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CHARACTERIZATION OF SEDIMENTARY ANZALI SAND FOR STATIC AND SEISMIC STUDIES PURPOSES

Hadi Ahmadi[1]† ---Abolfazl Eslami[2] --- Mahyar Arabani[3]

[1,3]*Faculty of Engineering, University of Guilan, Iran*

[2]*School of Civil and Environmental Engineering, AmirKabir University of Technology, Iran*

ABSTRACT

Anzali as one of the populated coastal cities in the Northern Iran, contains a particular type of marine sand which is worth to be investigated for many engineering practices. This particular sand is mainly composed of saturated fine grains and is highly prone to liquefaction phenomenon during seismic events. Geotechnical zonation of the subterraneous layers show that most of sandy sedimentary soils found below the surface in this area is formed by relatively clean and fine sand. In this research, the geotechnical characteristics of Anzali sand have been studied. It is done based on three sources of information, i.e. field studies, static tests and physical modeling by dynamic tests. In this regard, the overall zonation of this area has been carried out and the extent of the sandy area has been investigated. Anzali sand has been characterized by making use of a number of soil samples obtained from various parts on which, index tests have been carried out. Furthermore, based on laboratory shear tests and information gathered from in situ tests, the shear strength parameters and the critical limits for Anzali sand have been classified. Finally, large scale physical model tests were conducted to show the dynamic behavior of the sand under cyclic and dynamic loads and also the development of the excess pore water pressure during dynamic loading that could cause the liquefaction initiation.

Keywords: Anzali sand, Geotechnical characteristics, Shear strength, Liquefaction.

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Contribution/ Originality

In essence, the paper's primary contribution is to find or estimate Anzali Sand parameters which are required for prediction or analysis of liquefaction potential during seismic effects. This is done by a number of tests on samples extracted from locations in this area.

† Corresponding author

1. INTRODUCTION

Anzali port in Guilan province, located in 49° 28' 00" West and 37° 27' 30" North, is part of the Caspian Plain. Anzali sand is a particular type of sand found near the Caspian Sea, in the Northern Iran and covers a narrow strip along the coastal line. It is found that the level of ancient lakes affects on the type of sediments and their grain size distribution (e.g.Xiao *et al.* (2013)). Several investigations have been made on Anzali sand revealing many different parameters including static and dynamic soil parameters (Fattahzadeh, 2005; Asefi *et al.*, 2009; Hasani, 2009; Ghorbani *et al.*, 2013; Ahmadi *et al.*, 2014). It is found that the main characteristics of different soil layers in this area are often dominated by this type of sand. Anzali sand is mainly a finesandwith some silt contents. Geographical location of the area under study is shown in Figure 1. Caspian Sea is structurally formed by folded geological units with a trend parallel to its coast line. The beach itself covers entirely by Anzali Sand. Coastal sands are classified into alluvial sand or water-transported particles. Thus, coarse particles are very rarely found in this sand in comparison to other types of sand. The Caspian Sea is a narrow coastal strip and there is no mule due to intangible tide. Basically in most sandy beaches, such as the Caspian Sea coast, the sea waves are broken before they reach the shoreline. Breaking waves release most of energy caused by massive forces pushing them forward. The pressures due to released force take coastal sands out and drive them onto mainland. When the waves are reflected, a portion of the sea-sands are returned to the sea and this portion depends on the grains size of the sand. In this process however, some portion of the sand will always remain out of the water. This mechanism gradually drives the sand out from the sea water and makes dunes or sand walls of several decimeters. There are scattered sand dunes from Guilan to Gorgan, another area in the Northern Iran (and also the name of a city) in the Southeastern Caspian Sea (Talebi, 1998; Jackson *et al.*, 2002; Brunet *et al.*, 2003; Ranjbar, 2012).

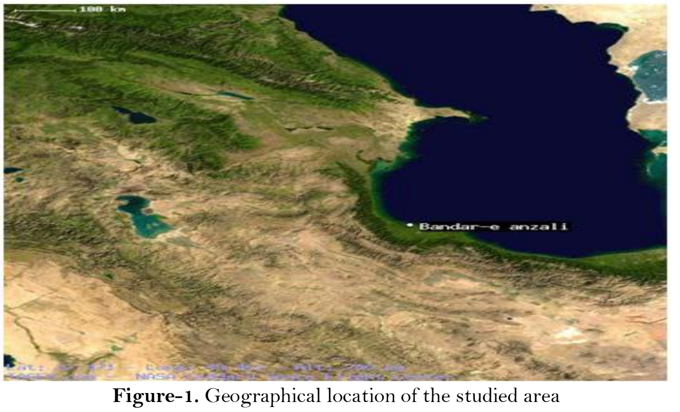

Figure-1. Geographical location of the studied area

2. GEOTECHNICAL ZONING AND FIELD TESTS

Many coastal areas of Anzali port are composed of uniform fine sand. Geotechnical studies which have been performed down to several meters in many parts, confirmed this property of

Anzali Sand. The sands are generally uniform, and composed of fine and very fine-grained particles with loose to medium density indices.

