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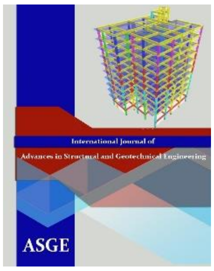

International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 Online ISSN 2812-5142

Special Issue for ICASGE'19

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ASGE Vol. 04 (03), pp. 25-46, 2020

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ABSTRACT

Construction on calcareous sandy deposits is a challenging task for geotechnical Engineers due to the difference in behavior and characterization of calcareous sands than those of conventional siliceous sands. Calcareous deposits exist in Egypt along the coasts of Egypt especially along the north coast. As it is known that these areas are under major development of new cities, ports, touristic, power generation and industrial facilities.
This article represents a comparative study between the calcareous sand which covering Coast west of Alexandria (northern coast of Egypt) between El Agamy and Marina El alamein with Siliceous and calcareous sand in other places. The geological and geotechnical properties of northern coast calcareous sand have been studied. The laboratory tests are including chemical, physical and mechanical properties. Where the chemical analyses of test sand were adopted to determine carbonate content. The micro structure of tested samples was investigated using both (XRD) analysis, thin section and scanning electron microscopy (SEM). The second part is the physical properties were including determination of specific gravity, grain size gradation and surface texture. The maximum dry density is also obtained using modified proctor test while the mechanical properties of tested soil were included both the shear strength using direct shear box and compressibility using consolidation test. A series of isotropically consolidated undrained direct shear tests were conducted using a Calcareous sand from north coast of Egypt. The tested north coast Egypt Calcareous sand is well graded sand with highly angular grains. Calcareous samples were tested at different initial densities (30%, 50% and 80%), with different carbonate content. The result of current study will compared with Siliceous and calcareous sand in other places for different researchers.

Keywords: *Calcareous sand, siliceous sand, carbonates content, and direct shear test, Consolidation compaction parameters*

INTRODUCTION

The calcareous sand are located in many places around the world, especially in vital places in coastal areas where ports, commercial, touristic and residential facilities are located Because of the problems encountered in implementing projects in these areas, they have received considerable attention from researchers to study the geological and the engineering characteristics of this soil. Due to the special nature of the calcareous sand, they are similar in their characteristics and differ significantly with the siliceous sand. The difference between the calcareous and siliceous sands is due to the high voids ratio, compressibility, the special crushable nature of calcareous sands, and percentages of the carbonates forming these sands. This particular nature of this soil has caused a significant change in the properties of this soil.

Most studies carried out on the calcareous sand have confirmed a great difference in the geotechnical and geological characteristics of the siliceous sand and that most of the experimental equations suitable for siliceous sands cannot be performed on the calcareous sand and need some modifications and corrections to apply. The soil formations in the North Coast of Egypt are predominantly calcareous. This article provides a research study covering the Behaviour of the calcareous sand of the North Coast of Egypt and its comparison with the calcareous sand and the siliceous sand from previous studies in Egypt and elsewhere in the world, Geological and geotechnical properties of calcareous sand and siliceous sand have been studied. The study is conducted through a series of laboratory tests involving chemical, physical and mechanical properties. The geological and geotechnical properties of northern coast calcareous sand have been studied. The laboratory tests are including chemical, physical and mechanical properties. Where the chemical analyses of test sand were adopted to determine carbonate content. The micro structure of tested samples was investigated using both (XRD) analysis, thin section and scanning electron microscopy (SEM). The second part is the physical properties were including determination of specific gravity, grain size gradation and surface texture. The maximum dry density is also obtained using modified proctor test while the mechanical properties of tested soil were included both the shear strength using direct shear box and compressibility using consolidation test. A series of isotropically consolidated undrained direct shear tests were conducted using a Calcareous sand from north coast of Egypt. The tested north coast Egypt Calcareous sand is well graded sand with highly angular grains. Calcareous samples were tested at different initial densities (30%, 50% and 80%), with different carbonate content. The result of current study will compared with Siliceous and calcareous sand in other places for different researchers.

GEOLOGY OF Northern coast of Egypt calcareous sand

The northwest coastal plain of Egypt comprises a sequence of eight carbonate ridges that took place during the Pleistocene (Shukri et al., 1956 and Butzer, 1960). The origin of these oolitic ridges are windblown material derived from the Tertiary limestone of the western desert, which later have been reworked by agitating water movements of beach waves (Hilmy, 1951). The coastal ridge is an elevated land from slopes gently landward and steeper seaward, this ridge is composed of white cross bedded, friable oolitic limestone. The coastal dunes are found close to the beach, they are composed of loose white oolitic carbonate sands washed from degradation of oolitic coastal ridges.

Carbonate minerals

Zahran, (2008) performed a chemical analysis for 20 representative samples collected from the first four ridges with the aim of determining the percentage of $CaCO_3$ and $MgCO_3$ Table (1). The data showed that calcium carbonate is the main component of these rocks. A slight decrease is noted southward toward the oldest ridge where, magnesium carbonate shows a marked increase toward the oldest ridge which is attributed to dolomitization of calcite by aging. This process may be enhanced by groundwater movement and due to leaching process by rainwater. In the present study, the $CaCO_3$ content ranges between 76.25 and 94.98% with a mean value of 86.67%.

Table (1): $CaCO_3$ and $MgCO_3$ contents of the studied carbonate ridges (Zahran, 2008)

Location	First ridge	Second ridge	Third ridge	Fourth ridge
$CaCO_3$ %	93.61	91.29	85.2	82.9
$MgCO_3$	1.95	3.16	5.51	6.97

Specific gravity

Calcareous sand specific gravity determined according to the Egyptian code for constructing materials the specific gravity values for calcareous sand samples were ranging from 2.7 to 2.75. The relatively high values of specific gravity for the studied samples was attributed to the minerals such as calcite and Aragonite, calcareous sands typically present higher specific gravities and void ratios than quartz silica sand (Morioka and Nicholson, 2000). The higher specific gravity values are due to their mineralogy composition which usually includes minerals such as calcite (specific gravity, Gs of 2.75) and aragonite (Gs = 2.95). Siliceous minerals, on the other hand, are less heavy, since they typically include quartz which is a mineral with a specific gravity value of 2.65.

X-Ray Diffraction Analysis

Agaiby, (2011) performed the X-Ray Diffraction analysis on North Coast in Egypt calcareous sand which revealed that the sample is composed of a major constituent of calcite and aragonite with no minor constituents and a trace constituent of quartz. The geochemistry analysis of the carbonate sample indicated that the CaO is the main compound with traces of several elements present in the sand sample with different percentages illustrated in Table (2)

Table (2): Elemental Content and Mineral Composition of Tested Sand (Agaiby, 2011).

SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO
0.28	0.02	0.12	0.02	< 0.01	0.02	55.40
Na2O	**K2O**	**P2O5**	**SO3**	**Cl**	**L.O.I.**	**---**
< 0.01	0.02	0.06	0.12	< 0.01	43.53	---

Salehzadeh, et al., (2008) studied the North Rock beach sand obtained from the coast of North Cornwall at Rock" beach opposite Padstowe-England. The result shewed that calcite and aragonite were the most prevalent carbonate minerals distinguishable in the soil using XRD method.
(Morales-Velez, 2014) performed X-Ray Diffraction on the calcareous soils collected in CaboRojo, Puerto Rico to evaluate the mineralogy of the calcareous sand. A summary table of the soil composition can be found in Table (3). The results show that the calcite and aragonite are the main carbonate minerals in addition to traces of magnesite, siderite and dolomite that found in some samples.

Table (3): Summary of results for the XRD Mineralogy tests (Morales-Velez, 2014)

Sample	Calcite	Aragonite	Magnesite	Siderite	Dolomite
Bucket	Yes	Maybe	No	No	No
B1S1	Yes	Yes	No	No	Maybe
B1S2	Maybe	Yes	No	Maybe	Maybe
B1S3	Maybe	Yes	No	Maybe	No
B1S4	Yes	Yes	Maybe	No	No
B1S5	Yes	Yes	Maybe	No	Maybe
B1S7	Yes	Yes	No	No	No
B2S1	Yes	Yes	No	No	No
B2S6	Yes	Yes	No	No	No
B2S8	Yes	Yes	No	No	No

1 Bucket = surficial samples; B#S# = Boring number/sample number

In the present study, Figure (1) XRD analysis reveals that the essential carbonate minerals are calcite and aragonite in addition to quartz as non-carbonate mineral where the chemical analysis shows enrichment of CaO (42.7-53.19) with a mean value of 48.54.

