THE EFFECT OF SILICA CONTENT ON THE PROPERTIES OF CARBONATE SAND

L'EFFET DE LA TENEUR EN SILICE SUR LES PROPRIETES DU SABLE CARBONATE

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SYNOPSIS: In order to study the effect of silica content on the engineering properties of carbonate sands, samples were tested with carbonate contents varying from 25% to 83%. The friction angle and ductility increased with increasing carbonate content. At carbonate contents of 45% and above the crushable nature of the particles dictated the shearing behaviour. However using the pore pressure coefficient as an indirect measure of soil skeleton compressibility revealed that soil skeletons containing carbonates exhibited a marked increase in stiffness under isotropic stresses due to the angular platey nature of the carbonate soil particles.

INTRODUCTION

Increasing engineering activity off-shore has resulted in a corresponding increased interest in the engineering behaviour of off-shore sediments. More than one third of the sea floor is covered by calcareous sediments in which carbonate minerals predominate (Poulos, 1980). Carbonate soils encountered in a marine environment consist either of skeletal remains of marine organisms or non-skeletal material which may be formed by precipitation from the surrounding water. Skeletal carbonates exist as thin walled shell fragments or skeletal grains with large intraparticle voids (Datta et al, 1979; Valent, 1974; Golightly and Hyde, 1988).

Limited experience with offshore foundations in carbonate soils has indicated that conventional methods of geotechnical analysis do not reliably predict the performance of foundations in such soils (Randolph, 1988). In particular piles driven into deposits containing skeletal sediments give unusually low bearing capacities despite high measured friction angles (Angemeer et al, 1973). This is largely attributed to the crushability of the skeletal particles which results in low values of both skin friction and end bearing capacity.

The distribution of carbonate materials in the marine environment is highly variable and different deposits contain varying amounts of silicous minerals (Nacci et al, 1975; Buchanan et al, 1967; Kogler, 1967). This variation will in turn affect the degree of problematic engineering behaviour of these deposits.

In order to study the effect of the silica content on the shear characteristics of carbonate sands various percentages of Leighton Buzzard silica sand were mixed with Dogs Bay Sand a skeletal molluscan carbonate sand. Stress controlled triaxial tests with pore water pressure measurements were then carried out on dense specimens over a range of effective consolidation pressures.

MATERIAL PROPERTIES

The two soils adopted for the various tests were Leighton Buzzard Sand, a sub-angular silica sand and Dogs Bay Sand, a platey angular skeletal molluscan sand from the west coast of Eire (Evans 1985). A summary of the physical properties of these sands is presented in Table 1.

The very different particle shapes of each sand are contrasted in the electron micrographs shown in Figure 1.

Figure 1(a) Leighton Buzzard Sand

Figure 1(b) Dogs Bay carbonate sand

The flat, platey angular molluscan fragments of Dogs Bay Sand lead to a very open matrix and close packing of particles is difficult to achieve without the initiation of crushing (Golightly and Hyde, 1988). This fact combined with the high intraparticle porosity means that the maximum and minimum voids ratios for this sand are twice those achieved for the silica sand. As a result the carbonate sand behaves in a similar way to loose silica sands and when sheared, tends to dilate only at relatively low confining stresses.

Table 1. Material properties

Property	Leighton Buzzard sand	Dogs Bay sand
G_s	2.65	2.75
D_{10} mm	0.6	0.24
D_{50} mm	0.82	0.44
Uniformity coeff. C_u	1.48	2.06
e_{min}	0.51	0.98
e_{max}	0.84	1.83
Length/width ratio	1.2	2.36
shape	sub-angular isometric	angular platey/flakey
specific surface m^2/m^3	$4.4x10^3$	$6.4x10^3$
intra- particle porosity $n_{intra}\%$	-	4-6
crushing coefficient	1.1	4.6
mineralogy	quartz	low and high Mg calcite with some aragonite
carbonate content %	-	85-95

The carbonate content of the Dogs Bay Sand lay between 85-90% [Golightly, 1989] and to this were added nominal percentages of 5%, 30%, 50% and 75% Leighton Buzzard sand. The actual average carbonate contents were then measured using a pressure calcimeter [Muller & Gastner, 1971; Birch, 1981; Chaney et al, 1982] and are given in table II. All the silica content values given in the figures of this paper are in fact for the nominal Leighton Buzzard sand contents.

