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Behavior of Expansive Soil Treated with Silica Fume Material

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Abstract

This research deals with the improvement of the mechanical properties of expansive clay soils by silica fume. The expansive soil was prepared in laboratory by mixing natural soil brought from (Nahrawan) city with different percentages of Bentonite (30, 50 and 70% by weight). The test program included the effect of Bentonite on natural soil then study the effect of silica fume on prepared soil by adding different percentages of silica fume (3,5, and 7% by weight) to the prepared soils and the influence of these admixtures were observed by comparing their results with those of untreated soils (prepared soils). The properties chosen for this comparison were specific gravity, the consistency limits, swelling percent and swell pressure. The results show that the plasticity index, the optimum moisture content, swelling percent and swell pressure increase with increasing the Bentonite percent, and the maximum dry density, specific gravity decrease with increasing the Bentonite percent. When the prepared soil treated with silica fume, the results show that plasticity index, specific gravity, maximum dry density swelling percent and swell pressure decrease with increasing the silica fume percent, while optimum moisture content and unconfined compressive strength increased with increasing silica fume percentages. And the perfect percentage of silica fume was obtained to be 7% which where decreased the swell and swell pressure in large percent.

The result showed that the addition of silica fume to expansive soils has in a positive effect to the geotechnical properties and these results will benefit the engineers or decision makers in using this additive.

Keywords: Improvement; Expansive Soil; Silica fume; Swell Pressure

تصرف الترب الأنتفاخية المعالجة بمادة السليكا فيوم

الخلاصه

تبحث هذه الدراسة في موضوع تحسين خواص الأطيان الأنتفاخية (الحد من إنتفاخ الأطيان) بأستخدام مادة السليكا فيوم. الترب الانتفاخية حضرت في المختبر بواسطة خلط تربة طبيعية (تربة مأخوذة من منطقة نهروان) مع نسب وزنية مختلفة من مادة البنتونايت (30 ,50 , 70 %) . برنامج العمل يتضمن دراسة تأثير مادة السليكا فيوم على الترب المحضرة بأضافة نسب وزنية مختلفة من مادة السليكا فيوم (3و5 , 7,%) إلى الترب المحضرة وتأثير هذا المزيج لوحظ من خلال مقارنة النتائج مع الترب الغير معالجة (الترب المحضرة) ان الخواص التي تم إختيارها للمقارنة تمثل الوزن النوعي, حدود أتربرك ,نسبة الأنتفاخ وضغط الأنتفاخ. بينت النتائج إن قيم

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مؤشر اللدونة ,محتوى الرطوبة الأمثل ,نسبة الأنتفاخ وضغط الأنتفاخ تزداد بزيادة نسبة البنتونايت , أما بالنسبة لقيم الكثافة الجافة والوزن النوعي تقل بزيادة نسبة البنتونايت . وعند معالجة الترب المحضرة بمادة السليكا فيوم بينت النتائج إن قيم مؤشر اللدونة , الوزن النوعي , نسبة الأنتفاخ وضغط الأنتفاخ تقل بزيادة نسبة مادة السليكا فيوم. بينما اظهرت النتائج زيادة نسبة ارطوبة المثلى وزيادة قابلية الأنضغاط بزيادة نسبة السليكا وتعتبر نسبة 7% من مادة السليكا فيوم النسبة الأفضل لتقليل نسبة الأنتفاخ وضغط الأنتفاخ نتستنتج من خلال النتائج أن إضافة مادة السليكا فيوم إلى الترب الأنتفاخية يشكل تأثير إيجابي وهذا بدوره مفيد للمهندس و أصحاب القرار في إستخدام تلك المادة كمضاف .

INTRODUCTION

The term of expansive soil applies to soil, which has the tendency to swell when its moisture content is allowed to increase. The problems associated constructed on theses clays are subjected to large uplift forces caused by swelling and inducing heaving, cracking and break up of both building foundations and slabs on grade members.

Several methods are available for stabilizing expansive soil. These include the use of chemical additives, rewetting, soil replacement, compaction control, surcharge loading and thermal methods. The most common methods employed for the stabilization of clayey soils are cement and lime stabilization. These methods produce a stabilizer layer of significant strength, which may not always be required in the subgrade of some structures. Besides, they are costly now days.