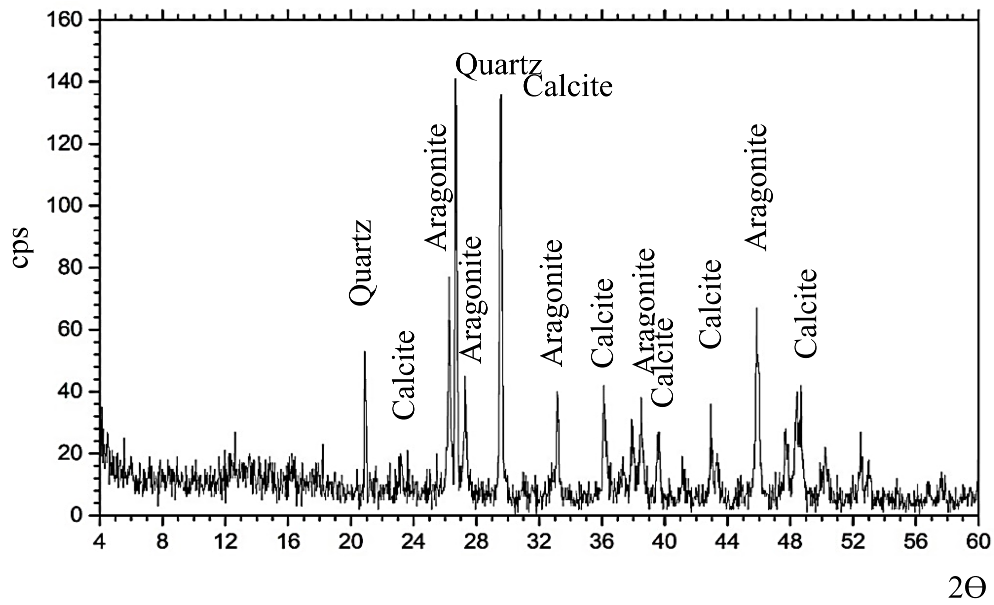


Fig. (1): X-ray diffractogram of sample no. 4 located at Sidi Kirayr.

Petrographical Analysis

Ismail (2000) reported a detailed microscopic for the Goodwyn (GW) soil which, is an offshore calcareous soil recovered from the seabed near the vicinity of the Goodwyn. These investigations suggest that this soil is very fragile in nature and consists mainly of the remains of marine organisms Figure (2). Ledge Point (LP) soil is a coastal aeolian calcareous soil. The typical microscopic images of LP soil obtained from Ismail (2000) presented in Figure (3) suggest that most of the LP soil comprised of bioclastic grains with discernible marine organisms. It consists of a variety of particle shapes, with most being rounded. The lack of fines and the presence of rounded particles are the most distinct differences between LP soil and GW soil.

Fig. (2): SEM micrograph for GW soil: (a) angular particles with different and (b) hollow fragile particles (after Ismail, 2000)

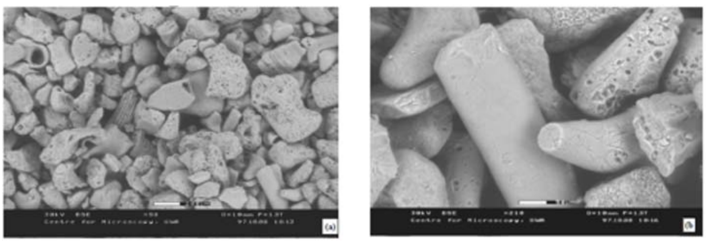


Fig. (3): SEM micrograph for LP soil: (a) particles with different origin (b) close up view of the particles showing rounded edges with high aspect ratio (after Ismail, 2000)

Dehnavi, et al., (2010) studied the Hormuz calcareous sand obtained from the northern beach of Hormuz Island. The grain composition of the soil can be seen in Figure (4). The soil is dominated by thin-walled mollusk and echinoderm plate fragments and thick-walled foraminifera.

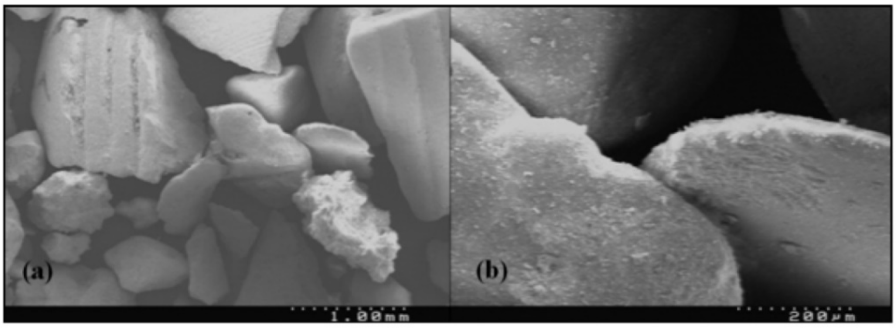


Fig. (4): SEM micrograph for the Hormuz calcareous sand; a: angular particles soil; b: close-up view of the particles showing hollow fragile particles (Dehnavi et al., 2010)

La Vielle, (2008) introduced a comprehensive review on Playa Santa calcareous sands and concluded that calcareous sand particles have two attributes cause their properties to differ from those of quarzitic soils. The first attribute, calcareous sands have significant intra-particle void space. The intraparticle void space is created by the particles made of shells that have not been fully broken apart or by corals that have cavities within the particle or on the surface. The second attribute is the angular particle shape. Photographs of a variety of calcareous soil particles are shown in Figure (5).

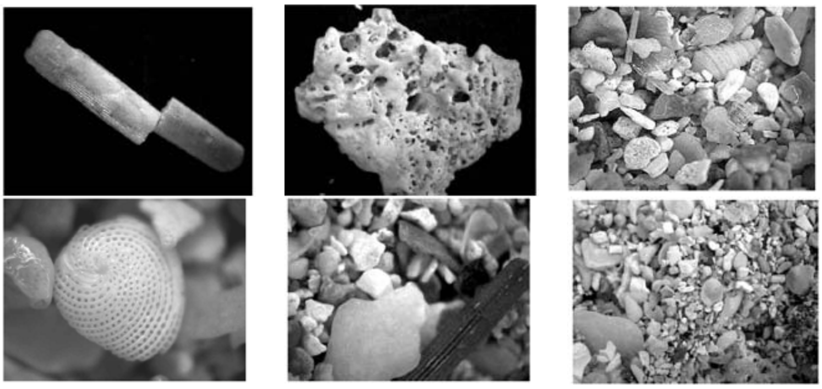


Fig. (5): Calcareous Soil Particles (Playa Santa) (La Vielle, 2008).

Agaiby, (2011) classified the sand of North coast of Egypt as Pelloidal limestone. Microscopically, the sand sample is fine to medium-grained composed of calcite as major constituent associated with rare amounts of aragonite, quartz and considerable amounts of fossil shells and fossil fragments Figure (6).

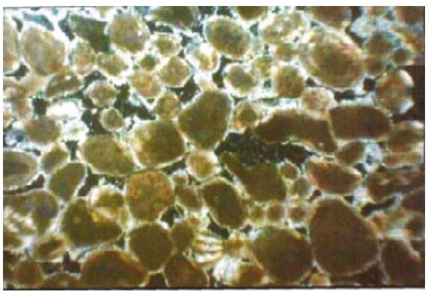


Fig. (6): A section of calcareous sand under microscope, (Agaiby, 2011).

Abdeltawab, et al., (2013) showed that the sands along the northern coast called calcareous sand composed of quartz grains and carbonate grains consist of ooids and intraclasts. The carbonates along the Northern coast that represented as ridges along the northern coast classified as oolitic limestone (oosparite). It is composed of coarse- grained ooids and intraclasts where the cement is mostly sparite (Figure (7).

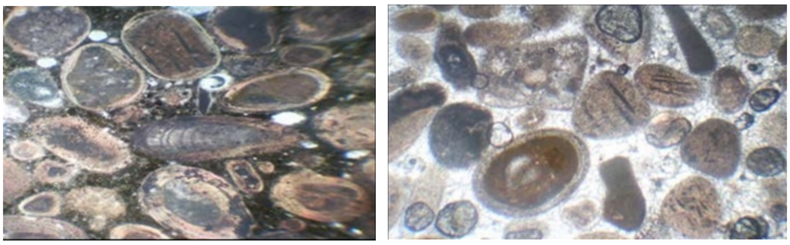


Fig. (7): (a) Photomicrograph of the course- grained ooids and intraclasts C.N. (b) Photomicrograph of the course- grained ooids and intraclasts in limestone (oosparite) C.N. (Abdeltawab, et al., 2013).

