

Modified State Parameter Evaluation of Liquefiable Sand Containing Plastic Fines

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Presentation Overview

- 1 Introduction:
- 2 Research Methodology
- 3 Results & Discussions
- 4 Conclusion



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1. Introduction

Soil Liquefaction – Flow Liquefaction & Cyclic Mobility

Flow liquefaction triggering mechanism

- Monotonically increasing loads (Embankment height, oversteepening, sediment accumulation, reservoir filling, construction load, etc...)
- The undrained effective stress path crosses instability line (**Fig. 1**)

Liquefaction Susceptibility Analysis

- Laboratory Testing (Direct measurement).
- Numerical analysis (constitutive models analysis)
- Field Tests.

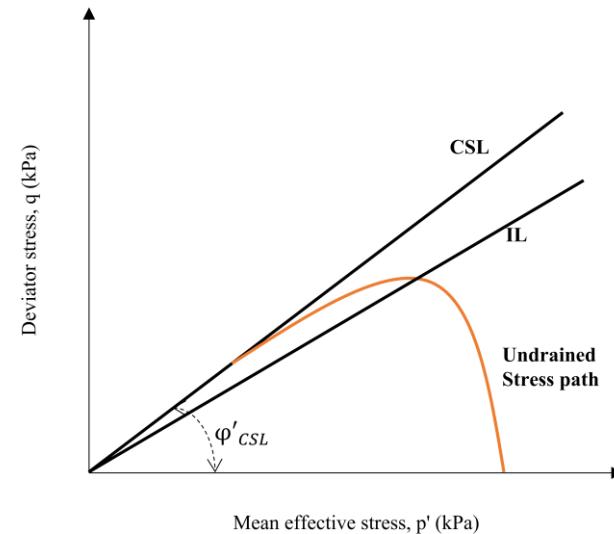


Fig 1. Undrained effective stress path (Loose Sand)



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Laboratory Testing (Element Testing)

- Direct measurement
- Sample Reconstitution Techniques → Dry funnel deposition, Water sedimentation, moist tamping, air pluviation, etc...
 - Dominating factors (Relative density, morphological characteristics, fines content)
 - Additional factors (Inherent fabric anisotropy, degree of saturation, volume change boundary conditions)
- Testing Method.
- Stress Levels.
- Assessment of Liquefaction Potential

Table 1: Reconstitution techniques

RECONSTITUTION TECHNIQUE	ADVANTAGES	DISADVANTAGES
Dry Deposition	<ul style="list-style-type: none">• Simple preparation• No separation of fines• Wide range of density	<ul style="list-style-type: none">• Density is effected by drop height• Larger particles moves toward edge while tamping
Moist Tamping	<ul style="list-style-type: none">• Simulates natural sedimentation process• Saturation process is easier	<ul style="list-style-type: none">• Fines separation• Segregation of heavy particle
Water Sedimentation	<ul style="list-style-type: none">• Simple preparation• No separation of fines• Wide range of density• Density control	<ul style="list-style-type: none">• Formation of layers• High stresses application

Undrained Monotonic Behaviour

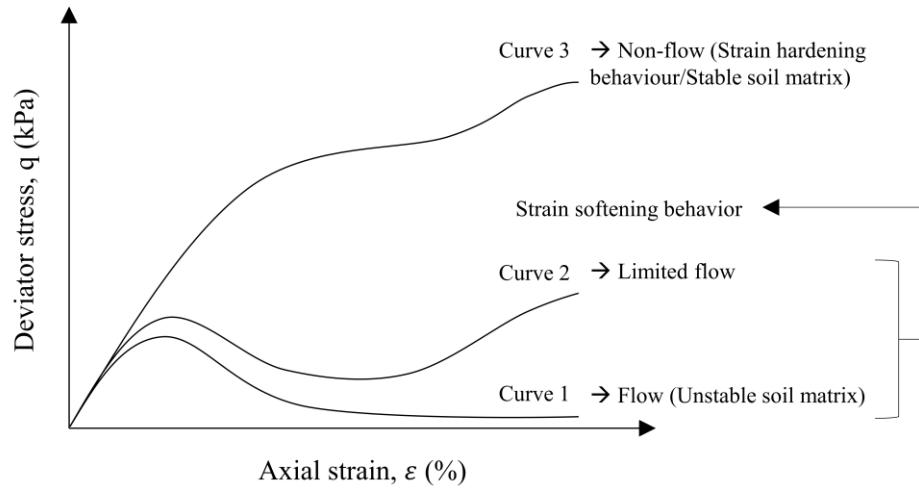


Fig 2. Undrained monotonic behaviour.

Cambridge $p' - q$ stress path:

$$p' = \frac{\sigma'_1 + 2\sigma'_3}{3} \quad p' \quad \text{Effective mean stress}$$

$$q = \sigma_1 - \sigma_3 \quad q \quad \text{Deviator stress}$$

$$\sigma'_1, \sigma'_3 \quad \text{Major and minor effective stress}$$

$$\sigma_1, \sigma_3 \quad \text{Major and minor stress}$$

Critical State Framework

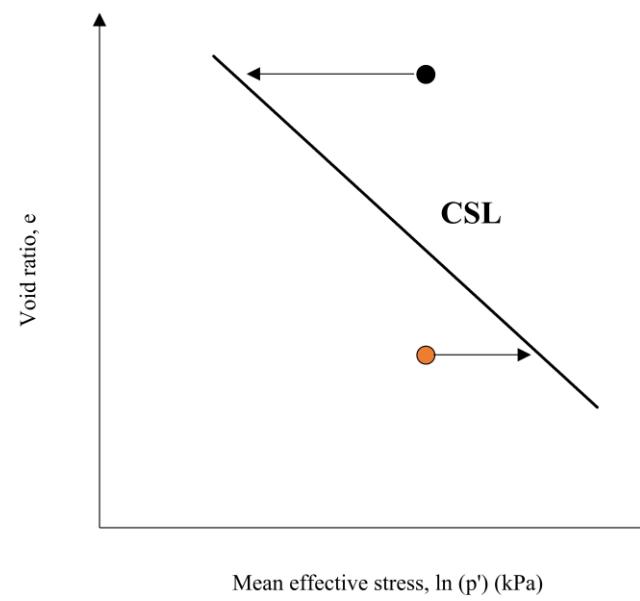


Fig 3. Critical state lines in $e - \ln(p')$ plane.

Critical State Line (CSL)

$$e = \Gamma - \lambda \ln(p')$$

Γ value of void ratio at $p' = 1 \text{ kPa}$

λ Critical state line slope

Wang et al. (2002) power function.

$$e = e_{lim} - \Lambda \left(\frac{p'}{P_a} \right)^\xi$$

P_a Atmospheric pressure, 100 kPa

State Parameter, ψ

- State Parameter, Been & Jefferies (1986)

$$\psi = e_o - e_{CSL}$$

- Stress State Parameter, Klutz & Coop (2001, 2002)

$$R_s = \frac{p'_o}{p'_{cr}}$$

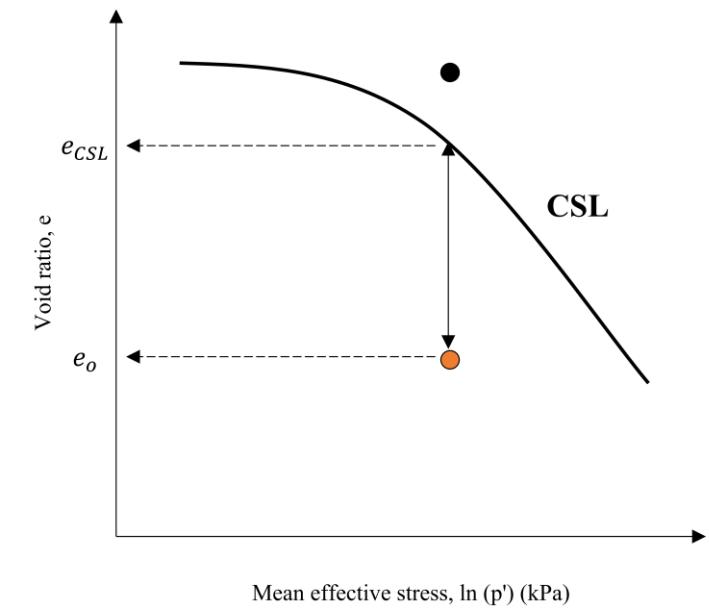
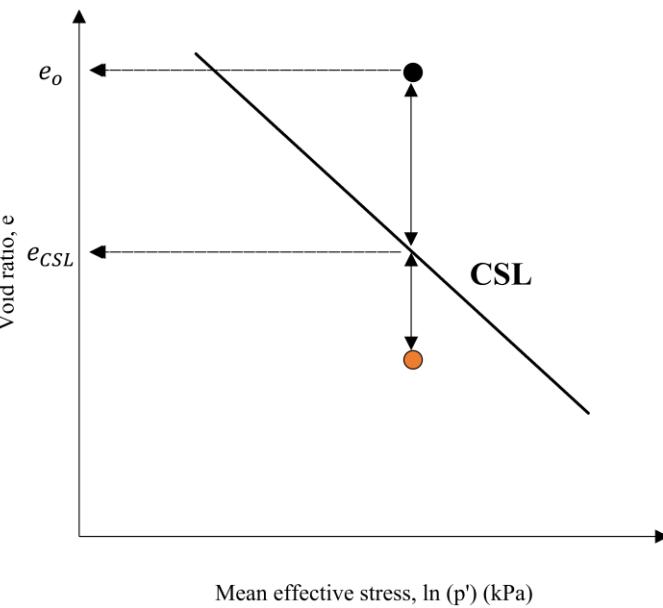


Fig 4. State parameter evaluation.

