Effect of Equivalent Granular state Parameter of Sandy silt on Residual Shear Strength using Static Triaxial test

Aarti Hiremath
Civil Engineering Department
D Y Patil College of Engineering, Pune

Mrs. Rupa Dalvi
Civil Engineering Department,
College of Engineering, Pune

Abstract

The flow failures of the alluvial sandy ground induces catastrophic damage such as tilting of structures, floating up of buried structures, spreading of embankment and permanent later displacement of ground. Some of the researchers have even noticed that the softening of the soil occurs in slope ground due to liquefaction, it is controlled by gravity forces. Based on these observations, in order to quantify the tendency of flow characteristics of sandy soils, a simple and reliable concept of steady state strength approach has been used. To evaluate the same, total ten tests are conducted with relative density varying as 30% and 45% and for same effective consolidation pressure of 120kPa.The residual shear strength of soil was calculated using the concept of Castro and Polous, 1985. It was observed that with increase in equivalent granular state parameter the residual shear strength reduces till threshold fines content and later on increases.

1. Introduction

Past research has debated the effect of non-plastic silt content on liquefaction potential of sand. Many studies suggested that liquefaction resistance increases with increase in silt content (Seed et al.1983, 1985; Tokimastu and Yoshimi 1983; Salgado et al. 2000; Polito and Martin 2001). However other studies concluded that potential for contractive behaviour is based on the deposition state either loose or dense (Lade and Yamamuro 1997; Kuerbis 1989; Zlatovic and Ishihara 1997).

Based on observation that different silt content in sand will produce different Steady state lines, been and Jefferies (1985, 1986) attempted to characterise effect of silt content on sand behaviour. They proposed to characterise sand behaviour with respect to its state parameter. Effect of fines content on static liquefaction of sandy silt was studied by Carl D.Loiggio,, Jerry A. Yamamuro, and Poul V.Lade. (2009). Rahman .M.M and Lo S.R predicted the equivalent granular steady state line of loose sand with fines content. However the effect of equivalent granular state parameter on residual shear strength of soil could not be predicted.

The focus of this study was to study the determination of equivalent granular state parameter and its effect on the residual shear strength of the soil. Systematic variation in fines content (0%, 5%, 15%, 25% and 30%) and densities (low and medium) were used to determine how each affects the liquefaction potential of sandy silt.

2. Experimental Investigation

2.1 Sample tested

Clean sand

Grain size distribution or the percentage of various sizes of soil grains present in given dry soil

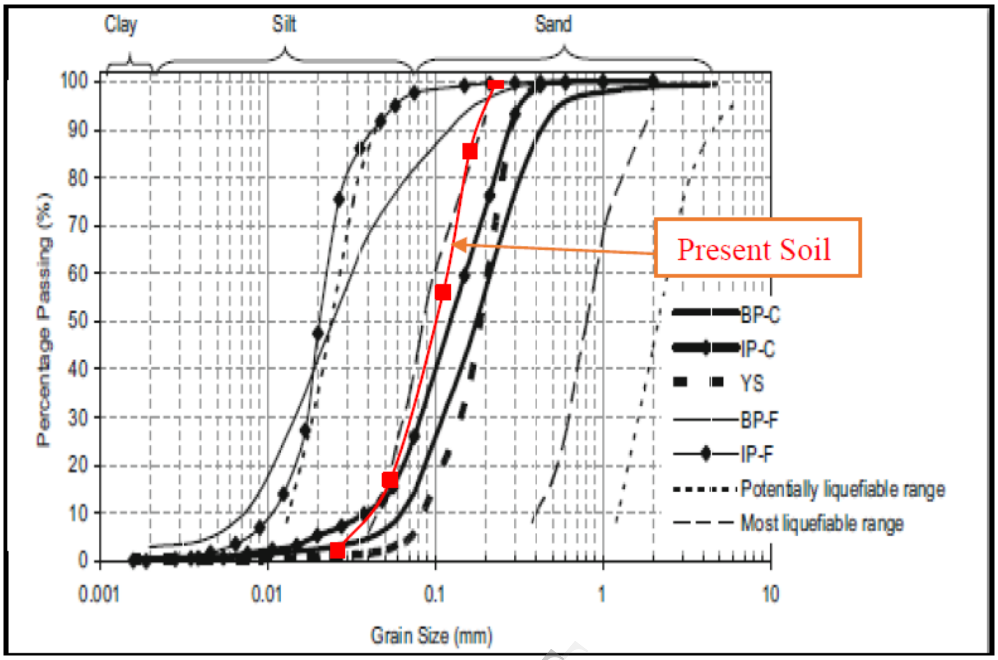


Figure 1. Grain size distribution curve for clean sand used in the proposed research work along with grain size distribution of soils susceptible to liquefaction proposed by Tsuchida (1970)

sample, is an important soil grain property. The sieve analysis procedure is confirming to IS 2720 Part 4 using mechanical sieve shaker.Also, when gradation of sand used in the current research work is superimposed on grain size distribution curve of soils susceptible to liquefaction proposed by Tsuchida (1970), it is observed that (Figure 1), the sand used for proposed research work falls well within the boundaries for most liquefiable soil.

Clean silt

Grain size distribution or the percentage of various sizes of soil grains present in given dry soil sample, is an important soil grain property. The sieve analysis procedure is confirming to IS 2720 Part 4 using hydrometer. Grain size distribution curve of the silt used for testing is as shown in Figure 2.