Fattahzadeh (2005) studied the characteristics of the soil in this area by data collection among 75 boreholes to a maximum depth of 23 meters at three different zones in Anzali. The zones include: a) 25 boreholes in Lijarki - Koliver axis (Lijarki is located in the east and Koliver is located in the Southwest of Anzali); b) 30 boreholes in Anzali-Kapourchal route (Kapourchal is located in the west of Anzali port) and c) 20 boreholes in Hasanroud-Setare Shomal (Hassanroud is located in the southeast of Anzali). On this account, in Lijarki - Koliver route, subsurface layers to a depth of 10m are composed of fine sands with some amount of silt and often categorized into SP, SM, and SP-SM classifications according to the Unified Soil Classification System (Table 1). A graphical representation of the soil properties with depth observed in four boreholes is shown in Figure 2. In addition, variations of SPT blow counts are also shown in Figure 3 which illustrates the range of SPT blow counts with depth observed in different burials. Also, at some boreholes interlayers of clay or silt soils have been observed with a maximum thickness of 4m. By moving from the Lijarki region towards Koliver, the amount of fine particles decreases and the portion of the coarse aggregates is grown. SPT blow counts were generally found to be between 5 and 30 in these layers, which indicates that the layer density indices are low to medium. Moreover, there are sublayers of loose sands in some of the boreholes to a depth of approximately 6 meters. In Anzali-Kapourchal route poorly graded sand had been found with some silt. In Kapourchal region, the thickness and the density of sand layers are reduced. At Hassanroud axis toward the Setare-Shomal (Anzali free zone), the fine sand with some silt can be generally observed in surface soils and at depths of 5 to 10 meters, there are clayey soil sublayers. In addition, the data of 30 boreholes drilled by geotechnical consultants in Northwest of Anzali have been collected and 20 additional boreholes have been collected in different regions. This indicated many layers of subsurface soils consist of uniform fine sands which are classified into poorly graded sand. In these boreholes, SPT blow counts are between 10 and 30 blows for sand layers that indicate these layers are of low to medium density indices. Although in some burials, higher blow counts up to 40 blows, were observed, indicating a dense soil layer.

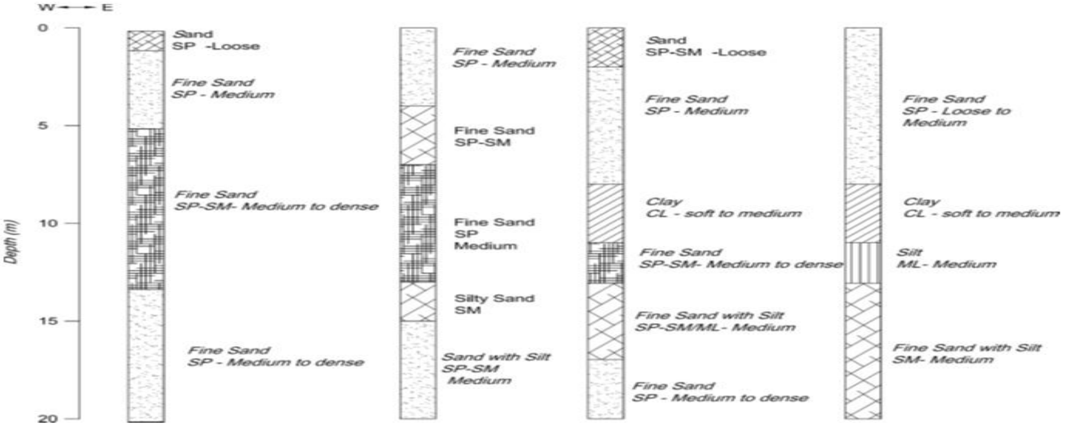

Figure-2. Subsurface profile in Anzali (West –East)

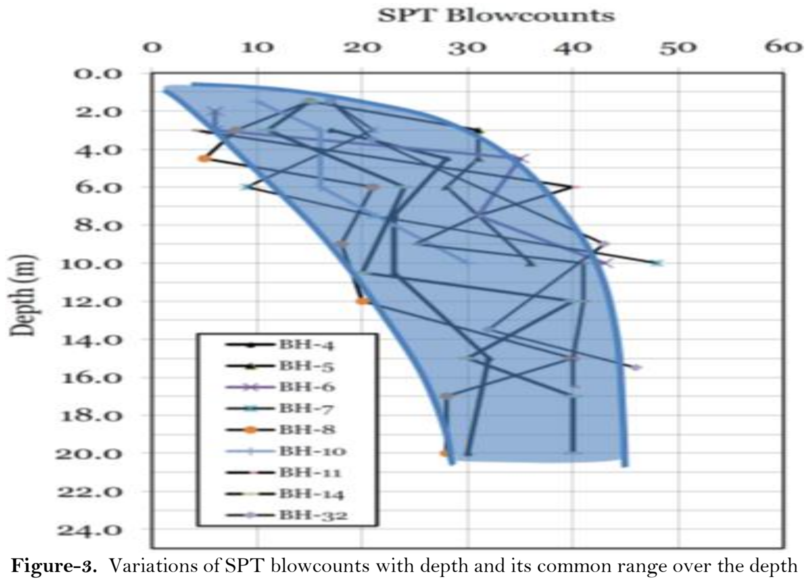

Figure-3. Variations of SPT blowcounts with depth and its common range over the depth

Table-1. Classification of subsurface layers in boreholes

Depth	Frequency						SPT
	SP	SP-SM	SM/SC	CL/CH	ML/MH	GP	
1	14	3	2	3	1		3-6
2	12	5	3	1	1	1	3-17
3	12	6	2	1	1	1	2-31
4	6	8	1	3	2	1	5-26
5	6	6	4	3	2		5-31
6	6	8	3	4	1		11-28
7	6	6	7	3			9-40
8	5	6	8	2			8-31
9	3	6	5	2			25-31
10	3	7	2	2	2		22-36

3. INDEX PARAMETERS OF ANZALI SAND

To evaluate the index parameters of Anzali sand, six soil samples from different locations of Anzali were selected at different depths. Grain size distributions of the soil samples for six types of sand, namely S1 to S6, were measured according to ASTM D-422 which are shown in Figure 4. Results of particle-size distribution of soils obtained in sieve analysis revealed that soil samples of different location do not have a serious difference in their grain size distribution. The samples are very similar to each other in regard with their physical shape and size. Moreover, they are very close to each other in their D_{50} which is between 0.21mm and 0.32mm. Previous geotechnical studies by different soil engineering agencies confirmed that the particle size distribution curve shown here is the dominant distribution of the Anzali Sand. For other soil properties a number of different tests including the modified density test (according to ASTM D1557-09), the relative density test (according to ASTM D4254-00 and ASTM D4254-00) and the specific gravity of solid particles (according to ASTM D854-10) were also carried out on different samples. Results of the particle-size distribution tests (Figure 4) and other tests as index values are listed in Table 2. Thus, based on the obtained results and compared it with the database on the Anzali sand, a typical particle size distribution curve can be assumed for Anzali sand which is shown in Figure 5(a) and 5(b). In Figure 6, a microscopic image of the Anzali sand particles is shown. This figure indicates that the Anzali sand particles mainly consisted of subrounded to subangular grains and also a rather uniform distribution of particles size which was earlier observed in grain size distribution tests.

