ESCUELA DE CONSTRUCCIÓN CIVIL
FACULTAD DE INGENIERÍA

Revista de la Construcción
Journal of Construction

Research Article

Relative density influence on the liquefaction potential of sand with fines

Mohamed Bensoula [1,*], **Mohammed Bousmaha** [2], **Hanifi Missoum** [3]

[1] LCTPE Laboratory, University of Mostaganem, Mostaganem (Algeria), Email: Mohamed.bensoula@univ-mosta.dz
[2] Department of Civil Engineering and Architecture, University Mohammed Boudiaf of Oran (Algeria), Email: bousmed2000@gmail.com
[3] LCTPE Laboratory, University of Mostaganem, Mostaganem (Algeria), Email: hanifimissoum@yahoo.com
*Correspondence: Mohamed.bensoula@univ-mosta.dz

Received: 10.01.2022; **Accepted:** 30.11.2022; **Published:** 29.12.2022

Citation: Bensoula, M., Bousmaha, M. and Missoum, H. (2022). Relative density influence on the liquefaction potential of sand with fines. Revista de la Construcción. Journal of Construction, 21(3), 692-702. https://doi.org/10.7764/RDLC.21.3.692.

Abstract: Liquefaction is a loss in soil's resistance which can lead to disastrous and expensive consequences in terms of human lives and material damages, hence the interest of this laboratory study. The article explores the relative density influence in addition to the main parameter of the fines content on the liquefaction potential of soils. The study is based on a very large number of undrained monotonic triaxial tests undertaken on samples of reconstituted saturated sand and silt mixtures with 6 levels of initial relative density ranging from 15 to 90%. The materials used are levied from different level of deepness in the coastal region of Kharouba in the wilaya of Mostaganem. In this experiment, the sand-silt mixtures were separated to form the study samples. The aim of this work is, on one hand, to confirm and update the results of previous works (Bensoula et al., 2018) and on the other hand the study of the influence of relative density on the liquefaction potential of soils and the introduction of the concept of relative density threshold. The results of the tests confirm that the studied soil is most likely to be liquefied at a fines content between 0 and 30% depending on the equivalent intergranular voids and the equivalent relative density. These parameters are primordial for the characterization of soils sensitivity to liquefaction. In this study, the results showed that the resistance to liquefaction increases in a linear way with the relative density up to a threshold relative density value according to the fines content, which means that increasing the relative density improves the liquefaction resistance but only up to a threshold value of relative density given according to fines content.

Keywords: Relative density, fines content, threshold of initial relative density, static liquefaction, undrained.

1. Introduction

The most used current methods for site stabilization act on the relative density and drainage conditions of the soil, but lately other soil stabilization technics have been used by improving the resistance to liquefaction by including geotextile layers and increasing the permeability of the soil. New methods for analytical reliability of the liquefaction potential evaluation have been introduced such as those leading to the results of cone penetration tests (Johari & Khodaparast, 2014), using the random finite element method (Johari et al., 2015) or based on shear wave velocity (Johari et al., 2019). Such methods need more research in order to set a consensus on liquefaction conditions of soil, as well such methods have to be subjected to validation via experimental methods. Our research is based on laboratory work, on sand-silk mixtures of the region of Mostaganem (Algeria).

The results of previous studies on liquefied soils have shown that the fines content influences considerably on the susceptibility of soil instability by liquefaction such as those studies carried out by (Abedi & Yasrobi, 2010) and (Baziar et al., 2011) who concluded that soils are likely to be liquefied at a critical fines content ranging from 10 to 15%, and also our study (Bensoula et al., 2018) where the critical fines content was 30%. It is well documented in the literature that relative density changes influence on the undrained sand behavior. The results of (Castro, 1969) showed a contracting and therefore a liquefying behavior with a strong softening at a low-density index. When the density index increases, the contracting behavior changes to a dilating behavior passing through a limited liquefaction phase.

The results accomplished by (Toki et al., 1986) on Toyoura sand showed that liquefaction resistance increases in a linear way with the relative density up to a relative density value Dr = 70%. (Polito & Martin II, 2001) carried out a series of triaxial tests on sand samples (Monterrey and Yatesville) mixed with non-plastic fines. They found a linear trend between the increase in relative density and liquefaction resistance for soil samples with a fines content below the threshold limit. We can also cite researches that dealt with the same subject such as (Kramer & Seed, 1988), (Chakrabortty et al., 2021), (Boulanger & Idriss, 2006), (Bray & Sancio, 2006), (Muley et al., 2012), (Cubrinovski & Rees, 2008), (Sadrekarimi, 2013), (Muley et al., 2012) and (Karim & Alam, 2017).

To clarify this situation, a large number of tests were carried out in the laboratory with a multicriteria analysis of the samples intervening simultaneously the three parameters influencing the liquefaction susceptibility of the soils, namely the content of fines, the equivalent intergranular voids and the initial relative density. In this article, we study a soil with fines contents going from 0 to 40% while varying the initial relative density from 15 to 90% in order to introduce the effect of the relative density influence on the resistance to liquefaction. This work is a continuation of a previous work (Bensoula et al., 2018), because in addition to the influence of fines on the liquefaction potential, the influence of the relative density on the liquefaction potential is studied in detail with the introduction of the relative density threshold concept calculated according to the fines content.

