The effects of dissipated energy on mechanical behavior of carbonate sands using monotonic triaxial tests

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ABSTRACT

Carbonate sediments which covered approximately 40% of the ocean surface, are located in temperate and tropical areas. This type of soil is typically observed near offshore hydrocarbon Industries. Understanding the mechanical behavior of these sediments was studied in recent decades. Intra-void ratio and particle breakage are two important parameters which affect shearing response of carbonate sediments. In this study two originally different carbonate sands obtained from the Persian Gulf were used. A series of undrained monotonic triaxial tests in different initial relative densities and confining pressures were performed to evaluate the mechanical behaviour of the used sands. The effect of particle breakage on the contraction and dilation phases of the carbonate soils was studied. The input energy done per unit volume of soils was calculated to investigate the effect of this important parameter on mechanical behavior of these soils.

Keywords: carbonate soils, The Persian Gulf, triaxial tests, input energy

1 INTRODUCTION

It was reported by many researchers that, there are some differences between the monotonic and cyclic behaviors of carbonate (or calcareous) and siliceous sands (Datta et al., 1979; Celestino and Mitchell, 1983; Coop, 1990; Brandes, 2011; Shahnazari et al., 2013).

Carbonate sediments are mainly formed by the skeletal remains of marine organisms. Due to different locations and fauna that make their formation, a wide variety of engineering properties can be found in these soils. On the other hand, carbonate deposits of different locations may behave dissimilar under monotonic and cyclic loadings (Kaggwa et al., 1988; Kaggwa, 1988; King and Lodge, 1988; Airey, 1993; Hassanlourad et al., 2008, 2011; Dehnavi et al., 2010; Wang et al., 2011).

Calcareous sediments cover approximately 40% of the ocean surface (Holmes, 1978). These kinds of soils are mainly located in temperate and tropical areas, near offshore hydrocarbon industries, such as the Persian Gulf and near the coasts of Australia.

Previous investigations on the mechanical behaviour of carbonate deposits showed that there are two important parameters which affect their behaviour under both monotonic and cyclic loadings: (a) Intra-particle void ratio and (b) particle breakage (Salehzadeh, 2000). There are considerable amount of intra-voids in the carbonate grains which can be filled by water or air. Various researchers concluded that, the grains of carbonate soils crushes under lower stress

than that of siliceous soils (Kwag et al., 1999; Shahnazari and Rezvani, 2013).

In this study, the mechanical behaviors of two originally different carbonate soils located in the Persian Gulf were investigated. A series of undrained triaxial monotonic tests was conducted on the reconstituted specimens of the calcareous sands. The effects of some important parameters, such as relative density (i.e., loose and dense conditions) and confining pressure (i.e., 100 kPa to 600 kPa) on mechanical behaviors of these granular soils were investigated. Different researchers believed that the dissipated energy is an important parameter to interpret the engineering behavior of soils (Shahnazari and Rezvani, 2013). The energy (or work) performed per unit volume of specimens was calculated in each test to study the effect of this parameter on the monotonic behavior of the used carbonate sands.

2 SOIL CHARACTERIZATION

The carbonate soils used in this study were obtained from the northern shores of the Persian Gulf, Bushehr Port (BP) and Hormuz Island (HI). Fig. 1 shows the locations of the obtained soils.

Some physical properties of BP and HI sands are demonstrated in Table 1. Grain size distribution analyses of two calcareous sands are showed in Fig. 2. It can be seen that BP sand is finer than HI sand.

The carbonate contents of HI and BP sands using

the British Standard 1377 test (1990) are approximately higher than 50%.

Table 1. Physical properties of the used carbonate sands.

Soil	Grain Shape	D ₅₀ (mm)	C _u	C _c	e _{min}	e _{max}	G _s
HI	angular	0.78	8.33	1.54	0.625	0.909	2.764
BP	subangular	0.43	7.87	0.84	0.726	1.051	2.709

Fig. 1. The location of the used soils.

Fig. 2. Grain size distribution analyses of the used calcareous sands.

3 SAMPLE PREPARATION

The air pluviation method was used to prepare the specimens in this study. This method of sample preparation was recommended by many various researchers (Bishop and Henkel, 1957; Ladd, 1978). Dry soil spread into a mold with an about zero height of fall, which is fixed within the triaxial apparatus and lined with a rubber membrane. The diameter and height of specimens were 70 mm and 140 mm, respectively. The samples were prepared in loose and dense conditions. To achieve the saturation condition, after flushing CO₂ and exuding de-aired water to the specimens, a back pressure of 200 kPa under an

effective pressure of approximately 10 kPa, was applied to the samples. Using this method of saturation, a B-value of greater than 0.95 was guaranteed. After that, the samples were isotropically consolidated under the desired pressures (i.e., 100 to 600 kPa). The loading procedure was applied at the strain control condition with a constant rate of 0.5 mm/min in undrained conditions.

