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***Research Article***

# IMPACT OF FINE CONTENT ON SOIL VULNERABILITY TO CATASTROPHIC EVENTS

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## ABSTRACT
The current study is focused on determining the shear strength parameters of silty sand from direct shear tests. Tests are performed on the reconstructed samples of Djiri's sand, Congo Republic, with 10%, 25% and 50% of silt content and constant relative density, Dr = 65% applying vertical stress of 50, 100, and 150 kPa. The effect of fines content on undrained shear strength is analysed as well. Therefore, soil shear parameters such as internal friction and dilatancy angles were determined and compared. The results obtained were expressed as graphs of shear stress against relative displacement, shear stress against fines content, variation of friction angle versus fines content and variation of angle of dilatancy versus fines content respectively. Then, it is noticed that once the soil sample has a silt content less than 10%, the shear strength, angle of internal friction and angle of dilatancy have tendency to increase leading to the resilient soil to the effect of erosion, landslides and collapse. However, the soil sample covering a silt content from 10% to 50% showed a decrease in shear strength, angle of dilatancy and internal friction angle leading to the vulnerable soil to the effect of erosion, landslides and collapse as well.

***Key words:*** *Disastrous Events, Silt, Sand, Fines Content, Shear Strength*

## INTRODUCTION
The soil deposits cover a certain content of silt and clay. Due to increasing of clean sands near engineering project areas, the use of mixture of sand including clayey sand, and sandy silt, will remain a practical alternative in renovation researches. The presence of fines in sandy soils can be a concern in engineering projects as a cause of geological phenomena amplification, leading to high risk for humanity and property. It is often supposed that the soil strength decreases with the increase in fines content (Koester, 1994). Therefore, the maximum content of fines is commonly limited to 10% in the majority of engineering projects (Maleki *et al.*, 2011). However, the accessibility to soils with small fines content is very occasional. But, soils with maximum fines content up to 10% have been found (Youssef *et al.*, 2022). The form of soil grains also affects the behaviour of engineering properties of soils (Mair *et al.*, 2002).
Until recent years, rare researches have been focused on the effect of fines content variation on the behaviour of sandy soils. Data on the properties of sandy soil such as the relationship between stress and behaviour of shear strength called attention of earlier studies. Thevanayagam (1998) focused his researches on the non-plastic silt effect on the undrained shear strength. Then, results obtained from this study showed that sand-silt covering silt content up to 30% revealed the behaviour of silt. Thian &Lee (2011) showed that the un-drained shear strength and pore pressure decrease with the increase in the clay content.

In spite of all the experience gained over the past years, direct shear tests are commonly used in geotechnical engineering. This type of test is used to determine the shear strength parameters for constructions design. All over the last 50 years, the direct shear test has been used in engineering industry due to its easiness and results provided. Strength properties of Sandy soil is often determined by using the direct shear test in determining internal friction angle, angle of dilatancy or the sand shear strength. Many academics have investigated the shear strength and dilatancy behaviour of sands. Evaluation of triaxial test results led to reach the critical and maximum values of friction angle of sand and silty sand. These works found that, the presence of silt content in sand increases significantly the shear strength parameter and the soil dilatancy. Variations were observed as well in small strains once the decrease of stiffness causes the increase in critical strength and maximum strength (Salgado *et al.,* 2000).

Triaxial compression tests performed by Kim *et al.,* (2005) on mixture of sand-silt indicated that the critical friction is reduced when fines content increases. Studies related to silt content effect on undrained strength of sand using a triaxial cyclic test performed by Gupta& Trivedi (2009) showed the decrease in internal friction angle with the addition of fines in the sand due to the fine grains compressibility. Relationship for silt content effect on strength and dilatancy properties was proposed by Xiao *et al.,* (2014). This model presented by Xiao *et al.,* (2014) from existing data agrees with Salgado *et al.,* (2000). Fines content effect on shear strength and dilatancy properties of sand was also reached by Ziaie *et al.,* (2019). So, the use of direct shear test in unsaturated conditions showed that the soil behaviour depends on its sand grains arrangement.

