp. 1–16, 1994.
[12] S. Thevanayagam and S. Mohan, "Intergranular state variables and stress-strain behaviour of silty sands," *Geotechnique*, vol. 50, no. 1, pp. 1–23, 2000.
[13] S. A. Naeini and M. H. Baziar, "Effect of fines content on steady-state strength of mixed and layered samples of a sand," *Soil Dyn. Earthq. Eng.*, vol. 24, no. 3, pp. 181–187, 2004.
[14] G. A. Athanasopoulos and V. C. Xenaki, "Liquefaction resistance of sands containing varying amounts of fines," *Geotech. Spec. Publ.*, no. 181, 2008.
[15] M. M. Monkul and J. A. Yamamuro, "Influence of silt size and content on liquefaction behavior of sands," *Can. Geotech. J.*, vol. 48, no. 6, pp. 931–942, 2011.
[16] Y. A. Hernández, I. Towhata, K. Gunji, and S. Yamada, "Laboratory tests on cyclic undrained behavior of loose sand with cohesionless silt and its application to assessment of seismic performance of subsoil," *Soil Dyn. Earthq. Eng.*, vol. 79, pp. 365–378, 2015.
[17] H. B. Seed, I. M. Idriss, and I. Arango, "Evaluation of Liquefaction Potential Using Field Performance Data" by H. Bolton Seed, 1 F. ASCE, I. M. Idriss, 2 and Ignacio Arango, 3 Members, ASCE," *Manager*, vol. 109, no. 3, pp. 458–482, 1983.
[18] Tokimatsu Kohji and Yoshiaki Yoshimi, "Empirical correlation of soil liquefaction based on SPT N-value and fines content," *Soils Found.*, vol. 23, no. 4, pp. 56–74, 1983.
[19] K. Ishihara and Koseki, "Cyclic shear strength of fines-containing sands," in *Earthquakes Geotechnical Engineering, Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, Rio De Janiero, Brazil*, 1989, pp. 101–106.
[20] W. F. Marcuson, M. E. Hynes, and A. G. Franklin, "Evaluation and Use of Residual Strength in Seismic Safety Analysis of Embankments," *Earthquake Spectra*, vol. 6, no. 3. pp. 529–572, 1990.
[21] J. P. Koester, "The Influence of Fine Type And Content On Cyclic Strength," *Gr. Fail. Under Seism. Cond. Geotech. Spec. Publ., ASCE*, vol. 44, pp. 17–33, 1994.
[22] C. Polito, "The Effects Of Non-Plastic and Plastic Fines On The Liquefaction Of Sandy Soils," *PHD Theis@Virginia Tech*, no. December, p. 274, 1999.
[23] M. Ghahremani and A. Ghalandarzadeh, "Effect of plastic fines on cyclic resistance of sands," in *Geotechnical Special Publication No 150: Soil and Rock Behavior and Modeling, ASCE*, 2006, pp. 406–412.
[24] I. B. Gratchev, K. Sassa, V. I. Osipov, and V. N. Sokolov, "The liquefaction of clayey soils under cyclic loading," *Eng. Geol.*, vol. 86, no. 1, pp. 70–84, 2006.
[25] S. S. Park and Y. S. Kim, "Liquefaction resistance of sands containing plastic fines with different plasticity," *J. Geotech. Geoenvironmental Eng.*, vol. 139, no. 5, pp. 825–830, 2013.
[26] E. E. Eseller-Bayat, M. M. Monkul, Ö. Akin, and S. Yenigun, "The Coupled Influence of Relative Density, CSR, Plasticity and Content of Fines on Cyclic Liquefaction Resistance of Sands," *J. Earthq. Eng.*, vol. 23, no. 6, pp. 909–929, 2019.
[27] A. F. Cabalar, S. Demir, and M. M. Khalaf, "Liquefaction Resistance of Different Size/Shape Sand-Clay Mixtures Using a Pair of Bender Element–Mounted Molds," *J. Test. Eval.*, vol. 49, no. 1, p. 20180677, 2021.
[28] W. C. Krumbein, "Measurement and geological significance of shape and roundness of sedimentary particles," *J. Sediment. Res.*, vol. 11, no. 2, pp. 64--72, 1941.
[29] American Society for Testing and Materials, "Standard Test Methods for Modulus and Damping of Soils by Resonant-Column Method," *ASTM Stand. D 4015-07*, vol. 92, no. Reapproved, pp. 1–22, 2007.
[30] S. Yamada, M. Hyodo, R. P. Orense, S. V. Dinesh, and T. Hyodo, "Strain-dependent dynamic properties of remolded sand-clay mixtures," *J. Geotech. Geoenvironmental Eng.*, vol. 134, no. 7, pp. 972–981, 2008.
[31] C. S. El Mohtar, V. P. Drnevich, M. Santagata, and A. Bobet, "Combined resonant column and cyclic triaxial tests for measuring undrained shear modulus reduction of sand with plastic fines," *Geotech. Test. J.*, vol. 36, no. 4, pp. 1–9, 2013.
[32] R. Sadeghzadegan, S. A. Naeini, and A. Mirzaii, "Effect of clay content on the small and mid to large strain shear modulus of an unsaturated sand," *Eur. J. Environ. Civ. Eng.*, vol. 8189, no. January, pp. 1–19, 2018.
[33] P. Alba, K. Baldwin, V. Janoo, G. Roe, and B. Celikkol, "Elastic-Wave Velocities and Liquefaction Potential," *Geotech. Test. J.*, vol. 7, no. 2, pp. 77–88, 1984.
[34] K. Tokimatsu, T. Yamazaki, and Y. Yoshimi, "Soil liquefaction evaluations by elastic shear moduli," *Soils Found.*, vol. 26, no. 1, pp. 25–35, 1986.
[35] K. Tokimatsu and A. Uchida, "Correlation between liquefaction resistance and shear wave velocity," *Soils Found.*, vol. 30, no. 2, pp. 33–42, 1990.
[36] Y. G. Zhou, Y. M. Chen, and Y. Shamoto, "Verification of the soiltype specific correlation between liquefaction resistance and shearwave velocity of sand by dynamic centrifuge test," *J. Geotech. Geoenvironmental Eng.*, vol. 136, no. 1, pp. 165–177, 2010.
[37] N. Akbari Paydar and M. M. Ahmadi, "Effect of Fines Type and Content of Sand on Correlation Between Shear Wave Velocity and Liquefaction Resistance," *Geotech. Geol. Eng.*, vol. 34, no. 6, pp. 1857–1876, 2016.
[38] B. O. Hardin and F. E. Richart Jr, "Elastic Wave Velocities in Granular Soils," *J. Soil Mech. Found. Div*, vol. 89, pp. 33–66, 1963.