Table II. Sample Compositions and friction angles

Leighton Buzzard sand content %	Average carbonate content %	Non-carbonate mineral content %	Friction angle ϕ'degrees
5	83	17	42
30	61	39	41.5
50	44.7	55.3	39
75	25	75	37

SAMPLE PREPARATION

Due to the presence of intraparticle voids in the carbonate sand additional techniques had to be developed to achieve full saturation. For each test sufficient sand was weighed and poured into a narrow necked flask and freshly de-aired distilled water was then poured into the flask. The sample was allowed to stand for a minimum of three hours, then a vacuum of 1 bar was applied to the flask while it was mechanically agitated for a further thirty minutes. The triaxial cell base was carefully de-aired, and the flask containing the saturated sample inverted over the former allowing the sample to pluviate through water while vibrating the former to achieve a final relative density of approximately 90%. The density was controlled by measuring the final height of the sample.

Samples were set up in the triaxial cell at an effective cell pressure $\sigma'_3$of 10KPa and the B value checked. Samples with B values less than 0.95 were discarded. Samples were then subjected to a total cell pressure of 700kPa and back pressures of 200, 400 and 600kPa to give effective consolidation pressures of 500, 300 and 100kPa respectively.

TRIAXIAL TESTS

Generally calcareous sands exhibit a higher angle of internal friction when compared to siliceous sands. When the Dogs Bay Sand was mixed with Leighton Buzzard Sand the effective friction angle gradually decreased with increasing silica sand content (Table II)

When sheared, samples with a nominal silica sand content of 5-50% (carbonate content 44.7-83%) behaved as ductile materials with no obvious peak shear strength even at high axial strains (Fig 2). The stress-strain curves for these three mineral compositions lie relatively close to each other and exhibit two phases of behaviour. Initially up to 1 or 2% axial strain the samples have a high stiffness. Following this the behaviour transforms to a lower stiffness high strain behaviour. The transformation was particular marked at the higher effective consolidation pressures.

The material with a 75% nominal silica sand content had a brittle stress-strain curve with a definite peak and sustained much higher deviator stresses. Thus although the friction angle decreased with increasing silica content, the dilatant behaviour resulted in a rapid increase in the mean normal effective stress and hence strength.

In all the specimens tested the pore water pressure initially increased and then dropped gradually (Fig. 3.). Dilatant behaviour occurred for all samples at 100kPa effective consolidation pressure. However, once again the results for samples with a nominal silica sand content of 5-50% were grouped separately from those with a silica content of 75%. At 300kPa and above the low silica samples showed little or no net negative pore water pressures or dilation.

Effective stress paths for the undrained triaxial tests have been plotted in terms of:

