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Study of the influence of non-plastic fines on the liquefaction resistance of sands

L. Jradi, J.C. Dupla & J. Canou
Université Paris-Est, Ecole des Ponts ParisTech, Navier, Champs sur Marne, France

B. Seif El Dine
Université Libanaise, Faculté de génie, Branche III, Hadath, Liban

ABSTRACT: The study of the influence of fines particles on the phenomenon of liquefaction of sands has been a controversial subject where no clear conclusions can be drawn as to in what manner the presence of these particles affect the liquefaction resistance of sand. This paper presents a study of the influence of non-plastic fines on the resistance to liquefaction of sand-fines mixtures. The study is carried out using a triaxial apparatus on reconstituted sand-silica mixtures for low fractions of fines. After presenting the soils used in this study, this paper presents the results of undrained monotonic liquefaction tests performed of sand specimens containing different fines fractions. Experimental results show that the increase in fines content up to 5% increases the resistance of sand to liquefaction. This result is due to the contribution of the fine particles to the overall chain forces and therefore they increase the resistance against liquefaction.

1 INTRODUCTION

It has been understood from literature that the presence of silt and clay particles will in some manner affect the resistance of sand to liquefaction. However, a review of studies published in the literature indicates that no clear conclusions can be drawn as to in what manner altering the fines content affects the liquefaction resistance of a sand under cyclic loading. This is particularly true for soils containing non-plastic fines. Many authors have studied the influence of fines content on the mechanical behavior of silty sands based on static monotonic tests. Belkhatir *et al.* (2010) have noticed a decrease in the deviatoric stress at peak with the increase in fines content up to 50% of fines. Whereas Pitman *et al.* (1994) have recorded that adding up to 40% of fines makes the silty-sand mixture more resistant. On the other hand, Naeini & Baziar (2004), Yang *et al.* (2006) and Dash & Sitharam (2011) have observed that the deviatoric stress at peak decreases until a certain value of fines content is reached, which is the threshold value, and then it increases after that with the addition of fines. These contradictory results could be attributed to the fact that these authors have tested different types of sands as well as different types of non-plastic fines or silts. In addition to that, the evaluation criteria for the susceptibility of soil to liquefaction differs from one author to another where some authors have evaluated this phenomenon in terms of global void ratio (Chang et al. 1982, Dezfulian 1984), or in terms of relative density (Kuerbis & Vaid 1988; and Polito 1999).On the other hand, Xenaki & Athanasopoulos (2003), Papadopoulou & Tika (2008) and Stamatapoulos (2010) have relied on the intergranular void ratio parameter for evaluating the liquefaction phenomenon.

This study aims to present the results of monotonic liquefaction tests for sand/non-plastic mixtures with low fines content in order to clarify and quantify the influence of fine particles (less than 5%) present in a sandy matrix on the initiation and development of the liquefaction phenomenon.