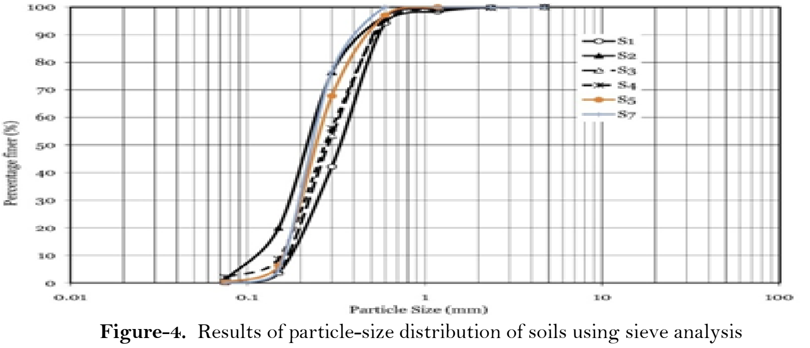

Figure-4. Results of particle-size distribution of soils using sieve analysis

Table-2. Index parameters for Anzali sand

Parameter	minimum	Maximum	Index
USCS	SP	SP	SP
D50 (mm)	0.21	0.32	0.21
Dmax (mm)	1.18	2.36	1.18
Cu	1.9	2.5	2.4
Cc	0.83	1.20	1.20
$\gamma_{d\,max}$ (KN/m^3)	15.1	16.9	16.9
$\gamma_{d\,min}$(KN/m^3)	14.0	15.8	15.6
e_{min}	0.57	0.69	0.57
e_{max}	0.69	0.89	0.71
Gs	2.59	2.70	2.67

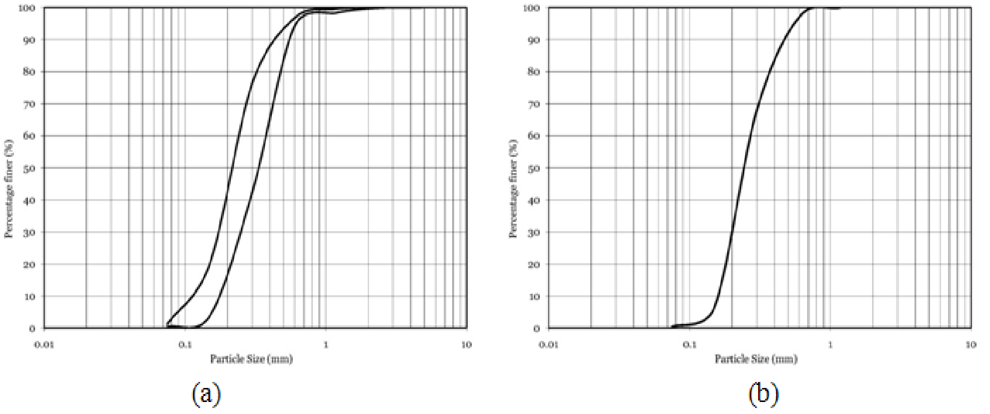

Figure-5. Amplitude distribution (a) and aggregation index (b) for Anzali sand samples

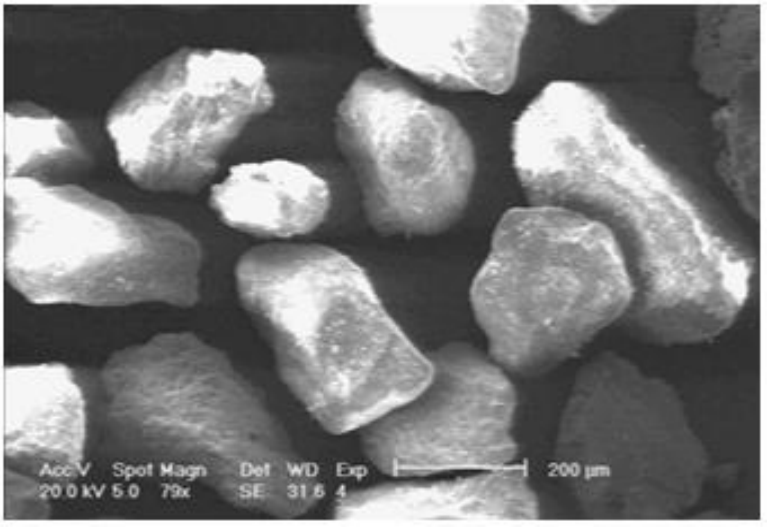

Figure-6. Microscopic image of Anzali sand (by the university of Guilan laboratory)

4. SANDS OF THE SOUTHERN COAST OF THE CASPIAN SEA

To compare Anzali sand with other soils on the southern coast of the Caspian Sea, some samples were taken at various locations around the area and their physical properties have been studied. Figure 7 shows the location of sampling points which covers a quite long route from the West to the East side of the Caspian Sea coastline. Again, the grain size distribution tests were carried out on these samples which are plotted in Figure 8 and their physical characteristics are presented in Table 3. According to test results, there are limited types of sands in all these regions extended along the southern coastline of the Caspian Sea. Generally, there are more coarse-grained soils on the west side of this strip with larger maximum grain size in comparison to other regions. In addition, there is a higher fine content in the center of the studied strip.

