مؤتمر الأزهر الهندسي الدولي العاشر

AL-AZHAR ENGINEERING
TENTH INTERNATIONAL CONFERENCE
*December 24 - 26, 2008*

**Code: C 71**

# COLLAPSIBILITY OF COMPACTED FINE SAND-BENTONITE MIXTURES

**Alnos A. Easa**
High Institute of Technology, Benha University, Egypt

## ABSTRACT

The collapsibility behavior of fine sand is considered one of the serious geotechnical problems facing foundations and constructions. One of the commonly used methods for underlying soil stabilization is compaction. In this study, collapse behavior of compacted fine sand-bentonite mixtures was investigated. Oedometer tests were carried out to study the effect of bentonite content on the collapse settlement of compacted fine sand-bentonite mixture. Samples of fine sand soil were mixed with different amounts of bentonite (0%, 5%, 10%, 15% and 20% by weight of dry fine sand). Maximum dry density ($\gamma_{dmax.}$) and optimum moisture content (OMC) were determined for each sample. Soil samples were prepared in oedometer ring at various compaction degrees (Ic= 90%, 95% and 100%) and OMC. The collapse potential was determined and investigated under applied pressure of 200 KN/m$^2$. The obtained results indicated that, the collapse potential decreases with the increase of bentonite content and compaction degree. Moreover, increasing the compaction effort decreases the risk of fine sand collapsibility.



**KEYWORDS: FINE SAND, BENTONITE, COMPACTION, OEDEMETER, SOAKING, COLLAPSE POTENTIAL.**

## INTRODUTION

Fine sand soils are widely distributed throughout the world especially in arid areas, deserts, and coasts…etc. In Egypt, fine sand soils are found in several arid and coastal areas in shape of loess, sand dunes and collapsing soils. In most situations natural fine sand contains other materials as calcium carbonate, calcium hydroxile, lime, silt, clay...etc, [1,2].
It is known that, structures like buildings, roads, railways, tanks, foundations…etc constructed on fine sand soil have many geotechnical problems. When loaded fine sand soil is exposed to any source of water, sudden and large collapse settlement occurs. The sudden collapse settlement causes sever damage to the structures. Thus, a suitable stabilization method is required and the collapsing behavior of this soil should be investigated, [2,3,4].
Generally, soil stabilization improves the mechanical properties of soil such as: (a) increases shear strength and bearing capacity; and (b) decreases swelling and settlement. Soil compaction is widely used since it is the least expansive method of soil stabilization. Recently, there are many methods of soil stabilization such as: (a) chemicals additives (lime, lime-flyash admixtures, cement, phosphoric acid compounds, bitumen, silica…etc); and (b) geogrids, geotextile, micropiles, anchors, soil nails…etc., [5,6,7,8].
In recent years, more job sites were done using a mixed-in-plant-system, where a mixture of one ore two soils as a base material is enriched with a clayish mineral, like bentonite or

kaolinite, to obtain homogenous products. For the various civil engineering construction techniques, bentonite is used either in form of a water-based slurry, as a powder or in granular form, [8,9,10]. Moreover, bentonites containing sealing materials are used, for many years, for sealing purposes in foundation, dike construction, hydraulic engineering and landfill construction. Because of their exceptional physical, structural and chemical properties, bentonites are offering manifold possibilities to protect the environment against the negative effects of dumping grounds, [11,12,13].

Researchers have been interested in studying the properties and the stabilization methods of soils. Less research has been directed towards the collapse settlements of compacted fine sand soil containing bentonite. In this study, effort has been made to investigate the effect of bentonite content on the collapse potential of compacted fine sand-bentonite mixture. The collapse potential was measured based on the results of oedometer tests. The results indicated that the increase of compaction degree and bentonite content has positive effect on collapse potential and total compressibility of compacted fine sand-bentonite mixture.

## MATERIAL PROPERTIES

## FINE SAND SOIL

Samples of fine sand were obtained from a borrow pit at costal area of El-Ajami district, Alexandria, Egypt. Buildings, roads and underground constructions in this district are subjected to geotechnical problems as soil settlements, soil collapse…etc. Soil samples were extracted from a depth of 0.75 m from natural ground surface.