$$p' = \frac{1}{3}(\sigma'_1 + 2\sigma'_3)$$

and

$$q = \sigma'_1 - \sigma'_3$$

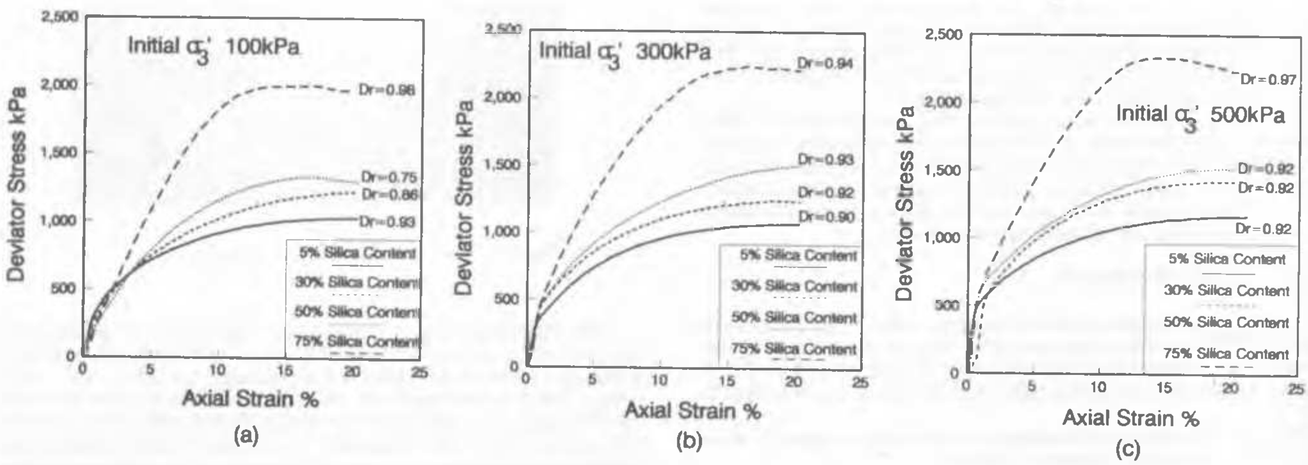

Figure 2 Triaxial stress strain curves

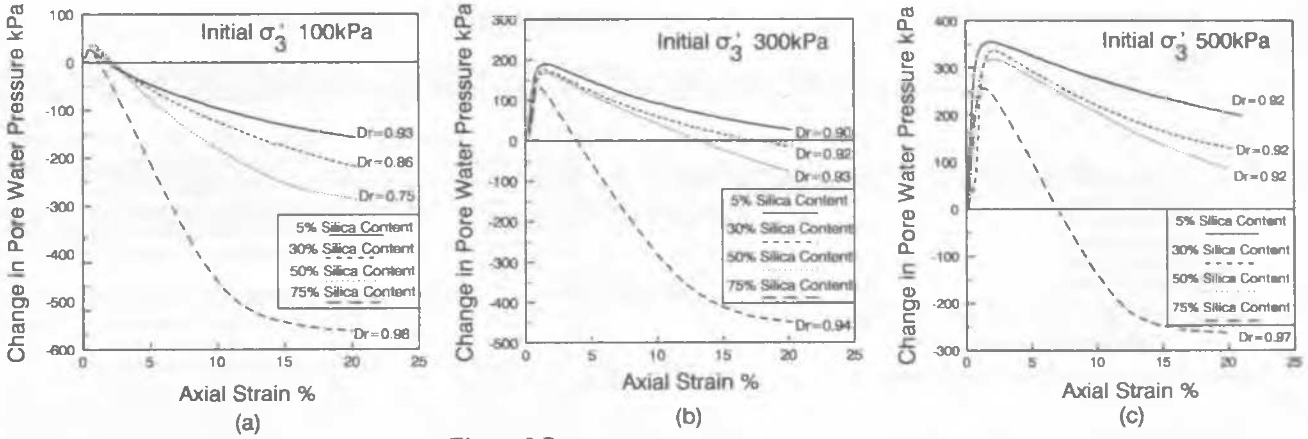

Figure 3 Pore water pressures

and are shown in figure 4 for various silica sand contents. The stress paths are characteristic of those for all sands, rising to the friction line of slope M and moving up this line towards the critical state. As the silica content increases the stress paths change from those typical of a loose sand to become more like those expected for a dense sand. For higher effective cell pressures the mean effective stress p' initially decreased before increasing. At minimum p' a phase transformation occurs (Ishihara and Okada, 1987) which coincides with the change in slope on the stress strain curves in Fig. 2. Airey and Fahey (1991) pointed out that this phase transformation marks the boundary between contractive and dilative behaviour. This point is particularly marked for the lower silica content samples at high effective consolidation pressures.

COMPRESSIBILITY OF SOIL SKELETON

The pore pressure coefficient B can be related to the compressibilities of the soil skeleton and voids by the following expression:

$$B = \frac{1}{1 + n\frac{C_v}{C_c}}$$

Skempton (1954)

where C_c = compressibility of soil skeleton; C_v = compressibility of voids and n = porosity of soil sample.

As expected the B value decreased with increasing effective confining pressure (Figure 5). However, Figure 5 also clearly shows that the overall B value increased with increasing nominal silica sand content. Assuming the voids to be saturated and thus having a constant compressibility then the only explanation for this phenomenon is that the stiffness of the soil skeleton increases with increasing carbonate content. This is quite the opposite to what was originally expected since the carbonate sand used in the tests is a highly crushable material. It would appear however, that under isotropic stress conditions the platey angular nature of the carbonate particles causes the soil skeleton to increase in stiffness. On the other hand when shearing stresses are applied to a high carbonate content sample