- Modified State Parameter, Bobei et al., 2009

$$\psi_m = \psi \left| \frac{\Delta p'}{p'} \right| e$$

$\psi > 0$	→ Flow behaviour (+ve ψ)
$\psi < 0$	→ Non-flow behaviour (-ve ψ)

Bobei et al., (2009)

$\psi_m \geq 0.039$	→ Flow behaviour
$0.033 \leq \psi_m \leq 0.038$	→ Flow to limited flow behaviour
$0.003 \leq \psi_m \leq 0.033$	→ Limited flow behaviour
$-0.005 < \psi_m$	→ Non- flow behaviour

2. Methodology

Soil Sampling

- Sand → Silver Beach, Famaguata Bay
- Alluvial Clay → EMU main campus, Famagusta

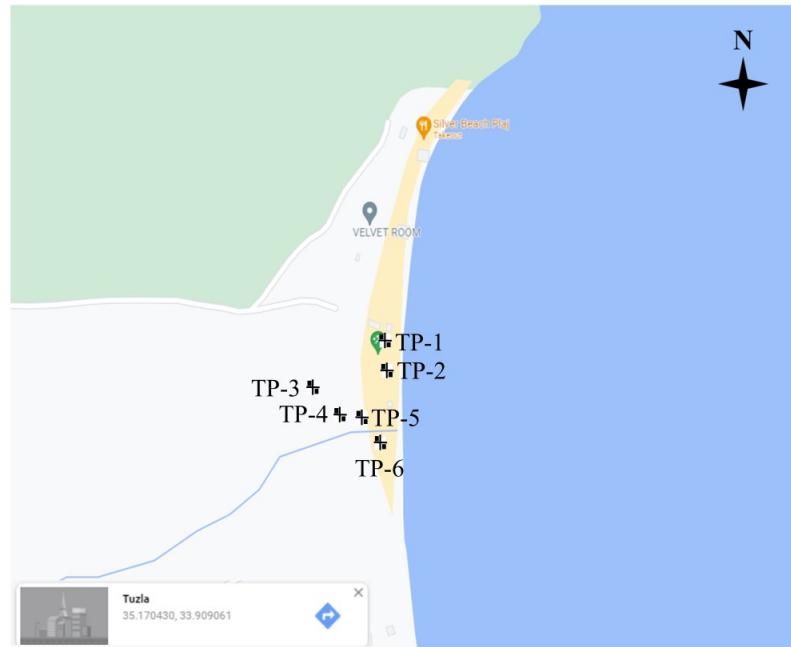


Fig 5. Sand sampling location (Google Maps)

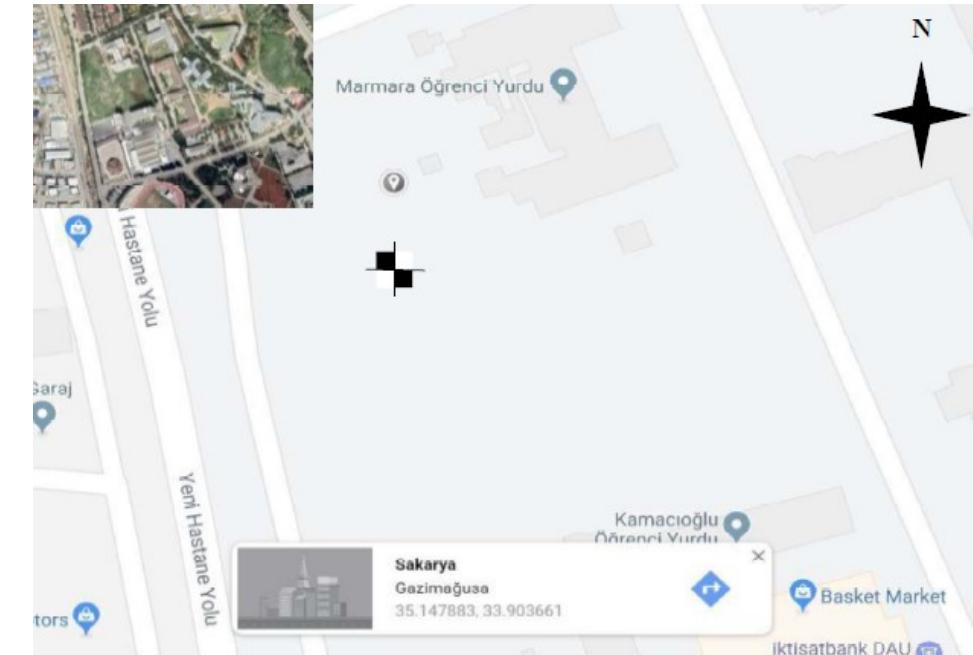


Fig 6. Alluvial clay sampling location (Google Maps)

Soil Properties and Particle-Size Distribution

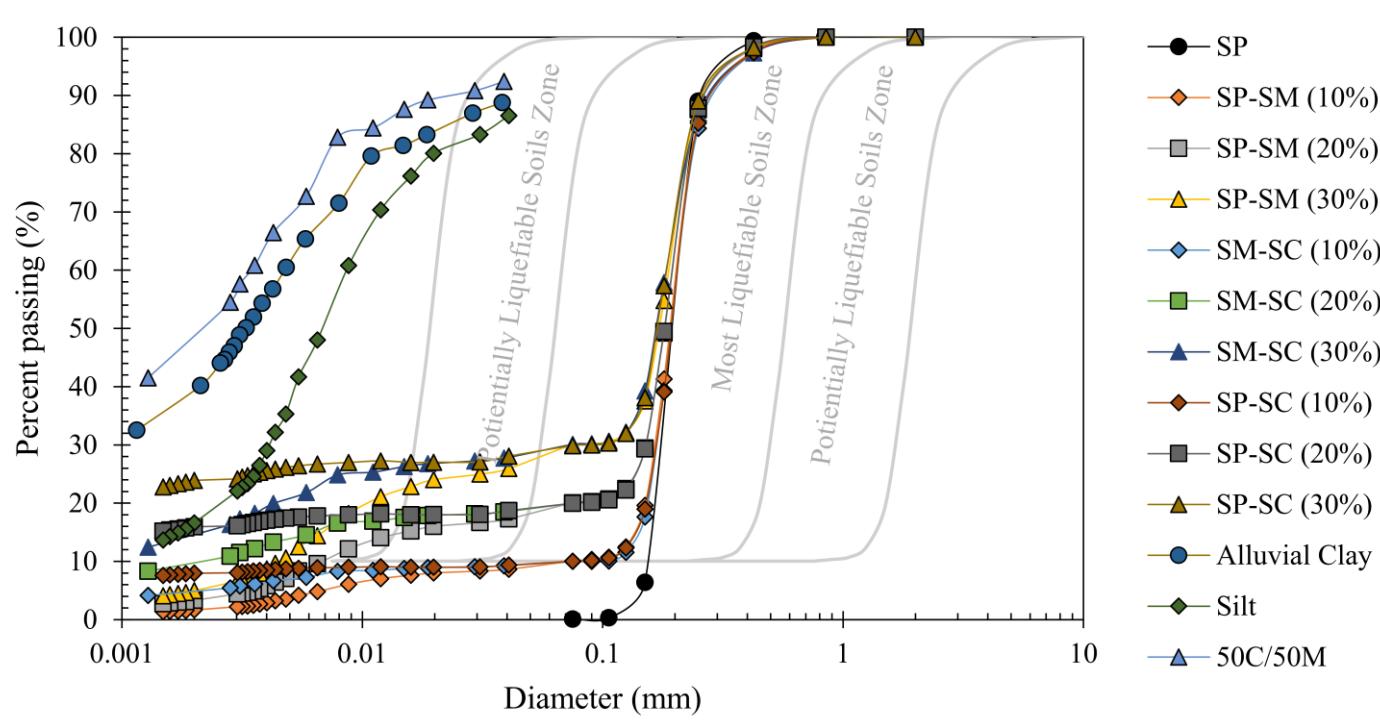


Fig 7. Particle-size distribution of soil groups.