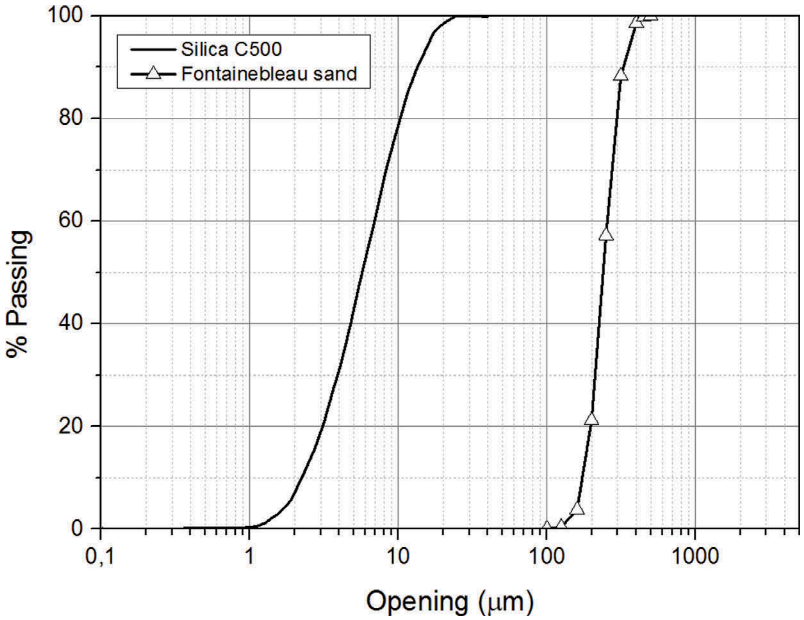

Figure 1. Particle size distribution of clean Fontainebleau sand and Silica C500

2 EXPERIMENTAL PROGRAM AND PROCEDURE

The experimental study was carried out on soil samples that were reconstituted in laboratory by mixing different amounts of silica C500 (non-plastic fine) with Fontainebleau sand. Silica C500 is a fine silica flour (SiO_2 > 99%) and it is characterized by a sub- angular grain shape. Fontainebleau sand is a well-known French reference sand that is widely used in France for academic research, it is a fine sand with mean particle diameter D_{50} = 210 μm. Figure 1 displays the particle- size distributions of the silica and sand used in this study. The experimental program included undrained monotonic tests for various values of the fines content at a confining pressure equal to 100 kPa. Undrained monotonic tests were performed at four values of fines content (0%, 1%, 3% and 5%) on loose and medium dense samples with initial density indices for sand matrix (I_{Dmat} = 0.10, 0.50 respectively for loose and medium dense material). The reconstituted specimens were prepared using the well-known wet tamping method.

A new triaxial device has been developed by the geotechnical team of NAVIER laboratory in order to study the mechanical behavior of soils. This triaxial apparatus involves placing a cylindrical specimen of soil of 100 mm in diameter and 200 mm in height into a cell that allows the consolidation and the shear of the specimen. This device allows to run both monotonic and cyclic loading by controlling either the displacement or the force using a 25 kN hydraulic actuator.

This device consists of the following elements

- a triaxial cell that rests on a slab (83 cm x 55 cm) fitted with a two column loading frame (Figure 2b);
- a rigid cylindrical metal base pierced with different pipes to ensure the passage of fluids between the inside and the outside of the cell (Figure 2c);
- an upper metal base, of the same diameter as the specimen and comprising also drainage circuits (Figure 2d);
- a confinement enclosure composed of several pieces (Figure 2e);
- a metallic cover having a central passage for the piston (Figure 2f);
- a piston sliding through the cover with low friction (Figure 2g);
- Porous stones that ensure drainage of the specimen, they serve as a filter to prevent the intrusion of particles into the drainage circuits of the apparatus.