Grain size analysis (by sieving) of sand is shown in Fig. 1. According to MIT classification system, soil samples are classified as fine sand containing 83.2% fine sand, 9.4% medium sand and 7.4% fines. Grain-size data indicate an effective diameter ($D_{10}$) = 0.085 mm, $D_{30}$ = 0.10 mm and $D_{60}$ = 0.125 mm. Based on the manner of testing and measuring in references [14,15], physical properties of fine sand are summarized in Table 1.

**Table 1: Properties of fine sand**

| Properties | Quantity | Properties | Quantity |
|---|---|---|---|
| Natural density ($\gamma_{nat.}$) | 13.1 $KN/m^3$ | Specific gravity ($G_s$) | 2.62 |
| Natural moisture content (w) | 2.5% | Friction angle ($\phi$) | $27^o$ |
| Maximum density ($\gamma_{max.}$) | 15.2 $KN/m^3$ | Uniformity coefficient ($C_u$) | 1.47 |
| Minimum density ($\gamma_{min.}$) | 12.0 $KN/m^3$ | Coefficient of curvature ($C_c$) | 0.94 |
| Relative density ($D_{r.}$) | 40% | | |

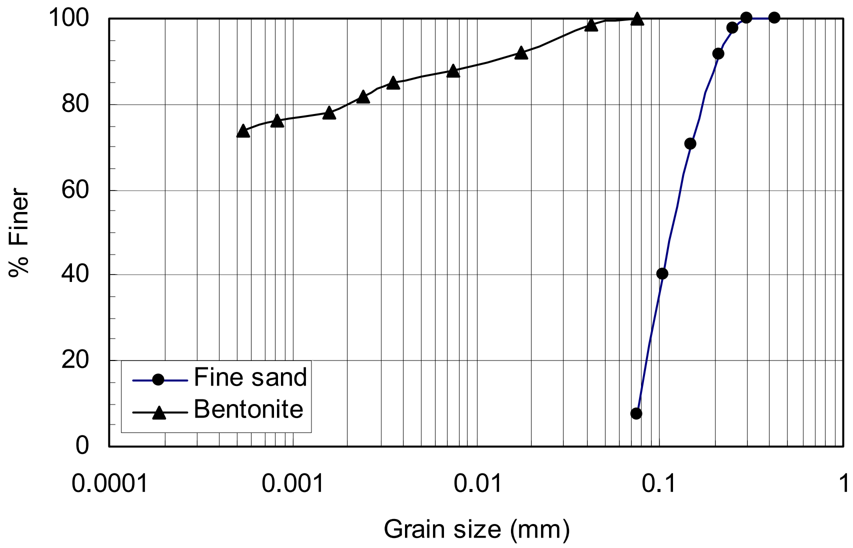


**Fig. 1. Grain size distribution curves for the used materials**

## BENTONITE

The used bentonite (powder) was obtained from a local supplier in Cairo, Egypt. A particle size analysis (by sedimentation) of bentonite is shown in Fig. 1. Geotechnical properties and chemical analysis of bentonite are given in Tables 2 and 3 respectively. Properties of bentonite indicate that it is very high plasticity and highly expansive material.

**Table 2: Geotechnical properties of bentonite**

| Properties | LL (%) | PL (%) | PI (%) | Clay (%) | Silt (%) | $G_s$ |
|---|---|---|---|---|---|---|
| Quantity | 305 | 62 | 243 | 80 | 20 | 2.62 |

**Table 3: Chemical analysis of bentonite**

| pH | EC (dS/m) | Cations (me/L) | | | | Anions (me/L) | | | | $CaCO_3$ (%) | CEC (cmol/kg) | Exchangeable cations | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | $CO_3$ | $HCO_3$ | CI | $SO_4$ | | | Ca | Mg | Na | K |
| 8.9 | 2.06 | 0.8 | tr. | 20 | 0.05 | 1.4 | 2.5 | 8.6 | 8.7 | 7.1 | 85.5 | 93 | 16.5 | 28.4 | 0.72 |

## SAMPLES PREPARATION

Five samples of fine sand-bentonite mixtures containing different amounts of bentonite were prepared. Each one, 15 kg in weight, was oven dried. Bentonite was added to the dry sand by weight of 0%, 5%, 10%, 15% and 20% and mixed with a spoon. Maximum dry densities ($\gamma_{dmax}$) and optimum moisture contents (OMC) were determined using standard Proctor test, as in references [14, 15]. Figure 2 represents the compaction results, where, $\gamma_{dmax.}$ and OMC are tabulated in Table 4. It is observed that, increasing the bentonite content (Bc) in compacted fine sand increases the values of $\gamma_{dmax}$ and OMC. For the purpose of this study, the soil sample is considered in natural state as it has OMC and dry unit weight depending upon compaction degree.