Testing Groups

- Sand (0% Fines)
- 10% Fines
- 20% Fines
- 30% Fines
- Fines Type
 - Silt, Clay and Silty CLAY/Clayey SILT
- **Fines separated by Sedimentation technique.**

Table 2: Sand-Fines mixtures index properties.

Properties	Sand-fines mixture category										Properties	Fine Proportions					
	Sand		Silty Sand			Silty-Clayey Sand			Clayey Sand				Alluvial Clay		50/50 Silt & Clay		
	SP	SP-SM	20%	30%	10%	20%	30%	10%	20%	30%		Silt	Clay				
G _s	2.72	2.68	2.66	2.65	2.67	2.65	2.64	2.65	2.63	2.62	G _s	2.575	2.611	2.609	2.598		
e _{max}	0.95	0.93	0.95	1.06	0.93	0.96	1.05	0.88	0.95	1.04	LL (%)	53	52	52	56		
e _{min}	0.63	0.62	0.65	0.69	0.61	0.65	0.68	0.59	0.64	0.67	PL (%)	25	33	31	27		
p _{d,min} (g/cm ³)	1.39	1.39	1.36	1.29	1.38	1.35	1.29	1.41	1.35	1.28	PI (%)	28	19	21	29		
p _{d,max} (g/cm ³)	1.66	1.65	1.61	1.57	1.66	1.60	1.57	1.66	1.60	1.56	LS (%)	16	15	15	12		
LL (%)	*	3.8	10.4	14.7	5.3	10.4	15.6	6.3	11.2	16.8	USCS	CH	MH	MH	CH		
PL (%)	*	1.4	6.6	8.9	3.8	6.2	9.5	2.9	5.4	10.2	SSA (m ² /g)	111	19	86	146		
PI (%)	*	2.4	3.8	5.8	1.5	4.2	6.3	3.4	5.8	8.7	CEC (meq/100g)	21.65	3.36	23.15	29.12		
LS (%)	*	*	1.0	2.0	*	1.0	2.0	*	2.0	5.0							
D ₁₀ (mm)	0.15	0.070	0.0066	0.0043	0.060	0.0023	*	0.055	*	*							
D ₃₀ (mm)	0.17	0.165	0.150	0.072	0.167	0.151	0.068	0.165	0.150	0.075							
D ₅₀ (mm)	0.19	0.190	0.180	0.168	0.192	0.180	0.166	0.193	0.180	0.165							
D ₆₀ (mm)	0.21	0.200	0.195	0.187	0.205	0.195	0.183	0.205	0.192	0.185							
C _u	1.32	2.85	29.55	43.50	3.42	84.78	*	3.73	*	*							
C _c	0.92	1.94	17.48	6.45	2.27	50.83	*	3.77	*	*							
USCS	SP	SP-SM	SP-ML	SP-ML	SM-SC	SP-CL/ML	SP-CL/ML	SP-SC	SP-CL	SP-CL							
SSA(m ² /g)	*	*	*	*	*	17.2	22	*	29.2	48							

* Test could not be performed.

- Groups are formed by percent dry weight for example, per 100 g of soil 10% silty sand = 10 g silt + 90g sand.

Table 3: Separated fine proportions index properties

Properties	Alluvial Clay	Fine Proportions		
		Silt	50/50 Silt & Clay	Clay
G _s	2.575	2.611	2.609	2.598
LL (%)	53	52	52	56
PL (%)	25	33	31	27
PI (%)	28	19	21	29
LS (%)	16	15	15	12
USCS	CH	MH	MH	CH
SSA (m ² /g)	111	19	86	146
CEC (meq/100g)	21.65	3.36	23.15	29.12

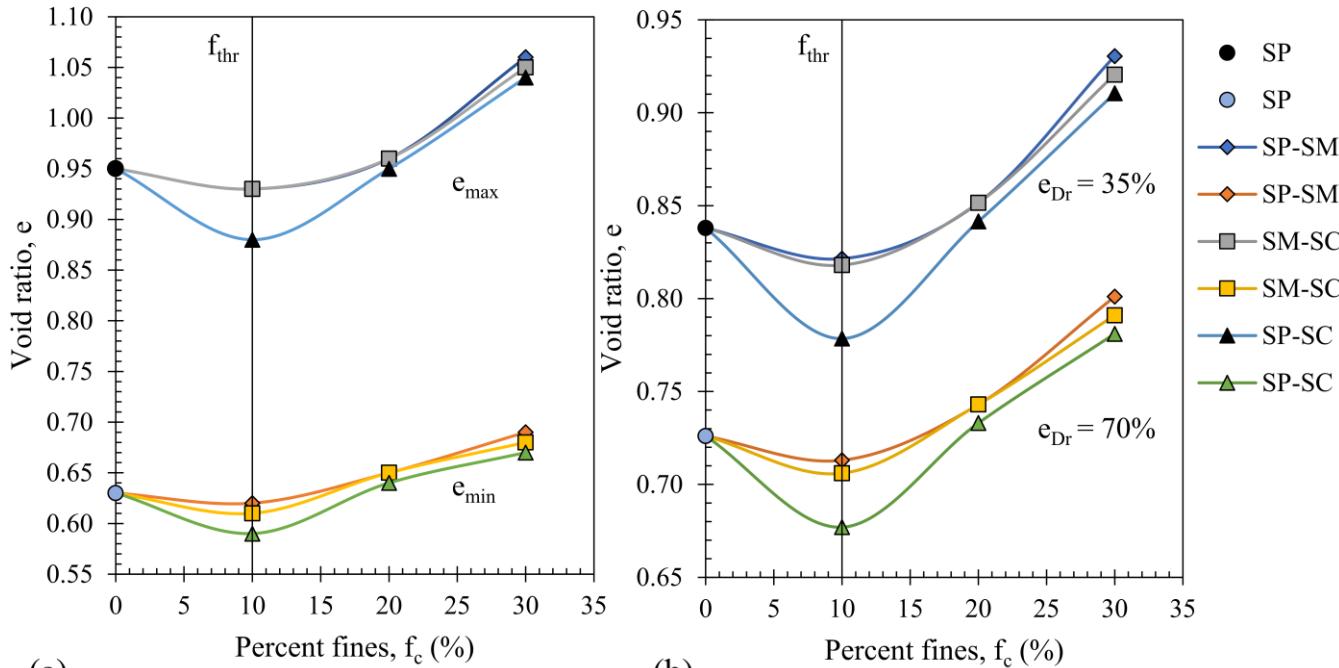


Fig 8. Void ratio variations with respect to fines content.

Specimen reconstitution technique:

- Dry funnel deposition
- Relative density, $D_R \rightarrow 35 \& 70 \%$
- Threshold fines content, $f_{thr} = 10\%$