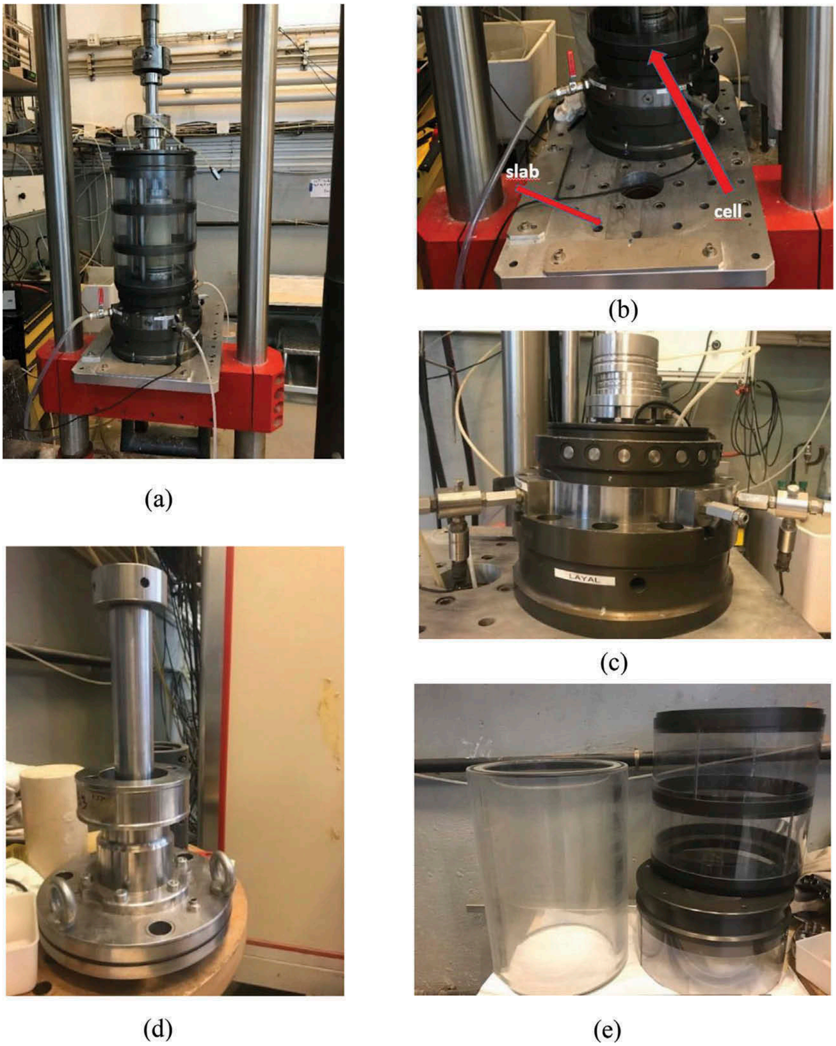

Figure 2. Triaxial cell used for this study

3 UNDRAINED MONOTONIC TESTS

3.1 *Typical results*

Figure 3 shows the result of a typical static liquefaction test performed on a very loose specimen of Fontainebleau sand (I_{Dmat} = 0.10) consolidated under 100 kPa. The shape of the shear curve presented in Figure 3a is characterized by a very marked low level peak of resistance reached for a relatively small axial deformation (of the order of 0.5%), followed by a sharp drop in the deviatoric stress to a zero value in this case, corresponding to a total collapse (total liquefaction) of the specimen.The evolution of the excess pore water pressure Δu (Figure 3b) presents a very high generation rate which reaches a maximum value of 100 kPa thus equalizing the value of the consolidation stress and causing at the same time a collapse of the specimen. Figure 3c presents the corresponding effective stress path. It is noted that after reaching the peak resistance, this path migrates progressively towards the origin of the axes until reaching zero value of deviatoric stress q for a zero value of the mean effective stress p'

