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Shear strength behaviour of a coral sand in Vietnam

Comportement en cisaillement d'un sable corail au Vietnam

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ABSTRACT: This paper presents a study on influences of the relative density (D_r) and cyclic load on shear strength behaviour of a coral sand in Vietnam. For this, direct shear tests and triaxial compression tests were carried out on a number of sand samples at different D_r values and loading cycles, respectively. The results from the direct shear tests indicate that the shear strength parameters of the sand comprise not only internal friction angle but also unit cohesion, also called as apparent unit cohesion. These parameters vary with changes of the relative density and the cyclic load. The shear strength increases with the increase of the relative density and increases after loading cycles. It is indicated from the triaxial tests that the dilatancy angle of the sand is not a constant and the accumulative strain of the sand increases with the number of loading cycles.

RÉSUMÉ: Cette étude présente des influences d'une densité relative (D_r) et la charge cyclique sur le comportement en cisaillement d'un sable corail au Vietnam. Pour cela, un essais de cisaillement direct et un essais de compression triaxiale ont été effectués sur un certain nombre d'échantillons de sable à différentes valeurs de D_r et de cycles de chargement, respectivement. Les résultats des essais de cisaillement direct indiquent que les paramètres de résistance au cisaillement du sable comprennent non seulement l'angle de frottement interne mais également la cohésion unitaire qui est aussi appelée la cohésion unitaire apparente. Ces paramètres varient avec les changements de la densité relative et de la charge cyclique. La résistance au cisaillement augmente avec l'élévation de la densité relative et après les cycles de chargement. Il ressort des essais triaxiaux que l'angle de dilatance du sable n'est pas constant et que la déformation cumulée du sable augmente avec le nombre de cycles de chargement.

KEYWORDS: coral sand, shear strength, cyclic, direct shear test, triaxial test.

1 INTRODUCTION

Coral sand, which is also called as calcareous sand, distributes quite popularly in South East Asia sea areas, particularly in Truong Sa island of Vietnam. Due to the increasing demand for construction in the Coral Sea areas in recent years, the investigation on the mechanical properties of the coral sand is necessary. A problematic feature of coral sand is high crushability of soil particles due to high confining pressure, shear stress and cyclic loading, leading to changes in the properties of the sand. Physical and mechanical characteristics of calcareous sands have been summarised in Murff (1987), Chengjie et al. (2013) and Wang et al. (2017). In a natural state, calcareous sediments behave differently from terrestrial silica sands, the most significant distinguishing feature being their tendency to exhibit volume reduction upon shearing, even at relatively low normal stresses. It was pointed out in Poulos (1988) that the tendency of volume reduction due to shearing plays a dominant role in the foundations on calcareous sediments. Shear characteristics of a calcareous gravelly soil have been studied through direct shear tests (Wang et al. 2016). It is indicated that calcareous gravelly soil has greater apparent cohesion, larger friction angle than quartz sand.

In this study, the shear strength behaviours of a coral sand (sampled from Truong Sa island of Vietnam) are investigated through direct shear tests and triaxial compression tests.

2 PHYSICAL PROPERTIES OF CORAL SAND

The coral ground in Truong Sa island of Vietnam contains stones, branches, gravels and sands. However, it is noted that only coral sand sieved having particle diameter smaller than 10 mm was used for the investigation of shear strength behaviour in this research. Soil particles having a diameter larger than 10 mm were removed through sieving. The physical properties of the sand are presented in Table 1.

Table 1. Physical properties of the coral sand

Properties	Value
Soil particle density, ρ_s (t/m^3)	2.820
Maximum dry density, ρ_{dmax} (t/m^3)	1.801
Minimum dry density, ρ_{dmin} (t/m^3)	1.450
Dry density at relative density D_r= 0.3; $\rho_{d0.3}$ (t/m^3)	1.555
Dry density at relative density D_r= 0.6; $\rho_{d0.6}$ (t/m^3)	1.661
Dry density at relative density D_r= 0.9; $\rho_{d0.9}$ (t/m^3)	1.766