2. Materials tested

The materials used are taken from the same site at different depths ranging from 0 to 5 m in the coastal region of Kharouba in the wilaya of Mostaganem (Lat: 35° 58' 54" North and Longitude: 0° 6'39" East). In this experiment, the sand-silt mixtures were separated to form the study samples. The fines content of the samples studied varies from 0 to 40% while the relative density used varies from 15% to 90%. The clean sand is named "S" and the silt "L", while sand-silt mixtures are named "SxLy", where x is the percentage of the sand present in the sample while y is the percentage of silt. Sand density (S100L00) is 2.67 and that of silt (S00L100) is 2.69, while the liquidity and plasticity limit have the values of 25% and 20% respectively. Figure 1 shows the granulometric curves of the materials used.

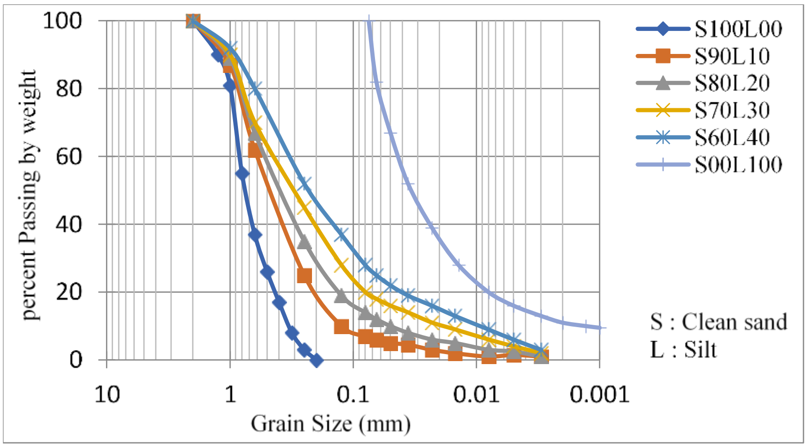


Figure 1. Granulometric curves of the materials used.

Geotechnical proprieties of sand-silk mixtures are regrouped in Table 1. Fc refers to fine content, Gs is specific weight of the mixture. The global void ratio e varies between 0.795 - 1.391 according to the proportions of silk and sand. e_{min} and e_{max} are minimum and maximum void ratios respectively. C_u and C_c are uniformity and curvature coefficient.

Table 1. Sand-silt mixtures geotechnical properties.

Properties	S100L00	S90L10	S80L20	S70L30	S60L40	S00L100
Fc (%)	0	10	20	30	40	100
Gs (g/cm^3)	2.670	2.671	2.675	2.677	2.679	2.690
e	0.795	0.742	0.703	0.678	0.701	1.321
e_{min}	0.519	0.461	0.418	0.401	0.457	0.707
e_{max}	0.844	0.791	0.753	0.727	0.744	1.429
C_u	2.34	4.62	10.40	22.50	33.00	36.67
C_c	1.05	1.08	1.70	2.18	2.45	5.47

3. Laboratory experiment procedures

The automatic triaxial apparatus used is an AUTOTRIAX 29-WF4632 "Automatic Triaxial System" illustrated in Figure 2. In this present study, the dry spill method (air pluviation) is used and the dry soil is deposited in the mold using a funnel which the drop height is controlled (Ladd, 1974), (Das & Chakrabortty, 2022). The final shape of the samples is cylindrical with a height H = 140 mm and a diameter D = 70 mm (H / D = 2.0). To obtain a good saturation, the carbon dioxide technique developed by (Lade & Duncan, 1973) is used. The quality of the saturation is evaluated by measuring the Skempton coefficient (B) whose value is equal to $B = \Delta u/\Delta\sigma$. The consolidation phase consists in rising simultaneously the pressure inside the cell using a hydraulic pressure generator and inside the sample by another hydraulic pressure generator.

Figure 2. Automatic triaxial device 29-WF4632 used. Source: own elaboration.

4. Tests results and discussion

According to (Vaid & Chern, 1983), the effective mean stress is inversely proportional to the interstitial pressure. Thus, liquefaction is observed when the shear stress is greater than the maximum shear strength. According to (Prunier et al., 2009), when the peak of undrained shear strength (S_u) is exceeded, an unstable regime is created until the critical state is reached. The formula for the critical shear strength is as follows:

$$q_s = M.p'_s \tag{1}$$

The critical shear strength S_{ucr} (Schofield & Wroth, 1968) is written as follows:

$$\sin \emptyset_s = \frac{3.M}{6+M} \tag{2}$$

Table 2 recapitulates the results of the undrained tests carried out for different values of the fines content (Fc = 0% to 40%) at an initial confining pressure of 100 kPa for the different relative densities studied which are represented graphically in Figure 3.