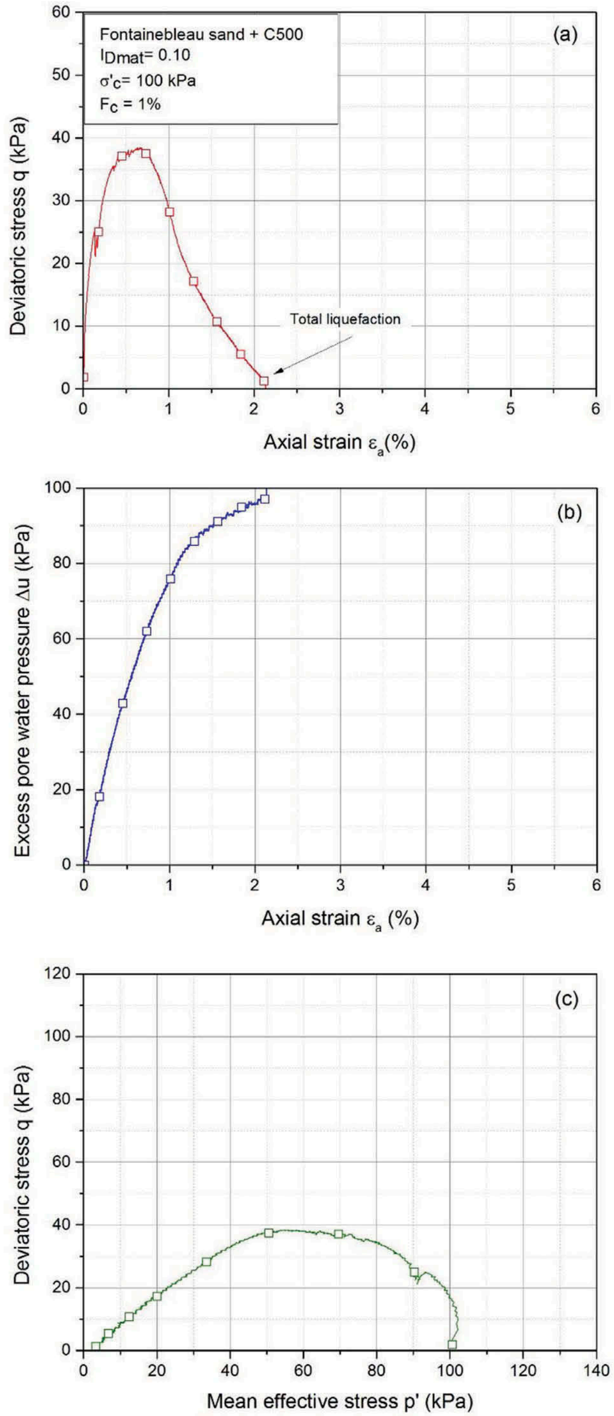

Figure 3. Undrained behavior of Fontainebleau sand-C500 mixture (loose state) (a) (q-ε_a) curve; (b) (Δu- ε_a) curve; (c) (q-p') curve

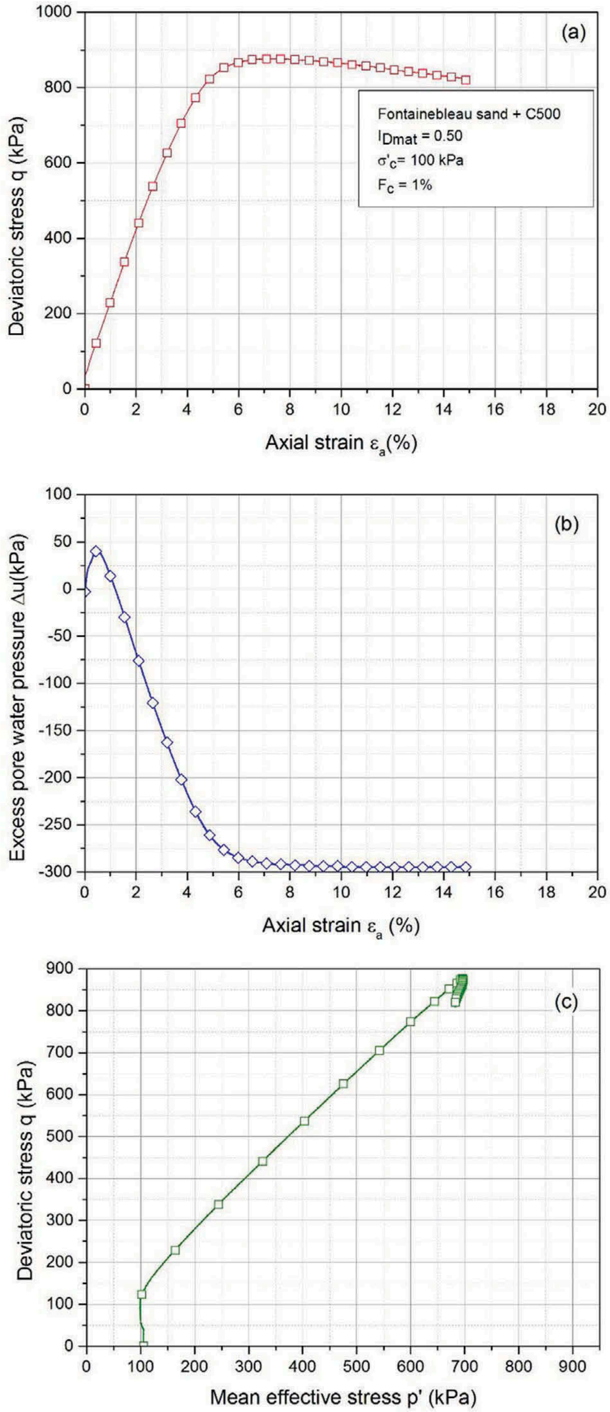

Figure 4. Undrained behavior of Fontainebleau sand-C500 mixture (medium dense state) (a) (q-εa) curve; (b) (Δu- εa) curve; (c) (q-p') curve