Sandoval, et al., (2012) studied the CaboRojo calcareous sand which collected from a beach in Puerto Real, CaboRojo, south-western Puerto Rico. This sand was uncemented and classified as being white to yellow, fine to medium-grained, poorly-graded, having sub-angular to angular grains and high intra-particle porosity Figure (8). This calcareous sand had at least 91% calcium carbonate content.

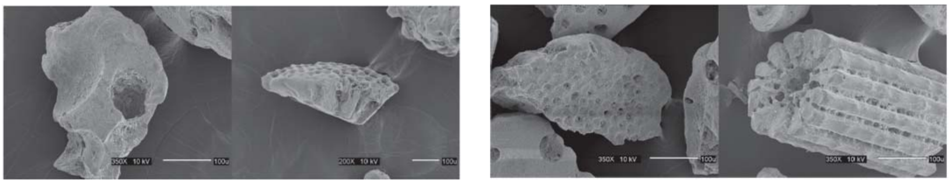


Fig. (8): Micrographs of CaboRojo uncemented calcareous sand. (Sandoval et al., 2012)

Spagnoli, et al., (2015) studied the mineralogy of the Dog's Bay sand using the scanning electron microscopy to obtain images of the sand particles Figure (9). It was found that the sand consists of particles which range from rectangular to platy in shape. They are mostly smooth in texture, but most have symmetrical pitting over the particle surface. Most SEM spectra showed at least 80% calcium, with trace amounts of silicon, sulphur, aluminium, sodium, chlorine, bromine, magnesium and iodine. A number of the spectra showed 100% calcium. These results confirm that the sample is in fact calcareous sand.

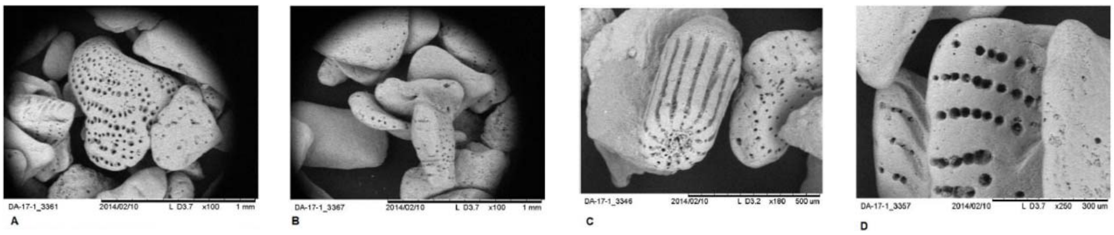
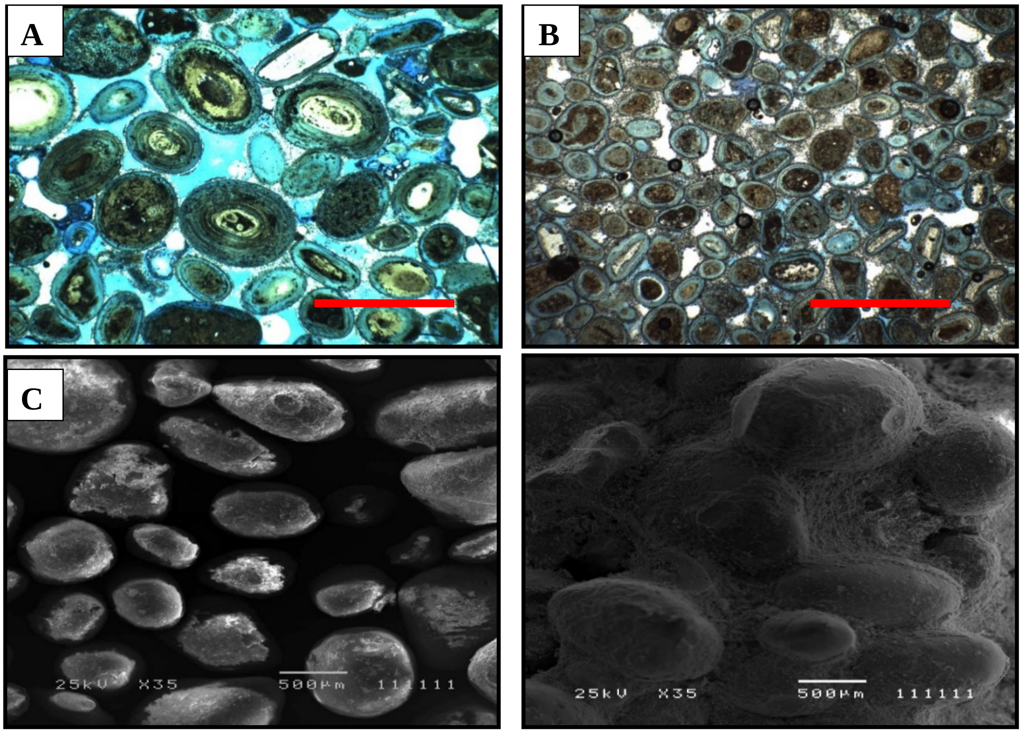


Fig. (9): Sample of images from SEM. A) Fossil-like particle; B) Rounded edges, some smooth, some pitted particles, oblong and rectangular shapes; C) Zero visible fines, mostly large particles; D) Symmetrical pitting in particles (Spagnoli et al., 2015)

The present study, Figure (10): the sandstones characterized by Bio-intra-oosparite facies. They are represented by grain stones. The framework consists predominantly of fine to medium, moderately well-sorted, rounded to subangular sand-size carbonate grains. The sand-size carbonate grains are composed mainly of ooids and intraclasts with variable amounts of bioclasts in addition to scattered detrital quartz grains. The cementing materials are less than 5% and is mostly microcrystalline spary calcite with high amount of intergranular pore spaces. These facies were deposited in high-energy environment. The bioclasts associated with ooids may indicate a shallow open marine subtidal environment.



Scale bar = 0.2 mm

Fig. (10): A- Photomicrograph of the medium- grained ooids and intraclasts in sample 8 (Al Jamiah), B- Photomicrograph of the fine- grained ooids and intraclasts in sample 13 (Marina El alamein), E- Scanning electron micrograph of subangular to rounded sand grains in sample 4 (Sidi Kirayr) and sample 12 (El Hamam), D- Scanning electron micrograph of sand grains cemented by microcrystalline calcite in sample 3 (El Agamy).

Physical Properties of Calcareous Sand

Grain size gradation test

The calcareous samples under investigation are classified as poorly graded sands (SP) for different investigates as conferment by figure (11). The tested sand has a uniform gradation (medium sand), with grain sizes mostly ranging from 0.2 mm to 1.0 mm, and fines content range from 0.30 %to 13.50 %. Referring the gradation curve, some of the index properties of the tested calcareous sand can be interpreted as effective diameter (D_{10}) that has a range from 0.06 to 0.30, uniformity coefficient (Cu), range from 1.7 to 6.4, and Coefficient of curvature (Cc) range from 0.68 to 1.22. The grain-size distribution curve for all the tested samples were presented in Figure (11) and Table (4). It can be concluded that the values of grading parameters can be agree with data obtained by (Agaiby, 2011).
While a comparison with different investigators, it has been found that, the mean diameter D_{50} are in range of (0.2٢ to 0.٨٢ mm) as classified in table (4). It is also found that the range of uniformity coefficient (Cu) are in range of (1.8 to ٤.١) and the fine content in range of (٠% to 9 %). It can be seen that the tested calcareous sand of sites under investigation are in range of the behavior of other one for different sites. On the other hand, the classification of calcareous sand is classified as SP according to ASTM system for different studied sites all over the world. It is also noticed that the graduation behavior of normal Silica sand are in range of calcareous sand as conformed by Figure (11) but there are significant variation on the mechanical properties as discussed in next topics.

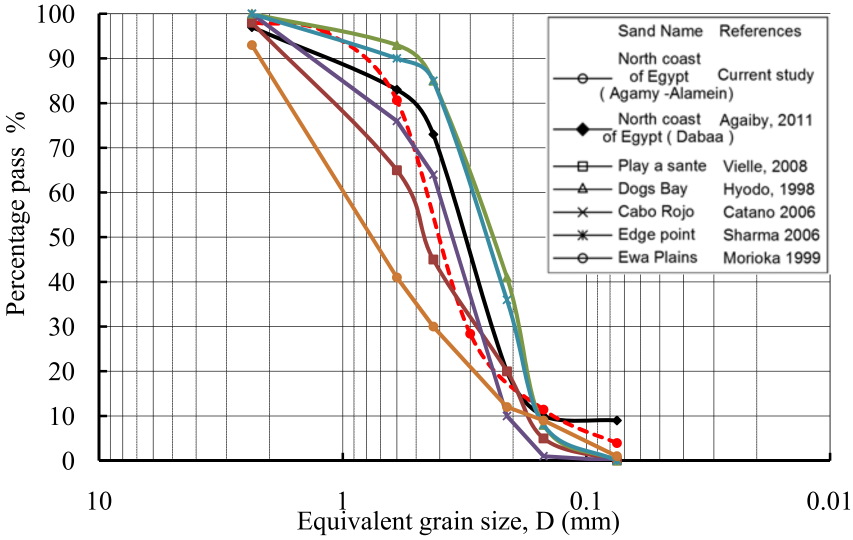


Fig. (11): Grain size distribution for tested samples in Egypt with other calcareous sand

Table (4): Comparison properties of calcareous sands worldwide.