3 DIRECT SHEAR TESTS OF CORAL SAND

3.1 *Influence of relative density*

To investigate the influence of relative density on the shear strength behaviour of the coral sand, direct shear tests on the sand having the relative densities D_r = 0.3, 0.6 and 0.9 were carried out. As for each relative density, three levels of normal stress, σ, were applied in the tests as 50, 100 and 150 kPa. Figs. 1-3 show the relationship between shear force and shear displacement of the samples having a relative density of 0.3, 0.6 and 0.9, respectively. It is indicated from the figures that the nonlinear post-peak softening behaviour of the coral sand are obtained, in which the peak appears more obviously in the cases of densed samples (D_r = 0.6 and 0.9) than that of the loosed sample (D_r= 0.3). The results indicate that the position of the peaks varies in the range from 3 mm to 5 mm of the shear displacement.

Table 2 shows the shear strength parameters of the coral sand with different relative densities. The results indicate that the shear strength parameters of the coral sand include not only internal friction angle, φ, as other granular soils but also unit cohesion, c, called as apparent unit cohesion. It is in agreement with the research of Wang et al. (2016). The cohesion in the coral sand is generated by the grain interlocking between coarse soil particles, which is different from the cohesion in clay soils, which originates from the bonding of the particles. The internal friction angle, φ, of the coral sand used in this study is in the range of 42.5 to 51.65 degrees. The apparent unit cohesion, c, is in the range of 45.23 to 88.36 kPa. These shear strength parameters increase with the increase of the relative density, D_r, of the soil. When D_r increases from 0.3 to 0.6, the internal friction angle increases by 19%, unit cohesion increases by 69%. When D_r increases from 0.3 to 0.9, the internal friction angle increases by 21%, unit cohesion increases by 95%.

Table 3 shows a comparison of shear strength parameters of silica sand and coral sand. The results obviously show that shear strength parameters of the coral sand are larger than those of the silica sand. Particularly, the apparent cohesion values of the coral sand are significantly larger than those of the silica sand.

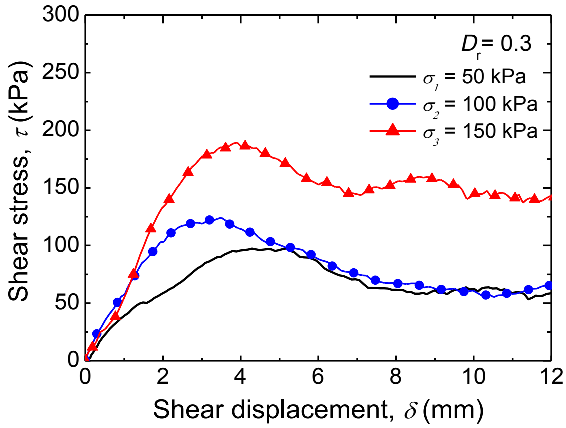

Figure 1. Shear stress vs. shear displacement, D_r= 0.3

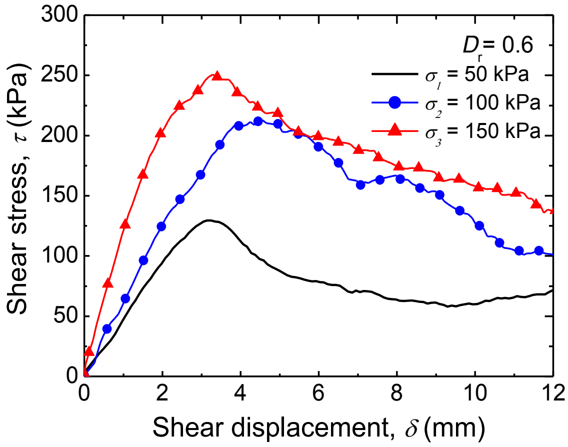

Figure 2. Shear stress vs. shear displacement, D_r= 0.6

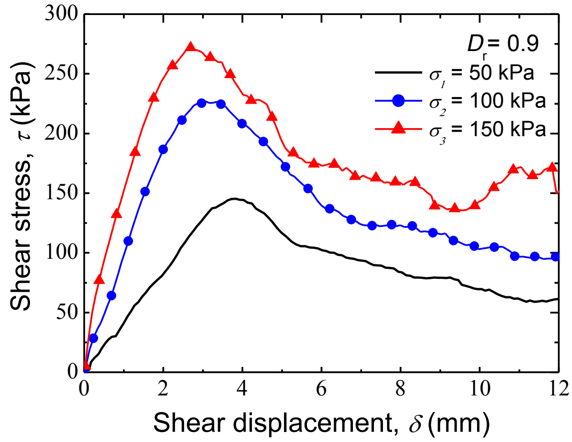

Figure 3. Shear stress vs. shear displacement, D_r= 0.9

Table 2. Shear strength parameters of coral sand with different relative densities