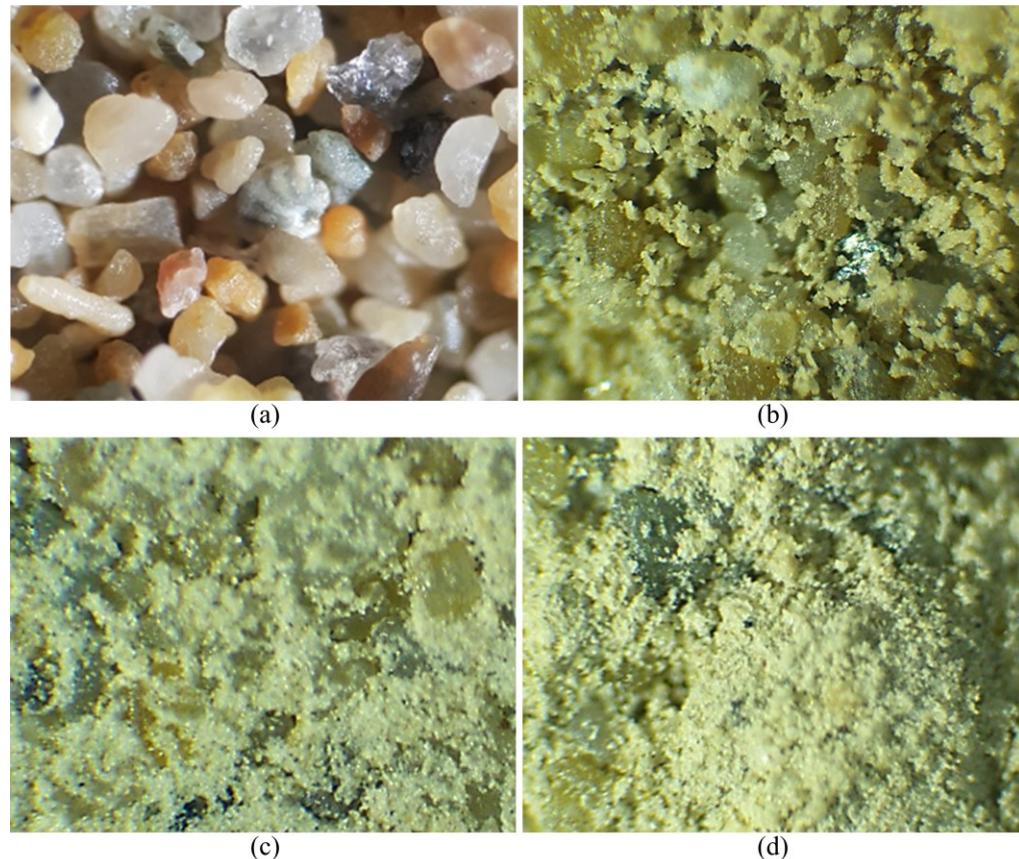
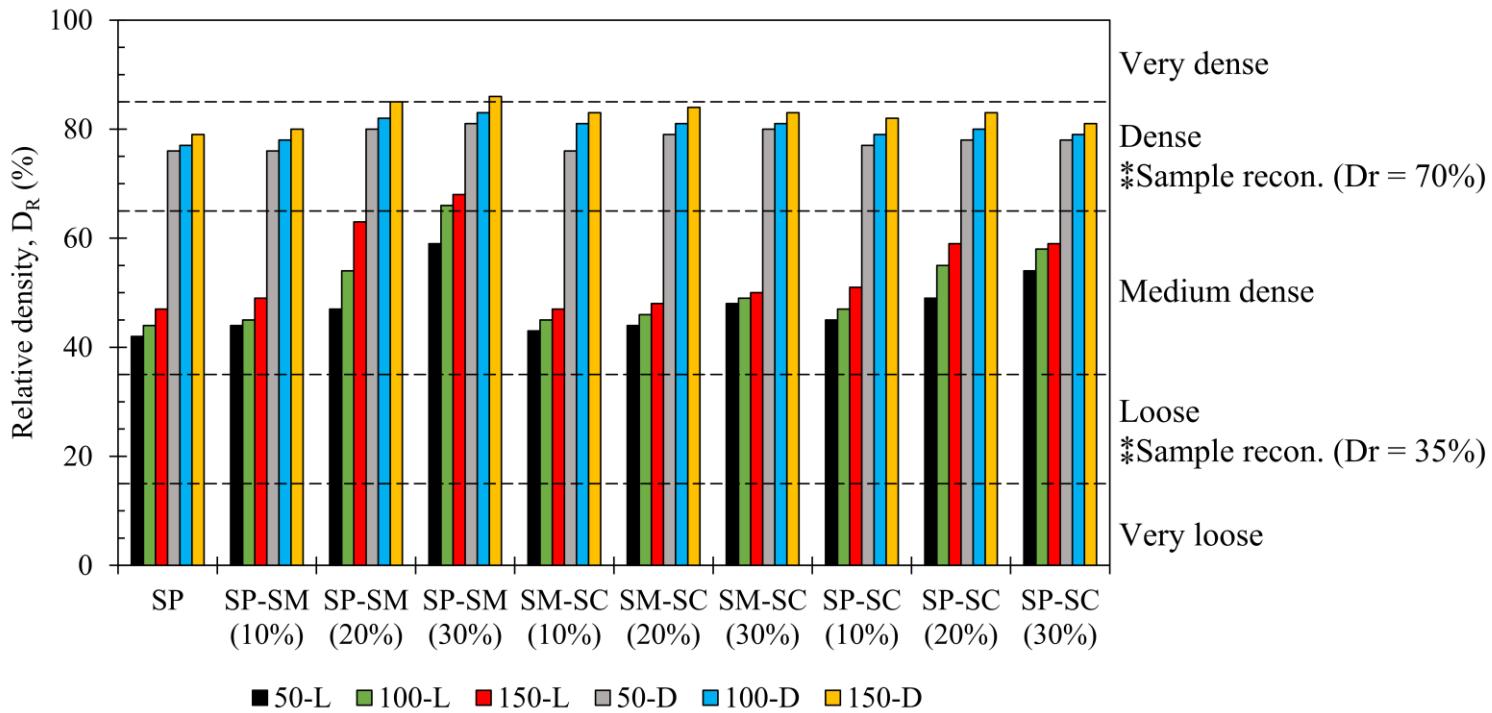
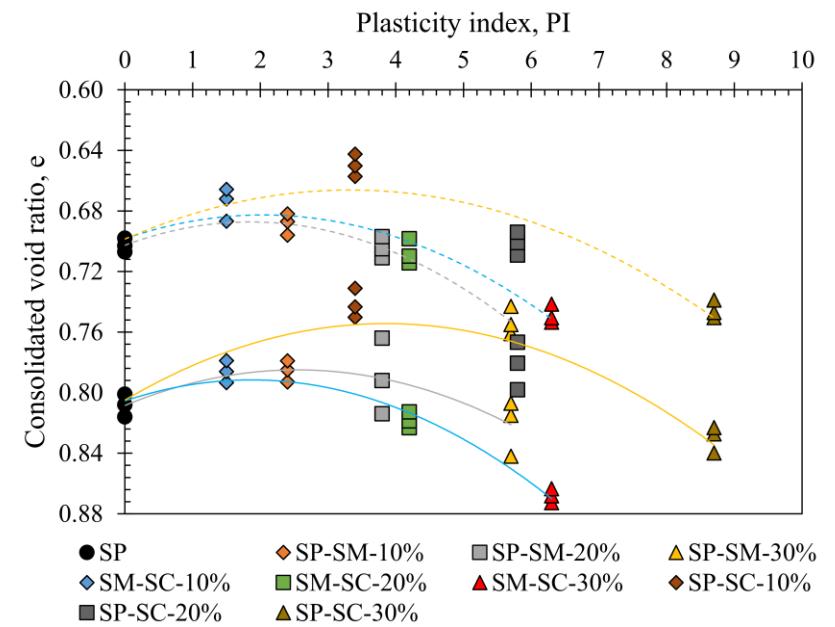


Fig 9. Optical microscope images of (a) Sand (b) 10% sand with fines, (c) 20% sand with fines and (d) 30 sand with fine

3. Results and Discussions



Very dense
Dense
*Sample recon. ($Dr = 70\%$)
Medium dense
Loose
*Sample recon. ($Dr = 35\%$)
Very loose