Zone No	Reference	e_{max}	e_{min}	Cu	Cc	D_{10} (mm)	D_{50} (mm)	FC %	Carbonate contents%	Specific Gravity (Gs)	uses
North coast of Egypt (Agamy - Alamein)	Current study	0.87 to 0.98	0.47 to 0.55	2.65	0.99	0.18	0.41	4.0	76.25 to 94.98	2.70 to 2.75	SP
North coast Egypt (Dabaa)	(Agaiby, 2011)	1.04	0.75	2.40	1.07	0.15	0.31	9.0	94.6	2.786	SP

North coast Egypt (Alamein)	Abdeltawab et al. 2013	1.25 to 1.35	0.65 to 0.69	2.5 to 2.63	1.08		0.4		99	2.73 to 2.83	SP
Playa Santa	(La Vielle, 2008)	1.22	0.8	2.75	0.88	0.16	0.48	0.0		2.75	SP
Dogs Bay	(Hyodo et al. 1998)	1.83	0.98	1.80	0.85	0.15	0.24	2.0	85 to 95	2.75	SP
CaboRojo	(Cataño Arango 2006)			2.86	1.61	0.14	0.36	2.0			SP
CaboRojo	Pando et al 2012	1.71	1.34	2.1	1.07		0.38		92.8	2.86	SP
Ledge point	(Sharma and Ismail, 2006)	1.21	0.9	1.84	0.88	0.15	0.22	2.0	91	2.76	SP
Ewa plains	(Morioka and Nicholson, 1999)	1.30	0.66	4.10	0.95	0.20	0.82	2.0	98	2.72	SP

Maximum and Minimum Void Ratios estimation

Comparison with of some geotechnical properties of other carbonate sands worldwide and the tested sand in current study were listed in Table (4). Whereas, the carbonate content for tested simple are found to be in range of (76.25% to 94.98%) but for other site are found to be (53.78% for Hormuz Calcareous Sand (Dehnavi et al 2010) to 100%for Kawaihae Harbor Calcareous Sand (Brandes et al 2011)), the specific gravity are also as same for tested samples are found to be in range of (2.70 to 2.75) and others for different site which is reached to minimum value of 2.7 for Dog's Bay Calcareous sand (Spagnoli et al., 2015) and maximum value of 2.93.for Hormuz Calcareous Sand (Shahnazari, et al 2013) On the other hand with comparison with different investigates the maximum and minimum voids ratio for tested simple are found to be in range 0.98 for maximum voids and 0.47 for minimum voids ratio while these values for different investigates are found to be as much as 2.31 for Goodwyn (Gw) (Sharma 2004) for maximum voids ratio and 0.472 for Hormuz Calcareous Sand (Shahnazari, et al 2013) for minimum voids ratio The maximum and minimum range of the silica sand voids ratios are in range of 0.973 and 0.5 respectfully.

In case of calcareous sand the volume of voids can include an extra component related to their intra-particle voids. This component could be large and is mainly related to calcareous sands with grains of biogenic nature. Thus, voids ratio of calcareous sand with large amounts of biogenic origin particles can be higher than those of siliceous sand with similar skeletal arrangements. Generally, many engineering properties are often linked to regular void ratios of the skeleton structure of sand. Since voids ratio values of calcareous sands are the sum of regular void ratio and intra-particle voids, engineering behavior may be difficult to deduce from total void ratio values, Arango (2006).

Based on the literature a relation between (emax – emin) against Mean particle size, (D50) (mm) will be illustrated in Figure (12) and upper and lower boundary will be suggested. For confirmation the upper and lower limit of calcareous sand difference between maximum and minimum voids ratio against Mean particle size, (D50) is illustrated in Figure (12) it clearly again presents the range of (emax – emin) which show that the term of (emax – emin) is distinctly decreased with the increase of mean particle size D_{50}.

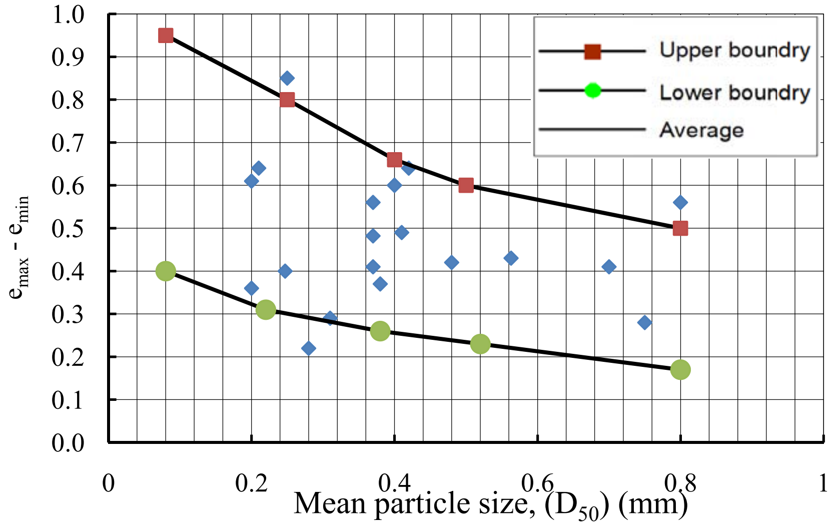


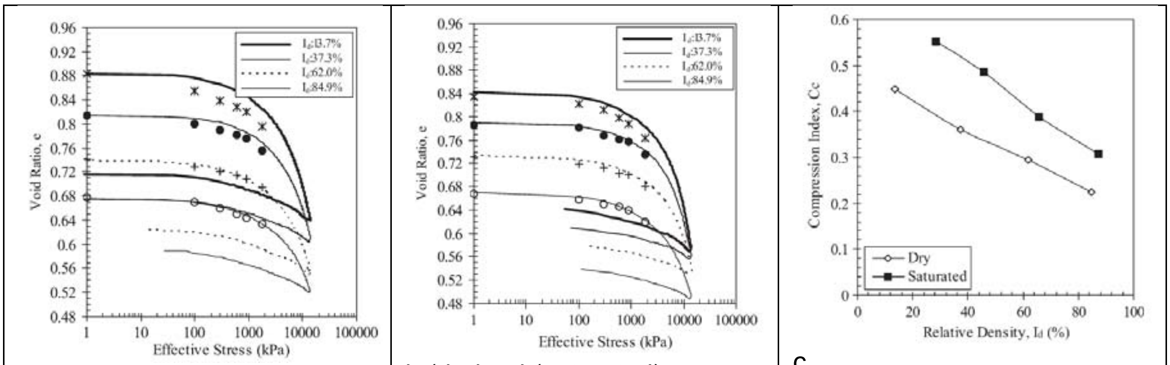
Fig. (12): The variation of Mean particle size, (D50) (mm) versus voids ratio (emax – emin) for calcareous sands

Mechanical properties of Calcareous Sand

The mechanical properties were investigated using both Consolidation test and direct shear test