Relative density, D_r	Internal friction angle, φ (°)	Unit cohesion, c (kPa)	Relative Int. friction angle (%)	Relative unit cohesion (%)
0.3	42.55	45.23	100	100
0.6	50.47	76.49	119	169
0.9	51.65	88.36	121	195

Table 3. Comparison of shear strength parameters of silica sand and coral sand

D_r	Silica sand		Coral sand		Increment	
	φ (°)	c (kPa)	φ (°)	c (kPa)	φ (°)	c (kPa)
(1)	(2)	(3)	(4)	(5)	(6)=(4)-(2)	(7)=(5)-(3)
0.3	39.00	0.57	42.55	45.23	3.55	44.66
0.6	42.95	3.75	50.47	76.49	7.52	72.74
0.9	44.66	10.25	51.65	88.36	6.99	78.11

3.2 *Influence of cyclic load*

To investigate the influence of cyclic load on variation of the shear strength characteristics of the coral sand, cyclic direct shear tests were carried out on the sand samples having a relative density D_r= 0.6. As for each level of normal stress of 50 kPa and 100 kPa, 50 loading cycles following displacement control manner with the controlled displacement of about 2 mm were applied. After that, monotonic load tests on the samples were conducted until the failure obtained.

Figures 4 and 5 show the relationship between shear force and shear displacement in the cyclic load tests under the normal stresses of 50 kPa and 100 kPa, respectively. Figures 6 and 7 show the relationship between shear force and shear displacement in the monotonic load tests under the normal stresses of 50 kPa and 100 kPa, respectively.

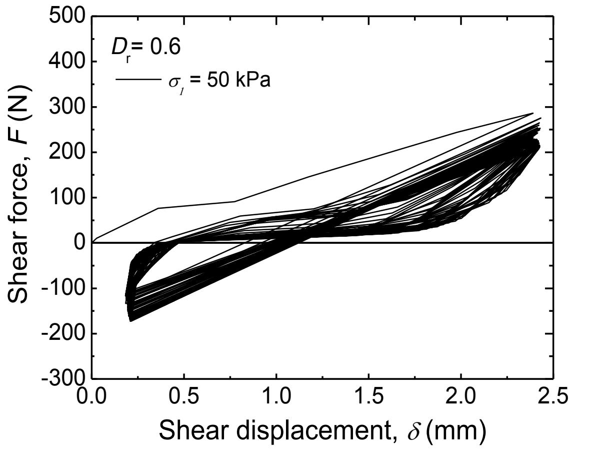

Figure 4. Shear force vs. shear displacement in cyclic load test under normal stress of 50 kPa.

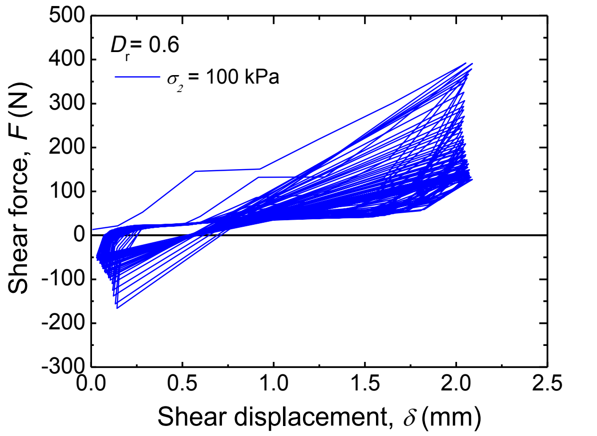

Figure 5. Shear force vs. shear displacement in cyclic load test under normal stress of 100 kPa.