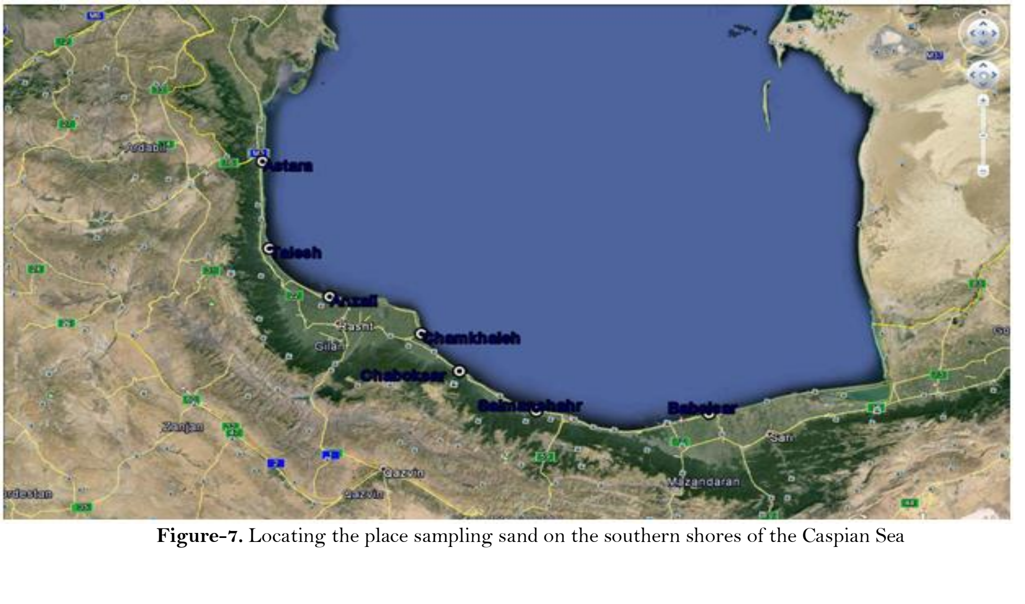

Figure-7. Locating the place sampling sand on the southern shores of the Caspian Sea

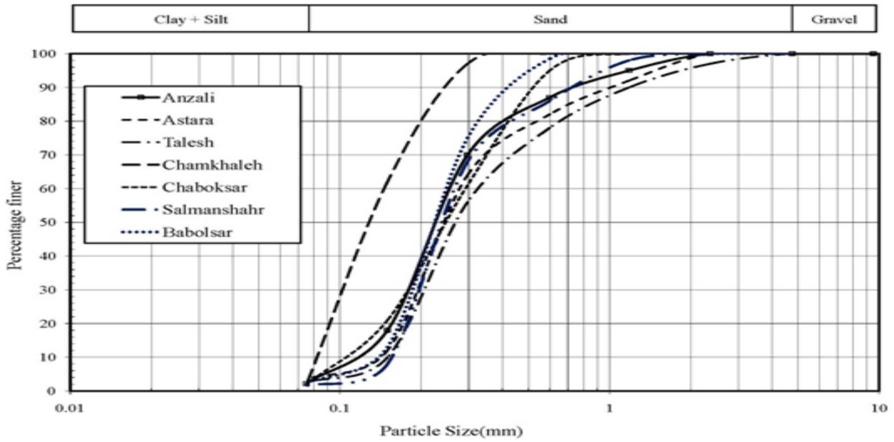

Figure-8. Results of particle-size distribution of sands on the southern shores of the Caspian Sea

Table-3. Index parameters for sands on the southern shores of the Caspian Sea

Parameters	Anzali	Astara	Talesh	Chamkhaleh	Chaboksar	Salmanshahr	Babolsar
USCS	SP	SP	SP	SP	SP	SP	SP
D50 (mm)	0.21	0.25	0.28	0.17	0.25	0.23	0.22
Dmax (mm)	1.18	1.18	2.36	0.45	0.6	1.18	0.6
Cu	2.40	1.71	2.33	1.09	2.55	1.56	1.80
Cc	1.20	0.81	0.84	1.39	1.05	0.79	1.00
$\gamma_{d\,max}$ (KN/m^3)	16.9						
$\gamma_{d\,min}$ (KN/m^3)	15.6						
e_{min}	0.57			0.682			
e_{max}	0.71			0.978			
Gs	2.67	2.65	2.68		2.65	2.67	2.65

5. SHEAR STRENGTH

Fattahzadeh (2005) based on the consolidated undrained triaxial tests, investigated the undrained behavior of Anzali sand for various percentages of silt contents. In these tests, samples were made by both drying density (DD) and reduced density (UC) methods. Test results showed that the remolding type has a significant effect on the behavior of sand in undrained condition. Based on the method of dry density for remolding soil samples, soil behavior was found to be at the transition zone and on the method of reduced density for loose samples, soil reached the steady-state with reduced shear strength. An example of the test set-up and the results are shown in Figure 9.

In order to calculate the steady-state shear strength of samples in triaxial tests, one can use the following equation:

$$S_{us} = \frac{q_{ss}}{2}\cos\phi'_{ss} \qquad (1)$$

Where p' and q are mean effective stress and the deviatoric stress respectively, and ϕ'_{ss} is the steady-state friction angle.

The steady-state shear strength parameters can be used to evaluate the liquefaction potential in loose sands. Triaxial test results showed that the steady-state friction angle is about 30 degrees for clean Anzali sand under 150 kPa cell pressure and it will be reduced to about 26 degrees withan increase of 20percents in the fine (silt) content.