The results of undrained monotonic compression triaxial tests performed on different fines contents are shown in Figure 3. During the tests, the two stress paths (p′, q) are recorded and plotted. When the fines content varies from 0 to 30%, the stress path in the plane (p', q) clearly shows the role of fines in decreasing the average effective pressure and the maximum stress deviator, while when the content of fines is equal to 40% there is an increase in the stress deviator which is due to the role of fines in the increase of soil dilatancy and the absence of the contractance phase.

These results show that despite the soil studied exceeds the threshold set by the Chinese criteria (Wang, 1979) it is susceptible to be liquefied at a fines content up to 30% and when the fines content exceeds this threshold of 30%, the mixture exhibits a dilating behavior and doesn't develop the contracting phase, meanwhile the critical stress deviators (q_{cr}) increase continuously. Moreover, many researchers like (Bray & Sancio, 2006), (Boulanger & Idriss, 2006) have recommended to not rely too much on these Chinese criteria.

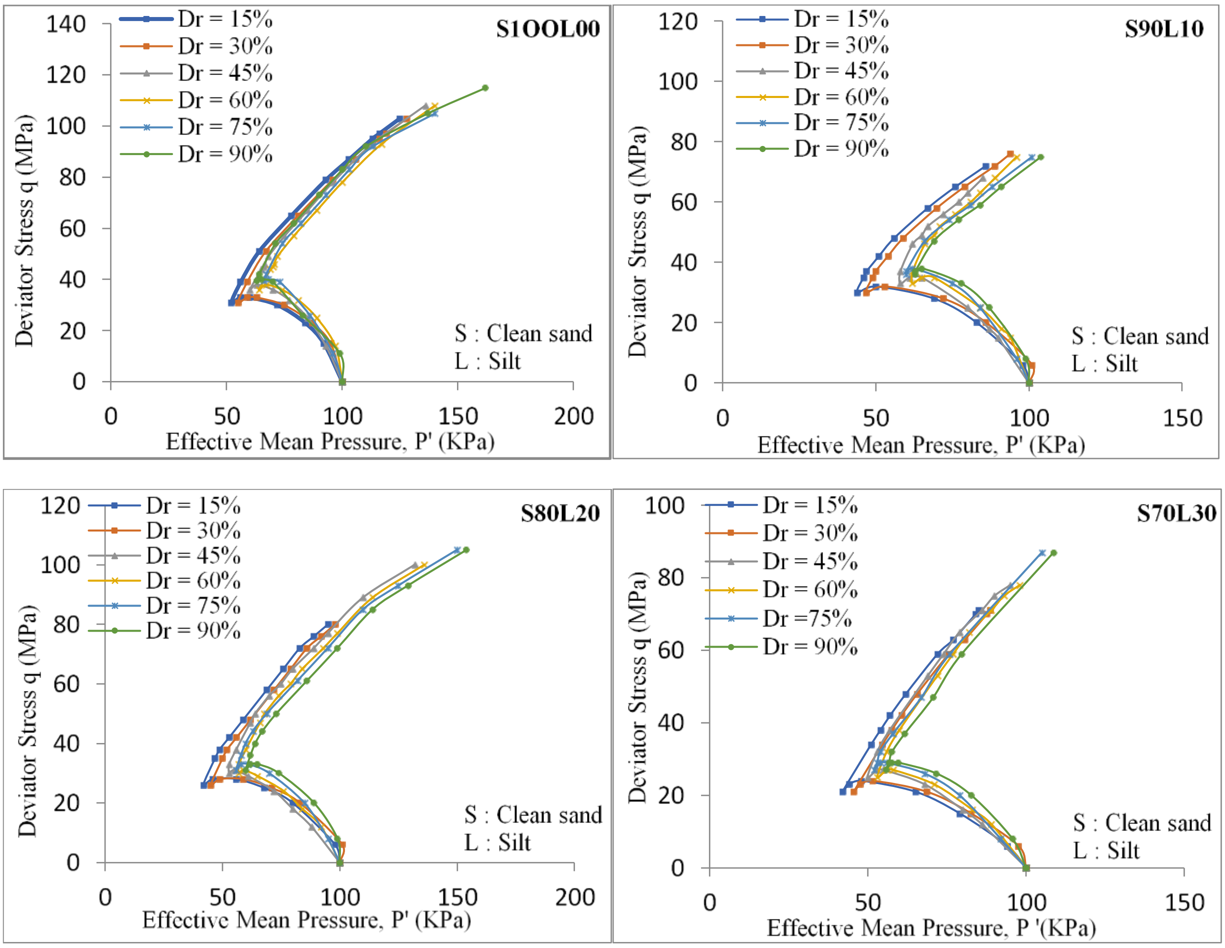
Table 2. Different values found during undrained monotonic tests depending on different values of relative density. Source: own elaboration.