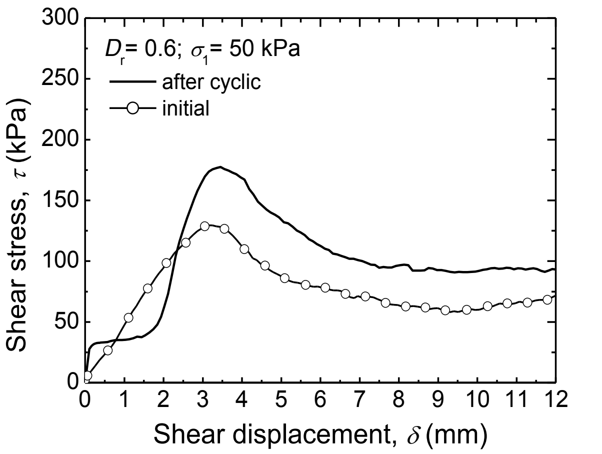

Figure 6. Shear force vs. shear displacement in monotonic load test under normal stress of 50 kPa.

It is indicated from Figures 6 and 7 that the shear strength of the coral sand considerably increases after cyclic load tests. At the beginning of the curve (after cyclic), it is seen that there is a horizontal line representing an increase of the horizontal displacement without an increase of the shear force. The range of the horizontal line coincides with the range of cyclic load amplitude applied in the former step. After the horizontal part, the shear force increases with the increase of the displacement and obtains a considerably higher peak value than that of the initial samples.

Table 4 shows a comparison of shear strength parameters of the coral sand at the initial status and after the cyclic load test. The results obviously indicate that the shear strength characteristics of the sand increase after the cyclic load test.

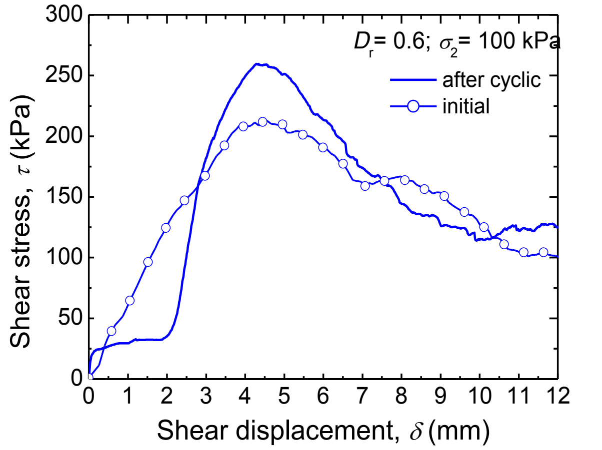

Figure 7. Shear force vs. shear displacement in monotonic load test under normal stress of 100 kPa.

Table 4. Comparison of shear strength parameters of coral sand at initial and after cyclic loading

D_r	Initial		After cyclic		Increment	
	φ (◦)	*c* (kPa)	φ (◦)	*c* (kPa)	φ	*c*
(1)	(2)	(3)	(4)	(5)	((4)-(2))/(2)	((5)-(3))/(3)
0.6	50.47	76.49	58.66	95.34	16.23%	24.64%

4 TRIAXIAL COMPRESSION TESTS OF CORAL SAND

Triaxial monotonic and cyclic consolidated-drained compression tests of the coral sand having a relative density, D_r, of about 70% were conducted under a confining pressure, p_0, of 150 kPa. Cylindrical specimens having a height of 100 mm and a diameter of 50 mm were used in the tests.

Figures 8 and 9 show the results of the triaxial tests. Figures 10 and 11 is the zoom-up of Figures 8 and 9, respectively. It is seen that post-peak softening behaviour is obtained and the dilatancy is not constant but reduced with the increase of axial strain. Focusing on the results in the case of cyclic loading, it is interesting to see that the deviatoric stress increases, indicating the stiffness increase, after cyclic loading (see Figures 8 and 10). Meanwhile, the volumetric strain increases, indicating the reduction of specimen volume, during cyclic loading (see Figures 9 and 11). Also, it is remarkable to see the results in Figures 8 and 10 that the accumulative strain increases with the number of loading cycles.