Later, Azizi and Ghadimi (2010) have investigated the critical state parameters at undrained conditions for Anzali sand using cyclic triaxial tests. Test samples were made by water pluviation and conventional compaction methods. The approximatelocation of the Natural Consolidation Line (NCL)is obtainedby making use of the results of the isotropically consolidated tests samples for a particular soil type. Also, the influence of the samples reconstitution method on the behavior of samples when approaching the NCL, was investigated. In dynamic loading, the effect of reconstitution of specimens on the formation of the excess pore water pressure and changes in the secant shear modulus were investigated. Isotropically consolidated curves for the NCL line is shown in Figure 10. Accordingly, for Anzali sand the NCL parameters were obtained as $N = 4.02$ and $\lambda = 0.36$.

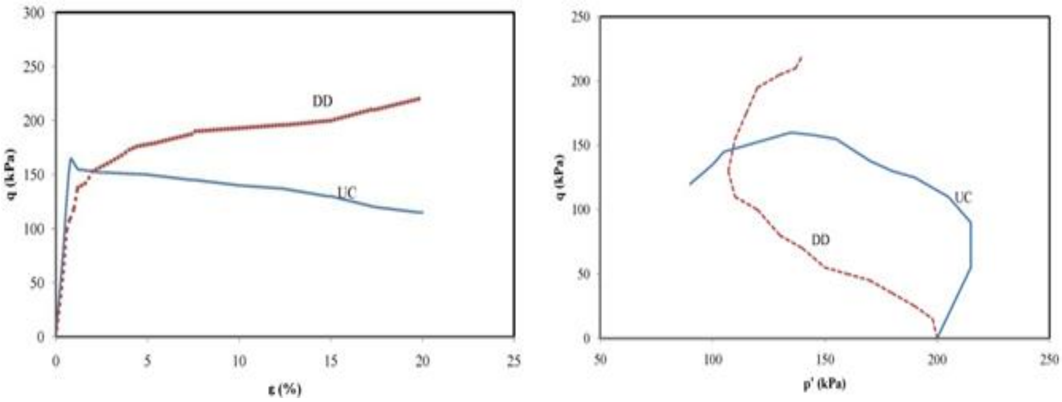

Figure-9. Curves of ε-q and p-q under confining pressure 200 kPa

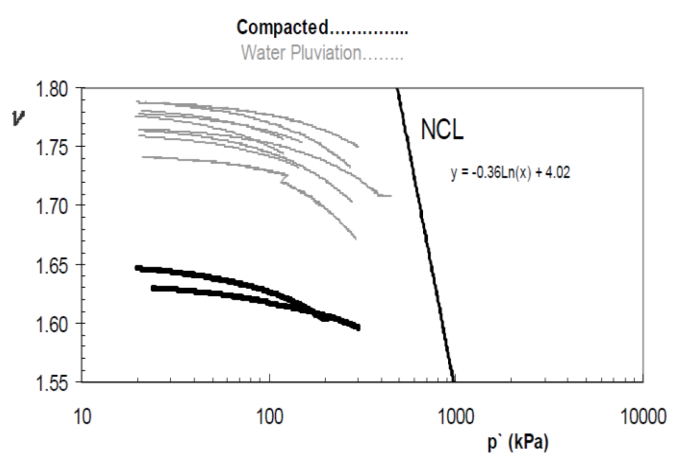

Figure-10. Isotropic consolidation of Anzali sand (Azizi and Ghadimi, 2010)

6. VOLUME CHANGE BEHAVIOR

To investigate the volume change behavior of Anzali sand under static shear loading, a series of strain-controlled direct shear test results under drained conditions were conducted. The tests were carried out in accordance with ASTM D3080-04 on samples of Anzali sand with density indices of 30, 50, 70, and 90%. A shear box of 6 × 6cm was used which was found to be appropriate for Anzali sand according to its mean grain size. Some results of direct shear tests on samples of Anzali sand are presented in Figure 11 for the density index of about 30% (initially loose sample) and in Figure 12 for density index of about 90% (initially dense sample). One should note that it is difficult to properly remold samples for a particular density index in a direct shear box. Similar results were obtained for the density indices of 50 and 70 percents. For each test series, six vertical stresses (σ'_v) of 25, 50, 100, 200, 300 and 500kPa were considered and vertical displacements (δ_v) as well as the horizontal displacements (δ_h) were recorded up to nearly 20% of the vertical to horizontal displacements ratios.

The results indicated that the Anzali sand showed an obvious dilation behavior, particularly for samples with rather density index. Also such a behavior can be observed for samples of lower density index and high vertical stresses. This may be a contradiction with the expected behavior of sands with different stress levels. The behavior is contractive for loose samples of fine Anzali sand at low density index, even though the sample might be at low vertical stress. Such behavior may be resulted from the type of the test, i.e. the direct shear test. Based on the drained direct shear test results performed on Anzali sand, the internal friction angle corresponding to the peak state (ϕ_p) at different stress levels and different density indices can be obtained by the following equation:

$$\phi_p = arc\tan(\frac{P_h}{P_v}) \tag{2}$$

According to the test results, the Anzali sand has a peak internal friction angle (ϕ_p) of about 31.8 to 39.7 degrees that with changes of the stress level. Figure 13 presents the results for the variations of the peak friction angle with different stress levels showing generally a decreasing tendency with the stress level as expected and reported in the literature (e.g. (Bolton, 1986; Budhu, 2011)).

In addition, the changes in the vertical and horizontal displacements during the test can be used to find the angle of dilation, (ψ_p) by the following equation:

$$\Psi_p = Arc\tan(\frac{\delta v}{\delta u}) \tag{3}$$

The results for the Anzali sand are shown in Figure 14. Based on these results, Anzali sand has dilation angle of about 1 to 5.3 degrees which reduces as the peak friction angle decreases with increase in the stress level. Moreover, as it may be expected for a given stress level, the angleof dilation reduces with reduction of the density index.