	Fc (%)	e	Dr (%)	$S_{ucr}/\sigma c$
S100L00	0 %	0.795	15 %	0.1604
S90L10	10 %	0.742		0.1494
S80L20	20 %	0.703		0.1331
S70L30	30 %	0.678		0.1127
S60L40	40 %	0.701		0.1291
S100L00	0 %	0.747	30 %	0.1705
S90L10	10 %	0.692		0.1556
S80L20	20 %	0.653		0.1390
S70L30	30 %	0.629		0.1178
S60L40	40 %	0.658		0.1325
S100L00	0 %	0.698	45 %	0.1765
S90L10	10 %	0.643		0.1604
S80L20	20 %	0.602		0.1402
S70L30	30 %	0.580		0.1207
S60L40	40 %	0.615		0.1399
S100L00	0 %	0.649	60 %	0.1798
S90L10	10 %	0.593		0.1669
S80L20	20 %	0.552		0.1449
S70L30	30 %	0.531		0.1278
S60L40	40 %	0.572		0.1448
S100L00	0 %	0.600	75 %	0.1846
S90L10	10 %	0.544		0.1707
S80L20	20 %	0.502		0.1495

S70L30	30 %	0.483		0.1319
S60L40	40 %	0.529		0.1507
S100L00	0 %	0.552	90 %	0.1900
S90L10	10 %	0.494		0.1775
S80L20	20 %	0.452		0.1545
S70L30	30 %	0.434		0.1383
S60L40	40 %	0.486		0.1566

This soil is liquefiable according to the results found at a fines content up to 30% in accordance with our previous research (Bensoula et al., 2018) and the real observations of the three recent earthquakes, Northridge in the United States in 1994 (Holzer et al., 1999) with fines content exceeding 35%, Kocaeli in Turkey in 1999 (Bray & Sancio, 2006) where the fines content were above 15% and Chi-Chi in Taiwan in 1999 (Ku et al., 2004) with fines content ranging from 36 to 53%.

Also, the observations noted in the case of soil ruptures due to static liquefactions reported by (Kramer & Seed, 1988), (Fourie & Tshabalala, 2005) where soils with a fine silt fraction higher than 20% have liquefied.



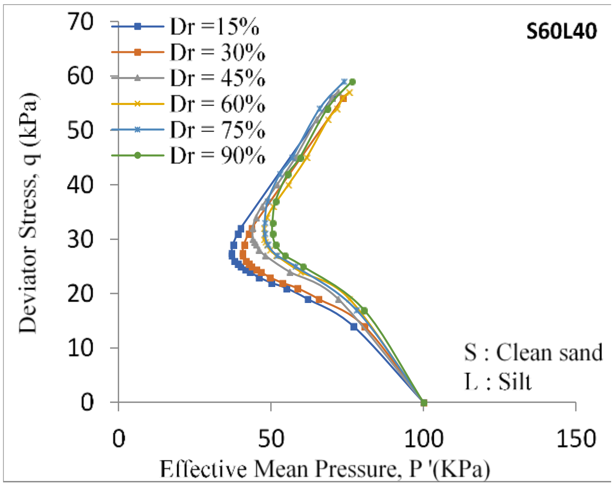


Figure 3. Results of the deviator stress in function of effective mean pressure.

This fine content threshold of 30% will be re-examined by introducing simultaneously two important parameters for the study of the susceptibility of soil liquefaction, namely, the equivalent intergranular voids noted (e*) and the equivalent relative density noted (D_r^*).

If the intergranular voids index (e*) is greater than the maximum void index of the clean sand according to (Thevanayagam & Mohan, 2000), then fines represent the dominant structure and control the shear resistance. They propose a definition of this given index in a form of the equation (3).

$$e^* = (e + \alpha.F_c)/(1 - \alpha.F_c) \tag{3}$$

where e is the global void index and a represents the fraction of fines participating in the resistance of the soil which is expressed with the equation (4) given by (Rahman et al., 2008).

$$\mathrm{r} = \mathrm{D}_{50(\mathrm{fine})}/\mathrm{D}_{10(\mathrm{sand})} \tag{4}$$

Thus, the value of α is expressed by the relation (5) where k = 1 – $r^{0.25}$ and F_{thre} is the percentage of fines in the sample which characterizes the predominance of fines behavior which equal to 0.438 in our study.

$$\alpha = 1 - [\{1 - \exp([-0.3(\mathrm{F_c}/\mathrm{F_{thre}})/\mathrm{k})]\}]\left(\frac{\mathrm{rF_{thre}}}{\mathrm{F_c}}\right)^{\mathrm{r}} \tag{5}$$

According (Toki et al., 1986) the resistance to liquefaction increases in a linear way with the relative density until reaching a relative density value Dr = 70%. Thus, (Polito & Martin II, 2001) have worked on sand samples (Monterrey and Yatesville) mixed with non-plastic fines, and they found that there is a linear trend between the increase in relative density and the liquefaction resistance in soil samples with fines content below the threshold. It is clear that the relative density affects in a very sensitive way the liquefaction potential of soils, from which (Thevanayagam et al., 2002) and (Shenthan et al., 2004) also introduced the concept of the equivalent relative density which is defined as follows:

$$\mathrm{D_r^*} = [(\mathrm{e_{max,cs}} - \mathrm{e^*})/(\mathrm{e_{max,cs}} - \mathrm{e_{min,cs}})]\mathrm{x}100 \tag{6}$$

The calculations of the intergranular voids index (e*) and of the equivalent relative density (D_r^*) for the different samples where the fraction of fines varies from 0 to 40% and the initial relative density from 15 to 90% are summarized in Table 3.