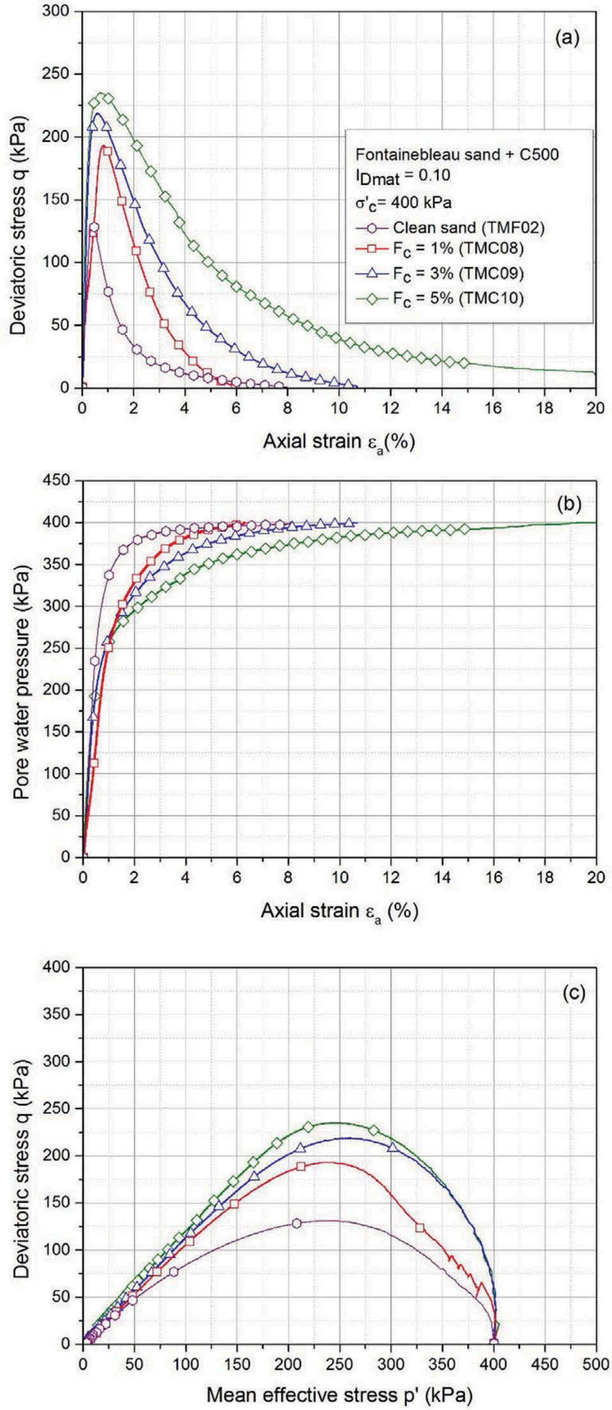

Figure 5. Influence of non-plastic fines (C500) on the mechanical behavior of loose Fontainebleau sand (a) (q-εa) curve; (b) (Δu- εa) curve; (c) (q-p') curve

indicating again the collapse and total liquefaction of the sample. On the other hand, the case of high density index (I_{Dmat} =0.50), the shear curve shows a continuous increase in the deviator stress which indicates a hardening behavior of the mixture (Figure 4a). The pore water pressure records a small increase at the very beginning stage followed by a sharp decrease that reaches negative values (- 300 kPa) indicating a dilatant and stable behavior of the mixture (Figure 4b).

3.2 *Influence of fines content*

Figure 5 displays the results of undrained monotonic tests performed on clean sand and sand/non-plastic fines mixtures at various values of fines content consolidated at 400 kPa and prepared at the same initial conditions. It shows that the fines content significantly influences the soil response. We note that the mechanical response of the samples is similar with the increase in the values of fines content. All the specimens present a contracting behavior. It is noted that the shear resistance increases from 125 kPa for the case of clean sand to 235 kPa for the case of sand with 5% fines (Figure 5a). Figure 5b shows that the excess pore water pressure generation rate decreases with the increase in fines content.

The stress paths in the (q, p') plane after reaching a peak resistance migrate towards the origin of the axes until reaching a null value of resistance and hence indicating the total liquefaction of the specimens. Therefore, it is noted that upon adding the non-plastic fines (C500) to sand, these particles participate in the shear resistance of the mixture and hence they decrease the liquefaction potential of the material.