2.2 Determination of Maximum density (γmax) and Minimum density (γmin) of sand and silt respectively

The maximum and minimum density has been computed by a procedure confirming to IS 2720 Part 14. Using these values, e_{max} and e_{min} are calculated

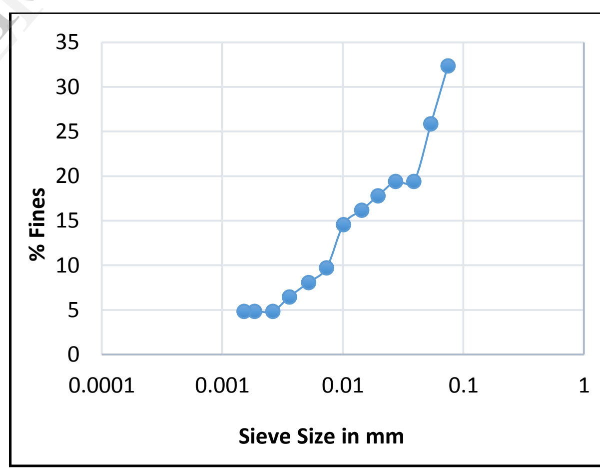


Figure 2. Grain Size Distribution curve for clean silt used in the Proposed Research Work

$Relative\ Density$ (%) = $((e_{max} - e)/(e_{max} - e_{min}))$ x100

…………………………………………………..…..(3.1)

Where $e= G \times \gamma_w \gamma_d$ -1
Where γ_w = Density of Water (9.81 kN/m^3)

Using these relations and basic equations in Soil Mechanics, the quantity of sand required to fill the known volume is calculated. Also quantity of water is

Table 1.Properties of clean sand

Properties Of Sand	Value	IS Code
γ_{max}	18.12 kN/m^3	IS : 2720 (Part 14)-1983
γ_{min}	15.34 kN/m^3	IS : 2720 (Part 14)-1983
G	2.67	IS : 2720 (Part 3/sec 1)-1980
e_{max}	0.8093	IS : 2720 (Part 14)-1983
e_{min}	0.5725	IS : 2720 (Part 14)-1983
D_{50}	0.28 mm	IS : 2720 (Part 4)-1985
C_u	2.56	IS : 2720 (Part 4)-1985
C_c	1	IS : 2720 (Part 4)-1985

Table 2. Properties of silt

Properties Of Sand	Value	IS Code
γ_{max}	15.17 kN/m^3	IS : 2720 (Part 14)-1983
γ_{min}	11.91 kN/m^3	IS : 2720 (Part 14)-1983
G	2.67	IS : 2720 (Part 3/sec 1)-1980
e_{max}	1.1070	IS : 2720 (Part 14)-1983
e_{min}	0.6547	IS : 2720 (Part 14)-1983
D_{50}	0.02mm	IS : 2720 (Part 4)-1985
C_u	1.6	IS : 2720 (Part 4)-1985
C_c	0.056	IS : 2720 (Part 4)-1985
LFC	27.07	H. K Dash & T.G.Sitharam

sample, is an important soil grain property. The sieve analysis procedure is confirming to IS 2720 Part 4 using hydrometer. Grain size distribution curve of the silt used for testing is as shown in Figure 2.

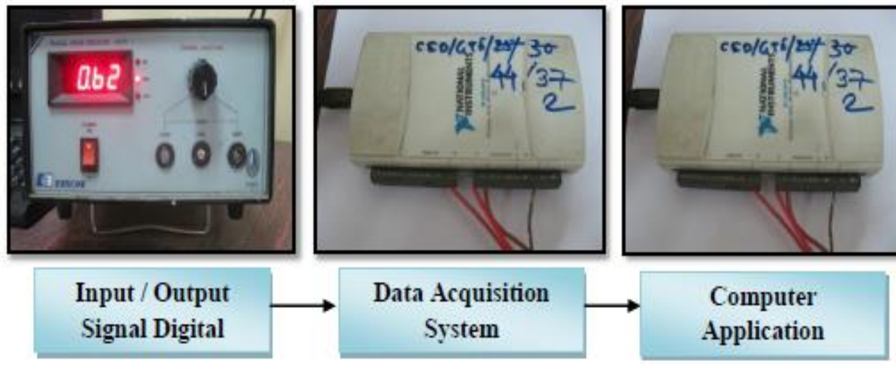
2.2 Determination of Maximum density (γmax) and Minimum density (γmin) of sand and silt respectively

The maximum and minimum density has been computed by a procedure confirming to IS 2720 Part 14. Using these values, e_{max} and e_{min} are calculated

$$Relative\ Density\ (\%) = ((e_{max} - e)/(e_{max} - e_{min}))\ x100 \quad \text{………………………………………………..…..(3.1)}$$

Where $e = G \times \gamma_w \gamma_d$ -1
Where γ_w = Density of Water (9.81 kN/m^3)

Using these relations and basic equations in Soil Mechanics, the quantity of sand required to fill the known volume is calculated. Also quantity of water is calculated. And the required relative density is achieved. Table 1. shows the properties of clean sand and Table 2. Shows properties of clean silt.



Photograph 1. Data acquisition system

2.3 Instrumentation

For any experimental work instrumentation has become an integral part now-a-day. As it produces controlled observations, accurate results and minimize the errors. To study the initiation of liquefaction using this equipment one transducer, LVDT and load cell are used. Transducer to measure pore water pressure, LVDT to measure axial strain and load cell to apply axial load Capacity of pore pressure transducer is with least count 0.1 kPa, capacity of LVDT is 10 mm with least count of 0.1 mm & capacity of load cell is 15 kN.

