Mitigation of collapse of marshes soil by nano silica fume

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Abstract. Marshes are water areas in the south of Iraq and cover about (35000) Km². Because of its strategical and economic importance in addition to tourism, this study is important. In recent years, many of problems had been observed in many structures constructed on marshes soils due to complex collapsible behavior of such soils. The soils of the marshes are considered as weak soil. This fact comes along because of water table being near the ground level or above it which is usually a fine sand and silty sand. The objective of this study is to investigate the effect of silica fume as Nano-materials on the collapsibility of disturbed marshes soils brought up from Alchibayish area (Thi-Qar) Governorate and Alhalfaiya area (Messan) Governorate collected at depth (1.0) m below the natural ground surface. All fundamental tests were performed on these soils. The effect of adding Nano silica fume on collapsibility of marshes soil by using three different percentages by weight of the dry marshes soil (1, 2, and 3) % were studied. The results of single collapse tests marked (3) % of Nano silica fume decreases the collapsibility sharply; more than 50 % of improvement in collapse potential has been achieved at these optimum percent of silica fume as Nano-material. Where considerable reduction is observed in compressibility by (45-50) % for marshes soil. In laboratory tests, results showed that these soils have high collapsibility and that the shear parameters increase when treated with Nano silica fume.

Keywords
Marshes soil, Nanomaterials, Collapse potential, compressibility.

1. Introduction
Collapsible soil is defined as partially saturated, characterized by low water content and a stable structure. These soils are often formed in the form of sediments, which in the dry state acquire significant resistance, due to the natural cohesion of their grains. They therefore have high bearing capabilities and are able to carry loads. After saturation and without additional loads, a significant reduction occurs in the rearrangement of the particles. Most of these soils have an open their sizes [1]. The reduction is generally due to broken granular bonds, resulting and loose structure, often composed of granules ranging from silt to fine sand [2]. The percent collapse is defined as the change in height of the soil specimen after soaking divided by the initial height of the soil specimen. There are many different methods for dealing with collapsible soil. If there is a shallow deposit of natural collapsible soil, the deposit can be removed and recompacted during the grading of the site. In some cases, (such as by compaction grouting) to reduce the collapse potential of the soil [3]. Another method for dealing with collapsible soil is to flood the building footprint or force water into the collapsible soil stratum by using wells. As the wetting front moves through the ground, the collapsible soil will densify and reach an equilibrium state. A deep foundation system, which derives support from strata below the
collapsible soil, could be constructed. Also, post-tensioned foundations or mat slabs can be designed and installed to resist the larger anticipated settlement from the collapsible soil [4].

Over the last 10 years, nanotechnology has got a significant development as a multidisciplinary subject. While nanotechnology is a new trend, it is not a unique combination of physics, chemistry, biology and engineering [5]. Nanomaterials are defined in the field of nanotechnology, as the production and use of materials in the nanoscale, whose particles size are smaller than 100 nanometers in one dimension [6].

Yonekura and Miwa (1993) studied Nano silica to increase compressive strength of sand [7]. Also, Noll et al. (1992) investigated the use of Nano silica to stabilize soil and reduce soil permeability [8]. Gallagher et al., (2007) studied Nano silica for increasing soil's cohesion/adhesiveness and studied the effect of Nano-silica on reducing soil permeability. Sand behaviour has been improved by the addition of nanomaterials analyzed in periodic loading conditions. It is thought that the improvement mechanism of colloidal silica is bonding between the gel and the individual sand particles. It is thought that this bonding and encapsulation maintains the soil structure during dynamic loading [9][10]. As a result, it was indicated that cohesion/adhesiveness depended on the percentage of nanomaterial increase [9].

2. Experimental Study

2.1 Properties of Raw Soil

Two types of natural marshes soils are used in the present study. The first soil was brought from AlChibayish area (Thi-Qar) Governorate about 380 km south of Baghdad, the other soil was brought from AlHalfaiya area (Messen) Governorate about 320 km south of Baghdad, near marshes. Disturbed samples were taken from (1-1.5) m below the natural ground surface, then packed in double nylon bags and transported to the Soil Mechanics Laboratory.