4 SHEARING RESPONSE IN UNDRAINED CONDITION

The samples of two sands were prepared in loose and dense relative densities and consolidated under 100, 200, 400 and 600 kPa. Fig. 3 shows the shearing response of HI and BP sands prepared in dense condition and consolidated under 600 kPa. It can be concluded from this figure that the strength of HI sand was more than that of BP sand.

Each undrained monotonic test can be separated into two phases. At the first phase which is generally called the contractive phase, the pore water pressure increases until it reaches to a maximum value. After that, in the second phase which is called the dilative phase, pore water pressure decreases and negative pore water pressure can be obtained. The point which separates contraction and dilation behaviors of the soils is called the phase transformation point (PTL) (Ishihara et al., 1975).

The results showed that dilative phase of the used sands occurred below the 5% axial strain. BP sands showed more contraction that HI sand (Fig. 3) which can be contributed to the higher particle breakage of BP carbonate sand.

Shahnazari et al. (2014) studied the effect of axial strain on the particle breakage of calcareous sands. They concluded that the most portion of crushing occurred on dilative phase of shearing response (Fig. 4).

The input energy per unit volume of specimens during an increment of straining in triaxial condition can be calculated as follows (Atkinson, 1993):

$$\delta W = q' \delta \varepsilon_s + p' \delta \varepsilon_v \quad (1)$$

in which, W is the energy (or work) done per unit volume of soil, q' is the deviatoric stress, ε_s is the shear strain, p' is the mean effective stress and ε_v is the volume strain (which is equal to zero in undrained triaxial tests). Table 2 shows the results of calculation of input energy in each phase of shearing response of the samples studied in this investigation.

It can be concluded from Table 2 that, more than 95% of input energy done at dilative phase. Obviously, the most portion of particle breakage must be occurred at this phase of monotonic response. This finding is similar to the conclusion stated by Shahnazari et al. (2014).

Fig. 3. Undrained shearing response of used carbonate sands; (a) deviatoric stress versus axial strain, (b) pore water pressure versus axial strain.

Fig. 4. The effect of axial strain on BP and HI sands under undrained condition (Shahnazari et al., 2014).

5 CONCLUSION

The monotonic shearing response of two calcareous sands which obtained from northern shore of the Persian Gulf was evaluated by triaxial apparatus. The specimens were prepared in different relative densities and consolidated under various confining pressures. All experiments were conducted in undrained condition. The following results can be concluded from the performed triaxial tests:

1) Due to different formation locations of BP and HI carbonate sands, their engineering behavior are

different.

2) HI sand shows higher strength than BP sand. In addition, comparison of the results obtained from BP and HI specimens showed that, lower pore water pressure obtains for HI sand at the end of each test.

3) Higher particle breakage occurred for BP grains. The most portion of crushing occurs at dilation phase in both BP and HI sands.

4) The tendency of contraction is more for BP sand which is contributed to the higher particle breakage.

5) More than 95% of the input energy done at dilation phase of shearing response for both BP and HI sands.

Table 2. The input energy done on contraction and dilation phases of the tests.

Soil	Density condition	Confining pressure (kPa)	ϵ_{PT}^a (%)	W_{Con}^c/W_{Tot}^b (%)	W_{Dil}^d/W_{Tot} (%)
BP	Loose	100	2.32	1.53	98.47
BP	Loose	200	2.54	2.81	97.19
BP	Loose	400	3.21	3.62	96.38
BP	Loose	600	4.64	4.75	95.25
BP	Dense	100	0.74	0.29	99.71
BP	Dense	200	1.87	1.28	98.72
BP	Dense	400	1.92	1.62	98.38
BP	Dense	600	2.75	4.13	95.87
HI	Loose	100	1.19	0.59	99.41
HI	Loose	200	1.49	0.97	99.03
HI	Loose	400	2.61	1.68	98.32
HI	Loose	600	3.65	4.22	95.78
HI	Dense	100	0.37	0.11	99.89
HI	Dense	200	0.54	0.39	99.61
HI	Dense	400	1.13	0.84	99.16
HI	Dense	600	1.31	1.37	98.63

^a ϵ_{PT} : the axial strain at phase transportation phase

^b W_{Tot} : the entire input energy done at triaxial test

^c W_{Con} : the input energy done at contraction phase

^d W_{Dil} : the input energy done at dilation phase

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