New methods continue to be researched to increase the strength properties and to reduce the swell behavior of expansive soils. Many investigations have studied natural fabricated and by product materials and their use as stabilizers for the modification of clayey soils. (Prabakar et al., 2003), (kalkan,2006), (Akbulut et al.,2007). In previous studies the effect of silica fume on the hydraulic conductivity and swelling pressure of clayey soils were investigated. It was seen that clayey soil-silica fume mixtures were shown to have low hydraulic conductivity and swelling pressure values. (kalkan and Akbulut,2004) examined the stability of silica fume for the construction of hydraulic barrier in landfill. They concluded that clay mixed with silica fume in different proportions, has higher binding strength, low swelling pressure, and high compressive and shear strength. (Abd El-aziz et al. ,2004) examined the effect of lime-silica fume stabilizers on engineering properties of clayey subgrades. They summarized that the plasticity index and swell potential decreases and CBR value increases significantly. (kalkan,2009) examined the suitability of using silica fume as a stabilization material to reduce development of desiccation cracks in compacted clayey linear and cover systems. Natural clayey soil and clayey soil-silica fume mixtures were compacted at the optimum moisture content and subjected to laboratory tests. The results show that the silica fume reduced development of desiccation cracks on the surface of compacted samples. it has been concluded that silica fume waste material can be successfully used to reduce the development of desiccation cracks in compacted clayey liner and cover system. (Al-Azzawi et al.,2012) studied effect of silica fume addition on behavior of sility clayey soils, different percentages of silica fume(5%,10% &15%) were used. They investigated that there is significant improvement on swelling pressure and compressive strength of composite samples with silica fume. The permeability of soil increased with increase in silica fume content. It is observed that the addition of silica fume decreases the development of cracks on the surface of compacted clay samples reducing the cracks width by 75% . (Negi Chhaya et al.,2013) investigated the effectiveness of silica fume on the geotechnical properties such as swelling characteristics, subgrade characteristics and unconfined compression strength of soil. The results showed a significant increase in CBR strength by 72% when addition 20% of silica fume and the unconfined compression strength of stabilized samples up to30% and the differential free swell of the clay is reduced from 50% to 7% with increase in silica fume from 0% to 20% respectively. (Abass 2013) studied the effect of engineering properties of kaolin clayey soils when blended with lime and silica fume. A series of laboratory experiments have been implemented for varieties of samples: (2.5%,5%,7.5%,10%) for lime and (2%,4%,6%) for silica fume. The effect on consistency limits tests, specific gravity, compaction test, unconfined compression test and California bearing ratio test. These results revealed that the optimal percentage of LSF combination was attained at a (2.5%L+6% SF), which served as control in this study. This optimal percentage: decrease liquid limit, plasticity index, specific gravity and maximum dry density; and raise the optimum moisture content, unconfined compressive strength and California bearing ratio. These results showed also, that the combination of LSF stabilization at (2.5%L+6%SF) is better than the optimal one which achieved by lime alone. (Abbawi, 2013) investigated treatment expansive soil with various percentages of silica fume contents (10%, 20%, 25%, 30% and 50%) to determine their effects on geotechnical properties such as Atterberge's limits, compaction, unconfined compression and swelling properties. The results show that the silica fume played an important role in improving the problem of swelling behavior in expansive soil. The silica fume decrease liquid limit and changed compaction parameters of expansive soils the moisture content values increased and the maximum dry unit weight values decrease. Also the silica fume increased unconfined compressive strength, decreased the compressibility and the vertical swelling percentages of clayey soil-silica fume mixtures. (Gupta and Sharma, 2014) conducted compaction test and California bearing ratio tests to examine silica fume as stabilizer for construction of flexible pavements in rural road with low traffic volume. They found that increases in silica fume content reduced maximum dry density and increase optimum moisture content. Also they concluded that CBR values for soaked and unsoaked samples increased by 108.85% and 118.21% respectively when silica fume content increased to10%. Al-Kubaisy (2013) investigated the effect of silica fume of wetting and drying cycles on swelling behavior of modified expansive clay soil. Also effect of silica fume on undrained shear strength cohesion and friction were studied. Silica fume contents used were (5%, 8% and 12%). The results show with addition silica fume, liquid limit and plastic limit decreased. However, plasticity index increased with increasing silica fume content, the maximum dry unit weight values decrease and moisture content values increased also it has been concluded that swelling pressure and swelling potential steadily decreased up to 60% and 79.3% respectively with increasing silica fume to 12%.

