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Shear Strength Characteristics of Uncemented Calcareous Sediments Collected from Passikudah Beach, Sri Lanka

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ABSTRACT: Calcareous sands and coral fragments are deposited in carbonate rich dynamic marine environments. Infrastructure development in Eastern coastal regions of Sri Lanka requires investigation of such deposits. Literature review shows that calcareous deposits have favourable strength properties, when compared to properties of non-calcareous sands. Calcification of such sediments is quantified in terms of Calcite Equivalent, which can be determined using a Calcimeter. This study compares calcite contents of fine, medium and coarse fractions of sand, and fine gravel in specimens obtained from Passikudah Beach. These size fractions show varying calcite contents. Calcareous sediments pack loosely compared to river sand with a similar grain size distribution. Direct Shear Test results yield greater peak and residual shear strengths for calcareous sediments, compared to river sand with similar grain size distribution. Saturated calcareous sediments record a greater peak and residual shear strengths, compared to dry calcareous sands. An increase in the angle of internal friction with increasing calcite content is also observed.

1 INTRODUCTION

Coral reefs produce calcareous matter that are further broken, rounded, sorted and deposited by waves and currents (Brandes, 2011). Coastal sediments of eastern Sri Lanka consist of dead coral fragments of varying shapes and sizes, and calcareous matter cemented to sand grains.

Physical and mechanical properties of calcareous sediments have been investigated by researchers to assess their suitability as engineering materials. Presence of intra-particle void spaces in carbonate matter and angular particle shapes create a very high ratio (LaVielle et al., 2008). Particles more susceptible to crushing under static loads, and shows brittleness, compared to regular silica sand (Morioka & Nicholson, 2000). They possess a high specific gravity, even with high intra-granular porosity. Shear strength and stress-strain behaviour of quartzitic sands are attributed to particle size distribution and relative density (Mitchell, 1993). In un-cemented calcareous sediments, angle of internal friction is found to increase with carbonate content and increased compaction (El-Amrani Paaza et al., 1998). Lee at el. (2011) attributes this increase to angularity of grains while Andrews & Martin (2000) attribute to mineralogical and textural differences. Andrews & Martin (2000) observes a reduction in frictional angle, and is attributed to particle crushing and rounding due to low grain hardness and high-intra particle voids.

2 PROCEDURE

Calcareous sediments were obtained from locations S1 to S8 of Passikudah beach area, within 100m from present shoreline. Table 1 lists the laboratory test programme.

Table 1. Laboratory test programme

Test	Specimen Nos.
Grain size distribution–BS813:103, 1985	S1 to S7, S7E,S8
Calcite equivalent–Calcimeter method	S1–S6, S8
Calcite equivalent–Oven dried method	S1–S6, S8
Specific gravity ASTM D854	S1
Dry density and Void ratio	S7,S7E
Direct shear test ASTM D3080-03	S7,S7E,S8

2.1 *Grain size distribution*

Specimens were wash-sieved through standard sieve sizes ranging from 63µm to 37.5mm. Specimen S7E was prepared, artificially, using river sand (i.e. S7E) to match the gradation of the specimen obtained from location S7.

2.2 *Calcimeter method*

The calibration procedure for the calcimeter used in this study is described in Ali et al. (2012). Pressure and volume change due to generated CO_2 is computed using the Ideal Gas Law. Mass of $CaCO_3$ was computed based on the number of CO_2

moles produced during the reaction with 0.1N HCl solution. A correction for number of CO_2 moles were made to account for dissolved CO_2, when an HCl volume greater than 20ml was used.

The specimens were oven dried at 105^0C for 24 hours, prior to obtaining its initial dry mass. An electronic balance with an accuracy of ±0.0001g was used. The amount of dry specimens selected ensured that measured Calcite Content did not exceed 1g. Calcite Content is expressed as the equivalent mass of Calcium Carbonate that produces the same number of moles of CO_2 gas when calcareous grains react with excess HCl.

2.3 Oven dried method

Specimens used in the above method were filtered with excess de-ionised water, oven-dried at 105^0C for 24 hours to obtain mass of dry sand. The difference in mass yielded the mass of carbonate matter, hence per cent Calcite Equivalent.

2.4 Packing of grains

Void ratio and dry density were compared for specimens S7. Each specimen was poured in to a graduated cylinder; tamped on the cylindrical wall using a mallet; and being vibrated on a vibrating table. The same specimens were pluviated in water, and tamped as done before. Specific gravity for specimen S1 was found to be 2.75.