Table 3. Results of the equivalent intergranular voids and the equivalent relative density. Source: own elaboration.

	Fc (%)	e	$\mathbf{e^*_{max}}$	$\mathbf{e^*_{max}}$	e*	Dr (%)	$\mathbf{D^*_r}$(%)
S100L00	0 %	0.795	0.519	0.844	0.795	15 %	15.00
S90L10	10 %	0.742	0.591	0.951	0.897		-16.26
S80L20	20 %	0.703	0.648	1.037	0.978		-41.34
S70L30	30 %	0.678	0.712	1.111	1.051		-63.66
S60L40	40 %	0.701	0.856	1.222	1.167		-99.38
S100L00	0 %	0.747	0.519	0.844	0.747	30 %	30.00
S90L10	10 %	0.692	0.591	0.951	0.843		0.33
S80L20	20 %	0.653	0.648	1.037	0.920		-23.38
S70L30	30 %	0.629	0.712	1.111	0.991		-45.27
S60L40	40 %	0.658	0.856	1.222	1.112		-82.50
S100L00	0 %	0.698	0.519	0.844	0.698	45 %	45.00
S90L10	10 %	0.643	0.591	0.951	0.789		16.92
S80L20	20 %	0.602	0.648	1.037	0.862		-5.42
S70L30	30 %	0.580	0.712	1.111	0.931		-26.88
S60L40	40 %	0.615	0.856	1.222	1.057		-65.63
S100L00	0 %	0.649	0.519	0.844	0.649	60 %	60.00
S90L10	10 %	0.593	0.591	0.951	0.735		33.51
S80L20	20 %	0.552	0.648	1.037	0.803		12.55
S70L30	30 %	0.531	0.712	1.111	0.872		-8.49
S60L40	40 %	0.572	0.856	1.222	1.002		-48.75
S100L00	0 %	0.600	0.519	0.844	0.600	75 %	75.00
S90L10	10 %	0.544	0.591	0.951	0.681		50.10
S80L20	20 %	0.502	0.648	1.037	0.745		30.51
S70L30	30 %	0.483	0.712	1.111	0.812		9.90
S60L40	40 %	0.529	0.856	1.222	0.948		-31.87
S100L00	0 %	0.552	0.519	0.844	0.552	90 %	90.00
S90L10	10 %	0.494	0.591	0.951	0.627		66.69
S80L20	20 %	0.452	0.648	1.037	0.686		48.48
S70L30	30 %	0.434	0.712	1.111	0.752		28.29
S60L40	40 %	0.486	0.856	1.222	0.893		-15.00

In accordance with the results of our previous research (Bensoula et al., 2018), Figure 4 clearly shows that when the intergranular void index increases, it tends to decrease the undrained critical shear resistance up to a fines content of 30%, and from this threshold the resistance increases.

However, according to the large number of tests carried out in this experiment and the variation in the initial relative density over a fairly wide interval, the linear correlation of the undrained critical shear resistance in accordance with the equivalent intergranular void index (Figure 5) is slightly corrected to be equal to the following formula:

$$\frac{S_{ucr}}{\sigma_c} = -0.133e^* + 0.256 \tag{7}$$

Figure 6 shows that when the fines content (Fc) ≤ 30%, the increase in undrained critical shear resistance is proportional to the increase in the equivalent relative density and as for the linear correlation of the undrained critical shear resistance according to the equivalent intergranular void index, a slight correction has been performed for the undrained critical shear resistance as a function of the equivalent relative density compared to the previous work (Bensoula et al., 2018) with a formula cited below:

$$\frac{S_{ucr}}{\sigma_c} = 0.0433D_r^* + 0.1423 \tag{8}$$

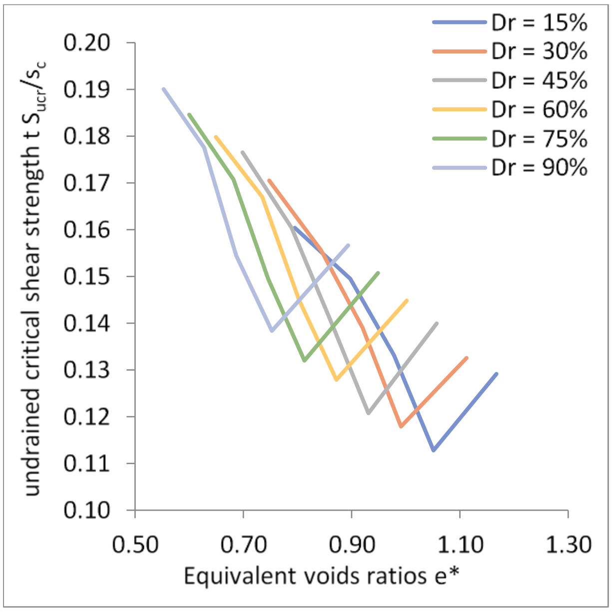


Figure 4. Undrained critical shear strength in function of the equivalent voids index Source: own elaboration.