Brazzaville City as the the northern part of the country, is located on geological deposits of silty sand, and has a relatively shallow phreatic water table. These conditions increase the erosion, landslides and collapse phenomena (Kempena, 2022). Because of the soil failure phenomenon, it is necessary to typify this granular mass as an engineering material. Under undrained conditions, the shear strength of sandy soils may be reduced by erosion at toe of a slope or rapid sediments accumulation and loading leading to environmental degradation. The pore water in a saturated sandy soil will increase because of volume contraction if the water drainage is obstructed. This is observed in a lower effective stress and therefore, a decrease in soil resistance to collapse. Several slopes failures can be activated by static and recurring mechanisms. Erosion, landslides and collapse events may conduct to disastrous failure when the shear strength of a vulnerable soil drops under the existing initial static load such as destabilising forces in a slope. Many cases of slopes failures have been reported by Olson & Stark (2003). To evaluate the occurrence of desastrous event, the undrained shear resistance of sandy soils during slopes failures is an essential parameter in undrained slopes stability analysis. The accurate assessment of the undrained soil strength is of supreme significance for the soil structures design, such as earthen dams, bridge supports and building foundations, with a purpose of protecting them from catasteophic events such as erosion, landslides and collapse. The understanding of failed soil is incessantly being studied because of new field and laboratory interpretations. Clear indication has considerably predisposed the research tendency to investigations of erosion, landslides and collapse phenomena into deposits of natural sandy soil. The fines effects on the mechanical behavior of sandy matrix soil are not yet completely agreed. Then, the current challenge is to increase important researches on the mechanical behavior of soils which are vulnerable to desastrous events in order to find measures for protecting them. The presence of fines may either increase or decrease erosion, landslides and collapse vulnerability. Many contributions have frustrated to report the fines influence behavior in soils of sandy matrix on erosion, landslides and collapse (Olson & Stark, 2003).

However, Silty sands are the most common type of soil involved in erosion, landslides and collapse phenomena. Seed *et al.,* (1983) observed that certain types of soils with fines content may be extremely vulnerable to erosion, landslides and collapse events. After performing various tests, Yamamuro and Lade (1997) confirmed that an increase in silt in a sand-silt mixture conducts to a decrease in undrained shear strentgh of silty sand at a constant total void ratio. The clean sand behavior differs from that of sand-silt

mixtures. There are inconsistent conclusions concerning this difference. Some academics have established that silt in the sand matrix decreases the undrained shear strength of sandy soil mixtures (Chang *et al.,* 1982). Therefore, founded on the existing results in the literature, fines content of a sandy soil lead to uniform behavior, and recent advances have been realised in this field. The stability of structures built on these types of soils depends on the posterosion, postlandslides and postcollapse effects of the soil shear resistance. The soils strength at the phase transition is critical for engineering design (Pitman *et al.,* 1994). Then, it is significant to illuminate about the main parameters that exert considerable effect on the soil shear strength and define the required principles for the design process. Yamamuro and Lade (1997) showed that intergranular void ratio probably controls the undrained strength of sand-silt mixtures. While, Thevanayagam *et al.,* (2002) specified that, elsewhere a definite value of Fc (the threshold value), a fraction of silt contributes to the soil skeleton restraint force, and these authors introduced a new parameter definite as the equivalent intergranular void ratio.

This wotk aims to evaluate by using the direct shear tests the effect of fines content on the soil vulnerability to erosion, landslides and collapse phenomena considered as disastrous events.

## MATERIALS AND METHODS

### *Study Area*

The study area is part of the Northern area of Brazzaville City, into Djiri district as shown in Figure 1. It has a relief made of flats, valleys and hills. The years 80's were considered less warm than the years 90's. The recent evolution of temperatures in Congo before 1970 and after is characterised plainly by two periods. The net temperature variation from 1932 to 2010 showed an increase in average temperatures of +0.5˚C to 1˚C in the preceding two decades. While, for the two recent decades, the maximum and minimum average temperatures in the 1990s increased. It is considered the maximum and minimum altitudes of 1100 m and 360 m respectively. The climate being tropical involves a rainy season from October to May, and dry seasons between January-February and June-September. The variation of annual rainfall is between 1250 mm and 1350 mm/year (Samba&Nganga, 2014). From hydrogeological point of view, the study area is part of Bateke's water table, with an area of 270 $km^2$. The aquifer composition is constituted by sandstone with a weak contribution to groundwater mineralogy. The use of $Ca^{2+}/Mg^{2+}$ ratio led to obtain two hydro chemical areas. The first zone includes the calcium minerals leading to weathering process and the second one has a highest ratio of $Ca^{2+}/Mg^{2+}$ showing the dissolution of magnesium (Matini&Moutou, 2010). The soils are settled on materials of sedimentary series from base to top, made of Inkisi's sandstone series, Stanley-Pool sandstone's series and Bateke's plateau series. In general, the soils have very low clay content (Nzila *et al.,* 2018). The Central Basin, inculdes the intracratonic depression of Central Africa with sediments accumulation, tectonic activity and erosion process for a long history. The geological background is founded on Precambrian to Paleozoic age formation which supports a Mesozoic to Cenozoic sedimentary cover that rests unconformably on a Precambrian basement. While, the Precambrian to Paleozoic basement appears downstream from the Stanley Pool and sedimentary cover is fashioned by basically sandy materials which outcrop upstream from Stanley-Pool's series (Kadima, 2011).