2.5 Direct shear test

Conventional Direct Shear tests were performed on specimens obtained from locations S7, S8 and S7E. 60mm×60mm specimens were subjected to normal stresses of 18.6, 26.6, 40, 66.8 and 93.6 kPa. A shear displacement rate of 0.094mm/min was maintained. Specimens of S7 were tested under dry and saturated conditions; S7E was tested under dry condition. S8A, S8B, S8C and S8D refer to calcareous sediment specimens with grain size ranges 0.063-0.212mm, 0.212-0.425mm, 0.425-0.6mm and 0.6-2mm, respectively. Fig. 2 shows the comparison between calcareous sediments from location S7 and the equivalent river sand used for the Direct Shear Test.

3 RESULTS

3.1 Grain size distribution

Fig. 1 shows grain size distribution curves for calcareous sediments tested. Table 2 lists relevant indices and group symbols based on Unified Soil Classification System (USCS).
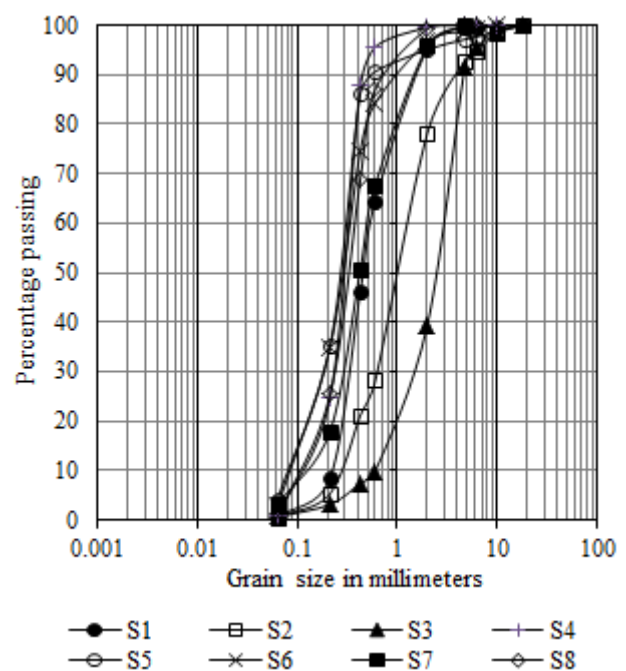

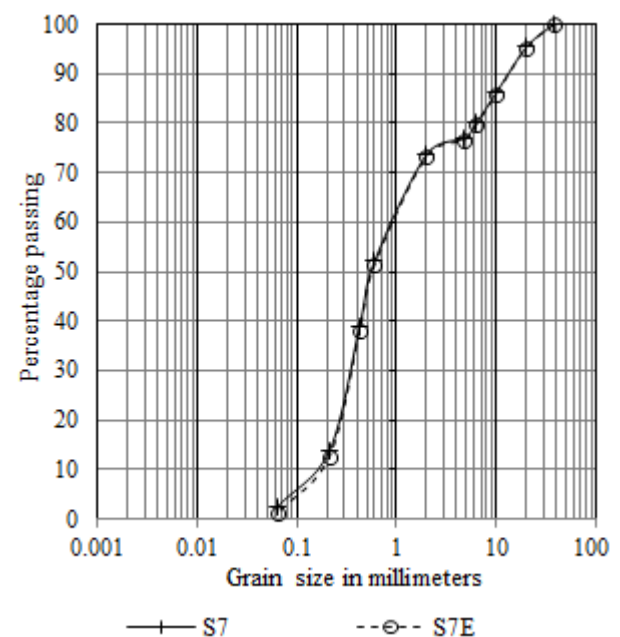Fig. 1 Grain size distribution of specimens S1 to S8

Fig. 2 Grain size distribution of specimens S7 and S7E.

Table 2. Particle size characteristics of specimens tested

Specimen No.	% <63μm	D_{10} (mm)	C_u	C_c	USCS symbol
S1	0.6	0.21	2.43	0.90	SP
S2	0.5	0.27	4.07	1.25	SP
S3	0.6	0.60	4.87	0.88	GW
S4	0.8	0.11	2.82	1.29	SP
S5	4.2	0.08	3.75	1.35	SP
S6	2.7	0.08	4.00	1.27	SP
S7	1.1	0.14	6.43	0.92	SW
S8	0.5	0.10	3.70	1.31	SP

3.2 Calcite equivalents

Fig. 3 compares measured calcite contents using oven dried method and calcimeter method. The specimens tested show a deviation of ±7.5%.

Table 3 shows Calcite equivalent determined using calcimeter method. The values are tabulated based on particle size ranges: <63μm, 63-212μm, 212-425μm, 425-600μm, 600μm-2mm, and 2-4.75mm.