**Table 4: Compaction results of investigated soil samples**

| Soil sample No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Bentonite content (%) | 0.0 | 5.0 | 10.0 | 15.0 | 20.0 |
| $\gamma_{dmax.}$ (KN/m$^3$) | 16.0 | 16.4 | 17.0 | 17.2 | 17.3 |
| OMC (%) | 7.0 | 8.5 | 11.5 | 14.2 | 17.0 |

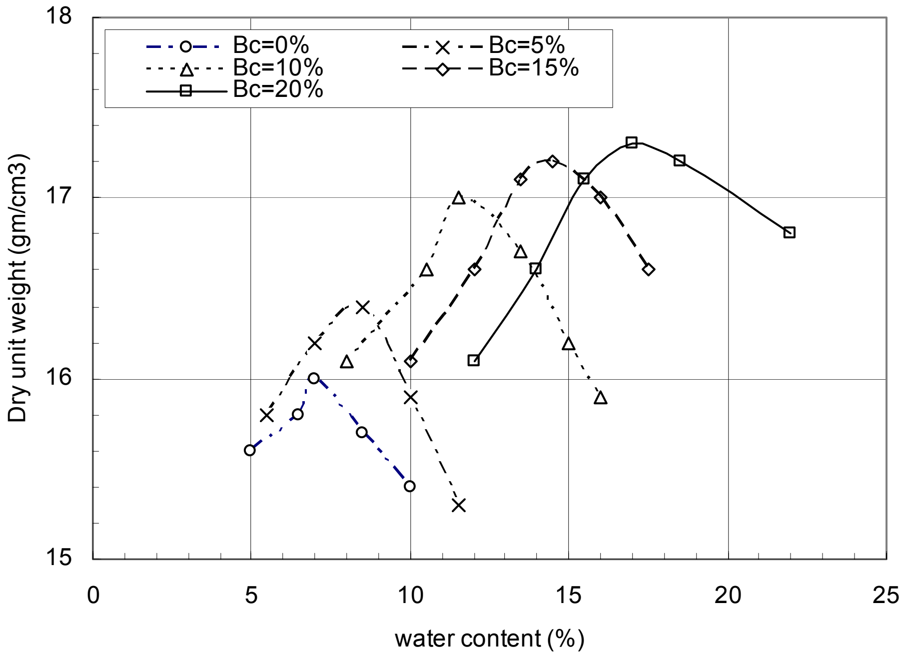


**Fig . 2. Compaction test curves for the investigated fine sand-bentonite mixtures**

## TESTING PROCEDURE

Three oedometer tests (OT) were carried out, for each soil sample, at optimum water content and variant compaction degree ($OT_1$, $OT_2$ and $OT_3$), as shown in Table 5. Specimens of the investigated soil samples were carefully placed and compacted in oedemeter ring (7.5 cm diameter and 2.15 cm high) at exact estimated weight based on the volume of oedemeter ring. Each soil specimen was incrementally loaded to specified stresses of 50, 100 and 200 kN/m$^2$ in natural state as mentioned in Table 5. At each applied stress, soil deformation was estimated using the recorded dial gauge readings until there was no deformation of soil specimen.

**Table 5: Oedometer tests variation for each soil sample**

| Oedometer test | $OT_1$ | $OT_2$ | $OT_3$ |
|---|---|---|---|
| Water content (%) | OMC | OMC | OMC |
| Compaction degree (%) | 90 | 95 | 100 |

As the soil specimen reached equilibrium under the applied stress of 200 kN/m$^2$, it was soaked with water. The soil specimen collapsibility (collapse deformation) was recorded at the equilibrium state. Then, the specimen was consolidated to 400 and 800 kN/m$^2$. After that, the soil specimen was unloaded gradually at 400, 200 and 0.0 kN/m$^2$, where the unloading deformations were recorded.