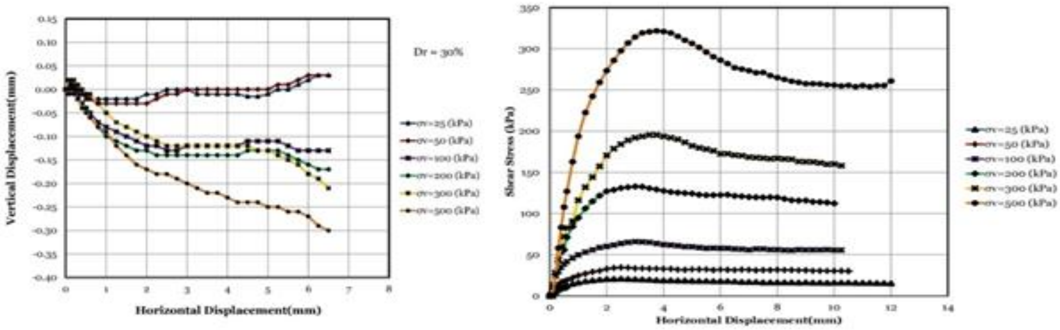

Figure-11. The result of drained direct shear test for relative density of 30%

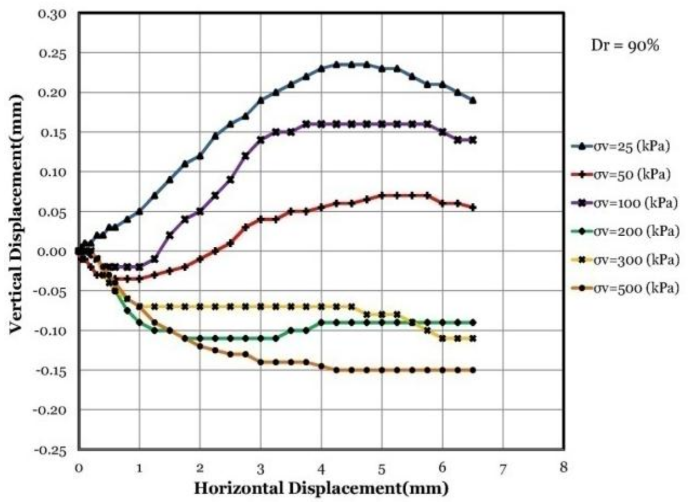

Figure-12. The result of drained direct shear test for relative density of 90%

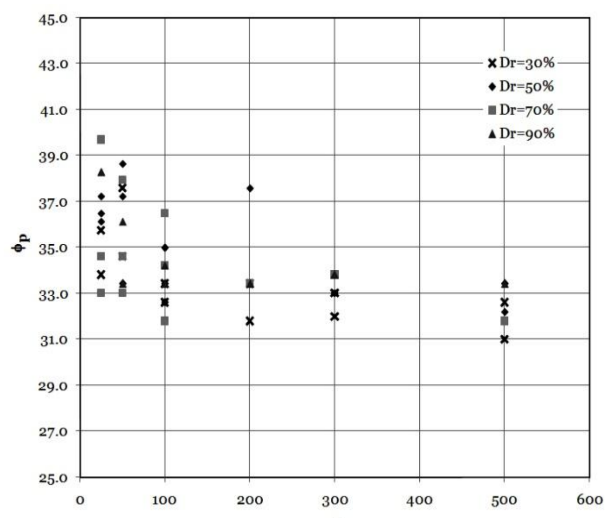

Figure-13. Peak internal friction angle (ϕ_p) versus vertical stress

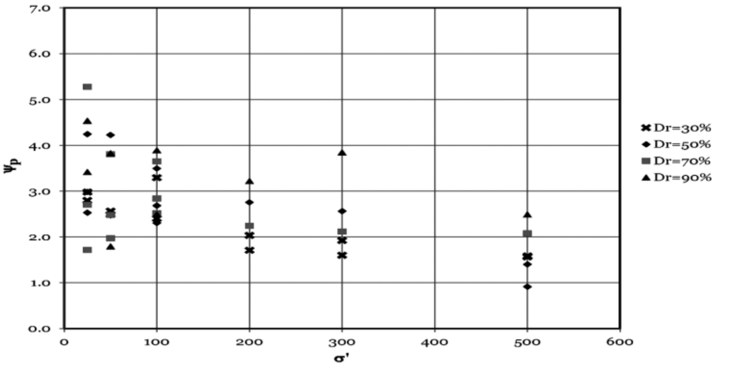

Figure-14. Dilation angle (ϕ_p) versus vertical stress

7. SEISMIC BEHAVIOR

The dynamic behavior of Anzali sand has been studied by physical model tests on a shaking table (Figure 15). A series of physical model tests were performed with characteristics presented in Tables 4 and 5. A sample of the results of these tests is presented in Figures 16 and 17. There are some measures for the pore pressure ratio in such tests (e.g. (Ishihara, 1993; Olson and Stark, 2003)). Based on these experiments, the pore pressure ratio (r_u) in all layers decreases with increasing the density index of the Anzali sand (Figures 18 and 19). For the horizontal acceleration of 0.22g, the condition of pore water pressure reduction to initiate a flow occurs at a density index of about 68% while for horizontal acceleration of 0.34%, the flow initiates for sample of higher density indices (about 78%). The test results also indicated that the change in the excess pore water pressure approaches its maximum when the horizontal acceleration increases and it takes a longer time to be dissipated when the maximum value is reached.