Significant variations in calcite equivalents in size fractions are observed. Locations S1 and S2 shows high Calcite Equivalent values in medium sand range while S6 has high Calcite Equivalent values in coarse sand and fine gravel ranges.
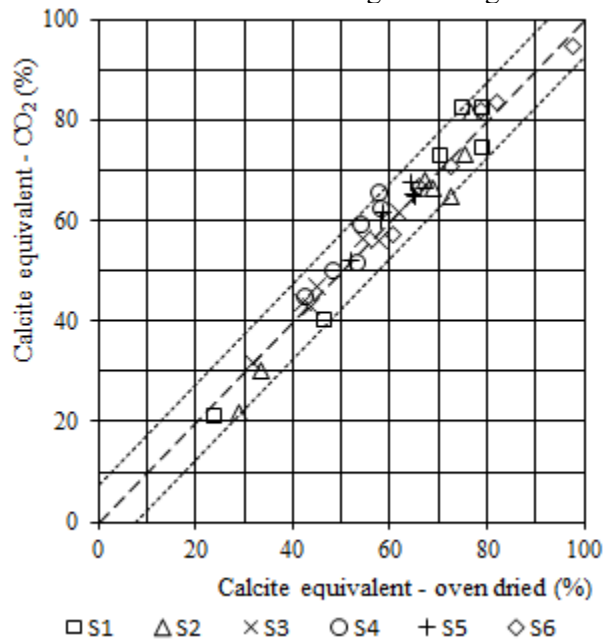

Fig. 3   Comparison of calcite equivalence based on oven dried method and calcimeter method.

Table 3. Calcite equivalent (%) - Calcimeter method

Size range	Calcite equivalent (%)					
	S1	S2	S3	S4	S5	S6
<63μm	74.7	64.9	61.5	51.8	52.2	57.4
63-212μm	73.2	66.5	56.2	62.2	60.1	71.0
212-425μm	82.7	73.1	56.4	65.6	61.4	66.8
425-600μm	82.6	67.8	43.0	59.4	67.5	81.9
600μm-2mm	40.7	30.3	31.7	50.0	65.3	83.6
2-4.75mm	21.2	21.7	46.9	44.8	64.8	94.7

3.3 Compactness

Fig. 4 compares compactness of calcareous sediments (S7) with river sand with equivalent grain size distribution, S7E. Results show greater void ratios in the case of calcareous sediments.

3.4 Direct shear test results

Fig. 5 and 6 show Mohr-Coulomb failure envelopes for residual and peak strengths, respectively.
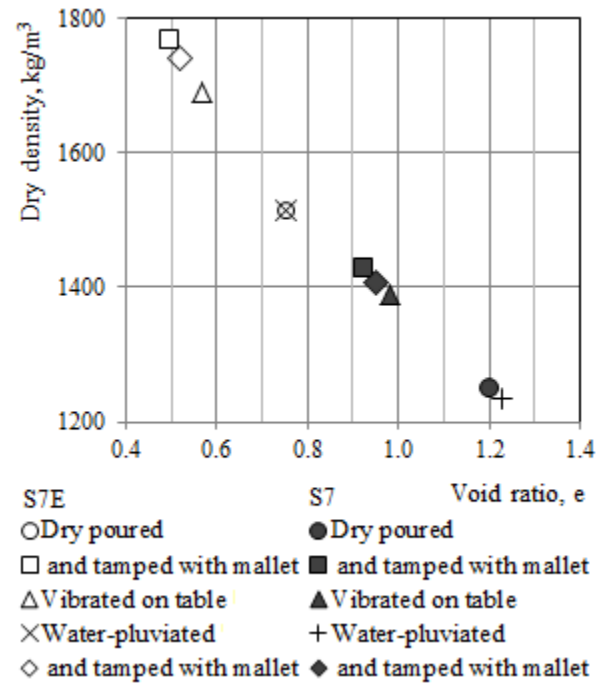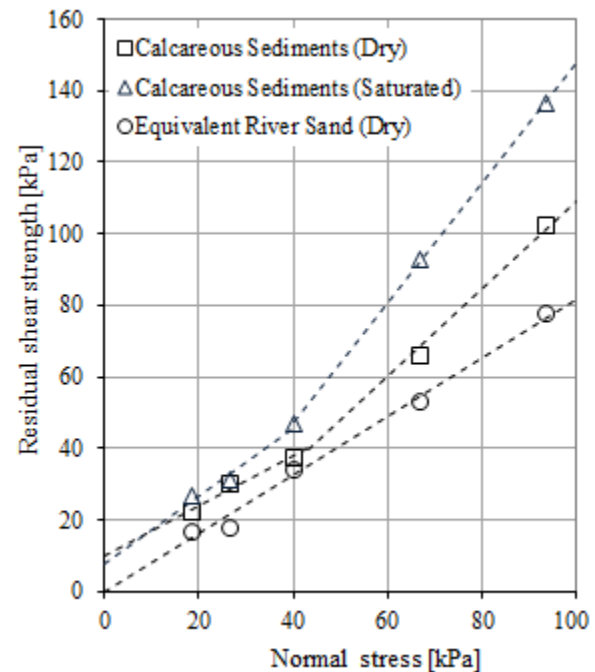

Fig. 4 Variation of Dry Density vs. Void Ratio

Fig. 5   Variation of τ_f-residual with σ_n

Table 4 lists effective angle of internal friction ϕ' and Apparent Cohesion, c' values. Results confirm that calcification increases shear strength of calcareous sediments. Saturated specimens yield greater shear strength over dry specimens.