## RESULT ANALYSIS AND DISCUSSIONS

Unquestionably, compressibility and collapse settlement for the compacted layers can be estimated in terms of the collapse potential (h/H) measured from the oedometer test for the representative soil sample. Where, h is the soil specimen deformation (vertical settlement) and H is the initial height of soil specimen (H=2.15 cm) equals oedometer ring high. Figures 3, 4 and 5 show the obtained results of soil compressibility (h/H) versus the applied stresses for soil specimens with different contents of bentonite at variant compaction degree. In addition to that, Fig. 6 represents the effect of bentonite content on collapse potential at various cases of studied compacted fine sand-bentonite mixture samples. Moreover, compressibility values of the investigated compacted fine sand under normal stresses of: (a) 200 kN/m$^2$ in natural and soaking cases, and (b) 800 kN/m$^2$ in consolidated case are tabulated in Table 6.

According to the obtained results, as shown in figures 3-5 and Table 6, it is evident that:

1- As seen in the above mentioned figures 3-5 and Table 6, the compressibility of compacted fine sand-bentonite mixture at natural state (i.e. at OMC and before soaking) decreases slightly as: (a) bentonite amount increases; and (b) compaction degree ($I_c$) decreases. For instance, at $I_c$ = 90%, the compressibility of compacted fine sand with 20% bentonite content (Bc) decreases by 27% less than that with 0.0% bentonite amount. While, at $I_c$ = 100%, the compressibility of fine sand with Bc=20% decreases by 22% less than that with 0.0% bentonite amount.

2- Compaction degree has significant effect on total compressibility of compacted fine sand-bentonite mixture. But, the total compressibility reduction percentage is almost the same for the same bentonite content and applied stress at variant compaction degree. It clears that at 800 kN/m$^2$ applies stress, the total compressibility of fine sand with Bc=20% decreases by about 55%-50% less than that of fine sand with Bc=0.0% for variant compaction degree.

**Table 6: Compressibility results of the investigated soil samples**

| Soil properties | | Compressibility of soil sample [(h/H) x 100] | | | |
|---|---|---|---|---|---|
| | | Stress = 200 KN/m$^2$ | | | Stress= 800 KN/m$^2$ |
| | | Natural state | Soaking state | Collapse Potential | Consolidation state |
| $I_c$ = 90 % $w_c$ = OMC | Bc = 0.0% | 4.61 | 12.92 | 8.31 | 21.2 |
| | Bc = 5.0% | 4.1 | 10.63 | 6.53 | 17.13 |
| | Bc = 10.0% | 3.64 | 8.31 | 4.67 | 13.51 |
| | Bc = 15.0% | 3.45 | 6.71 | 3.26 | 10.71 |
| | Bc = 20.0% | 3.36 | 5.98 | 2.62 | 9.58 |
| $I_c$ = 95 % $w_c$ = OMC | Bc = 0.0% | 3.7 | 10.02 | 6.32 | 17.12 |
| | Bc = 5.0% | 3.11 | 7.76 | 4.65 | 13.56 |
| | Bc = 10.0% | 2.84 | 6.32 | 3.48 | 10.62 |
| | Bc = 15.0% | 2.67 | 4.88 | 2.21 | 8.08 |
| | Bc = 20.0% | 2.53 | 4.35 | 1.82 | 7.05 |
| $I_c$ = 100 % $w_c$ = OMC | Bc = 0.0% | 1.83 | 5.70 | 3.87 | 10.73 |
| | Bc = 5.0% | 1.68 | 4.33 | 2.65 | 8.53 |
| | Bc = 10.0% | 1.54 | 3.45 | 1.91 | 7.05 |
| | Bc = 15.0% | 1.46 | 2.40 | 1.03 | 5.61 |
| | Bc = 20.0% | 1.42 | 2.24 | 0.82 | 5.04 |