The analysis of the influence of fines content on the behavior of loose sands is presented in a synthetic manner in Figure 6 that presents the plot of the peak resistance as a function of fines content. It is noted that the latter presents an increase in resistance upon increasing the fines content, this result is coherent with those already found by Dezfulian 1984, Pitman et al.

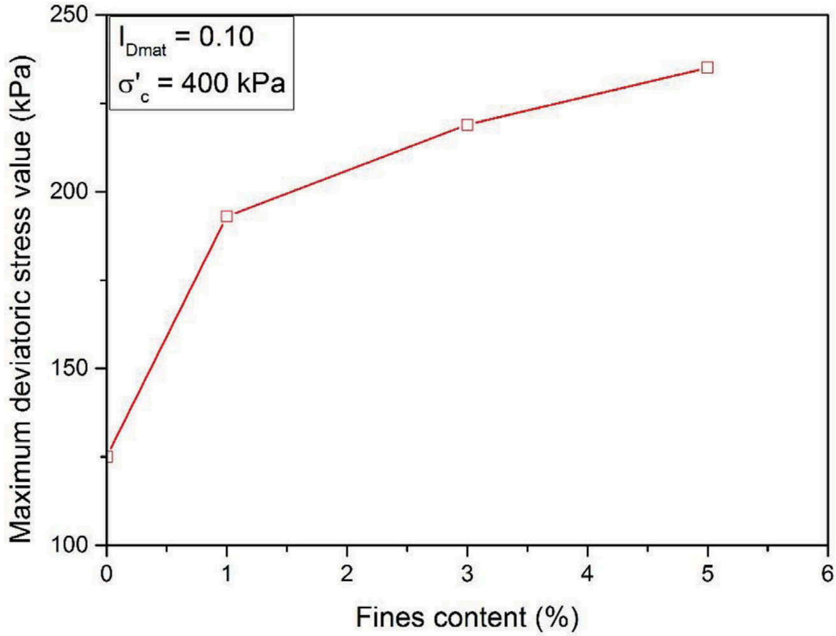

Figure 6. Influence of Fines Content on Peak Shear Resistance

1994 and Amini and Qi 2000 who had also reported an increase in the shear resistance of sands with the increase in non-plastic fines content. This increase in the resistance upon adding fines could be attributed to the fact that the sand skeleton structure will remain unchanged and the fine particles will be placed between the sand grains where these particles will increase the friction between the grains and therefore they will favor dilatancy. As the sand structure remains unchanged, the modification of the soil resistance could be attributed to the fine particles. Indeed, the fine particles contribute to the overall chain forces and therefore they increase the resistance against liquefaction.

4 ANALYSIS OF THE INITIATION OF INSTABILITY

The instability of loose sands under monotonic loading is initiated at the peak resistance. Beyond this peak, the material softens and develops large deformations. In other words, this phenomenon takes place when the effective stress state crosses the instability zone.

The initiation of the instability is characterized by two parameters that are the deviator stress at the initiation of the instability q_{inst} and the mobilized friction angle at the initiation of the instability Φ_{inst}. Figure 7 presents the stress paths corresponding to clean sand and a mixture of clean sand with 1% fines content. It may be observed that for each series of tests, the points corresponding to the initiation of liquefaction are aligned and joined by a line that passes through the origin axis. This instability line has been already defined by Lade (1993) and it is interesting here to note that this definition of the instability that joins the peak resistance at different consolidation stresses with the origin of axes is also applicable for the sand-fines mixtures. It is also interesting to note that this line is affected by adding fines where we can notice that the instability friction angle increases from 15° for clean sand to 19.5° upon adding 1% fines. The value of instability friction angle for clean Fontainebleau sand has been studied in the literature by Benahmed (2001) for a density index equal to zero and was reported to be equal to 11.8°. Indeed the evolution of the instability line with the increase in the fines content is presented in Figure 8. It is noted that we have a set of instability lines that pass through the origin and whose evolution is a function of the fines content value Fc. As the fines content increases, the slope of the instability line increases in the (q, p') plane as well as the instability friction angle that increases from 15° for the case of clean Fontainebleau sand to 25° for Fc = 5%.