Compressibility

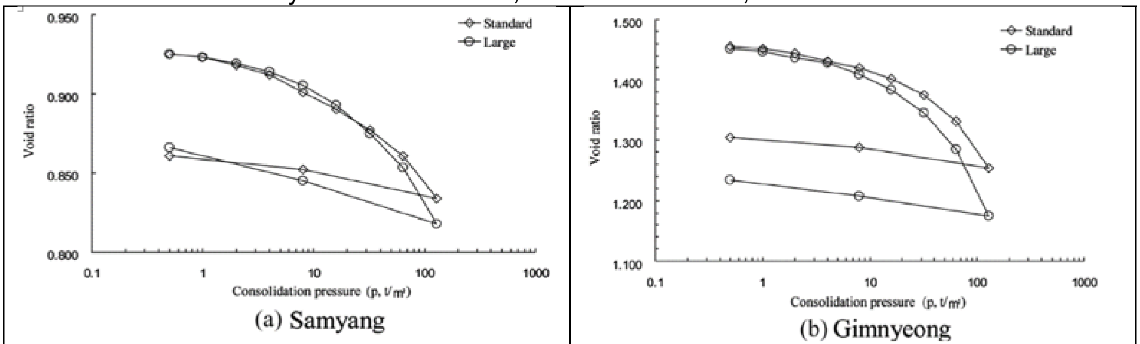
Settlement in sands has three main components, namely; particle rolling, particle sliding, and particle crushing (due to destruction of grains) (Bowles, 1996). Settlement is dependent on the compressibility of granular material. (Fang, 1991; Al-Sanad et al., 1993; Uygar et al., 2006; Grine, 2007; Kim et al., 2008) conducted one-dimensional oedometer tests on carbonate sand to determine its compressibility characteristics. (Kim et al., 2008) found the oedeometer tests gave fairly good estimate of settlement when compared with the settlement measured on site. Typical results from one-dimensional oedometer testing in both drained and dry conditions on sand samples (Uygar et al., 2006) showed that as the initial relative density increases compressibility decreases as expected Figure (13) a,b Curvature in the looser samples is more obvious and in samples tested in drained condition compressibility is higher for the same effective stress levels. If the compression index, Cc is calculated along the linear part of the normal compression curve obtained in each test, this behavior comes out to be more evident. As Figure (13) c indicates, under normal loading conditions up to elevated stress levels there is a linear relationship between compressibility and initial relative density. Thus the main factor governing the behavior of sand in this respect is the initial formation density (or void ratio) whereas; the saturation seems to be the main factor affecting the magnitude of compression.



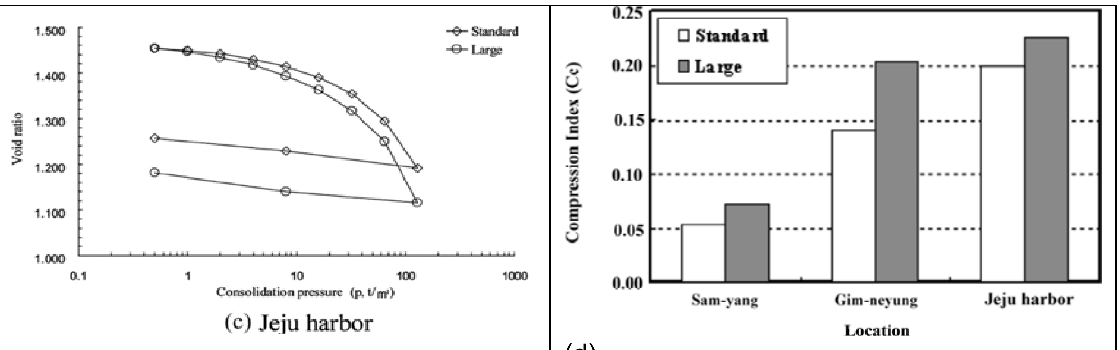
a (dry condition) | b (drained (saturated) condition | c

Fig. (13): Oedometer test results for sand. (Uygar et al., 2006)

Figure (14) shows the e-log (p) curves of compression tests conducted on Samyang, Gimnyeong, and Jeju harbor sand specimens remolded by raining technique and tapping (Kim et al., 2008). Test results obtained from both standard size and large size ring boxes having 10.4 cm in inside diameter by 3.4 cm in height are presented together. Both results show a very similar trend, but for tests conducted using the large size ring box, the compression index Cc is greater, as shown in Figure (14). Considering the particle size of sand, the compression tests using the large size ring box is recommended and its result is more reliable. Comparing the compression magnitude of the tested sands, Samyang sand was compressed about 3.2% of the specimen height. Gimnyeong and Jeju harbor sands were compressed about 8.4% and 11.1%, respectively. It could result from the mineral composition and the particle surface characteristics of sands. Where Samyang sand is one of silicate sands, which contain over 60% of SiO2, Al2O3 and Fe2O3. XRD test results also show that feldspar (K, Na, Ca, Ba (Al, Si) 4O8) and quartz are the principal minerals. In addition, the particles of Samyang sand have fine cracks and a very low degree of porosity. Therefore, a small compression was expected for this sand. On the other hand, Gymnyeong and Jeju harbor sands show a bigger compression than Samyang sand because these sands contain a large amount of CaCO3 and have many pores on the surface. In addition, Jeju harbor sands have an angular shape and cause more compression due to cracking and shattering of particles under pressure. Because the property for particle cracking and shattering depends on the type of mineral and particle shape, angular sands containing a large amount of CaCO3 are more susceptible to cracking and shattering than other sands mainly formed with SiO2, Al2O3 and Fe2O3, such as silicate sands.



(a) Samyang silica sand | **(b) Gymnyeong calcareous sand**

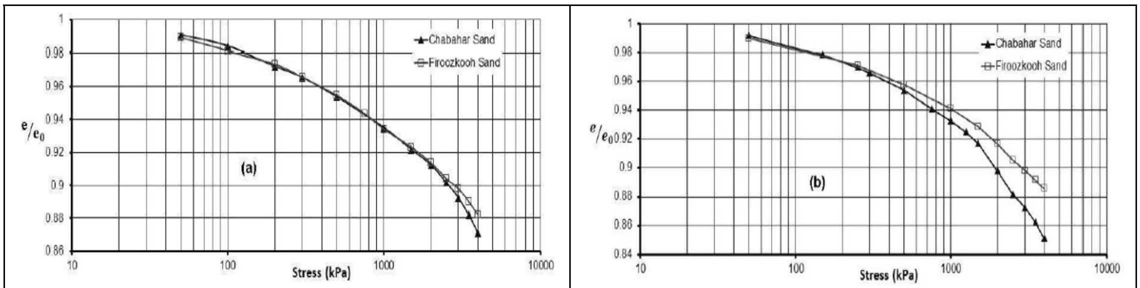


(c) Jeju harbor calcareous sand

(d)

Fig. (14): a, b) and c Relationship between void ratio and pressure (d) Values of compression index using both standard size and large size ring boxes. (Kim et al., 2008)

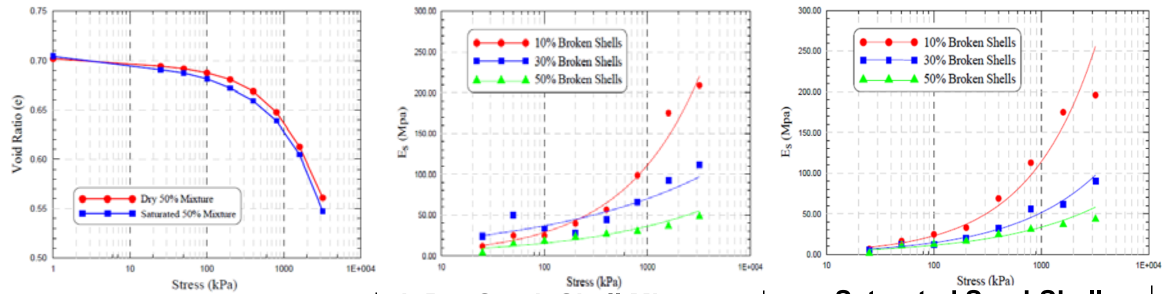
Figure (15) a, b show the compressibility of dense and loose sands under one dimensional loading (Hassanlourad et al., 2014), as the void ratio is divided by the initial void ratio versus normal stress. As shown in these figures, the compressibility of loose carbonate sand is generally more than quartz sand under stressful conditions. The compressibility of dense samples is more analogous to the quartz sand, although by the end of the loading process, carbonate sand once again demonstrates a higher level of tendency towards contraction. This trend is more evident as stress is increased. When loose carbonate sand experiences vertical stresses of about 250 kPa, its compressibility is intensified; however, this trend begins under vertical stresses of about 2.5 MPa for dense samples. This behavior can be ascribed to the higher initial void ratio and fragility of carbonate sand grains, because carbonate sand grains have less stiffness (hardness of 3 for calcite and 7 for quartz on the Mohs scale) and weaker planar geometry (compared to volumetric geometry grains of quartz sand).