### *Soil material*

In the current study, sand and silt were used as soil samples collected from Djiri district, Congo Republic. The material selection is founded on its accessibility or easy location and classified as silty sand (ASTM, 2004) from studies carried out by Kempena (2021). Then, the selected material is classified as sand (SP) and silt (ML) according to the Unified soil classification (ASTM, 2011).

*Sample Preparation*

Specimens collected at different depths present the silty fines content that did not exceed 23%. In the experimental work, the separation of sand and silt was carried out for its usage to create the test samples. Then the direct shear tests were carried out on mixtures of sand and silt by using Digital direct shear apparatus in "GeoConsul" Laboratory. The fact that most erosion, landslides and collapse events occur in silty sand, silt contents ranging from 0% to 50% were submitted to tests. Moreover, it is noticed that disastrous events such as erosion, landslides and collapse vulnerability is extremely affected by soil relative density (Yamamuro & Kelly, 2001; Maheshwari & Patel, 2010). The grain size distribution is shown in figure 2.

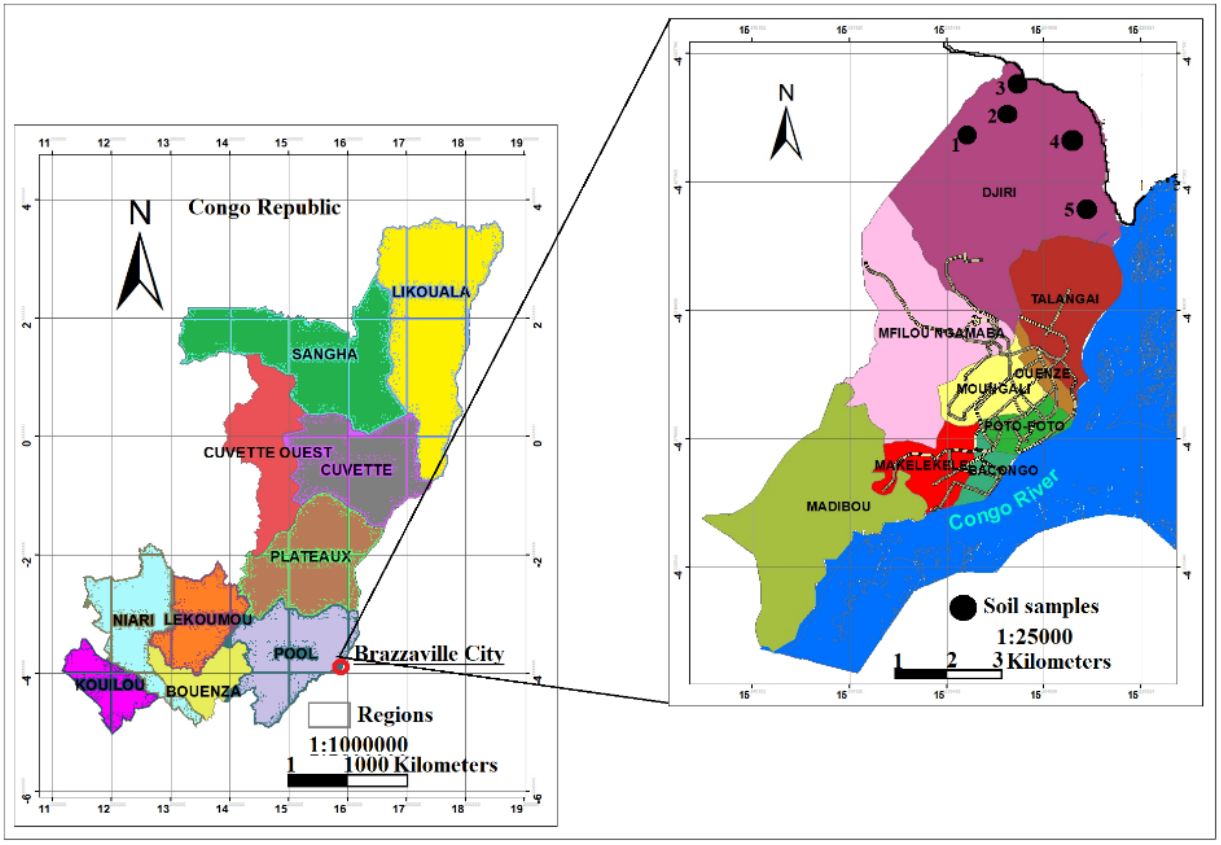



**Figure 1: Study area**

The curves of particle size distribution for all silty sand collected are shown in Figure 2. Di represents the soil diameter and being i% the soil weight which is finer. The silt plasticity index, Ip = 5%, and Cu = D60 / D10 = 3.3 and Cc = (D30) 2 / D60.D10 = 1.8 are coefficients of uniformity and curvature, respectively. Giving the ASTM D2487-11(2011) classification, the sand used in this work is poorly sorted (SP), being the silt inorganic (ML).