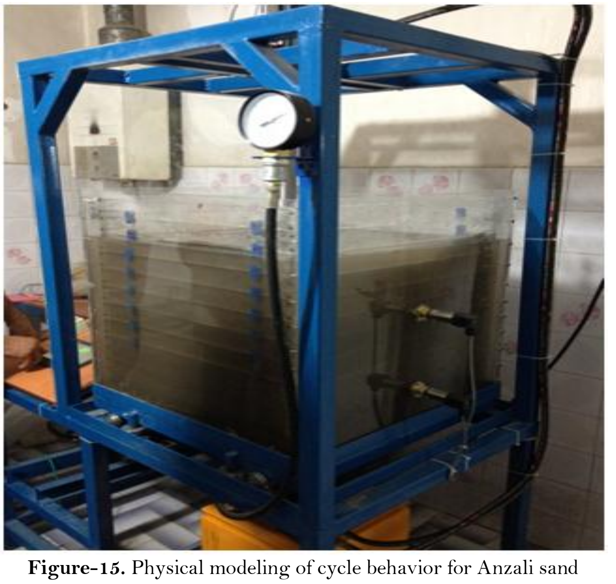

Figure-15. Physical modeling of cycle behavior for Anzali sand

Table-4. Specification of tests on Anzali sand

Test No.	D_r (%)	γ_{sat} (kN/m³)	e	a_{max}	loading (kPa)	Drainage
1	20	19.4	0.706	0.22g	-	One-way
2	32	19.6	0.672	0.22g	-	One-way
3	40	19.7	0.649	0.22g	-	One-way
4	51	19.9	0.619	0.22g	-	One-way
5	68	20.2	0.575	0.22g	-	One-way
6	20	19.4	0.705	0.34g	-	One-way
7	32	19.6	0.672	0.34g	-	One-way
8	40	19.7	0.649	0.34g	-	One-way
9	54	19.9	0.613	0.34g	-	One-way
10	68	20.2	0.575	0.34g	-	One-way
11	78	20.4	0.530	0.34g	-	One-way
12	33	19.6	0.670	0.22g	1.6	One-way
13	33	19.6	0.670	0.22g	3.2	One-way
14	33	19.6	0.671	0.34g	1.6	One-way
15	32	19.6	0.672	0.34g	3.2	One-way
16	33	19.6	0.671	0.50g	-	One-way
17	33	19.6	0.670	0.11g	-	One-way
18	32	19.6	0.672	0.22g	-	Tw-way
19	32	19.6	0.672	0.34g	-	Tw-way

Table-5. Properties of cyclic loading on Anzali sand

Test No.	T (sec)	f	□	A (mm)	a_{max} (m/s²)	Equations of motion (mm)	Equations of acceleration (m/s2)
1	0.891	1.122	7.052	10	0.497	x=10sin(7.052t)	a =49.73sin(7.052t)
2	0.597	1.675	10.52	10	1.107	x=10sin(10.52t)	a =110.73sin(7.052t)
3	0.421	2.375	14.92	10	2.22	x=10sin(14.92t)	a =222sin(14.92t)
4	0.343	2.915	18.32	10	3.36	x=10sin(18.32t)	a =335.6sin(18.32t)