| Table 1 Physical and Chemical properties of the soils |
|-----------------------------------------------------|
| Property                                            |
|                                                    |
| γmax (kN/m³)                                       |
| γmin (kN/m³)                                       |
| e_max (-)                                          |
| e_min (-)                                          |
| Relative density (%)                                |
| Soil classification (USCS) SP                       |
| Specific gravity                                   |
| TSS %                                              |
| SO3 %                                              |
| PH                                                 |
| O.C%                                               |
| AlChibayish                                        |
| AlHalfaiya                                         |
| Standards                                          |

| Property       | AlChibayish | AlHalfaiya | Standards                |
|----------------|-------------|------------|--------------------------|
| γmax (kN/m³)   | 12.77       | 12.32      | ASTM D698-78[11]         |
| γmin (kN/m³)   | 11          | 10.64      |                          |
| e_max (-)      | 1.5         | 1.63       |                          |
| e_min (-)      | 0.86        | 0.88       |                          |
| Relative density (%) | 60  | 60  | -                         |
| Soil classification (USCS) SP | SP | SP |                |
| Specific gravity | 2.47  | 2.55  | ASTM D854-00[12]      |
| TSS %          | 32          | 41         | Earth manual E8        |
| SO3 %          | 6.4         | 5.8        |                          |
| PH             | 7.3         | 7.5        | Bs (1377-1975)          |
| O.C%           | 8.66        | 9.32       |                          |

2.2 Nano Silica Fume

The Nano Silica Fume used in this study named as CAB-O-SIL is made in Germany. It has a specific surface area 200 m²/g. The chemical composition of Nano Silica Fume was shown in
Table 2. The Nano Silica Fume used in this work conforms to the chemical and physical requirements of ASTM C1240-03[13]. According to the manufacture company average primary particle size is 12 nanometers.

| Properties                        | Value | Oxide composition | Oxide content |
|-----------------------------------|-------|-------------------|---------------|
| Max.Moisture content %            | 1.5   | SiO₂              | 99.8          |
| Color                             | white | Al₂O₃             | 0.05          |
| Particle size (11-13) nm          |       | Fe₃O₄             | 0.003         |
| Specific surface area 200 m²/g    |       | Na₂O              | 0.05          |
| Tare density 2.4 g/cm³            |       | K₂O               | 0.03          |
| Bulk density < 0.1g/cm³           |       | MgO               | 0.01          |
| Ignition loss 1 %                 |       | TiO₂              | 0.03          |
| PH 3.7-4.7                        |       | HCl               | 0.025         |

3. Collapsible test

Four samples were prepared, one in the natural state and three mixed with different percentages of Nano-silica fume added to the natural marsh soil. The percentage of Nano-silica smoke is 1%, 2%, and 3%, in terms of the dry weight of soil. The mixed samples were determined by single collapse (or single oedometer) test using oedometer cell and the procedure test is according to ASTM D5333, 2003[14]. Soil samples with a diameter of 75 mm and a thickness of 19 mm. The pressure multiplied every 24 hours until the required stress (200 kPa). In this test, vertical static load increases were applied at regular intervals (24 hours) and the pressure load was doubled with each increase to the maximum required (12.5, 25, 50, 100, 200, 400 and 800 kPa). After applying 200 kPa stress and waiting 24 hours, distilled water was added to the cell and left for 24 hours. Additional thickness changes (ΔH) were recorded. The collapse potential (Cp) is calculated using equation (1). Table 3 shows the severity problem of collapse potential.

\[ C.P = \frac{\Delta e}{1 + e_0} \]  

Where: 
C.P = Collapse Potential, \( \Delta e \) = void ratio before and after soaking, \( e_0 \) = Initial voids ratio.

| Collapse Potential (%) | Severity of Problem |
|------------------------|---------------------|
| 0                      | No problem          |
| 0.1-2                  | Slight              |
| 2.1-6                  | Moderate            |
| 6.1-10                 | Moderately severe   |
| >10                    | Severe              |

The results of single collapse test can be shown in figures (1) and (2). The collapse potential of untreated marshes soil was relatively high. The addition of Nano silica fume led to reduction in collapse potential from 11.6% to 2.66% with increase in the Nano silica fume percentage to 3%, and increasing dry unit weight depending on the added material quantity. The collapse potential transform from sever to moderate as shown in table (3).
Figure 1: single collapse test of Al Chibayish soil treated by Nano silica fume.
Figure 2: Single collapse test of AlHalfaiya soil treated by Nano silica fume.

4. Instrumentation and measurement

4.1. Linear Variable Differential Transformer (LVDT)

The maximum total settlement of raft foundation was recorded using two LVDTs placed at the middle of the upper surface of raft foundation. The LVDTs transducers were calibrated by comparing the output voltage with a known deflection (using digital vernia).