UNDRAINED MONOTONIC BEHAVIOUR

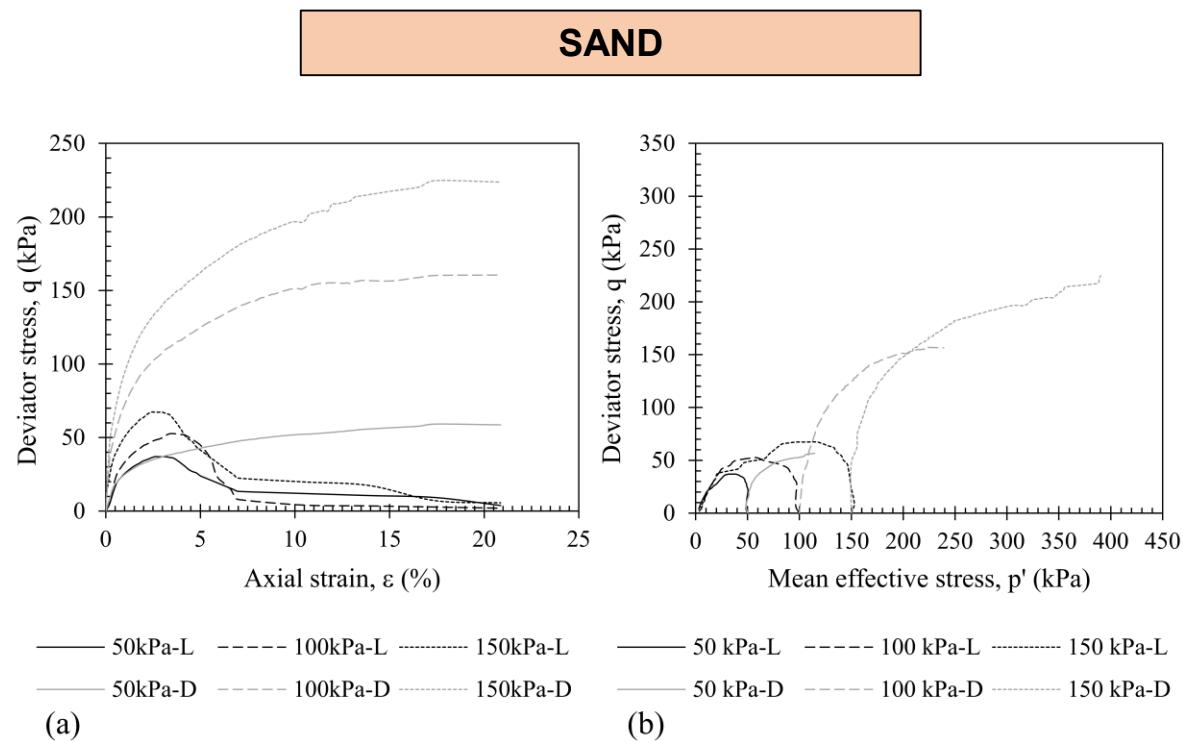


Fig. 13: SP (a) stress-strain curve (b) Undrained stress path

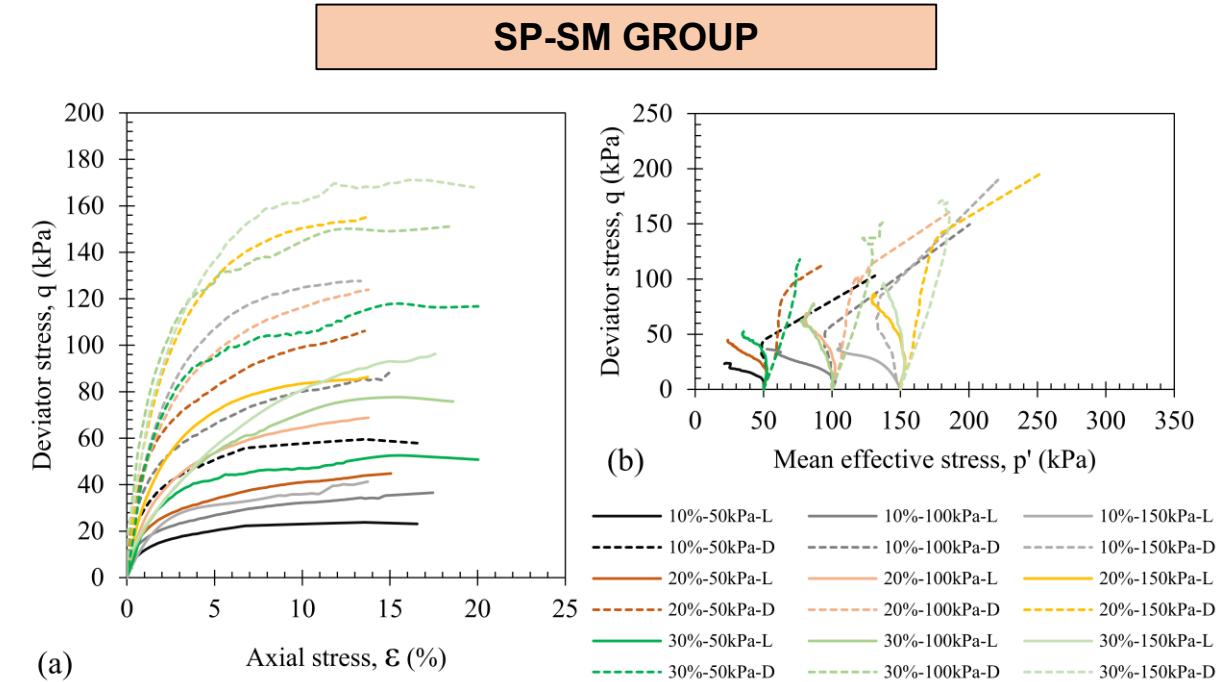


Fig. 14: SP-SM (a) stress-strain curve (b) Undrained stress paths

SM-SC GROUP

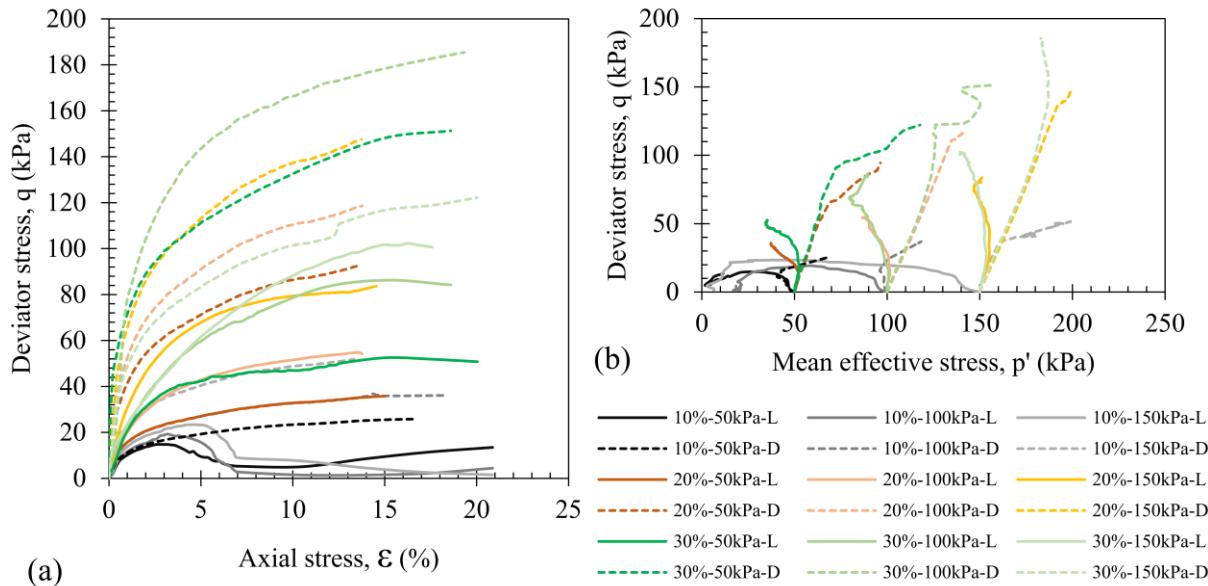


Fig. 15: SM-SC (a) stress-strain curve (b) Undrained stress paths