Pore pressure transducer is used to measure the pore water pressure

LVDT is mounted on the triaxial cell as to measure axial deformation.

The air water system comprises of two cylindrical chambers with balloon arrangement, one used to apply confining pressure to simulate field condition and other used to saturate the specimen so as to simulate the liquefied soil. Capacity of each chamber is 1000kPa with least count 1kPa.

Vacuum Pump is used to remove the air voids present in between soil particles after soil is reconstituted.

Carbon-di-oxide is used to replace the air as it is easily soluble in water and accelerates saturation of the soil specimen.

Calibration are necessary for making instruments compatible with data acquisition system. Calibration involves conversion of analogy signals from Display units of instruments to the exact output of instruments and records for given time interval as shown in Photograph 1.

Calibration quantifies and improves the measurement performance of the instrument. Benefits of maintaining properly calibrated equipment include reduced measurement errors, consistency between measurements and the assurance of accurate measurements.

2.4 Scanning Electron Microscope analysis

Scanning electron microscope analysis was conducted at Pune University .The objective of the analysis was to observe the shape, roughness of the sand and silt particle along with their mineral composition as they play an important role in characterizing the shear strength of the soil.

The sand particles reflected angular shape as shown in Photograph 2. indicated that it has less internal angle of friction due to which soil exhibit more shear strength. The surface of sand particle observed was rough, with increase in density the bonds between adjacent soil particles become stronger and ultimately shear strength increases as indicated in Photograph 3.

The milky lustre is due to presence of minerals presented in Photograph 4.

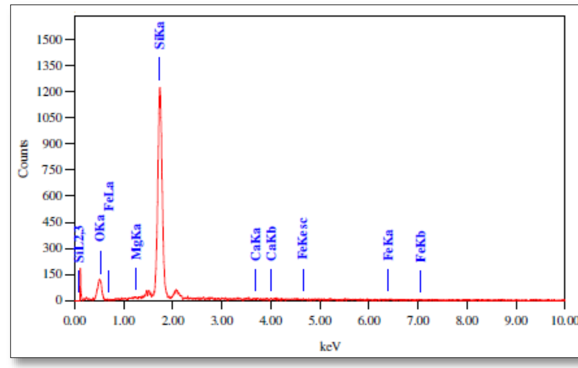
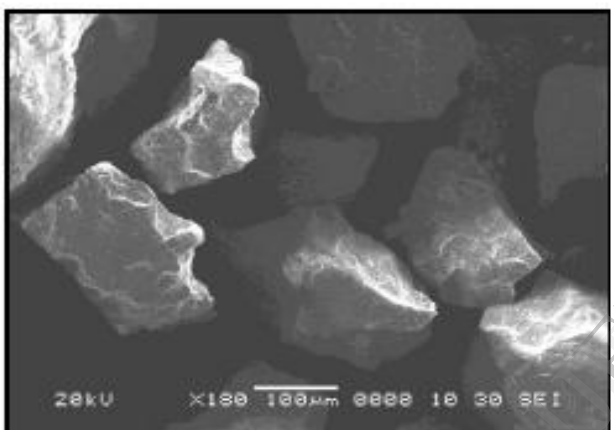
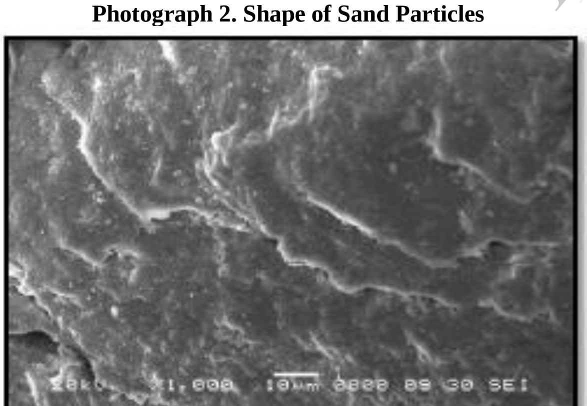


Figure 3. Counts Vs. KeV



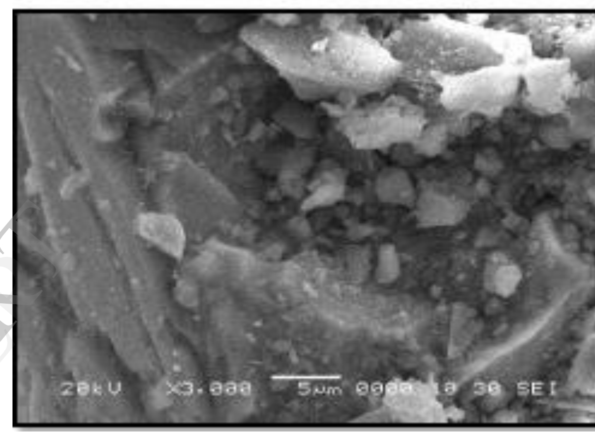
Photograph 2. Shape of Sand Particles



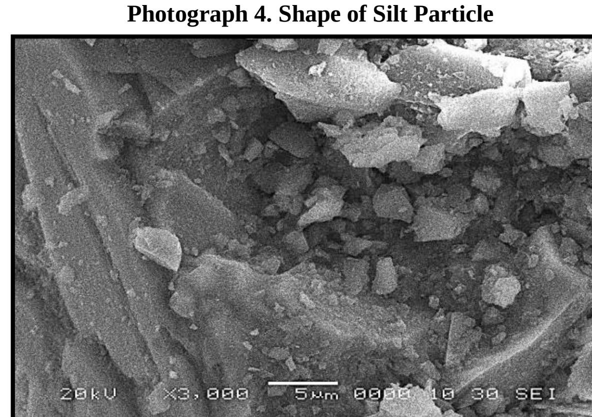
Photograph 3. Surface of Sand particle

Table3. Mineral composition

Element	(keV)	mass%	Error%	At%
O K	0.525	26.69	2.64	39.24
Mg K				
Si K	1.739	71.33	0.89	59.75
Ca K	3.690	1.06	2.24	0.62
Fe K	6.398	0.92	4.52	0.39
Total		100.00		100.00