***Laboratory experiment procedures***

*Soil sample preparation*

Specimens' preparation methods significantly affect the erosion, landslides and collapse behaviour of soils (Ladd, 1974; Mulilis *et al.*, 1977). The soil specimen preparation must be in such a way as to repeat

the soil field conditions. Then, the optimal specimen preparation methods are important in decisive potential of sandy soils vulnerability to disastrous events. Various techniques of sample reconstitution have been debated for procedure in the laboratory, involving moist tamping, dry pouring and water sedimentation (Vaid *et al.*, 1999).

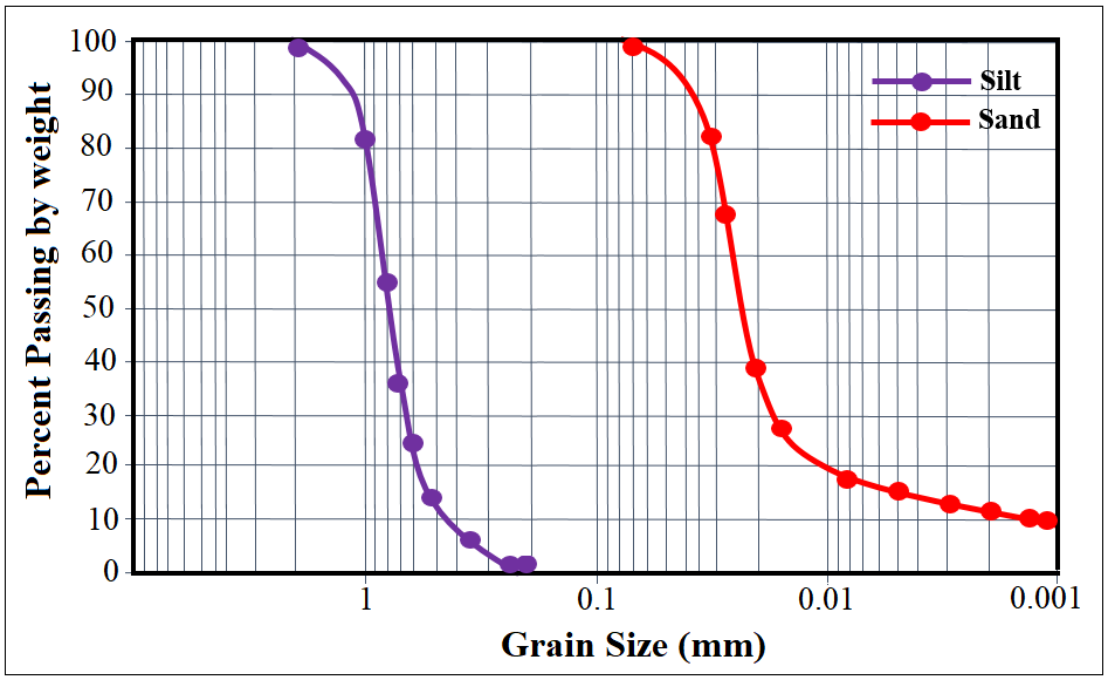



**Figure 2: Curves of grain size distribution from tested materials (Kempena, 2021).**

Despite several available methods for sample preparation in sandy soil, but the choice of preparation method depends on its capacity of describing the sample field conditions. Therefore, in the present work the moist tamping method was the one selected to perform laboratory tests. Then the wet tamping method used to sample preparation, considered 6% moisture content by using experiments under unsaturated conditions (Ladd, 1974). The estimation of undrained critical shear resistance is determined from the behaviour of sand samples in undrained direct shear tests (Vaid & Chern, 1983). During this test, the soil specimen reaches peak undrained shear resistance. Erosion vulnerability is produced when shear strain applied to the soil sample surpasses the peak shear resistance as a result of applied stresses. An unstable regime Past that point, is developed in the soil sample until the critical state is reached, being this position a stable state. In undrained conditions, the shear resistance at stable state is predictably the critical shear resistance (Prunier *et al.*, 2009).