SP-SC GROUP

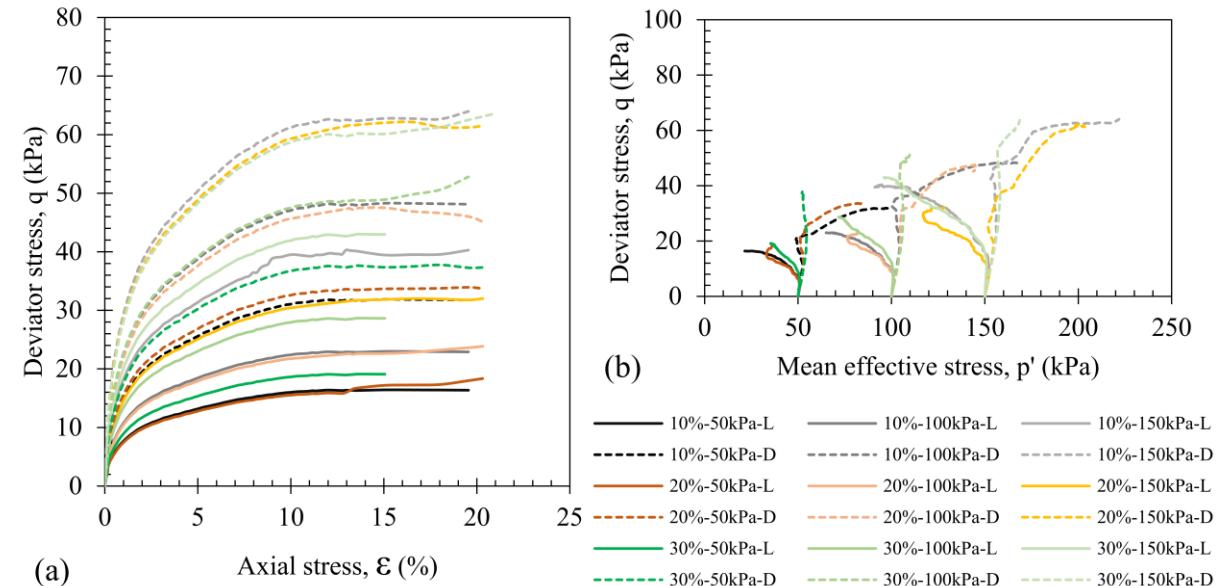


Fig. 16: SP-SC (a) stress-strain curve (b) Undrained stress paths

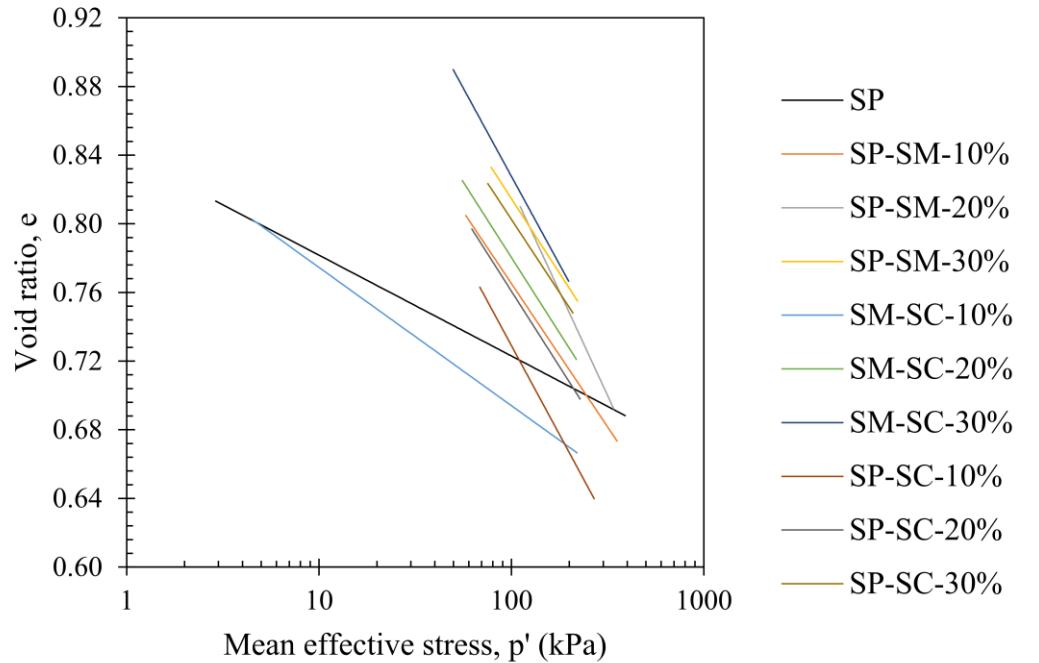


Fig. 17: Effect of fines content on critical state line (CSL) locations.

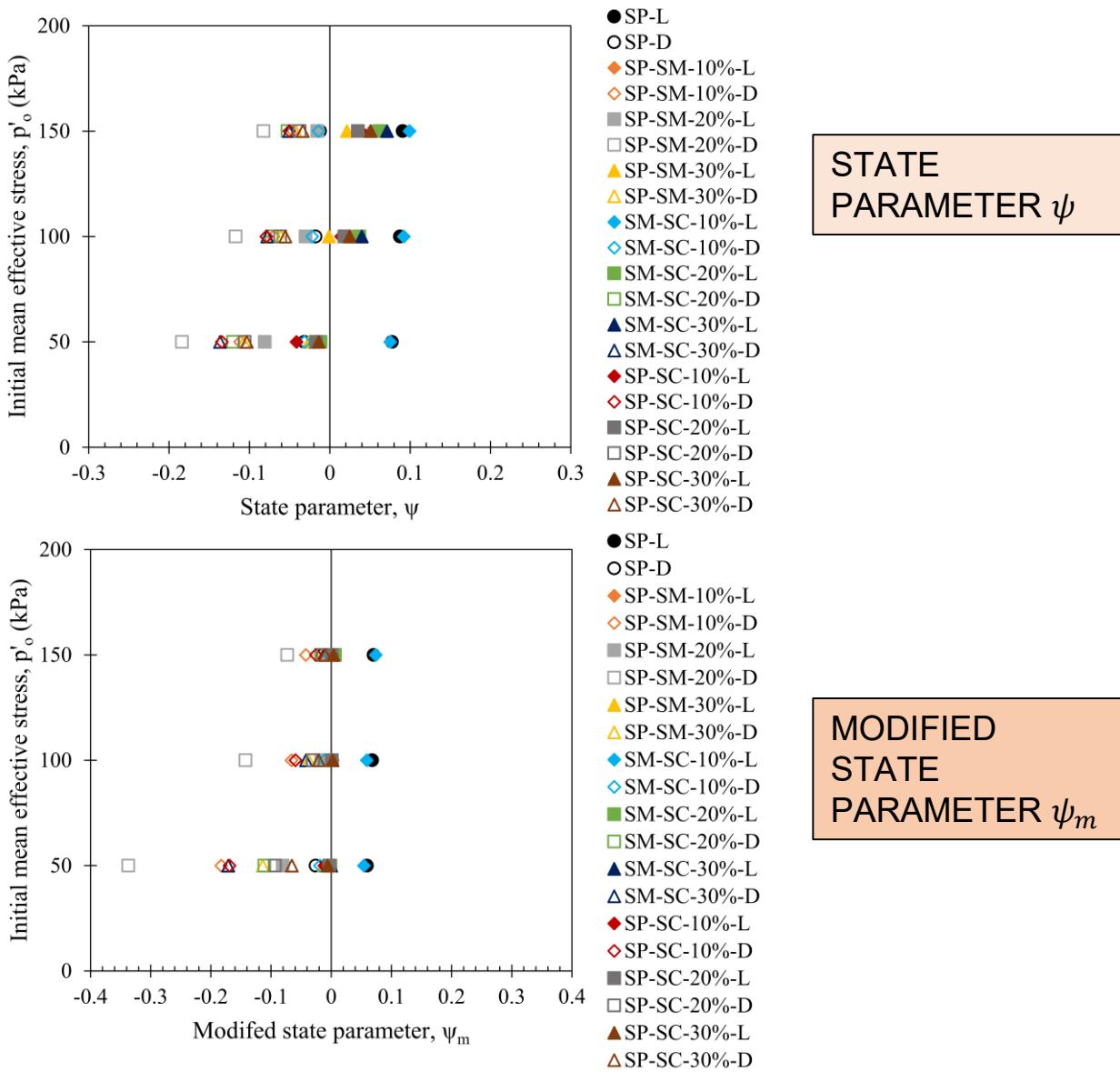


Fig. 18: (a) State parameter and (b) Modified state parameter variations.