5 CONCLUSIONS

The following conclusions are derived from the results of this study:

The shear strength parameters of the coral sand comprise not only internal friction angle, φ, as other normal granular soils but also unit cohesion, *c*, called as apparent unit cohesion. The parameters vary with changes of the relative density of the sand and are influenced by the cyclic load.

The shear strength of the coral sand increases with the increase of the relative density. Also, the shear strength increases after cyclic loading.

The dilatancy angle of the coral sand is not a constant and the accumulative strain of the calcareous sand increases with the number of loading cycles.

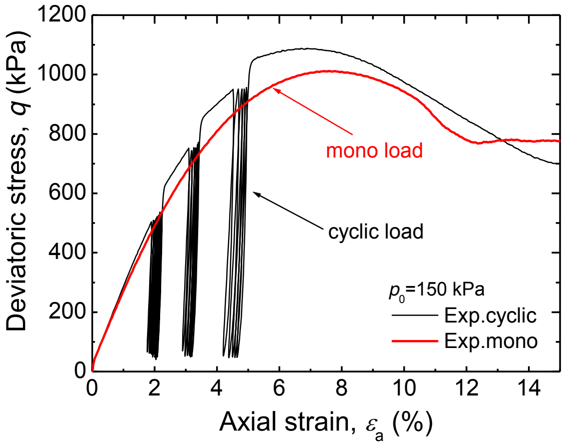

Figure 8. Deviatoric stress q versus axial strain ε_a.

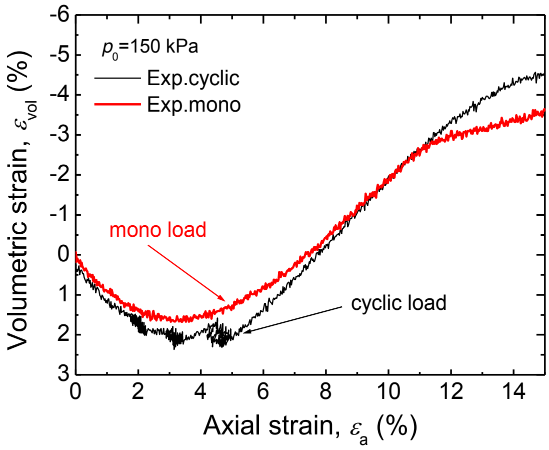

Figure 9. Volumetric strain ε_{vol} versus axial strain ε_a.

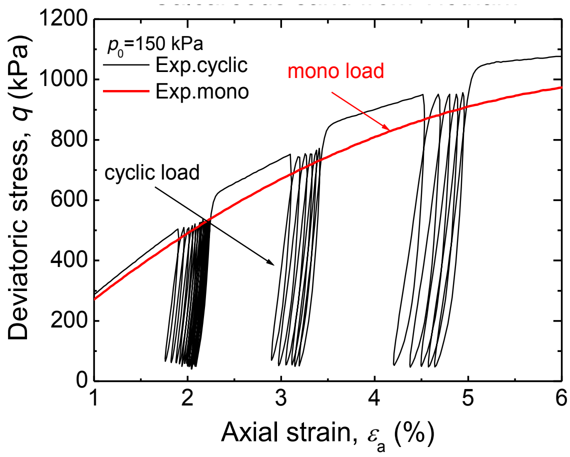

Figure 10. Zoom-up of Figure 8.

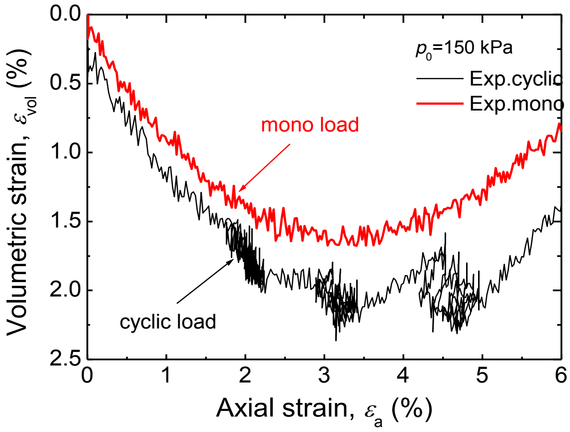

Figure 11. Zoom-up of Figure 9.

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