Photograph 4. Shape of Silt Particle



Photograph 5. Surface of Silt particle

Similarly silt particles indicated Flaky shape and rough surface as shown in Photograph 4. & Photograph 5.

Sr. No.	Name of Test	Fines Content	Relative Density	Voids Ratio	Effective Stress
1	M-00	0%	30%	0.7382	120 kPa
2			45 %	0.7072	120 kPa
3	M-05	5%	30%	0.6769	120 kPa
4			45 %	0.6461	120 kPa
5	M-15	15%	30%	0.6141	120 kPa
6			45 %	0.5761	120 kPa
7	M-25	25%	30%	0.5951	120 kPa
8			45 %	0.5569	120 kPa
9	M-30	30%	30%	0.6389	120 kPa
10			45 %	0.5987	120 kPa

Table 4. Testing Program

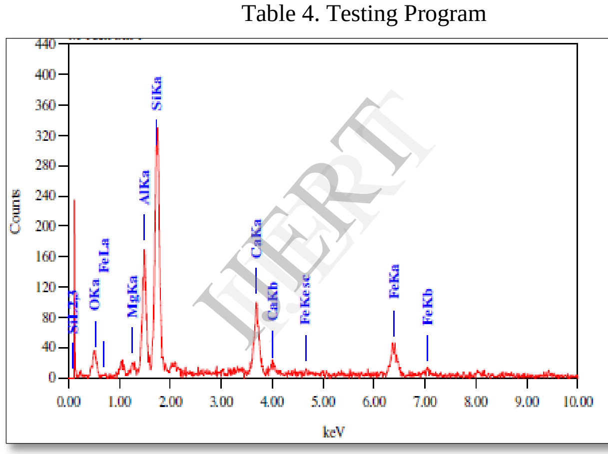


Figure 3. Counts Vs. KeV

Testing procedure

Test was planned with moist tamping method for size 75mm x 150 mm and fines varying before and after ‘Threshold Fines Content’. Detailed testing program is given in Table 4.

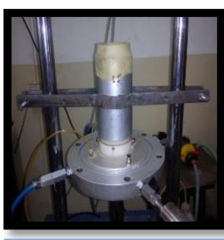
Testing procedure

Initially a weighed amount of soil is determined from relative density tests shown in Photograph 3.18, then it is mixed with five percent of water as shown in Photograph 3.19.The split mould along with a membrane is placed on the triaxial base. The mould is filled with approximately same amount of soil with fixed amount of blows. After the mould is completely filled with soil Photograph 3.21, its end is made water tight using O-rings. After the specimen is prepared it is subjected to vacuum to avoid the disturbances during further process. Now, the spilt mould is removed and thee density of the specimen is ensured by measuring the height of the specimen as shown in photograph 3.22. The triaxial cell is placed over the specimen. The cell is completely filled with water by means of a motor and if these is no leakage detected than carbon-di-oxide is supplied to accelerate the saturation rate of the specimen. By simultaneous application of confining pressure and back pressure, the specimen is saturated till 100%. The 100% saturation is measured by using Skempton Pore pressure parameter (B value) defined as ratio of change in confining pressure to the change in the pore pressure. The B value greater than 0.96 indicated the specimen is 100% saturated.

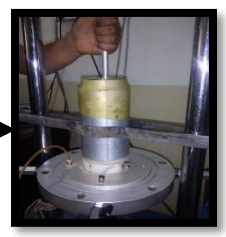
The specimen is isotropically consolidated at an effective stress of 120kPa. Now, the specimen is sheared at a constant rate of 0.01 %/min, this is minimum possible strain at which there is uniform dissipation of pore water pressure. The LVDT is mounted on the cell to measure the deformation during shear. The reading are recorded till a visual failure pattern of specimen is observed Photograph 3.23.

Photograph 6. Dry weight

Photograph 7. Wet weight



Photograph 8. Empty mould



Photograph 9. Filled mould

Photograph 10. Check for density

Photograph 11. Sample with cell

4. Results and discussion

4.1 Stress- strain Behaviour, pore pressure generation and effective stress path in Strain-Controlled Undrained Triaxial Test.

Strain controlled consolidated undrained (CU) tests were conducted on the samples with fines content varying as 0%,5%, 15%, 25% and 30% with two relative densities(RD) subjected to same effective consolidation pressure, 120kPa.

For RD 30%

Figure 5. Shows that clean sand has maximum deviator stress and with an increase in fines content leads to a decrease in the deviator stress till threshold fines content and later on increases. This decrease results from the role of fines in reducing the soil dilatancy and amplifying the phase of contractancy of the sand-silt mixtures.