3.5 Variation of residual shear strength with calcite equivalent values

Fig. 7 represents variation of residual shear strength with calcite equivalent for samples with size ranges 63-212μm, 0.212-0.425mm, 0.425-0.6mm and 0.6-2mm.
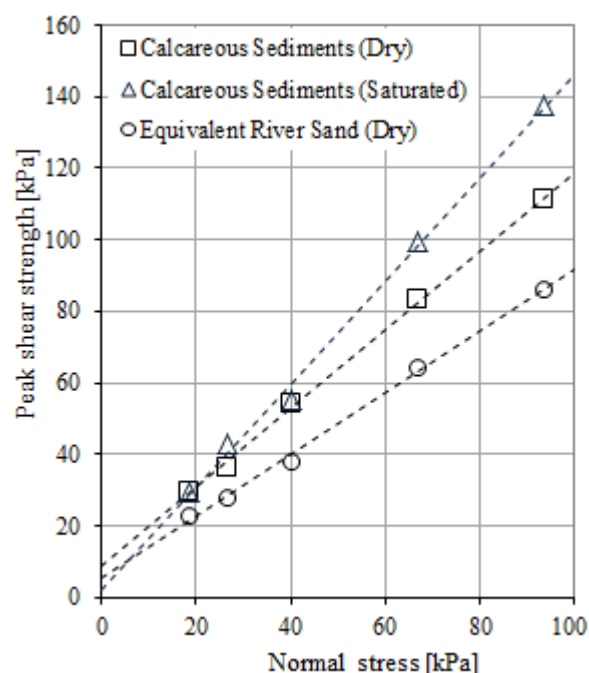
Fig. 6 Variation of τ_f -peak with σ_n

Table 4. Shear strength parameters ϕ' and c' (kPa).

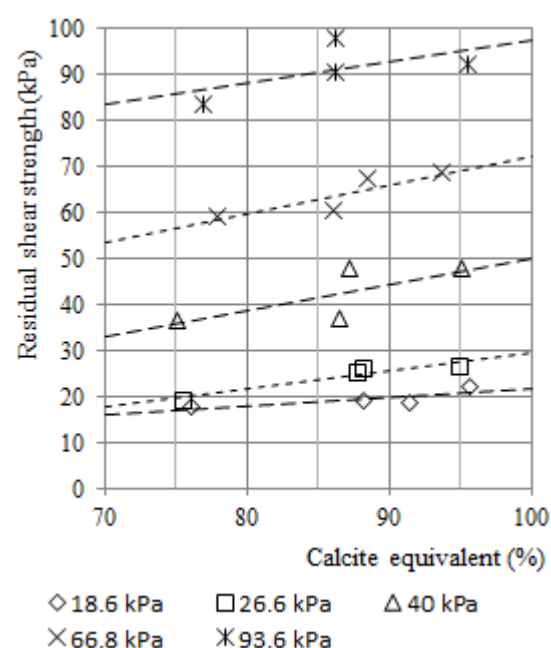| Specimen type	σ'_n range (kPa)	Residual Strength		Peak Strength	
		ϕ'	c'	ϕ'	c'
S7E-Dry	All	39	0	41	5
S7-Dry	<43.2	35	10.2	48	9
	>43.2	51	<0		
S7-Saturated	<40	44	8	55	2
	>40	59	<0		

Fig. 7 Variation of residual shear strength with calcite equivalent for specimens S8A, S8B, S8C and S8

4 DISCUSSION AND CONCLUSIONS

Calcite equivalent determined using calcimeter method compares well with oven dried method. Calcareous sediments tested show varying amount of calcite equivalents in their respective grain size ranges, and is attributed to presence of coral fragments.

Observed high initial void ratios during packing of calcareous sediments compared to equivalent river sand can be attributed to angularity of grains and textural differences.

Direct shear tests performed on dry calcareous sediments yield greater residual and peak shear strengths compared to equivalent river sand. A significant increase in residual shear strength at higher normal stresses is observed for dry calcareous sediments. The failure envelope with regard to residual strength has a greater slope, indicating strength gains due to particle crushing.

Direct shear tests performed on saturated calcareous sediments yield greater residual and peak shear strengths compared to dry calcareous sediments. Observed increase in shear strengths and volumetric strains may indicate an increase in the number of particle contacts, and a possible increase in normal effective stress at particle contacts. These assertions however require confirmation through further studies.

Residual shear strength is found to increase with calcite equivalent values, particularly at higher normal stress values.

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