**STATE
PARAMETER ψ**

**MODIFIED
STATE
PARAMETER ψ_m**

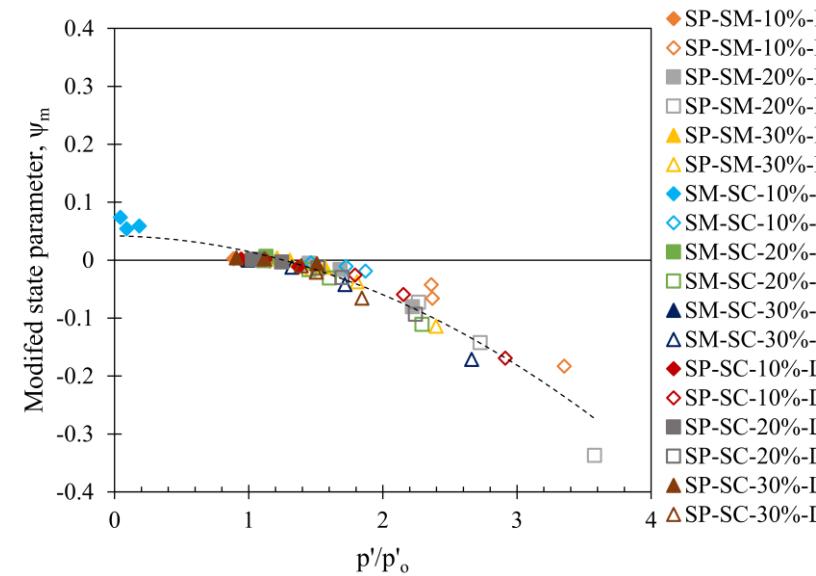
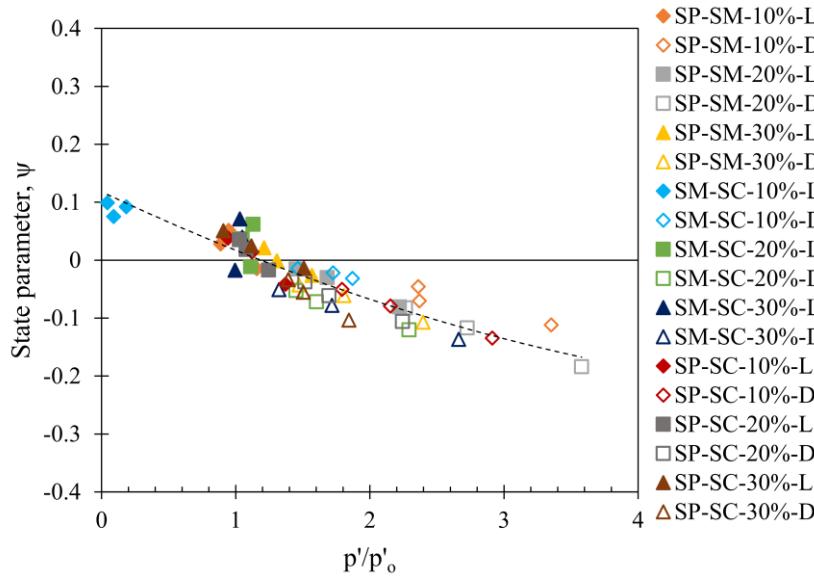


Fig. 19: (a) State parameter and (b) Modified state parameter variation with respect to p'/p'_o

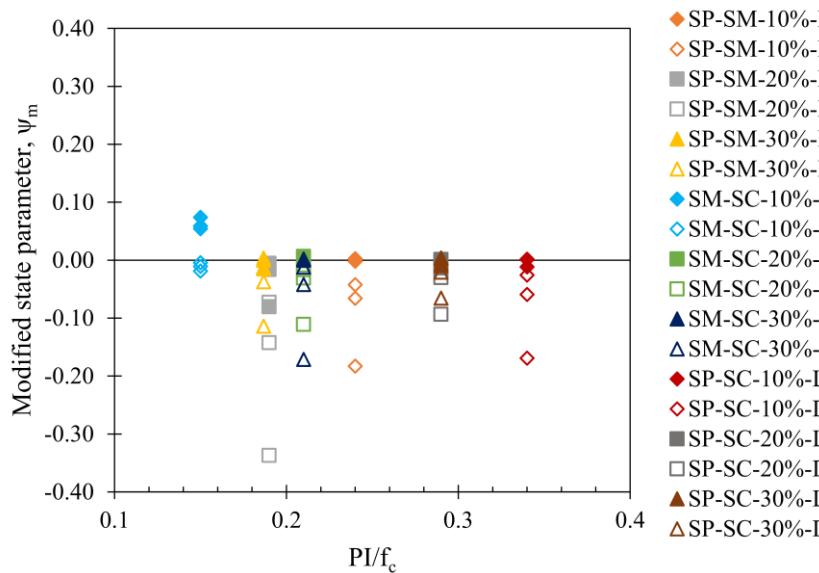


Fig. 20: (a) State parameter and (b) Modified state parameter variation with respect to PI/f_c

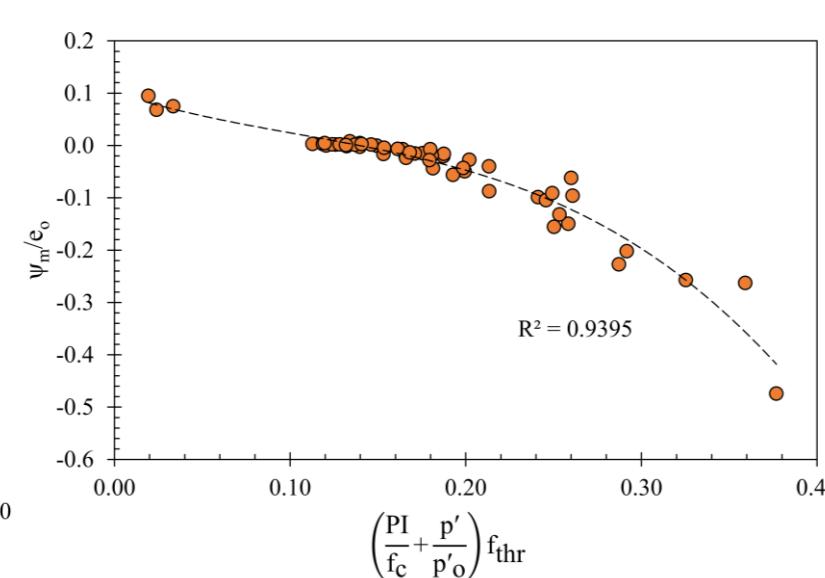
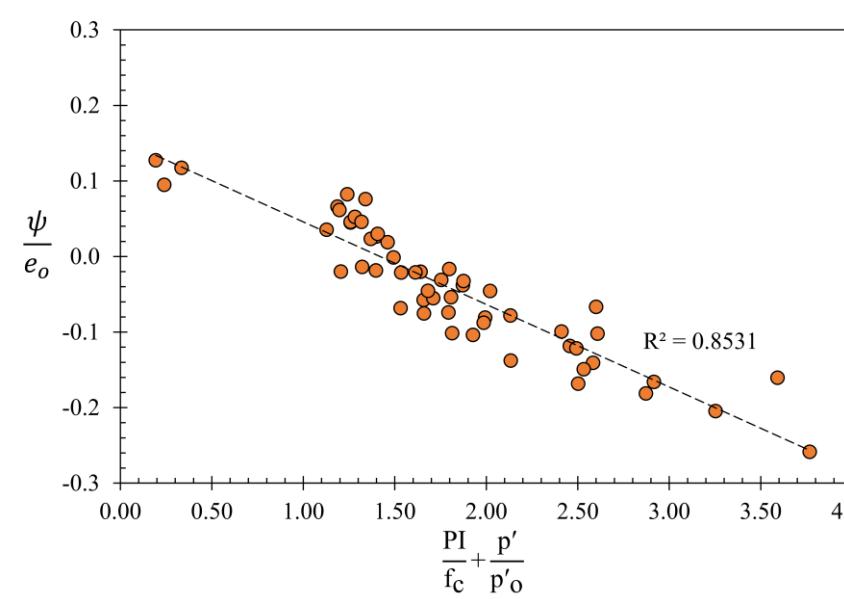


Fig. 21: (a) State parameter and (b) Modified state parameter variation with respect to $\left(\frac{PI}{f_c} + \frac{p'}{p'_o}\right)f_{thr}$

State parameter (ψ) estimation:

$$\frac{\psi}{e_o} = -a \left(\frac{p'}{p'_o} + \frac{PI}{f_c} \right) f_{thr} + b$$