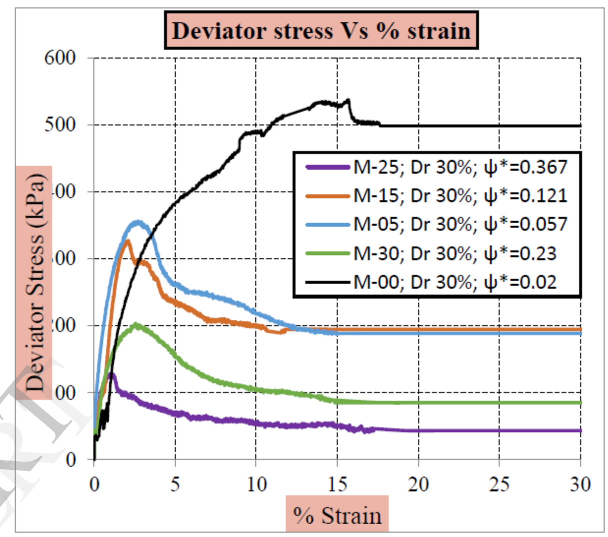


Figure 5. Stress- strain behaviour at different fines content at relative density 30%

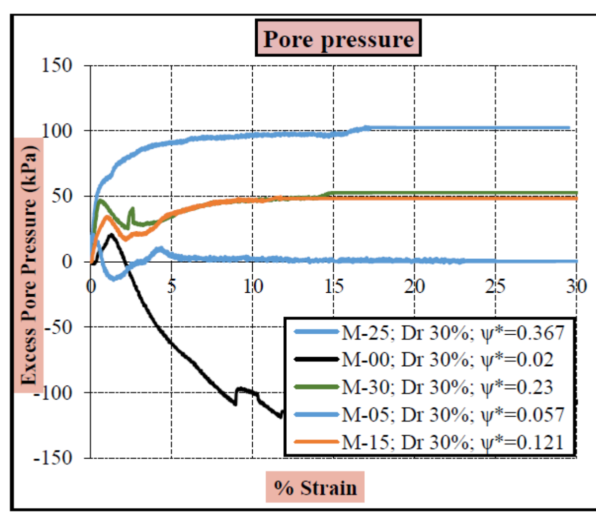


Figure 6. Excess pore water pressure generation Vs. % strain at different fines content at relative density 30%

Figure 6. shows that with increase in fines content there is increase in positive pore water pressure due to which soil exhibits contractive behaviour till threshold fines content later on the positive pore pressure reduces leading to dilative behaviour of the soil. Figure 7.

shows stress path in p'-q plane where it is clear that the role of fines in the decrease in average effective pressure and maximum deviator stress.

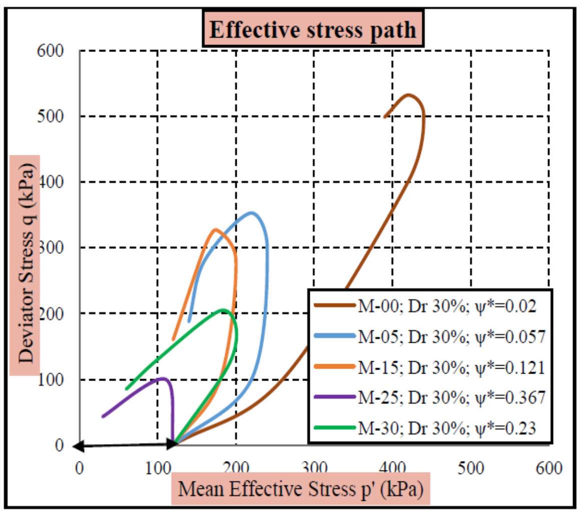


Figure 7. Effective stress path at different fines content at relative density 30%

For RD 45%

Figure 8. Shows same observations as that of Figure7. but the deviator stress is increased due to increase in relative density for all fines content. Figure 9. Shows the amount of pore water pressure developed is less than that developed for 30% relative density. Foiigure10. shows observations similar to that of Figure 7

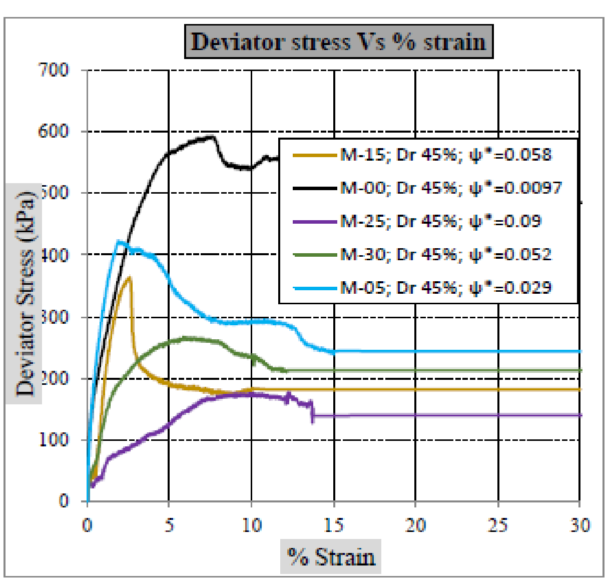


Figure 8. Stress- strain behaviour at different fines content at relative density 45%