4.2. Data Logger

The LVDTs were calibrated and connected to the data logger unit which provides a connection with the computer laptop. The data logger was calibrated to give direct readings for raft foundation settlement for rigid raft. The data logger is of 2 channels for LVD readings, to attain the required accuracy, 10 reading were recorded every 1 second for each channel.

4.3 The Steel Container

The tests were carried out using a steel container with internal dimensions (600*400*400) mm. The steel container is made of plate joined together by 6mm thick (75*75*6) mm steel angle bolted together and welded to the steel plate. The container was sufficiently rigid and exhibited no lateral deformation during the preparation of the bed of soil and during the test. Figure (3) shows details of the complete setup, which consist of mainly of steel container, loading frame and accessories.
5. Model preparation

5.1. Untreated condition

The natural soils brought from marshes consist of large lumps. They were left for air drying for a sufficient period of time. The soil was mixed thoroughly with the required amount of water corresponding to optimum moisture content. The wet soil covered tightly with a nylon sheet and left for 24 hours. The wet soil was spread into steel container in layers each about 100 mm in thickness. Each layer was compacted with a special hammer (120 * 120) mm in size and about 10 kg in weight. The final depth of the bed of the soil required three layers of compacted soil, 400 mm in thickness. The footing was placed in position and the loading assembly was also fitted in the required place. Two LVDTs were fitted on the footing to measure the deformation. The load increment was applied gradually and the vertical deformation was recorded.

5.2. Treated condition by mixing Nano silica fume

In this series the wet soil was mixed thoroughly with 3 % Nano silica fume by weight and then compacted inside the steel container, obtained good results. The same procedure for untreated soil was also followed.

6. Model Tests for Improving Marshes Soils

The model tests were loaded incrementally with corresponding stage the model was flooded by adding water on the top surface of the bed of soil. The results are presented in two forms, the first is a relationship between the applied stress and the settlement percent (S/b %) in addition to the final deformation recorded at the end of the floating. The second form relates the settlement percent versus time during the floating period. The mixing technique was used for improving the behavior of marshes soil 3 % Nano silica fume concentration percent was mixed thoroughly with the soil and then compacted as discussed in previous section. Figures (4), (6) and Figures (5), (7) illustrate the relationship between the settlement ratio plotted against the applied stress and time respectively. Prior to flooding, the Nano silica fume has reduced the settlement by 50% and as flooding commenced the rate of the settlement increase rapidly for the untreated soil exhibited a slower rate. The Nano silica fume has also reduced the settlement by (40-45) % after soaking.

7. Shear Strength Tests

A series of direct shear tests were carried out to determine the shear strength parameters of soil. The specimen size was (60*60*20) mm. A calibrated proving ring of (200) kg capacity and (0.002) mm precision dial gage for vertical deformation reading was used, while for horizontal deformation a (0.001) mm gage was used. The rate of strain was (0.3) mm/min.
To predict the shear strength parameters, (8) samples which were obtained from two soils samples, (2) samples of them were tested in natural state, while the other (6) samples were tested after treating with 1%, 2% and 3% Nano silica fume.

The summary of the results of direct shear tests conducted on the two soils for both before and after treatment state is given in figures (8) and (9).

**Figure 4:** Applied Stress versus Settlement Percent of AlHalfaiya Soil

**Figure 5:** Settlement Percent versus Time during the Floating Period of of AlHalfaiya Soil

**Figure 6:** Applied Stress versus Settlement Percent of AlChibayish Soil.

**Figure 7:** Settlement Percent versus Time during the Floating Period of of AlChibayish Soil.

**Figure 8:** Effect of Nano silica fume on the cohesion.

**Figure 9:** Effect of Nano silica fume on the internal friction angle.
8. Conclusions
1. Increase in concentration of nano silica fume in water used in compaction process of soil causes increase of the maximum dry unit weight and increase of the optimum moisture content.
2. The collapse potential is reduced with increase of nanomaterials percent. The lowest collapsible potential was obtained when the marshes soil was improved with cement dust.
3. The rate of settlement during the flooding was sufficiently reduced from about (50-60) % when the marshes soils were treated with 3% Nano silica fume.
4. There is an increase by approximately (1.5) folds in the cohesion at samples containing 3% Nano silica fume. The angle of friction slightly increases with increasing Nano silica fume.

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