$a = 0.1092$

$b = 0.155$

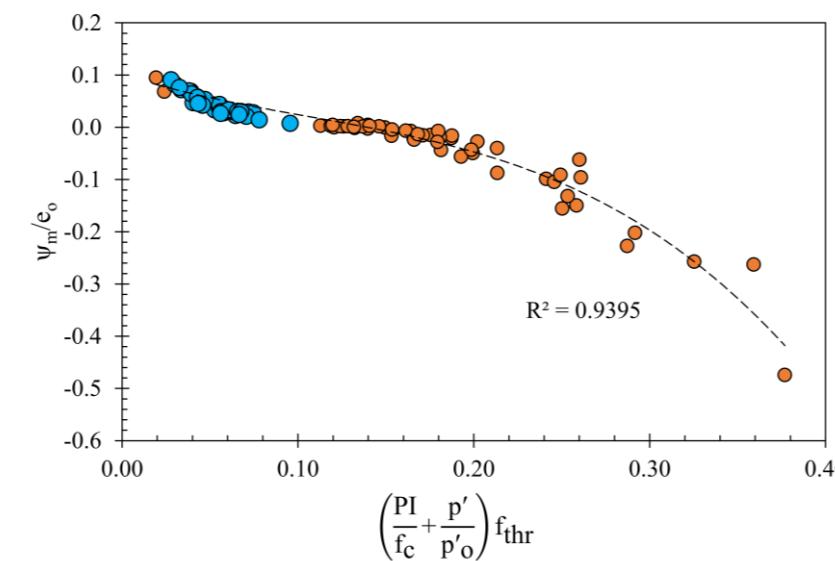
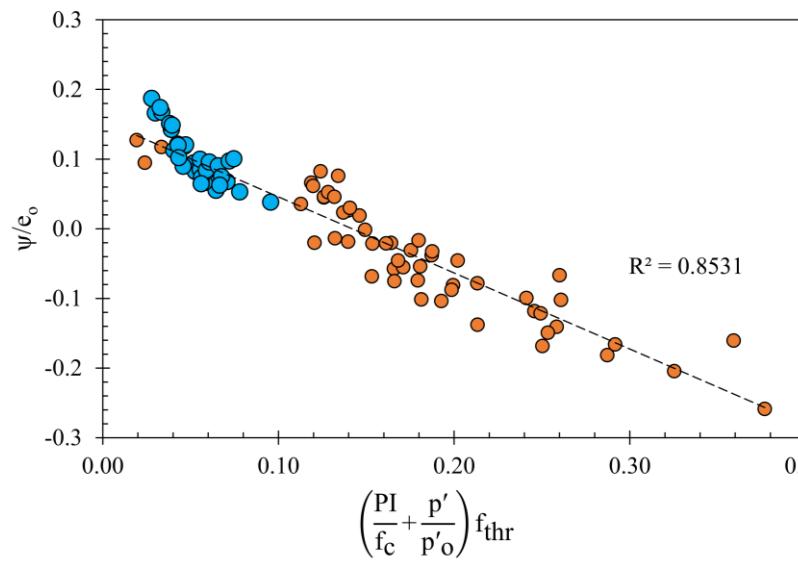


Fig. 22: (a) State parameter and (b) Modified state parameter comparative study (Hsiao & Phan, 2016)

Modified state parameter (ψ_m) estimation:

$$\frac{\psi_m}{e_o} = -a \left(\frac{p'}{p'_o} + \frac{PI}{f_c} \right) f_{thr}^3 + b \left(\frac{p'}{p'_o} + \frac{PI}{f_c} \right) f_{thr}^2 - c \left(\frac{p'}{p'_o} + \frac{PI}{f_c} \right) f_{thr} + d$$

$a = 13.969$

$b = 4.4628$

$c = 1.0753$

$d = 0.1011$

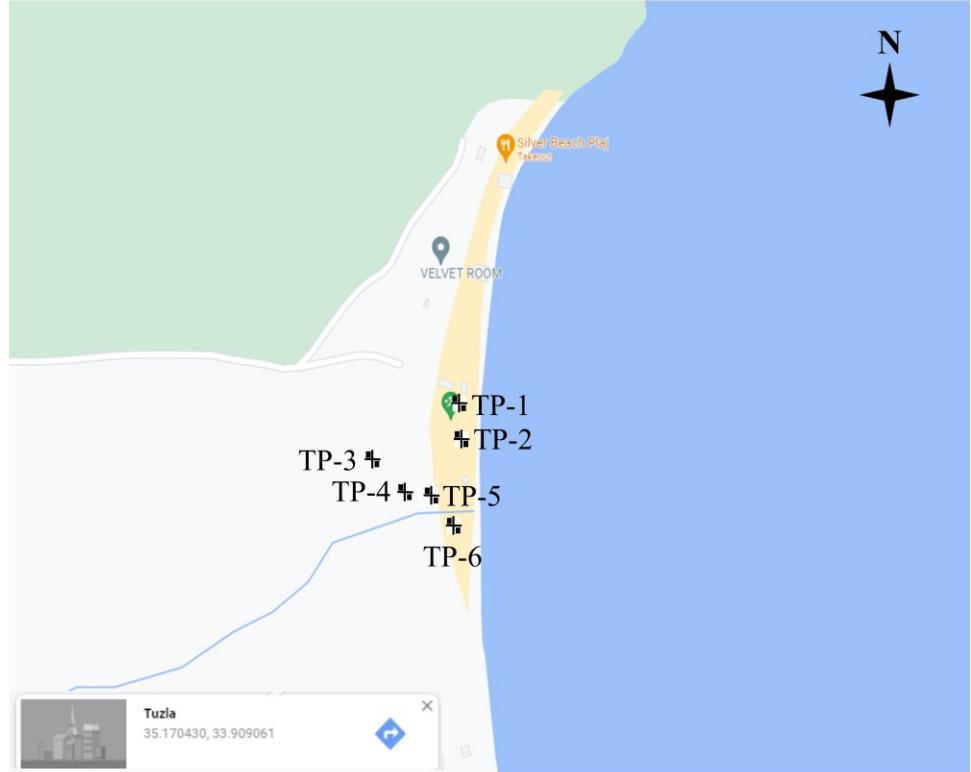


Fig. 23: Sampling and Test pits locations



(a)



(b)

Fig. 24: Sampling site condition (a) Before 6 and (b) after 6 months

Does the soil erosion prone region can indicated the liquefaction susceptibility of site?

Detachability-Liquefaction Prediction Index

$$DLPI = \sum_{I=1}^m (w_i \ dl_i)$$

dl_i Detachability-liquefaction rating

w_i Entropy weight

B: Classification and ranking based on DLPI

DLPI score	Rank	Detachability and liquefaction potential
< 50	4	High
50–100	3	Considerable
100–150	2	Moderate
> 150	1	Low

Geotechnical parameter	H_s (scale: 1–10)	Remarks with respect to parameter's impact on detachment and liquefaction potential
Gravel (%)	6	Due to higher weight, the higher the gravel content, the lower the detachability and liquefaction potential. Generally, low gravel contents were observed
Sand (%)	9	The higher the sand content, the higher the detachability and liquefaction potential. Generally, higher sand contents were observed
Fines (%)	7	Moderate fines (clays) content minimizes the detachability and liquefaction potential. However, excess high plastic clays may induce landsliding. The soils under study are mostly sands, with few clays
LL (%)	6	The higher the LL, the higher the tendency of the soil to liquefy. Given the nature of the analyzed soils, excess rainwater could cause them to liquefy
PL (%)	6	The higher the PL, the lower the ability of the soil to liquefy. The PL is usually a function of the quantity and nature of clays present in a soil
PI (%)	6	The higher the plastic index of a soil, the lower its detachability and liquefaction potential. Soils with high PI tend to have high viscosity. Mostly, low PI scores were observed in this study
LI (%)	7	The higher the LI (> 1) of a soil, the weaker it is in natural state. Hence, lower LI indicates higher liquefaction potential. Mostly, the LI values were ≤ 0
w (%)	4	The higher the water content, the more the reduction in effective stress and the higher the detachability and liquefaction potential. However, very low moisture content (as seen in the soils) reduces the cohesiveness of clay particles, thus making the soil dispersible, even under dry conditions
n (%)	7	The higher the porosity, the higher the infiltration of the granular materials, and the higher the grain wetting which reduces the effective stress
k (m/s)	7	Higher permeability coefficient influences the infiltration rate and grain wetting and subsequently a reduction in effective stress
C (kPa)	9	The higher the cohesion of a soil, the lower its detachability and liquefaction potential and vice versa. Generally, the tropical soils have low cohesion
ϕ ($^{\circ}$)	8	The higher the frictional angle of a soil, the lower its detachability and liquefaction potential and vice versa. Generally, the soils have low–moderate frictional angle
MDD (g/cm 3)	7	The higher the MDD, the lower the detachability of soil and vice versa. Generally, the soils have low MDD scores
OMC (%)	7	The higher the OMC, the lower the detachability of soil and vice versa. Generally, the soils have low OMC scores
ρ (g/cm 3)	6	The higher the bulk density, the lower the detachability and liquefaction potential of a soil. Sands usually have lower density than clays
G (no dimension)	6	The higher the specific gravity, the lower the detachability and liquefaction potential of a soil. Sands usually have lower specific gravity than clays

4. Conclusions

- Amongst all soil groups tested, SP-L and SP-SM-10%-L prepared at loose state exhibited flow to limited flow behaviour.
- The presence of plastic fines resulted in shifting of the critical state line with increasing steepness.
- The steepness of CSL indicated that for higher stresses, the specimens will exhibit contractive behaviour for soil in both loose and dense states.
- The addition of fines content in the sand completely altered the stress-strain response due to an increase in plasticity.
- Comparison between state parameter and modified state parameter values.



THANK YOU!



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