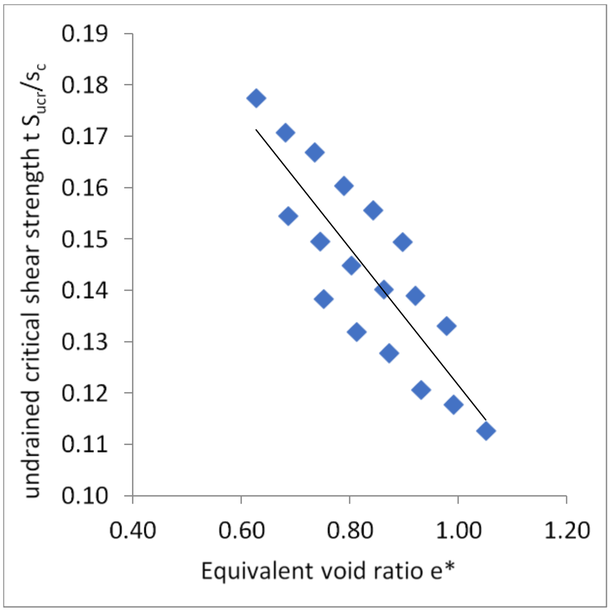


Figure 5. Correlation of undrained critical shear strength in function of an equivalent voids index (e*). Source: own elaboration.

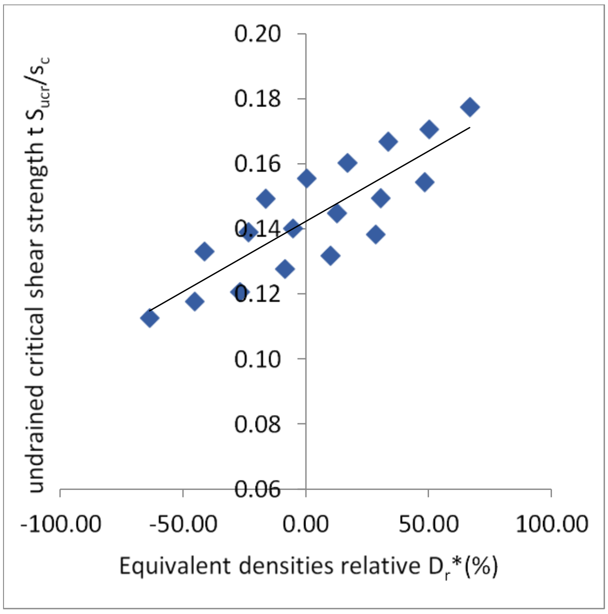


Figure 7. Correlation of undrained critical shear strength with respect to equivalent densities relative (D_r^*). Source: own elaboration.

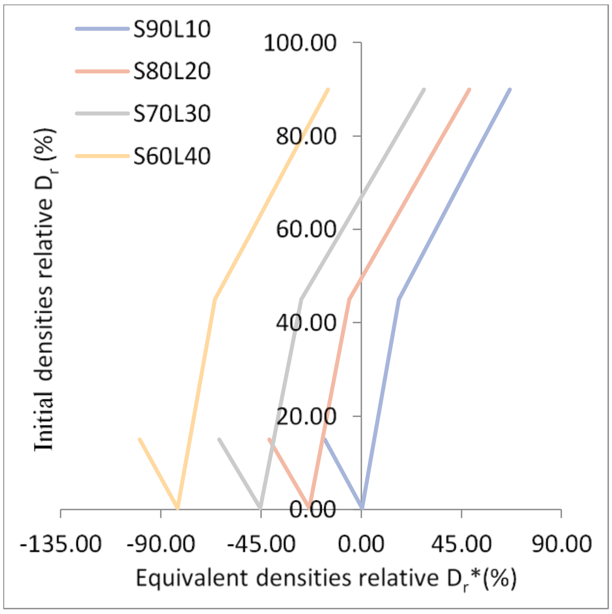


Figure 6. Variation of Initial densities relative Dr in function of the equivalent relative densities Dr*. Source: own elaboration.

Figure 7 shows that when Dr > 30%, the equivalent relative density is proportional to the initial relative density and conversely proportional in the opposite case. The resistance to liquefaction increases in a linear way with the relative density up to a relative density threshold value depending on the fines content of the samples. The relative density threshold noted D_{Tr}, was calculated (Table 4) and plotted on the curve of Figure 8 where the value of S60L40 correspond to the fine content of 40% was removed because it exceeds 100%.

Table 4. Values of the relative density threshold D_{Tr} according to fines content (Fc). Source: own elaboration.

	Fines content Fc (%)	Initial equivalent relative density thresholds D_{Tr} (%)
S100L00	0 %	11.49
S90L10	10 %	29.70
S80L20	20 %	49.52
S70L30	30 %	66.92
S60L40	40 %	103.33

Figure 8 clearly indicates that the relative density threshold as a function of the fines content influence on the liquefaction potential of the soil studied whose equation is given by the formula:

$$D_{Tr}(\%) = 186.11\ \mathrm{Fc}\ (\%) + 11.491 \tag{9}$$

It is clear that the relative density threshold is proportional to the fine content, therefore, the increasing in the relative density improves the resistance to liquefaction.