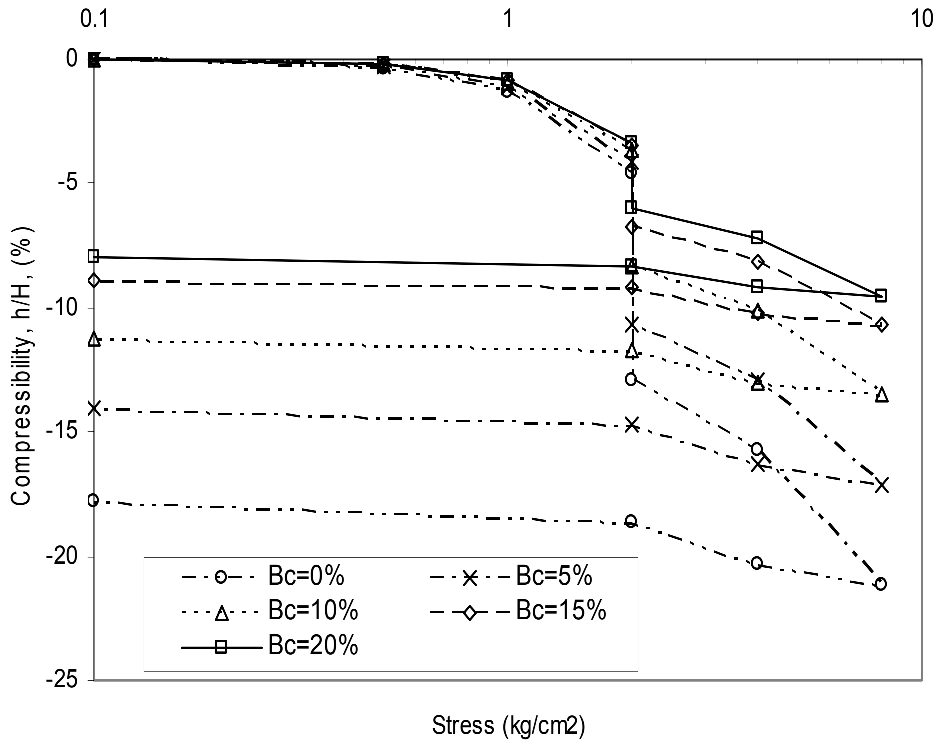


**Fig . 3. Effect of bentonite content on compacted fine sand at 90% compaction degree**

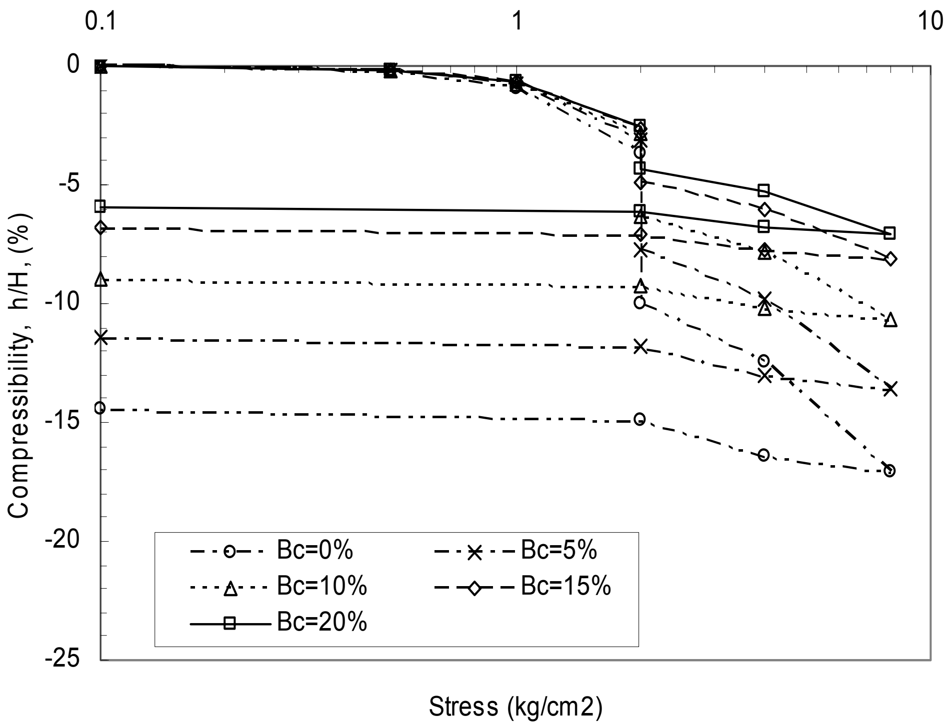


**Fig . 4. Effect of bentonite content on compacted fine sand at 95% compaction degree**

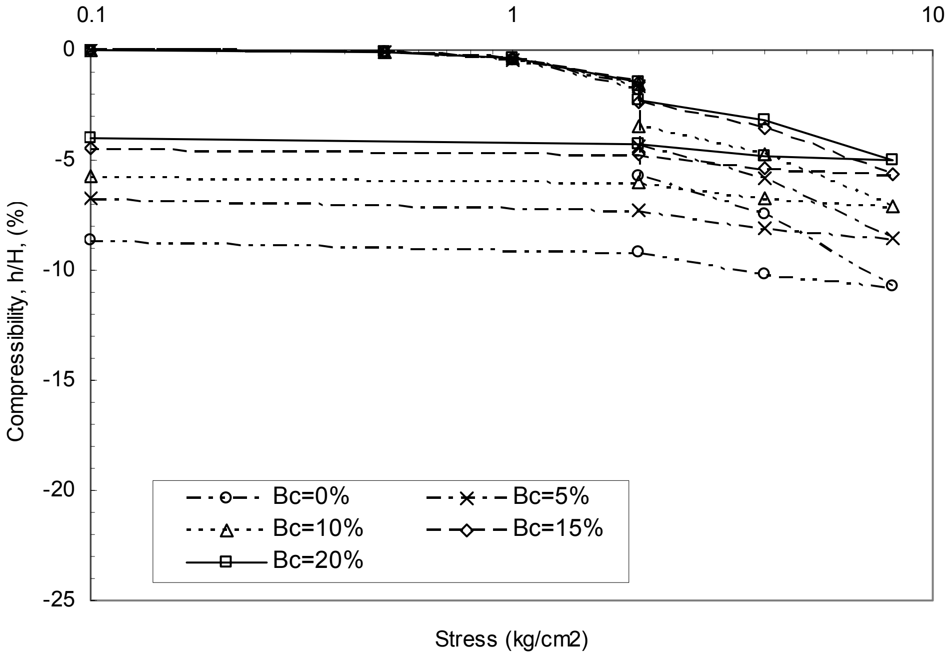


**Fig . 5. Effect of bentonite content on compacted fine sand at 100% compaction degree**

3- Referring to figure 6 and Table 6, the collapse potential of the investigated compacted fine sand-bentonite mixtures, after soaking, decreases with: (a) the decrease of compaction degree, and (b) the increase of bentonite amount. It appears that at $I_c$ = 90%, the collapse potential of compacted fine sand with Bc=20% decreases by 68% less than that of fine sand with 0.0% bentonite amount. Also, at $I_c$=100%, the collapse potential of fine sand with Bc=20% decreases by about 80% less than that of fine sand with 0.0% bentonite amount.

4- The unloading expansion of compacted fine sand-bentonite mixture decreases slightly as the increase of bentonite amount and compaction degree, refer to Figs. 3-5. On the other side, the expansion percentage is almost the same for fine sand with variant bentonite contents and variant compaction degrees. It appears that the unloading expansions of the investigated fine sand-bentonite mixtures at 0.0 applied stresses are about 20% of total compressibility under 800 $kN/m^2$ applied stresses.

In addition to the above mentioned discussions, the compaction degree has significant positive effects on the collapse potential, as shown in Fig. 7. It can be seen that:

1- The collapsibility variations for the studied samples at the same compaction degrees depend upon the bentonite amount. These variations decrease gradually with the increase of compaction degrees.

2- Assuming a semi-linear relationship between the collapse potential and the compaction degree, a trend can be drawn (represented by doted lines). It is seen that, regardless of the bentonite contents for Ic > 105%, the collapse potential closely lumped together reaching almost zero value. However, more researches are needed to obtain the exact behavior of the collapse potential.