## RESULTS AND DISCUSSION

### *Results*

From 9 tests performed by using the Digital direct shear apparatus, the results determined the effect of different silt percentage on the behavior of soils parameters and the dilatancy for sandy soil. The shear stress variation can be seen in Figure 3 with its corresponding shear deformation in different silt content for a density of 65% applying vertical stress of 50,100, and 150 kPa.

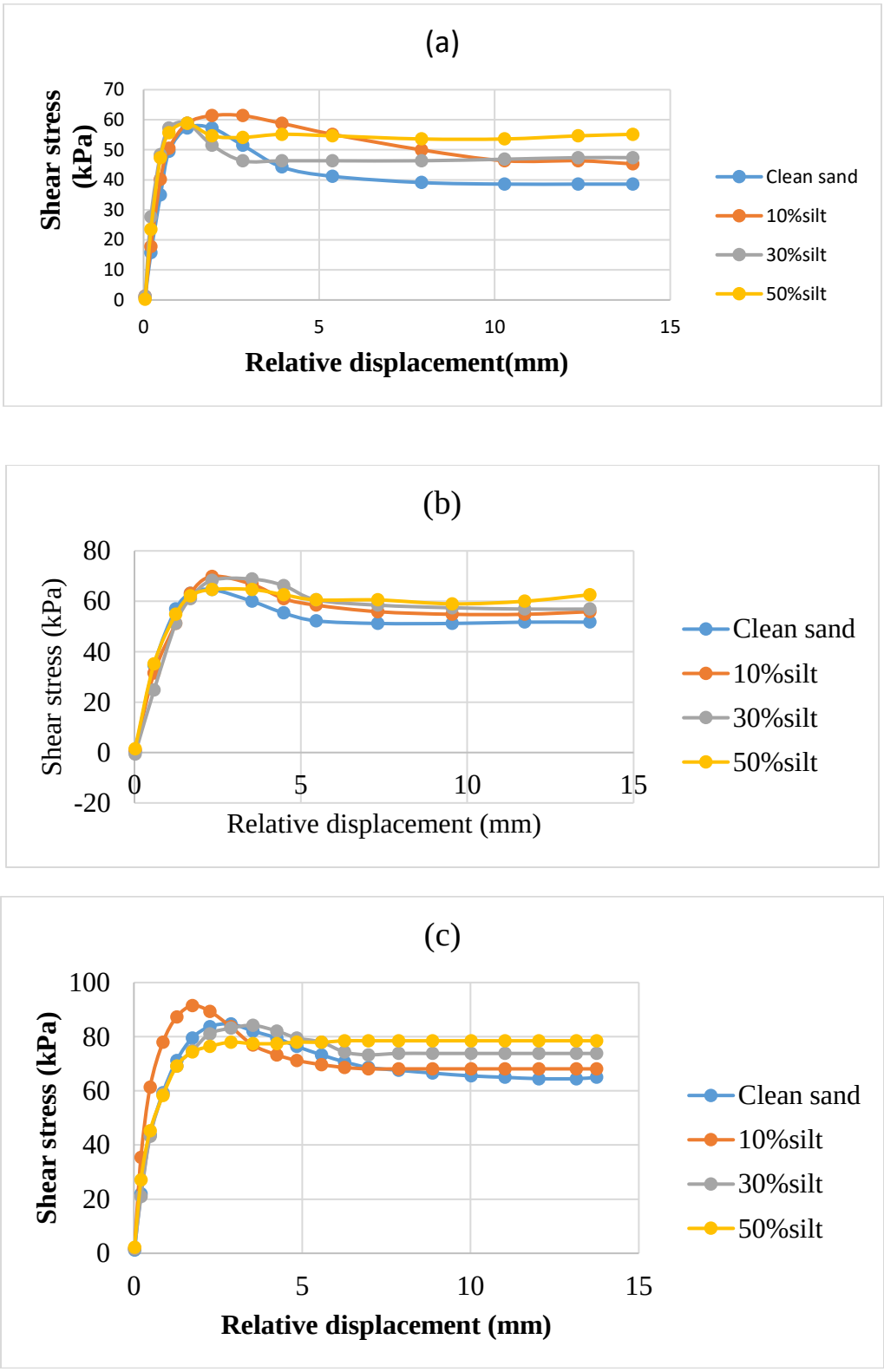



**Figure 3: Shear Stress against relative displacement**

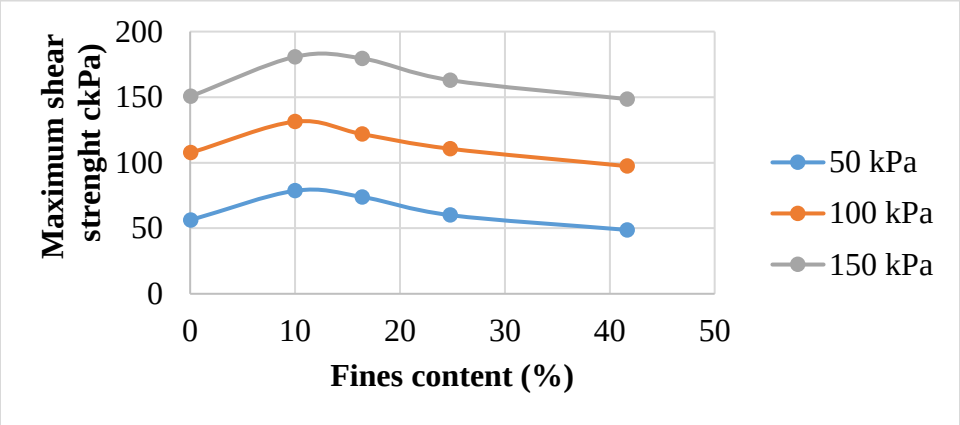
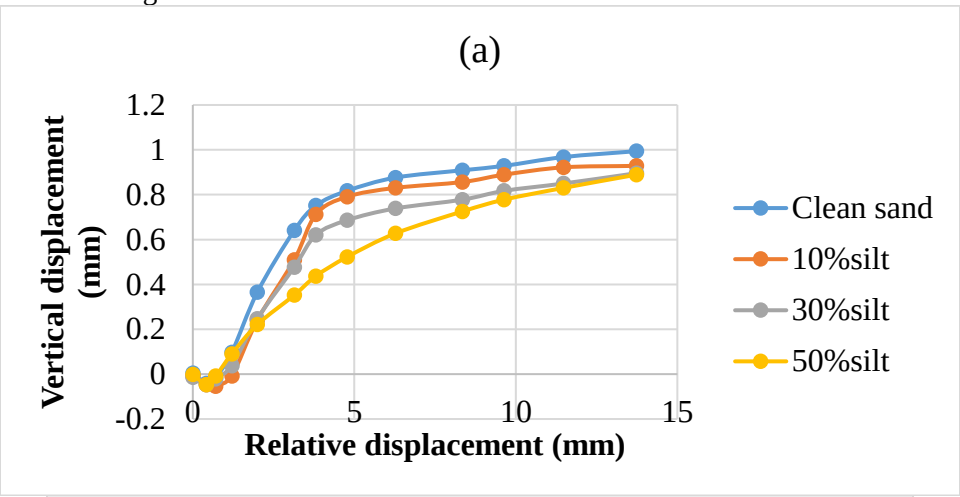