(a) densely packed samples **(b) loosely packed samples**

Fig. (15): Normalized void ratio versus normal stress (Hassanlourad et al., 2014)

One dimensional compression test using oedometer performed by (Ata et al., 2017) on Calcareous sand obtained from northern coast of Egypt in order to have a better insight and identification of the compressibility and crushability of sand-shell mixtures. The effect of sand mixture saturation is also investigated. Figure (16) a show the relationships between voids ratio (e and Δe) and normal stress increment (e-log σ and Δe-log σ) for dry and saturated 50% sand-shell mixtures. The maximum change in the void ratio for saturated case over the dry one increases by 11.35% under the same stress level. This increase is due to the effect of water lubrication of the particles which facilitate particle movement under stresses. The soil modulus (Es) is found to decrease with samples saturation. The decrease in soil modulus for saturated samples ranges between 6.30% and 19.0% of its value for dry samples. Figure (16) b and c show the relationship between soil modulus and normal stress for dry and saturated samples of the calcareous sand-shells mixture, respectively.



a Dry and Saturated 50% Sand-Shell Mixture | **b Dry Sand- Shell Mixtures** | **c Saturated Sand-Shell Mixtures**

Fig. (16): One dimensional compression test result (Ata et al., 2017)

Compression index (Cc) and recompression index (Cr)

The compression index (Cc) represents the compressibility of the soil. The steeper the slope, the higher the value, the more compressible the soil is under loading. (Teng, 2013). The present study Figure (17) shows when the relative density increases, Cc and Cr value decreases. For dense specimens, the sand are closely packed together and the void ratio is smaller so there are little possibilities for particle rearrangement to take places. Hence, the compressibility of sand is the smallest meanwhile, for loose specimens, there is higher void ratio for more particle rearrangement to occur so compressibility of sand is the largest. Also shows that the increase in carbonate content leads to increase in compressibility. Also the increase in carbonate content leads to increase Cc and Cr value. This observation is in agreement with observation by (Uygar et al., 2006, Grine, 2007, Kim et al., 2008, Teng, 2013, Hassanlourad et al., 2014 and Ata et al., 2017) , Table (٥). Seems to suggest that value increases with carbonate content.

Table (5): Compression index (Cc) and recompression index (Cr) (After Teng, 2013)

Soil Type	Location	Reference	Carbonate content (%)	Cc	Cr	Initial Void(e_0)
Artificial carbonate sand	----	Grine, 2007	97	0.275	0.012	0.9
Silicate sand	Samyang	Kim et al. 2008	5	0.055	-	0.925
Carbonate sand	Gymnyeong	Kim et al. 2008	89	0.14	-	1.3
Silicate & carbonate sand	Jeju harbor	Kim et al. 2008	54	0.2	-	1.46
Dogs Bay Sand	West of Republic of Ireland	Coop, 1990	88	0.335	0.008	-
North Coast of Egypt	North Coast of Egypt	Ata et al. 2017	98.5% to 99.8%.	0.1163	-	0.705
North Coast of Egypt	North Coast of Egypt	Current study	76.25 to 94.98%	0.035 to 0.08	0.009 to 0.025	0.83

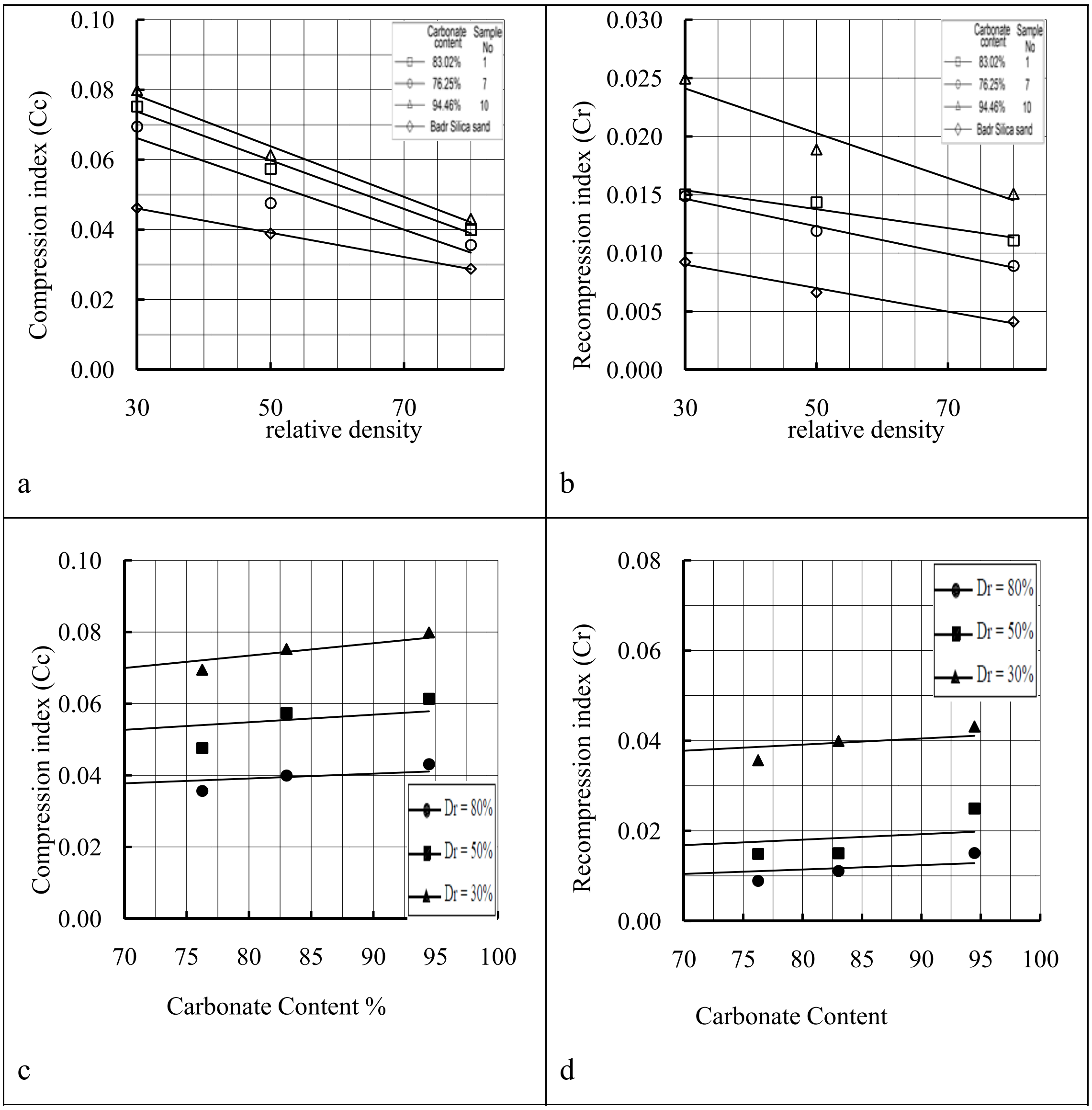


Fig. (17): Comparison the compressibility of calcareous sand for different relative density and carbonate content with Badr Silica sand

For mechanical properties of tested sample, it has been found that, the values of shear angle obtained from direct shear box are in the range of (40º to 49º) at relative density of 50%. These higher values in shear angle confirm the lower values of compressibility of calcareous sand obtained in Table (5). Where the values of compression index Cc are in range of (0.035 to 0.08). It can be concluded that the tasted simple provided higher shear strength with lesser compressibility compared with other site.

Relation between Secant constrained Modulus for calcareous and silica sand

The present study Figure (18) shows Normalized of secant constrained Modulus at Effective vertical stress=200 kPa plotted versus Carbonate content and the Normalized of secant constrained Modulus factor varied from 0.415 to 0.688 and the average equal 0.541,

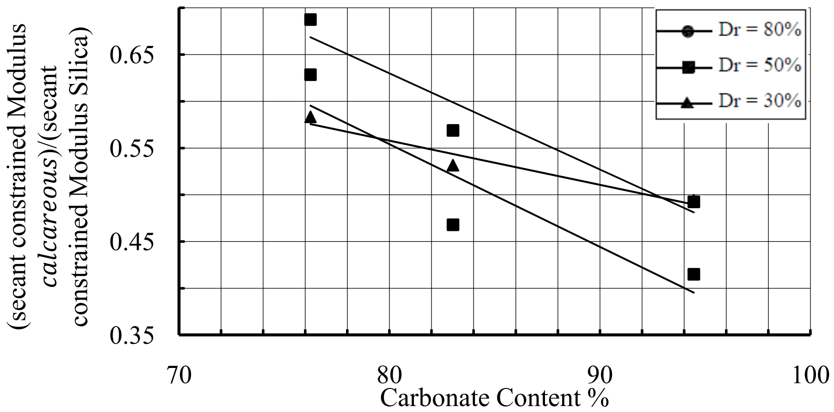


Figure (18): Normalized of secant constrained Modulus at Effective vertical stress=200 kPa versus Carbonate Content

Shear Strength

Terzaghi et al. (1996) concluded that the angle of shearing resistance of carbonate materials could be higher than that of terrigenous sands. Calcareous materials typically have friction angles on the order of 44o to 49o and often exceeding 50°, while terrigenous sands typically range from 35o to 40o as presented in (Noorany, 1985; Murff, 1987; Beringen et al., 1982; Datta et al., 1979). This high value could be a result of angular geometry and particles roughness as explained by Noorany (1985). Also, it could be due the fact that failure occurs within the particle itself not at the particle surface as occurs in non-crushable sand. Table (6), Morioka (1999), summarizes some mechanical properties of different types of carbonate sand from several locations.