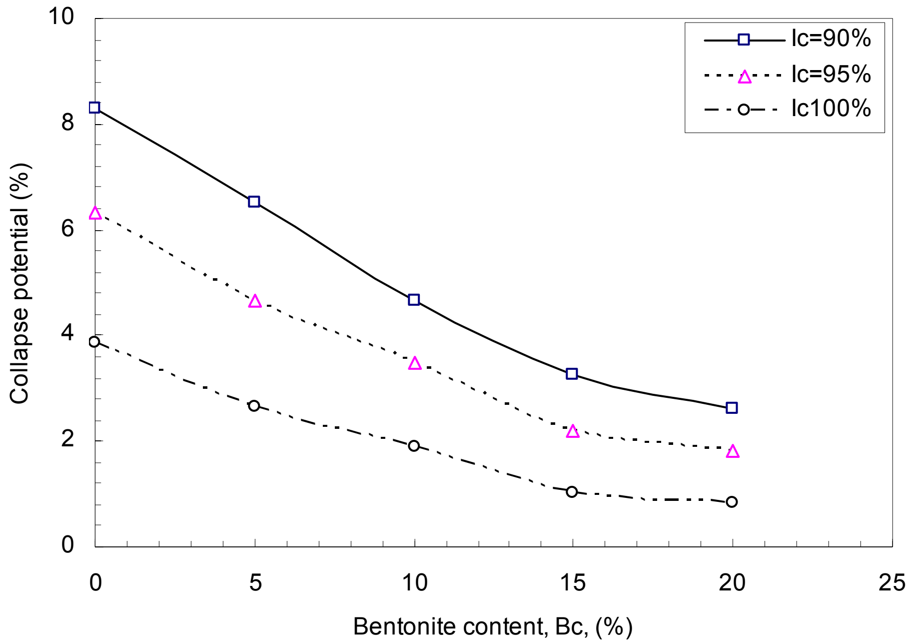


**Fig . 6. Effect of bentonite content on collapse potential at variant compaction degree**

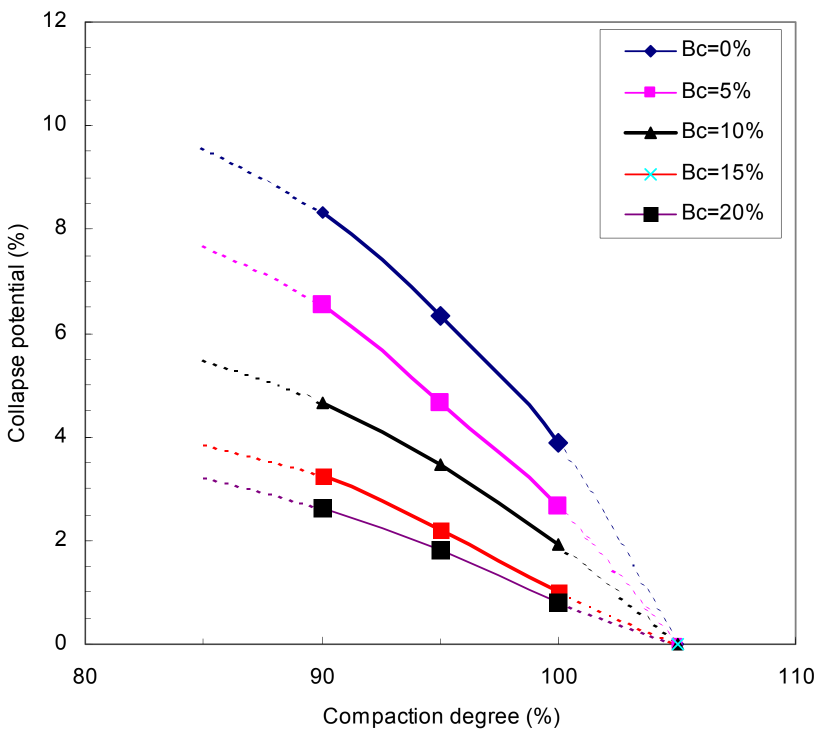


**Fig . 7. Effect of compaction degree on collapse potential at variant bentonite content**

## CONCLUSIONS

Oedometer tests were carried out to study the effect of bentonite amount on the collapsibility of compacted fine sand. Based on the obtained results, the following conclusions can be made:

1- Increasing the betonite content in compacted fine sand-bentonite mixture increases the values of optimum moisture content and maximum dry density ($\gamma_{dmax}$.).
2- Betonite content (Bc) and compaction degree (Ic) have a significant positive effects on the compressibility and collapsibility of compacted fine sand. Where, the collapsibility decreases with the increase of bentonite content compaction degree.
3- Assuming a semi-linear relationship, the collapse potential reaches zero value at compaction degree greater than 105% regardless of bentonite content in compacted fine sand. It is recommended that the foregoing assumption should be investigated.
4- In the arid areas, which have calcareous fine sand it is recommended that the compaction effort should be increased to avoid the risk of collapsibility.
5- Fine sand-bentonite mixtures can be utilized in stabilizing fine sand soil as an alternative to excavation and complete soil replacement. Mixtures may reduce construction and maintenance costs of foundations and highways constructed on fine sand.