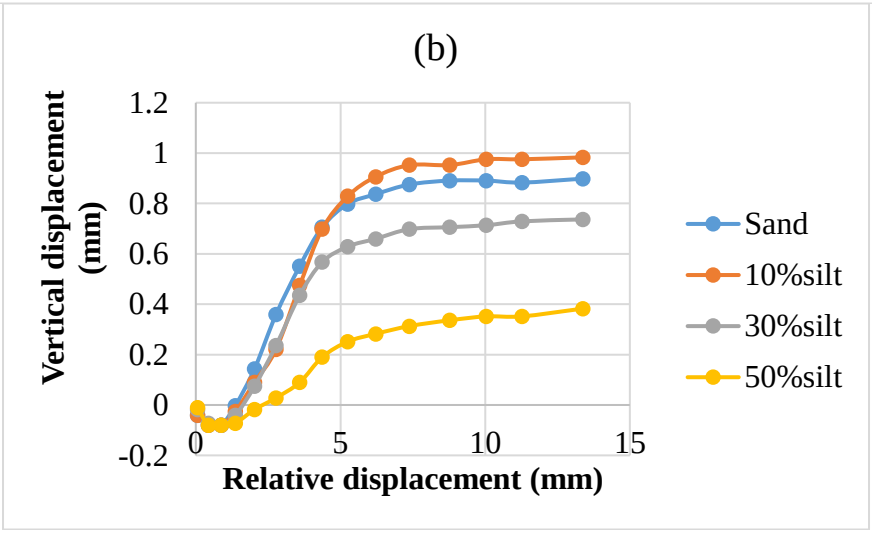



**Figure 4: Shear strength versus the fine content**

From Figure 4, one can notice the increase of shear strength for the sand mixture for of silt content inferior to 10% and then the shear strength decrease is observed for silty content superior to 10%. These changes observed in the fines content related to the increase or decrease of shear strength of soils determine the importance of the disastrous events when the soil becomes vulnerable to erosion, landslides and collapse events being the fines content between 10% and 50%.