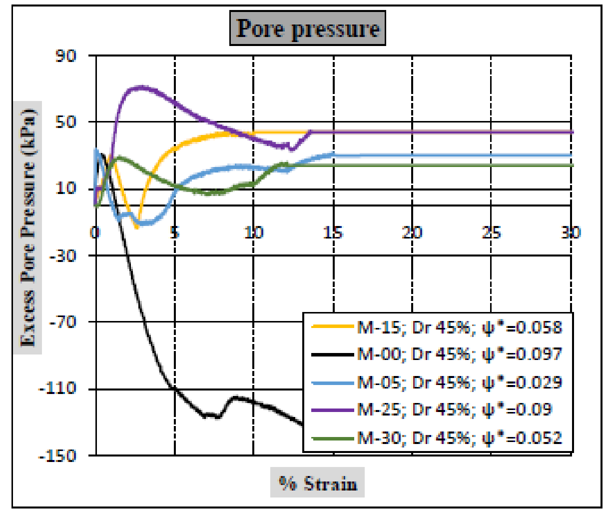


Figure 9. Excess pore water pressure generation Vs. % strain at different fines content at relative density 45%

4.2 Determination of equivalent granular state parameter (ψ*) for varying fines content (FC)

The concept given by Been and Jeffries (2004), and Mizanur Rahman (2011) as shown in Figure 11. was used to plot an equivalent granular steady state line and determine the corresponding state parameter as explained in subsequent Figure 12.

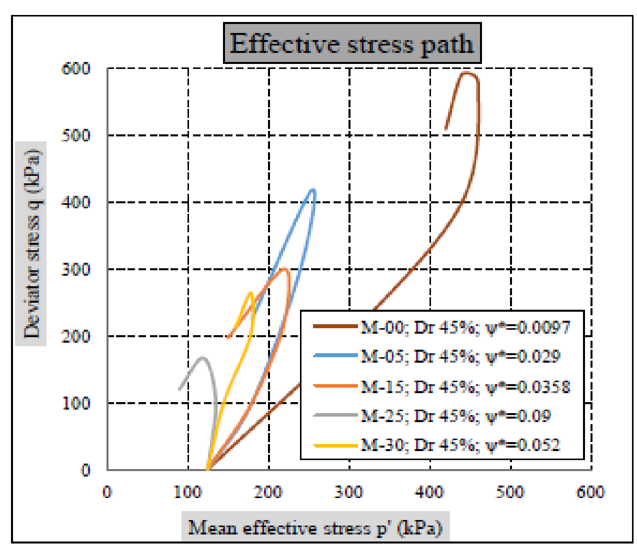


Figure 10. Effective stress path at different fines content at relative density 45%

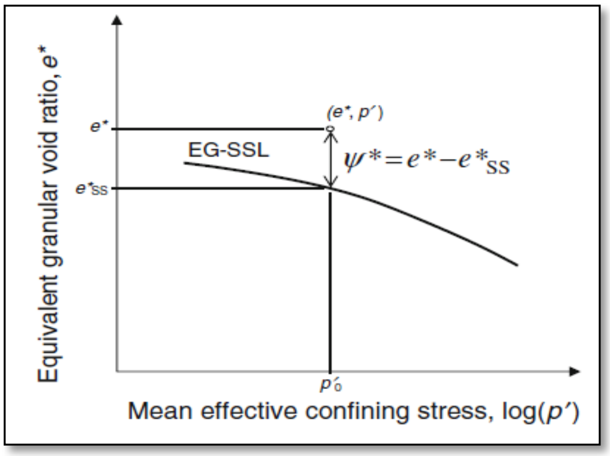


Figure 11. Ref: Mizanur Rahman Acta Geotechnica (2011)

4.3 Determination of undrained shear strength of the sand with varying fines content.

The concept given by Castro and Polous, 1985 (Figure 13.) was used to determine the undrained shear strength of the silty sand.

$S_{su} = q_s \cos \Phi_s$ …………………………………… *eq (1.)*

$\sin \Phi_s = q_s /(\sigma'_{3s} + q_s)$………………………......*eq (2.)*

$q_s = (\sigma'_{1s} - \sigma'_{3s})/2$……………………….…….*eq (3.)*

4.4 Relationship between Undrained residual strength Vs. Equivalent granular states

Figure 14. Shows that with increase in equivalent granular state parameter the residual

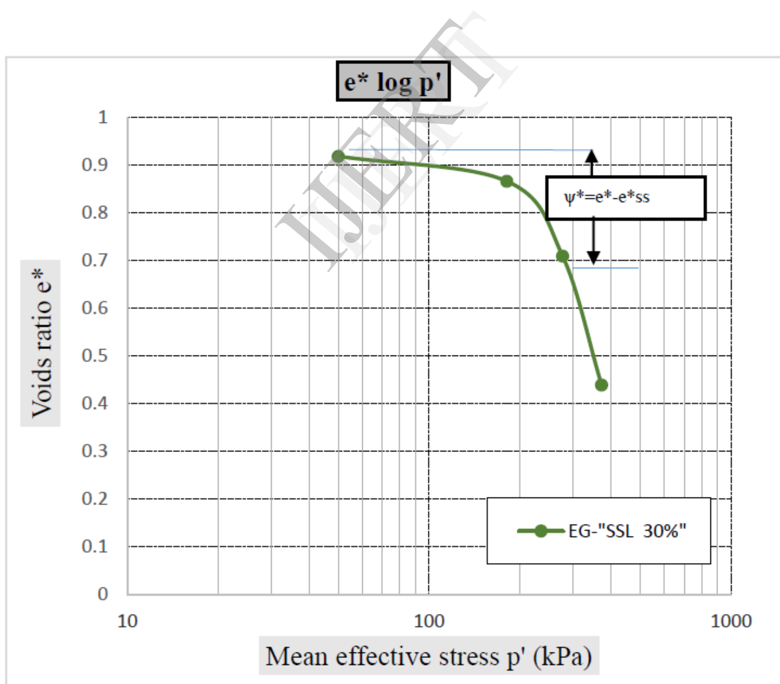


Figure 12.Intergranular voids ratio (e) Vs. mean effective confining pressure (p' kPa)