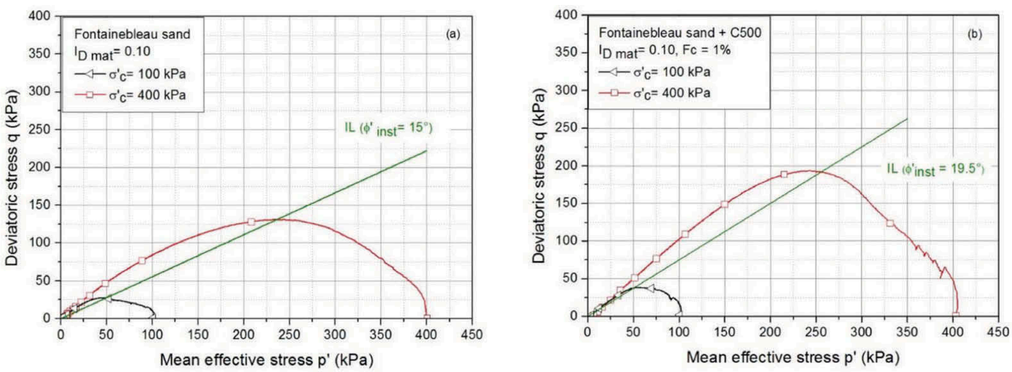

Figure 7. Plot of the instability line in the (p′,q) plane

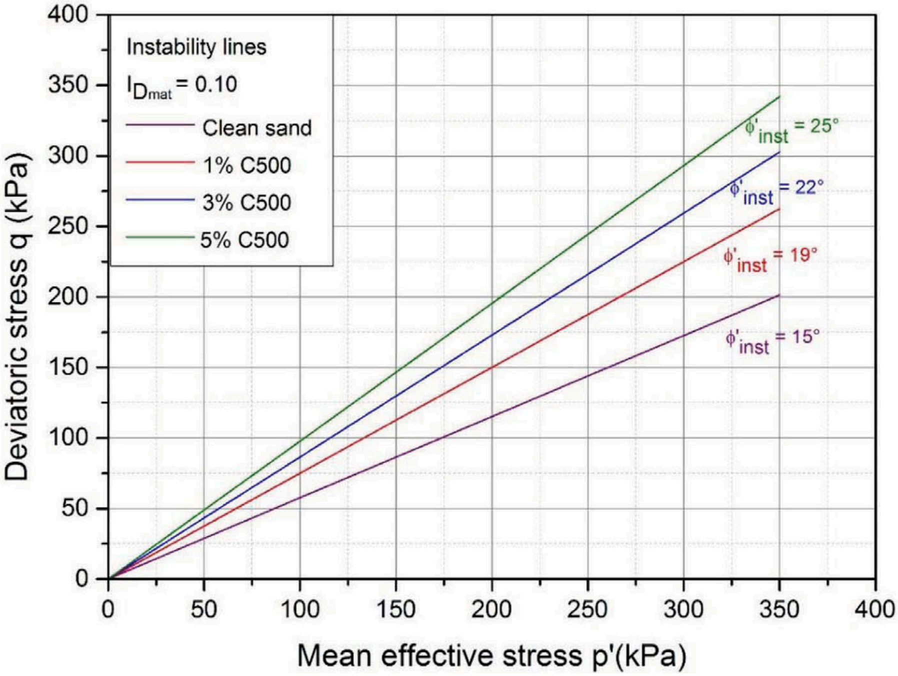

Figure 8. Evolution of the instability line for sand- fines mixtures

5 CONCLUSIONS

This paper has presented a study of the influence of the presence of fines on the resistance to liquefaction of a reconstituted sand–silica mixtures. Analyses were performed on loose mixtures with low values of fines content. Undrained monotonic tests showed that the increase in the fines content up to 5% decreases the tendency of the sand–fines mixture to liquefy, and consequently increases its resistance.

This study has also allowed to develop a testing protocol based on the use of a new servo-hydraulic triaxial setup (Φ 100mm) allowing to shear specimens under monotonic loading.

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