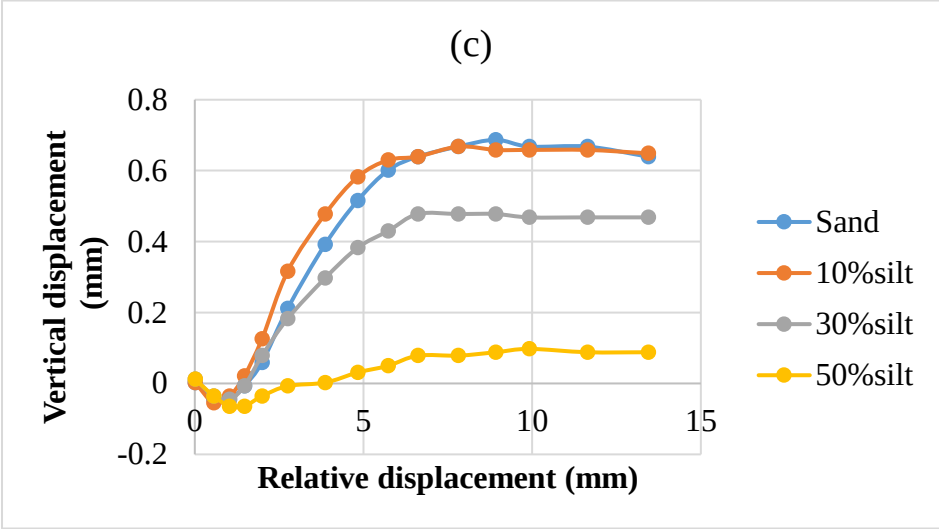



**Figure 5 (a, b, c): Relative displacement against vertical displacement**

The sample volumetric behaviour can be seen in Figure 5. In this Figure, the behaviour of soil depends on the dilatancy process showing by the sand structure.

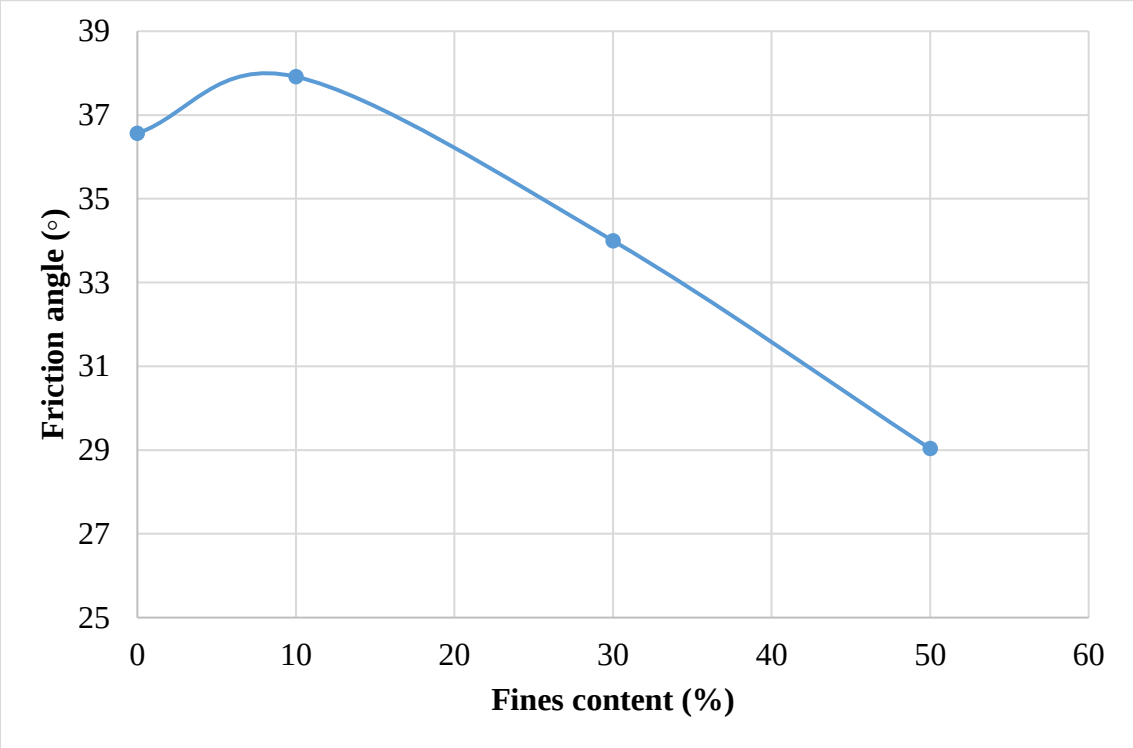



**Figure 6: Variation of friction angle versus fines content**

Figure 6 shows the variation of the friction angle in silty sand samples. From this Figure, it is noticed the increase of friction angle in silty sand samples for the silt content inferior to 10% and then the decrease of friction angle is observed for silt content superior to 10% with tendency to become vulnerable to disastrous events.