## REFERENCES

[1] El-Nahas, F.; Hassn, A.; Helmy, H.; and Abdel-Sayed, H., “Some Geotechnical Constrains on the Development of Red Sea Coastal Areas”, The Ninth International Colloquium on Structural and Geotechnical Engineering, Ain-Shams University, Cairo, Egypt, 2001.
[2] El-Saadany, M.M.; Abou-Rayan, A.M.; and Easa, A.A., "Effect of Lime on the Collapsibility of Compacted Fine Sand", Civil Engineering Research Magazine, Al-Azhar University, Naser City, Cairo, Egypt, 24, 1, 214-232, 2002.
[3] Abu-Hajar, O. S., “Methodology of Protecting Engineering Structures Against the Risk of Sand Movement in Deserts”, The Eighth Arab Structural Engineering Conference, Cairo, Egypt, 3, 1183-1192, 2000.
[4] El-Sohby, M. A., “Critical Evaluation of Collapsibility Measurements for Cemented Sand”, Brazil Engineering Sixth Int. Conf., Rio de Janeiro, Brazil, 593-596, 1996.
[5] Aiban, S. A.; and Dobroslav, Z., “Centrifugal Modeling Bearing capacity of Shallow Foundation on Sand”, Journal of Geotechnical Engineering, 121, 10, 704-712, 1995.
[6] Sahu, B.; and Jumo, I. J., “Soil Stabilization Using Lime and Fly-Ash”, Al-Azhar Engineering Fifth International Conference, Cairo, Egypt, 4, 212-220, 1997.
[7] El-Sohby, M.; Tarek, M. F.; Ibrahim, A.M.; and Sherif, M. M., “Shear Strength and Mechanical Behavior of Collapsible Cemented Sand”, Al-Azhar Engineering Sixth International Conference, Cairo, Egypt, 3, 41-53, 2000.
[8] Rotta, G.V., Consoli, N.C., Prietto, P.D.M., Coop, M.R. and Graham, J., "Isotropic Yeilding in an Artificially Cemented Soil Cured Under Stress", Geotechniqe, 53 (5), 493-501, 2003.
[9] Koch, D., " Bentonite as a Basic Material for Technical Base Liners and Site Encapsulation Cui-off Walls", Applied Clay Science, 21, pp. 1-11, 2002.
[10] Gleason, M.H., Daniel, D.E. and Eykholt, G.R., "Calcium and Sodium for Hydraulic Containment application", J. of Geot. and Geoenvir. Eng., ASCE, 132 (5), 438-445, 2005.
[11] Tang, G.X., Graham, J. and Wan, A.W., "On Yielding Behaviour of an Unsaturated Sand-Bentonite Mixture", Proc. 2nd Int. Conf. Unsaturated Soils, Beiging, China, pp 149-154, 1998.
[12] Alawaji, H.A., "Swell and Compressibility Characteristics of Sand-Bentonite Mixtures Inundated with Liquids", Applied Clay Science, 15, pp. 411-430, 1999.
[13] Haug, M.D. and Wong, L.C., "Impact of Modeling Water Content on the Hydraulic Conductivity of Compacted Sand-Bentonite Liner Material", Canadian Geotechnical Journal, 49, 253-262, 2006.
[14] Bowles, J. E., “Engineering Properties of Soils and Their Measurement”, McGraw-Hill, New York, 1986.

[15] Egyptian Code for Soil Mechanics and Foundation Design & Construction, "Laboratory Testing", ECSMFDC, Building Research Institute, Giza, Egypt, 2001.

**NOTATIONS**

EC = Electrical conductivity
dS/m = Desisiemen per meter
Ca = Calcium
Mg = Magnesium
Na = Sodium
K = Potassium
Me/L = Milliequivalents per liter
tr. = Trace
$CO_3$ = Carbonate
$HCO_3$ = Bicarbonate
CI = Chloride
$SO_4$ = Sulphate
$CaCO_3$ = Calcium Carbonate
CEC = Cation exchange capacity
cmol/kg = Centimole per kilogram