Table (6): Values of Angle of Shearing Resistance of Several Calcareous Sediments Types, Morioka (1999).

Calcareous Sand Type	φ'	cc	Cr
Quiou Sand	--	0.33	--
North Rankine	43.7	0.5	--
Dog's Bay	42	0.76	--
North West Shelf	39	0.17 to 0.19	0.004 to 0.006
Kingfish B	45	0.16 to 0.21	0.006
Venezualen Basin	--	0.64 to 0.89	0.032 to 0.079
North Africa Coast	--	0.34 to 0.65	0.04 to 0.11
Pierre Shale	--	0.30 to 0.32	--
Bombay Mixture	39	--	--
Halibut	42	--	--
Barry's Beach	48	--	--
Bass Straight	48	--	--
Ewa Plains	43	0.13 to 0.16	0.003 to 0.005
North Coast of Egypt Current study	٣٢.١٥ o to 52.50o	0.035 to 0.08	0.009 to 0.025

(Sharma, 2004) performed Triaxial undrained shear (CIU) tests for Goodwyn calcareous and Toyoura siliceous sands (Ishihara, 1993) for similar initial relative density (63%) were performed. These results reveal that samples at similar relative densities show totally different behavior: a strong dilative behavior in siliceous sand (dilatancy) and a dilative-contractive behavior in calcareous sand (particle crushing). Siliceous sand in a loose state forms an assemblage of the particles with points of contact and large gaps between the particles. When shear stress is applied, inter-granular contacts are dislocated and the particles tend to fill the gaps (contractive behavior). By contrast, as the material densities and the initial gaps have become sufficiently filled by the particles, further shearing leads to rearrangement of the formation and the volume tends to increase'. This shear-induced volume increase is termed dilatancy. Evaluating dilatancy is one of the most important aspects for modeling the behavior of sand. On the other hand, the grains of calcareous sands tend to crush relatively easily even under moderate stress levels. The stress path for the Goodwyn sample shows somewhat dilative behavior after the phase transformation stage" Then after showing a peak stress at relatively large strain level, it reverts back towards residual strength (critical state). It is physically expected that although calcareous particles start to rearrange their formation at the initial stage of loading (pre-peak dilation), they are easily crushed by inter-granular contacts, and hence fragments of particles would fill the gap (post-peak contraction). Note that the steeper CSL for calcareous sand is due to the high angularity of the grains, and thus higher friction angle.

(La Vielle, 2008) performed a series of isotropically consolidated undrained monotonic and cyclic triaxial tests in order to investigate the liquefaction susceptibility of uncemented Playa Santa sand from Porto Rico calcareous sands. It was found that Playa Santa calcareous sand had greater cyclic strength and is less susceptible to liquefaction compared with quartzitic sands tested in that study.

Brandes (2008) performed simple shear test on six sands and undrained cyclic tests on three samples of the sands. To consider is the Contrast in stress-strain behavior between the quartz sands and the carbonate sands. In every case shear stresses increase uniformly, which is indicative of loose granular behavior. However, there are significant differences in terms of volume changes. Whereas the quartz sand tests show consistent compression during shearing, the carbonate tests indicate some compression early on, but then dilation during the later stages. This is true despite roughly similar void ratios and overlapping normal stresses in the two sets of tests. The same is also the case when considering results from the other tests listed in Table (7) The most logical explanation for this is that the more angular carbonate grains need to undergo more normal displacements, i.e. dilation, as they are shearing past each other, when compared to the more rounded quartz Sands. Dilation in the carbonate sands is responsible for higher peak friction angles for the carbonate sands. The friction angle of the quartz soils is on the order of 28^{o}, as is expected for this type of mineral, whereas the carbonate soils average about 35^{o}.

Table (7): summary of static shear tests from (Brandes 2008)

sand	Relative density (%)	Void Ratio	ϕ_{pk}	σ_n (kPa)
Ottawa	15	0.72	28.8	100-1500
Tampa Bay	15	0.92	28.0	91-1145
East Island	15	1.14	34.70	86-1151
Maui Dune	66	0.79	34.60	50-480
Kawaihae	30	0.77	35.70	52-509

Brandes (2011) performed monotonic and cyclic simple shear tests in order to compare the response of loose skeletal calcareous sands from areas of shallow water surrounding the islands of Hawaii with that of quartz sands. The rests are also intended to provide strength and cyclic degradation characteristics for these sediments, especially for the calcareous sands. It was found that the peak mobilized angles of shearing resistance are larger for the calcareous sands than for the quartz sands which could be due to differentiations of volume change resulting from mineralogical and textural contrasts. At high normal stress levels, particle breakage and rounding during shearing could cause a substantial decrease in angle of

shearing resistance which was found to be more severe in the calcareous sands than quartz sands due to lower hardness of calcareous sand and the higher intra-particle voids. Cyclic liquefaction resistance was found to be higher in calcareous sands than in quartz sand. This may be attributed to the differences in grain geometries and gradation. Cyclic resistance was found to increase also with increasing density. Average stiffness and damping ratio trends were found to be lower for the calcareous sands than those for quartz sands.
Abdel-Tawab et al. (2013) presented a comparative study between the calcareous sand which exists along the Mediterranean coastal line and quartizitic sand extracted from Abo Rawash quarry area. It was found that the calcareous sand has a peak angle of shearing resistance ranges from 28^o to 32.6^o and cohesion of about 6 kPa, while the Abo Rawash quartizitic sand has a peak angle of shearing resistance about 38$^°$ and cohesion of about 8 kPa.
(Van, et al., 2015) performed nine drained triaxial tests (CD-TX) on the S1 material which came from one of the actual reclamation sites (is very similar to Quiou calcareous sand). To analyses the stress–strain behaviour of the material over a large range of strain levels. And found the peak shear angles for the S1 material were about 45–50, depending on relative density. This high shear angle is a result of the angularity of the carbonatic soil particles. The peak shear angle will drop at very large stress levels due to particle crushing, but this is well beyond the typical working stress levels at this site. The residual shear angle was about 40– 42.

Relation between tan ϕ for calcareous and silica sand

In the following section the result of the shear test Based on the literature will be analyzed to attempt to fined Relation between tan ϕ_p for calcareous and silica sand
(Brandes 2011) conducted direct shear test Table (7) on tow samples of silica (Ottawa and Tampa Bay) and three samples of carbonate sand, form this results ϕ_p for silica sand were varied from 28^o to 28.8^o and tan ϕ_p varied from 0.53 to 0.55 and the average tan ϕ_p equal 0.54, the results ϕ_p for calcareous sand were varied from 34.6o to 35.7o and tan ϕ_p varied from 0.69 to 0.72 and the average tan ϕ_p equal 0.70, a factor (Fϕ) between tan ϕ_p for calcareous and silica sand varied from 1.29 to 1.31 and the average factor (Fϕ) equal 1.30,
(Al Douri, et al. 1992) conducted direct shear test Table (8) on dry and wet samples of silica and carbonate sand, form this results ϕ_p for silica sand were varied from 40^o to 42.60^o and tan ϕ_p varied from 0.84 to 0.92 and the average tan ϕ_p equal 0.88, the results ϕ_p for calcareous sand were varied from 41.20o to 51.40o and tan ϕ_p varied from 0.86 to 1.25 and the average tan ϕ_p equal 0.99, a factor (Fϕ) between tan ϕ_p for calcareous and silica sand varied from 1.023 to 1.36 and the average tan ϕ_p equal 1.13, also ϕ_u for silica sand were varied from 37^o to 42.40^o and tan ϕ_u varied from 0.75 to 0.91 and the average tan ϕ_u equal 0.85, the results ϕ_u for calcareous sand were varied from 39.20o to 46.40o and tan ϕ_u varied from 0.82 to 1.05 and the average tan ϕ_u equal 0.95, a factor (Fϕ) between tan ϕ_u for calcareous and silica sand varied from 1.093 to 1.154 and the average factor (Fϕ) equal 1.12.
(Giang, et al., 2017) conducted direct shear test Table (9) on (MOL) samples of silica sand and (SMOL) artificial samples of carbonate sand and (S2,S3,S4,S5 and S6) samples of carbonate sand form this results ϕ_p for silica sand were varied from 28.4^o to 32.10^o and tan ϕ_p varied from 0.54 to 0.63 and the average tan ϕ_p equal 0.59, the results ϕ_p for calcareous sand were varied from 28.80^o to 42.20^o and tan ϕ_p varied from 0.55 to 0.91 and the average tan ϕ_p equal 0.71, a factor (Fϕ) between tan ϕ_p for calcareous and silica sand varied from 1.02 to 1.44 and the average factor (Fϕ) equal 1.20,
(current study) conducted direct shear test on one sample of silica (Badr silica sand) and three samples of carbonate sand, form this results ϕ_p for silica sand were varied from ٣٠.٦٠ ^{o} to ٥٠.٣5^o and tan ϕ_p varied from 0.59 to 1.21 and the average tan ϕ_p equal 0.0.90, the results ϕ_p for calcareous sand were varied from ٣٢.١٥ ^{o} to 52.50^o and tan ϕ_p varied from 0.63 to 1.30 and the average tan ϕ_p equal 0.97, a factor (Fϕ) between tan ϕ_p for calcareous and silica sand varied from 1.02 to 1.24 and the average factor (Fϕ) equal 1.13,
New factor (Fϕ) relation between tan ϕ_p for calcareous and silica sand will be suggestion from the following relationship:-