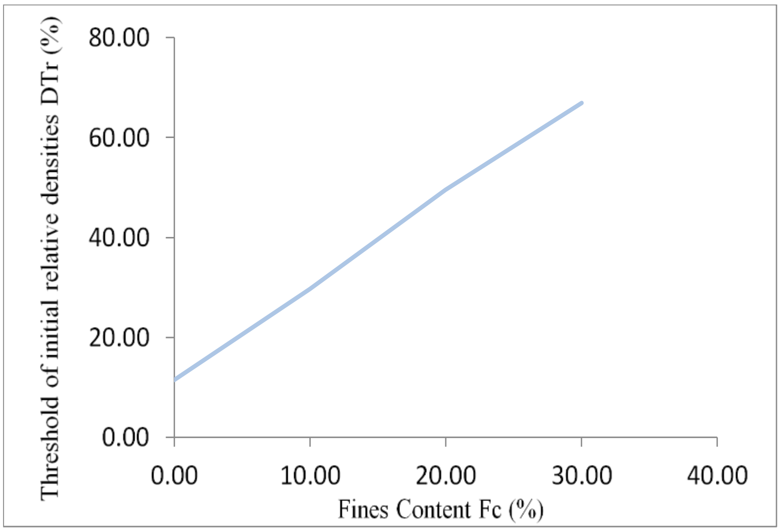


Figure 8. Variation of Threshold of initial relative densities D_{Tr} (%) with respect to of the fines content (Fc).

5. Conclusions

This work was carried out with the aim of confirming and updating the results of our previous work (Bensoula et al., 2018) since in this study the number of undrained monotonic triaxial tests undertaken on samples of reconstituted saturated sand and silt mixtures was widely increased with 6 levels of initial relative density (15 to 90%) with a step of 15%. On the other hand, it makes it possible to highlight the influence of the relative density on the liquefaction potential in addition to the main parameter of the content of fines.

These results confirm that the soil locally available in the region of Kharouba Mostaganem) is liquefiable when the fine content is less than 30% exceedingly the threshold given by Chinese criteria. Then, it is clear that fine content plays an important role in the behavior of soil with respect to liquefaction.

This study summarizes that the equivalent intergranular void index and the equivalent relative density are very important to study the potential of soil liquefaction. It was shown that undrained critical shear strength is inversely proportional to the equivalent intergranular void index on one hand, and on the other hand is proportional to the increase of the equivalent relative density and for this reason minor corrections have been carried out to the two correlations mentioned in our previous work.

This work showed that the resistance to liquefaction increases in a linear way with the relative density up to a relative density threshold value depending on the content of fines, hence the introduction of the concept of relative density threshold in this work which makes it possible to determine the relative density threshold as a function of the content of fines. The relative density threshold was calculated and a correlation as a function of fine content was introduced.

The test results clearly show that the resistance to liquefaction rises while increasing the relative density, which means that increasing the relative density improves the resistance to liquefaction but only up to a threshold value of given relative density according to fines content.

References

Abedi, M., & Yasrobi, S. S. (2010). Effects of plastic fines on the instability of sand. Soil Dynamics and Earthquake Engineering, 30(3). https://doi.org/10.1016/j.soildyn.2009.09.001

Baziar, M. H., Jafarian, Y., Shahnazari, H., Movahed, V., & Amin Tutunchian, M. (2011). Prediction of strain energy-based liquefaction resistance of sand-silt mixtures: An evolutionary approach. Computers and Geosciences, 37(11). https://doi.org/10.1016/j.cageo.2011.04.008

Bensoula, M., Missoum, H., & Bendani, K. (2018). Liquefaction potential sand-silt mixtures under static loading. Revista de La Construccion, 17(2). https://doi.org/10.7764/RDLC.17.2.196

Boulanger, R. W., & Idriss, I. M. (2006). Liquefaction Susceptibility Criteria for Silts and Clays. Journal of Geotechnical and Geoenvironmental Engineering, 132(11). https://doi.org/10.1061/(asce)1090-0241(2006)132:11(1413)

Bray, J. D., & Sancio, R. B. (2006). Assessment of the Liquefaction Susceptibility of Fine-Grained Soils. Journal of Geotechnical and Geoenvironmental Engineering, 132(9). https://doi.org/10.1061/(asce)1090-0241(2006)132:9(1165)

Castro, G. (1969). Liquefaction of sands. Harvard Univ, Harvard Soil Mech Ser 81.

Chakrabortty, P., Nilay, N., & Das, A. (2021). Effect of Silt Content on Liquefaction Susceptibility of Fine Saturated River Bed Sands. International Journal of Civil Engineering, 19(5). https://doi.org/10.1007/s40999-020-00574-9

Das, A., & Chakrabortty, P. (2022). Large strain dynamic characteristics of quaternary alluvium sand with emphasis on empirical pore water pressure generation model. European Journal of Environmental and Civil Engineering, 26(12). https://doi.org/10.1080/19648189.2021.1916605

Fourie, A. B., & Tshabalala, L. (2005). Initiation of static liquefaction and the role of K0 consolidation. Canadian Geotechnical Journal, 42(3). https://doi.org/10.1139/t05-026

Holzer, T. L., Bennett, M. J., Ponti, D. J., & Tinsley III, J. C. (1999). Liquefaction and Soil Failure During 1994 Northridge Earthquake. Journal of Geotechnical and Geoenvironmental Engineering, 125(6). https://doi.org/10.1061/(asce)1090-0241(1999)125:6(438)

Johari, A., & Khodaparast, A. R. (2014). Analytical reliability assessment of liquefaction potential based on cone penetration test results. Scientia Iranica, 21(5).