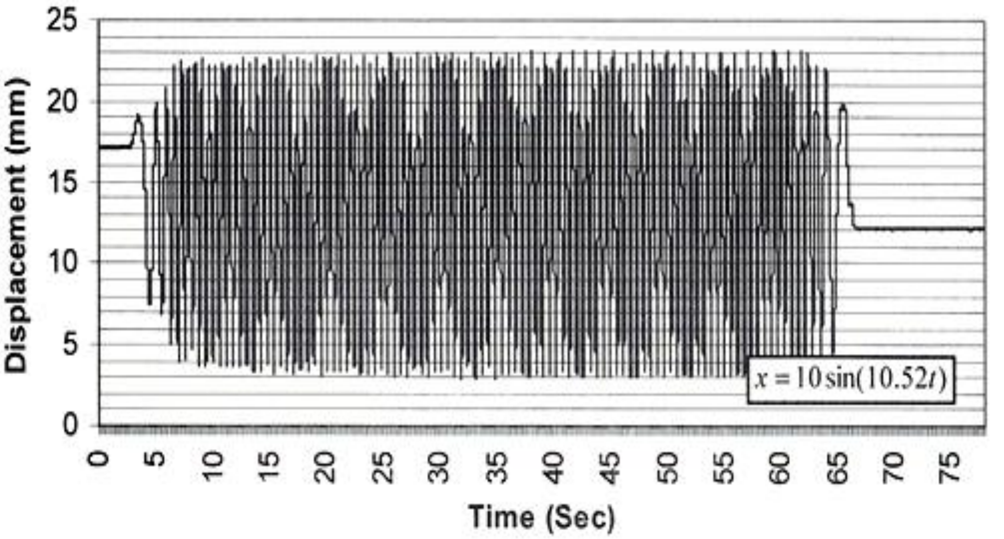

Figure-16. Displacement-time cure for amax=0.11g

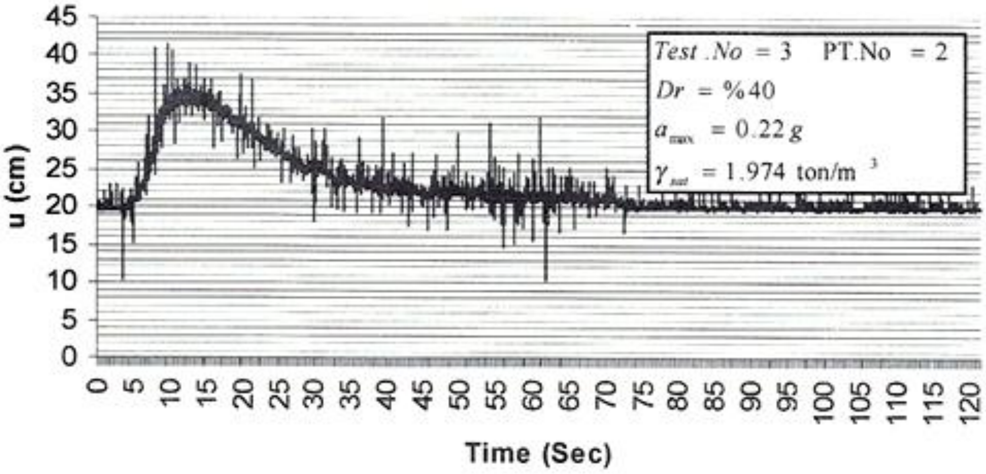

Figure-17. Pare water pressure versus time of cyclic loadimg for Dr=40%

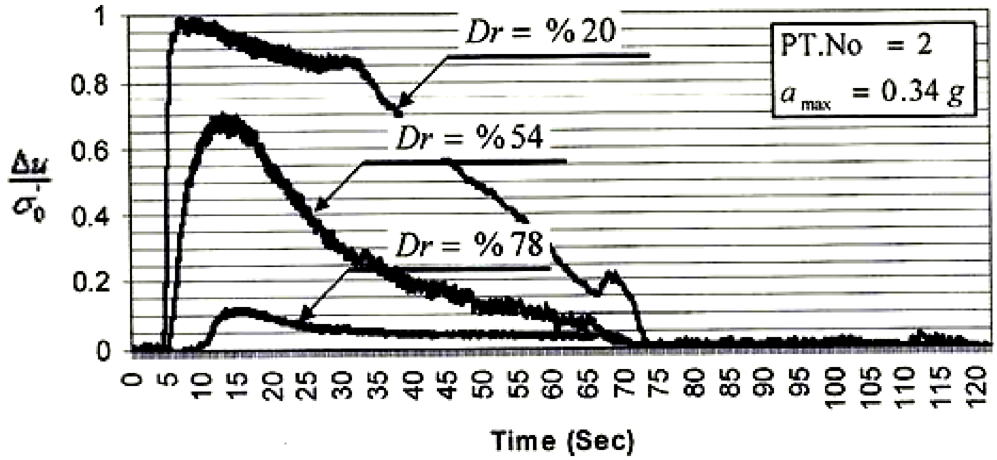

Figure-18. Pare water pressure ratio versus relative density

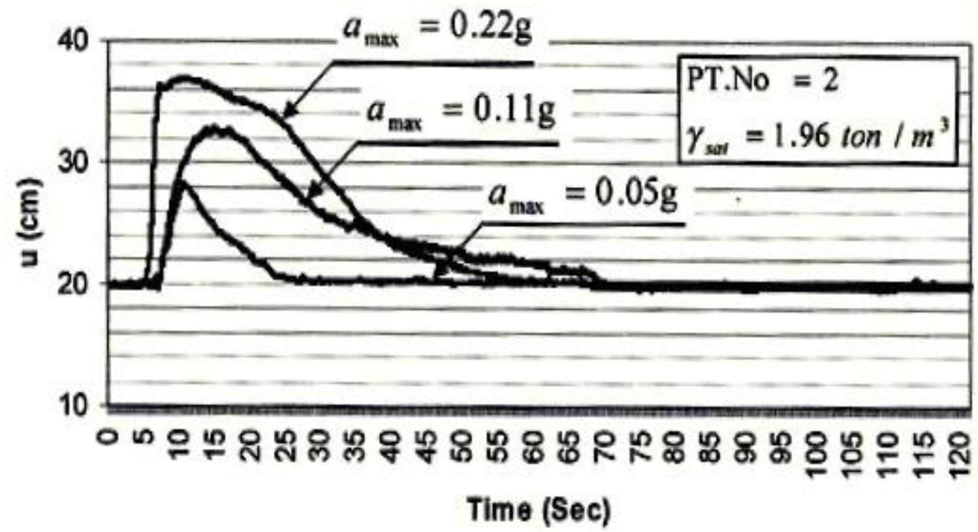

Figure-19. Pare water pressure versus acceleration

8. CONCLUSIONS

Anzali sand was introduced as a particular type of sand which is worth to be invetigated for many engineering practices. This particular sand composes of mainly of saturated fine grains. In this study, the geotechnical properties of Anzali sand, as an important class of sand in the Northern Iran, extended along the coastline of the Caspian Sea, was investigated. Three different approaches were taken in characterizing the Anzali sand: (a) field investigations based on available data collected from different sources, (b) experimental data and (c) physical modeling by dynamic tests. Geotechnical zonation shows that most of the subsurface layers of this region is composed of sandy soils which are clean and fine-grained. It is generally made up of silica sands and, as observed in microscopic digital images, subrounded particles. The mean size, D_{50}, for Anzali sand is about 0.2 to 0.3mm and the grain size distribution curve indicates a poorly graded sand with a relatively narrow range for the grain sizes. Also, studies showed that the shear strength for clean sand with 150kPa confining pressure, the steady-state friction angle is about 30 degrees and it reduces to about 26 degrees when the fine (silt) contents increases by 20%. The critical state parameters can be considered as $N = 4.02$ and $\lambda = 0.36$ for Anzali sand. According to the results of the direct shear tests, the Anzali sand has peak internal friction angles (ϕ_p) of about 31.8 to 39.7 degrees depending on the level of applied stress; the higher the stress level, the lower the peak friction angle. In addition, the angle of dilation is between 1 and 5.3 degrees and it decreases with decrease in peak friction angle. Dynamic tests and physical modeling on Anzali sand on shaking table apparatus also showed that the pore water pressure generation during cyclic loads depends on the initial void ratio of the samples and it shows a decreasing tendency as the density index increases.

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Competing Interests: The authors declare that they have no competing interests.

Contributors/Acknowledgement: All authors contributed equally to the conception and design of the study.

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