$$F_\emptyset = \frac{\tan \emptyset p \text{ calcareous}}{\tan \emptyset p \text{ silica}} = 1.10$$

This factor depended on the relative density and confining pressure.

Table (8): static shear test Results from (Al Douri, et al. 1992)

Sand type	Test No.	Density	γ (KN/m3)	σv	ζ_p Shear stress(KPa)	ζ_u Shear stress(KPa)	$Ø_p$	$Ø_u$
Silica	1	D	16.2	160	151	137	41	37
	2		15.6	110	98	90.5	42	39.3
	3		15.8	55	49.7	44.5	42	38.9
	4	M	15.1	160	147	145	43	42.2
	5		14.9	110	92.9	92.9	40	40.2
	6		15.2	55	50.2	50.2	42	42.4
	7	L	14.2	160	142	142	42	41.6
	8		14.6	110	92.2	92.2	40	40
	9		14.3	55	49.6	49.6	42	42
New North Rankin (N.N.R)	1	D	12.3	160	154	147	44	42.5
	2		12.2	110	106	96	44	41.3
	3		13	55	54.6	44.8	44	39.2
	4	M	10.4	160	151	150	43	43.1
	5		10.2	110	106	106	44	43.8
	6		10.5	55	49.9	49.9	42	42.2
	7	L	9.4	160	141	141	41	41.4
	8		9.5	110	101	101	43	42.5
	9		9.4	55	48.2	48.2	41	41.2
Old North Rankin (O.N.P)	1	D	13.3	160	156	151	44	43.3
	2		12.8	55	56.5	52.7	46	43.8
	3	M	11.9	160	151	151	43	43.2
	4		12.1	55	49	46.2	44	40
Bass Strait (B.S)	1	D	15.2	160	165	161	46	45.2
	2		17.2	160	202	168	51	46.4
	3		16.7	55	73.6	49.2	49	41.8
	4	M	14	160	161	157	45	44.4
	5		14.2	55	56.6	56.6	46	45.8
	6	L	13.2	160	156	156	44	44.3
	7		13.4	55	54	54	45	44.5
Barry's Beach (B. B.)	1	D	13.9	160	175	162.3	47.6	45.4
	2		14.2	55	62	56.5	48.4	45.7
	3	M	12.6	160	164.1	164.1	45.9	45.9
	4		12.7	55	56.2	56.2	45.6	45.6
(0.5- CSIRO)	1	D	10	160	159.2	156.4	44.9	44.4
	2		9.9	55	55.1	53.5	45.1	44.2

Sand type	Test No.	Density	γ (KN/m3)	σv	$ζ_p$ Shear stress(KPa)	$ζ_u$ Shear stress(KPa)	$Ø_p$	$Ø_u$
	3	M	8.9	160	155.6	155.6	44.2	44.2
(0.25- CSIRO)	1	D	10.7	160	163	153.2	45.4	43.8
	2	M	9.9	160	154.9	154.9	44.1	44.1
SATURATED New North Rankin (N.N.R)	1	D		160	158.4	152.8	44.7	43.7
	2			110	115.5	106.1	46.4	43.9
	3			55	59.7	50	47.3	42.3
	4	M		110	115.2	115.2	46.3	46.3
	5			55	47.2	47.2	40.6	40.6
	6	D		110	103.1	103.1	43.1	43.1
	7			55	49.2	49.2	41.8	41.8

Table (9): Direct shear test results (Giang, et al., 2017)

sample	Normal stress σv(KPa)	Relative density Dr (%)	Residual shear strength ζr(Kpa)	Residual friction angle Ør(°)
MOL	50.00	44.70	28.00	28.40
	100.00	48.00	56.00	29.40
	200.00	52.50	116.00	30.10
	50.00	81.90	31.00	31.50
	100.00	82.40	62.00	31.70
	200.00	83.70	135.00	32.10
SMOL	50.00	44.60	30.00	30.90
	100.00	47.00	63.00	32.10
	200.00	49.50	137.00	34.50
	50.00	82.80	38.00	36.90
	100.00	84.10	71.00	35.20
	200.00	87.60	157.00	38.10
S2	50.00	42.70	27.00	28.80
	100.00	46.90	63.00	32.10
	200.00	47.80	142.00	35.50
S3	50.00	41.90	28.00	29.20
	100.00	44.70	70.00	35.10
	200.00	47.30	146.00	36.10
S4	50.00	44.00	31.00	31.70
	100.00	46.50	75.00	36.70
	200.00	48.50	157.00	38.10
S5	50.00	43.30	32.00	32.90
	100.00	46.10	77.00	37.70
	200.00	50.60	163.00	39.20
S6	50.00	44.10	38.00	36.90

	100.00	47.80	89.00	41.60
	200.00	52.10	181.00	42.20

CONCLUSIONS

Northern coast of Egypt Calcareous sand under investigator in the present study similar to most calcareous sand in the world where it deposited in high energy coastal environment and composed mainly of loose white oolitic carbonate minerals (calcite and aragonite) in addition to quartz as non-carbonate fraction.

The specific gravity values were ranging from 2.7 to 2.75 while other Calcareous sand were ranging from 2.7 to 2.95 and the $CaCO_3$ content ranges between 76.25 and 94.98%.and other Calcareous sand were ranging from 50 to 100 and siliceous sand equals 2.650 The relatively high values of specific gravity for Calcareous sand are due to their mineralogy composition There is a minor effect of carbonate contents on the specific gravity.

The present Calcareous sand samples characterized by Bio-intra-oosparite facies. The framework consists predominantly of fine to medium, moderately well-sorted, rounded to subangular sand-size carbonate grains. The sand-size carbonate grains are composed mainly of ooids and intraclasts with variable amounts of bioclasts in addition to scattered detrital quartz grains.

The North Coast calcareous sands classify as poorly graded sands (SP). (Medium sand), with mean grain sizes (D_{50}) mostly ranging from 0.247 mm to 0. 563 mm, and fines content of ranging from 0.30 %to 13.50 %. Uniformity coefficient (Cu), ranging from 1.7 to 6.4, Coefficient of curvature ranging from 0.68 to 1.22.

Calcareous sands are characterized by having high compressibility than siliceous sand, which is considered one of the main deficiencies of its engineering behavior and classify as problematic soil. The increase in carbonate content leads to increase in compressibility thus the compression index Cc and the recompression index Cr value increase. The compression index Cc and the recompression index Cr value are higher foe dense Calcareous sands than loose Calcareous sands This observation is in agreement with other calcareous and siliceous sands in the literature New factor Normalized of secant constrained Modulus (calcareous to siliceous sands) equal 0.55.

The calcareous sand had a peak friction angle of about ٣٢.١٥° to ٥٢.٧٥° (average 44.50°) while the quartzitic sand had a peak friction angle about 30.60° to ٥0.3٥° (average 41.50°). This difference in peak friction angle is likely to be due to the percentage of carbonate content in the calcareous sand and the high angularity of the grains, and thus higher friction angle than siliceous sands, the present study is harmony with most of the previous studies

New factor ($F\phi$) relation between tan ϕ_p for calcareous and silica sand will be suggestion from the following relationship:-

$$F_{\emptyset} = \frac{\tan \emptyset p \text{ calcareous}}{\tan \emptyset p \text{ silica}} = 1.10$$

Generally The North Coast calcareous sands have similar properties to the other calcareous sand like grain size, voids ratio, compressibility, a friction angle.

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