Johari, A., Khodaparast, A. R., & Javadi, A. A. (2019). An Analytical Approach to Probabilistic Modeling of Liquefaction Based on Shear Wave Velocity. Iranian Journal of Science and Technology - Transactions of Civil Engineering, 43. https://doi.org/10.1007/s40996-018-0163-7

Johari, A., Pour, J. R., & Javadi, A. (2015). Reliability analysis of static liquefaction of loose sand using the random finite element method. Engineering Computations (Swansea, Wales), 32(7). https://doi.org/10.1108/EC-07-2014-0152

Karim, M. E., & Alam, M. J. (2017). Effect of nonplastic silt content on undrained shear strength of sand–silt mixtures. International Journal of Geo-Engineering, 8(1). https://doi.org/10.1186/s40703-017-0051-1

Kramer, S. L., & Seed, H. B. (1988). Initiation of soil liquefaction under static loading conditions. Journal of Geotechnical Engineering, 114(4). https://doi.org/10.1061/(ASCE)0733-9410(1988)114:4(412)

Ku, C. S., Lee, D. H., & Wu, J. H. (2004). Evaluation of soil liquefaction in the Chi-Chi, Taiwan earthquake using CPT. Soil Dynamics and Earthquake Engineering, 24(9–10). https://doi.org/10.1016/j.soildyn.2004.06.009

Ladd, R. S. (1974). Specimen Preparation and Liquefaction of Sands. Journal of the Geotechnical Engineering Division, 100(10). https://doi.org/10.1061/ajgeb6.0000117

Lade, P. v., & Duncan, J. M. (1973). CUBICAL TRIAXIAL TESTS ON COHESIONLESS SOIL. ASCE J Soil Mech Found Div, 99(SM10). https://doi.org/10.1061/jsfeaq.0001934

Muley, P., Maheshwari, B. K., & Paul, D. K. (2012). Effect of Fines on Liquefaction Resistance of Solani Sand. 15 WCEE, 2012.

Polito, C. P., & Martin II, J. R. (2001). Effects of Nonplastic Fines on the Liquefaction Resistance of Sands. Journal of Geotechnical and Geoenvironmental Engineering, 127(5). https://doi.org/10.1061/(asce)1090-0241(2001)127:5(408)

Prunier, F., Laouafa, F., & Darve, F. (2009). Material stability analysis based on the local and global elasto-plastic tangent operators. Computational Geomechanics, COMGEO I - Proceedings of the 1st International Symposium on Computational Geomechanics.

Rahman, M. M., Lo, S. R., & Gnanendran, C. T. (2008). On equivalent granular void ratio and steady state behaviour of loose sand with fines. Canadian Geotechnical Journal, 45(10). https://doi.org/10.1139/T08-064

Sadrekarimi, A. (2013). Influence of fines content on liquefied strength of silty sands. Soil Dynamics and Earthquake Engineering, 55. https://doi.org/10.1016/j.soildyn.2013.09.008

Schofield, A., & Wroth, P. (1968). Critical state soil mechanics. In Engineering (Vol. 1).

Shenthan, T., Nashed, R., Thevanayagam, S., & Martin, G. R. (2004). Liquefaction mitigation in silty soils using composite stone columns and dynamic compaction. Earthquake Engineering and Engineering Vibration, 3(1). https://doi.org/10.1007/BF02668849

Thevanayagam, S., & Mohan, S. (2000). Intergranular state variables and stress-strain behaviour of silty sands. Geotechnique, 50(1). https://doi.org/10.1680/geot.2000.50.1.1

Thevanayagam, S., Shenthan, T., Mohan, S., & Liang, J. (2002). Undrained Fragility of Clean Sands, Silty Sands, and Sandy Silts. Journal of Geotechnical and Geoenvironmental Engineering, 128(10). https://doi.org/10.1061/(asce)1090-0241(2002)128:10(849)

Toki, S., Tatsuoka, F., Miura, S., Yoshimi, Y., Yasuda, S., & Makihara, Y. (1986). CYCLIC UNDRAINED TRIAXIAL STRENGTH OF SAND BY A COOPERATIVE TEST PROGRAM. Soils and Foundations, 26(3). https://doi.org/10.3208/sandf1972.26.3_117

Vaid, Y. P., & Chern, J. C. (1983). Mechanism of deformation during cyclic undrained loading of saturated sands. International Journal of Soil Dynamics and Earthquake Engineering, 2(3). https://doi.org/10.1016/0261-7277(83)90014-1

Wang, W. (1979). Some Findings in Soil Liquefaction (Earthquake Eng). https://books.google.dz/books?id=nz7XGwAACAAJ