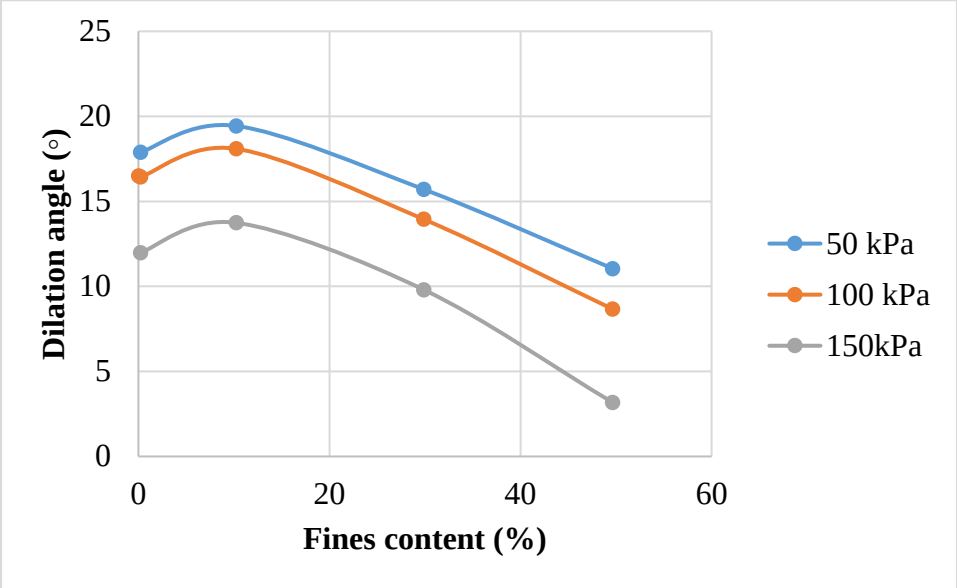



**Figure 7: Variations of dilation angle versus fines content**

***Discussion***

The results of the experimental study revealed that the increase of the silt content up to 10%, causes the increase and decrease of the friction angle. Similar results have been found by Yosefpour&Hamidi (2015) and Vu-To, *et al.*, (2016). These results obtained by authors before mentioned are close to those found in the current study using the Figure 5. However, in the results of Xiao *et al.*, (2014) despite the low fines content from 7% to 20% considered, but the soil behaviour is the same comparing with the current study. The difference remains just in the peak friction angle. Then in the current study, the peak friction angle is found once the soil sample holds 10% of silt content and 7% represents the peak friction angle (Gupta&Trivedi, 2009). This peak's locations difference is due to the difference among soils properties such as particle grain distribution, particle form and density. So, it can be concluded that both studies have an agreement among the results obtained.

The variation of dilatancy against the silt content applying vertical stresses of 50, 100 and 150 kPa is shown in Figure 7. From this Figure, one can observe the increase of dilatancy in the mixture with the increase of the silt content and the decrease observed once the silt content is superior to 10%. Due to the 6% of water content used in the experiment the soil was considered unsaturated in the current study. Comparing the results obtained with those obtained by Vu -o-Anh *et al.*, (2016), using drained triaxial tests on sand, all results obtained have some similarity. Then it can be deduced that the incremental limited water content used in the current study did not affect significantly the variation of dilatancy angle in the silty sand, while more analysis on this topic will perform tests in drained condition.

## CONCLUSION

From the current study, 9 different direct shear tests were carried out to evaluate the effect of silt percentage on the shear strength properties of sand applying different values of vertical stress. The samples were prepared with silt contents of 10%, 25% and 50%, and compacted at 65% of relative density. The samples of sandy soil were analysed under vertical stresses of 50,100,150kPa and, giving the following results:

- The samples behaviour depends on the sand grains arrangement.

- An increase in the silt content in mixtures with silt 10% increases the dilatancy. But, next, with an increase in silt content into mixtures covering from 25% to 50%, the dilatancy decreases, and with the decrease of the vertical stress, an increase is observed in the angle of dilatancy as well.
- The peak shear strength and friction angle of samples of sandy-soil increases once the silt content is up to 10%, and then the decrease is observed with an increase of silt content.
- The increase of silt content with decrease in shear strength means the creation of an environment susceptible to erosion, landslides and collapses.

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