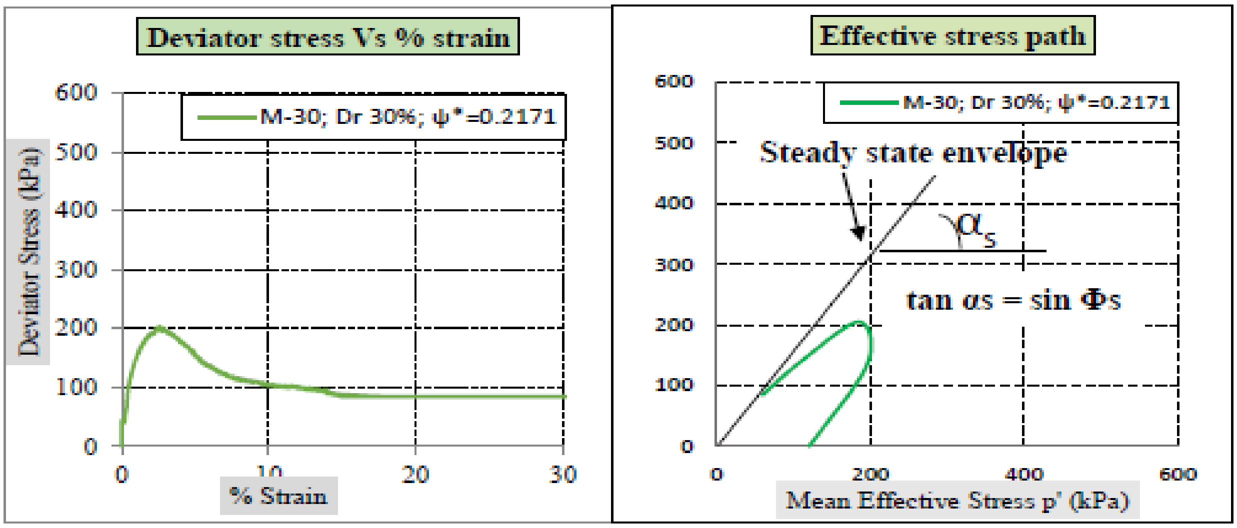


Figure 13. Determination of internal angle of friction (Φ_s)

Table 5. Undrained shear strength of sand silt mixture for RD =30%

Fines content (%)	α_s	φ_s	Ψ*	Ssu (kPa)
0	41	60.37	0.02	123.11
5	42	64.21	0.057	40.78
15	43	68.83	0.121	28.89
25	44	74.94	0.367	5.59
30	43	71.61	0.23	13.38

Table 6. Undrained shear strength of sand silt mixture for RD 45%

Fines content (%)	α_s	φ_s	Ψ*	Ssu (kPa)
0	41	57.07	0.02	138.7
5	42	60.37	0.057	55.61
15	43	64.21	0. 058	42.85
25	44	68.83	0.09	21.66
30	43	66.39	0.052	42.67

shear strength reduces till threshold fines content. In this laboratory investigation, for range 5 % to 25% fines content in normally consolidated undrained compression triaxial test, the following expressions are suggested to evaluate the undrained residual shear strength which is function of equivalent granular state parameter

Ssu =72.37 + 558.37 (ψ)……for RD = 30% eq (4.6)*

Ssu = 44.683- 108.07 (ψ)……for RD = 40% eq (4.7)*

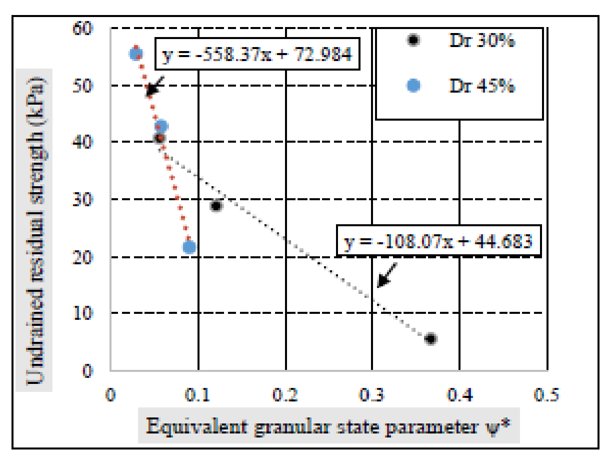


Figure 14. Undrained residual strength Vs. Equivalent granular state Parameter

5. Comparison with previous research work

Undrained shear strength and global voids ratio

As discussed above the fines content play an important role in determination of equivalent granular state parameter [Md. Mizanur Rahman . S. R. Lo, Md. Abdul Lahil Baki. (2011)]. The residual shear strength is investigated in the present research work by comparing the results obtained from present study with previous research work [Noureddine Della et. al. Acta Polytechnica Hungarica (2010)], as shown in Figure 15. and Figure 16.

Figure 15. Shows that with increase in fines content the undrained shear strength decreases till threshold fines content later on it increases. Whereas, in Figure 16, it was observed that with increase in fines content goes on reducing irrespective of the threshold fines content. In present work the role of non-plastic fines was considered and in previous work the role of plastic fines was considered.