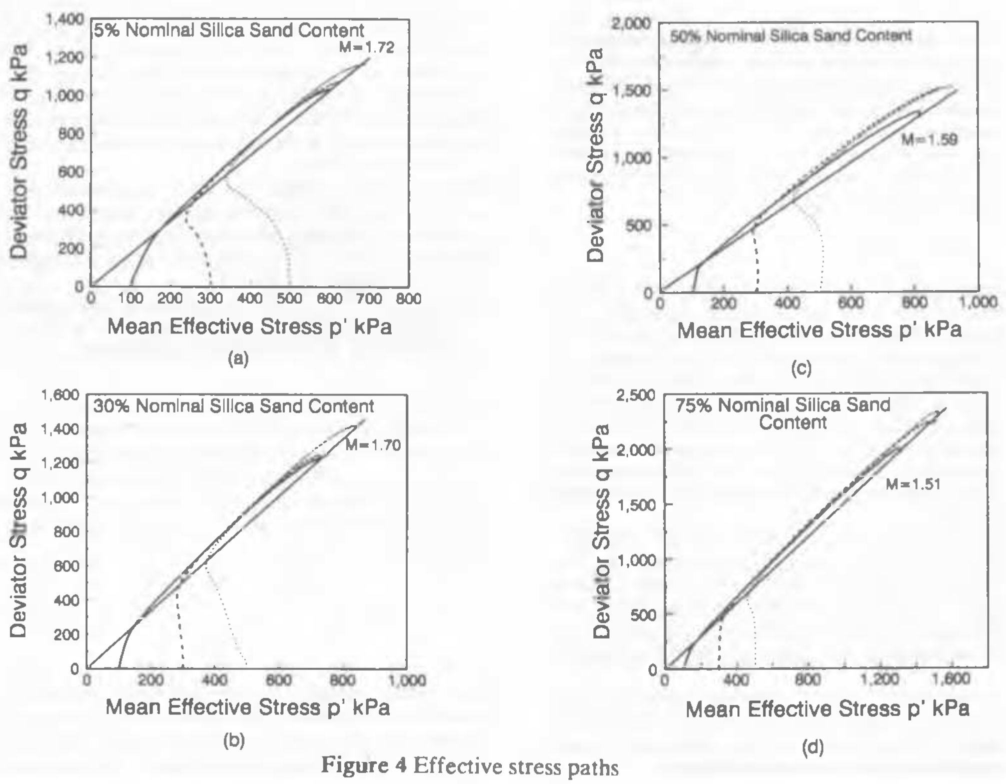

Figure 4 Effective stress paths

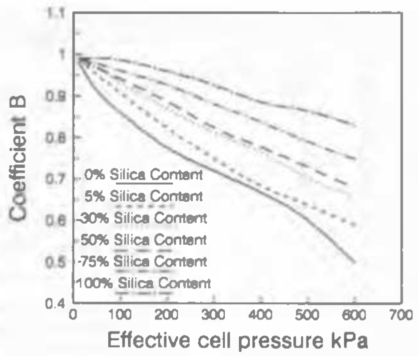

Figure 5 Pore water pressure parameter B

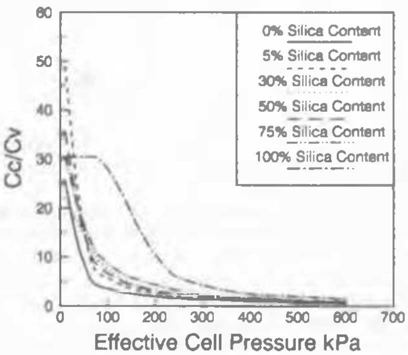

Figure 6 Variation of compressibility ratio

then the breakable nature of the particles dominates the behaviour resulting in a marked reduction in dilation.

Figure 6 shows the relationship of the compressibility ratio Cc/Cv to the effective cell pressure. It can be seen that for the sands containing carbonates if Cv is assumed constant then the soil skeleton stiffness increases rapidly as the cell pressure is increased from 10kPa to 100kPa, while for the pure silica sand the same increase in stiffness requires a 300kPa increase in effective confining pressure. Data supporting this phenomenon were presented by Poulos (1980) showing a decrease in compression index as carbonate content increased for both soft normally consolidated soils from shallow depths and stiff samples from greater depths.

CONCLUSIONS

Samples with nominal silica sand contents of up to 50% (actual carbonate contents above 45%) behaved as ductile materials, and their stress-strain and pore water pressure behaviours could be grouped together. The stress-strain curves exhibited two phases, an initial low strain high stiffness followed by a high strain ductility. These two behaviours were separated by a phase transformation evident in the effective stress paths. Because of the breakable nature of the particles, dilation under shear was suppressed particularly at higher effective cell pressures. In contrast to this the composite containing 75% silica sand exhibited a brittle stress strain curve with associated dilatant behaviour.

A study of Skempton's B value revealed that for a given effective confining stress, it increased with increasing silica sand content. If it is assumed that the voids were saturated and had a constant compressibility then it can be concluded that the stiffness of the soil skeleton under isotropic stress conditions increases with increasing carbonate content. This behaviour was observed for all carbonate contents.

The breakable nature of the individual carbonate particles has a dominant influence on the soil behaviour when shear stresses are applied, while the angular platey nature of the carbonate sand increases the stiffness under isotropic stress conditions.

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