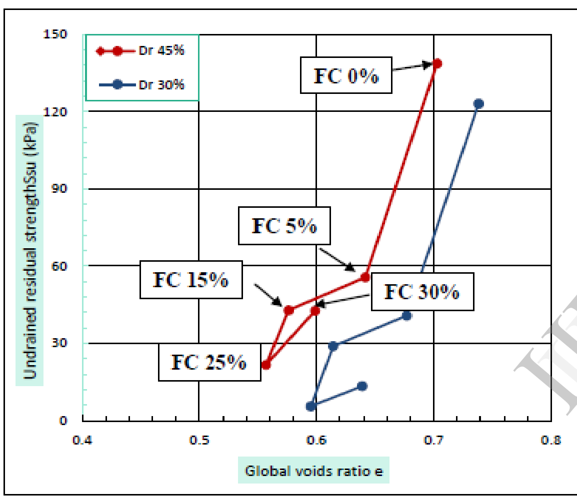


Figure 15. Undrained Residual Strength vs. Global voids ratio

Undrained shear strength and relative density

As relative density increases the natural voids ratio decreases and due to close packing of the soil mixture, the undrained shear strength increases. Figure 17, shows that with increase in relative density from 30% to 45% the shear strength increases for all fines content. The residual shear strength of clean sand is maximum as compared to sand with varying fines content. These observation as in good correlation with the previous work done by Noureddine Della et.al. Acta Polytechnica Hungarica (2010), Figure 18.

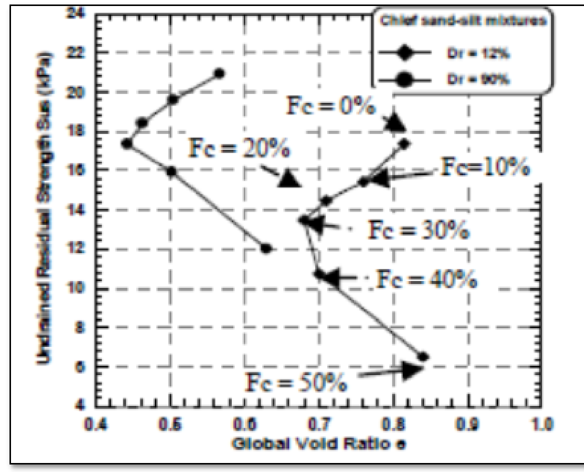


Figure 16 Undrained Residual Strength Vs. Global voids ratio [Ref:Noureddine Della et. al. Acta Polytechnica Hungarica(2010)]

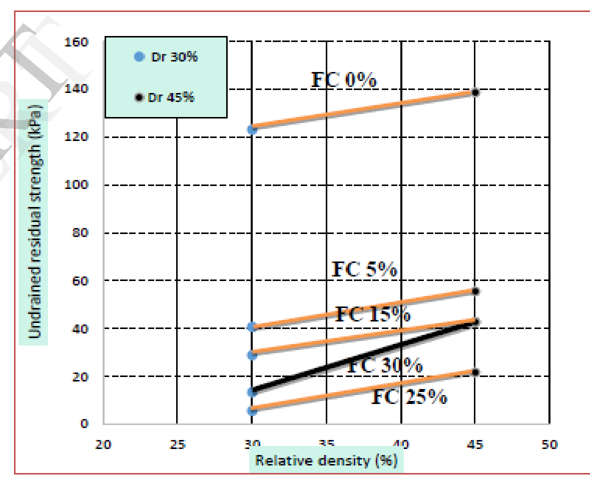


Figure 17. Undrained Residual Strength Vs. Relative Density

5. Conclusions

Based on the experimental work carried out in the present study, the following conclusions are drawn:

1. It is seen for all the tests that pore water pressure increases with time initially and then remains constant or decreases after attaining a peak. This stage could be considered as initiation of liquefaction.
2. The undrained residual strength reduces with increase in fines content (non-plastic), global voids ratio and equivalent granular voids

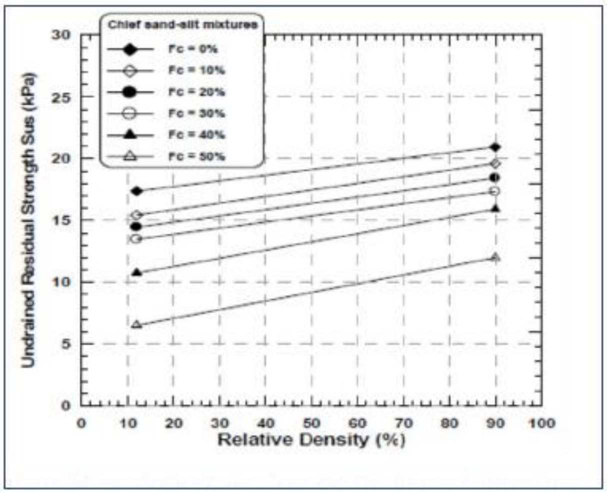


Figure18. Undrained Residual Strength Vs. Relative Density [[Ref:Noureddine Della et. al. Acta Polytechnica Hungarica(2010)]

ratio up to 25% fines content. Beyond that it reduces with increase in fines content, global voids ratio and equivalent granular voids ratio.

3. The undrained residual strength increases with increase in relative density.
4. The equivalent granular state parameter determined are positive which indicates contractive behaviour.
5. The equivalent granular state parameter value reduces with increase in relative density.
6. For same effective consolidation pressure, the undrained residual strength of sand-silt mixture increases with increase in value of equivalent granular state parameter.
7. The peak and undrained strength of sand are sensitive to presence type of fines content.
8. The strength of silty sand up to 25% fines content is less than that of clean sand. It means that the strength of soil is weakened with increase in fines content upto 25%

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