Chemical Modification of Clayey Soils by Silica Fume

The chemical reactions must be explained to understand silica fume clay modification. To produce the modification of clayey soil, the important two effects are: the quantity and quality of silica fume added to clay and the chemical composition of clay. The active silica reacts with calcium hydroxide and forms calcium in clay .The pozzolanic process may be written as:

$Ca(OH)_2 + SiO_2$ C-S-Hl ….. (1)

$Ca(OH)_2 + Al_2O_3$ C-S-H ….. (2)

Calcium Silicate Hydrate, C-S-H, is cemented materials. The silicate gel proceeds immediately to coat and bind clay lump in the soil and to block off the soil voids. In time, this gel gradually crystallizes into well-defined calcium silicate hydrate such as tobermorite and hillebrandite. The micro-crystals can also mechanically interlock. It is thought that the material from this reaction becomes stronger but more brittle than pervious form (kalkan, 2009).

Experimental Work
Materials Used
Soil

The soil samples used in this study were prepared in the laboratory by mixing natural soil with different percentages of Bentonite. The natural soil was brought from Al-Nahrawan city (23Km) east of Baghdad and the soil is a brown clayey soil. Standard tests were performed to determine the physical and chemical properties of the soil . Grain size distribution of soil used revealed 33.7% sand, 16.3% silt and 50 % clay as shown in Figure 1. According to the U.S.C.S the soil is classified as (CL). The Bentonite was obtained commercially. Table1 shows physical and chemical properties of both soils. The natural soil was dried in laboratory at $60C^0$ for 48 hours then grained and sieved (passing No.40 (0.425mm) U.S). Four types of soil were prepared as follows:

Soil A: Represents a sample of the natural soil.

Soil B: Represents a laboratory prepared soil made by mixing soil with Bentonite at a ratio of (30%) by weight.

Soil C: Represents a laboratory prepared soil made by mixing soil with Bentonite at a ratio of (50%) by weight.

Soil D: Represents a laboratory prepared soil made by mixing soil with Bentonite at a ratio of (70%) by weight.

Silica fume

The American Concrete Institute ACI 116R (1996) Defines silica fume as “very fine, (with particles about100 times smaller), non-Crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon Silica Fume color is either an premium white or gray. Densified silica fume from Elkem Materials Company in Dubai has been used as a mineral admixture added to the mixture of this research. The percentages used are (3%, 5%, and 7%) of soil weight. The chemical composition of silica fume used in this investigation is presented in **Table 2**. The silica fume used in this work conforms to chemical and physical requirements of ASTM C 1240-03 Because of its high silica content as given in Table 2, this high amount provides good pozzolanic action and it’s extremely fineness, high specific area, silica fume is therefore, a very effective pozzolanic material.

Preparations of Clay Soil- Silica Fume Mixtur

To prepare a sample, the soil was dried in an oven at approximately 105C^0 before grinding process, the soil and silica fume mixed together in the dry state. The amounts of silica fume were selected to be 3%, 5% and 7% of the total weight of the clay soil- silica fume mixtures. The dry soil and silica fume were then mixed with the required amount of water for optimum moisture content. All mixing was done manually, and proper care was taken to prepare homogenous mixtures at each stage of mixing.

Soil Testing:

The tests listed below were conducted on disturbed samples (soil with Bentonite & soil with Bentonite and different percentages of silica) for the purpose of soil classification and geotechnical identification.

The Grain Size Distribution Tests of soil type **A** were determined in accordance with ASTM D (422-63)**.** As shown in Figure 1 the soil is composed of 33.7% sand, 16.3% silt and 50% clay. According to the U.S.C.S. the soil is classified as CL.

The Specific Gravity was determined in accordance with ASTM D (854-400)

Consistency Limits Tests were conducted according to ASTM procedure designed ASTM D (4319-95**)** to determination the liquid limit and plastic limit.

Compaction Characteristics: The compaction characteristics of the four types of soils were conducted in accordance to ASTM D (698-78) and obtained using standard compaction effect.

Unconfined Compression tests: were carried out to determine the unconfined Compressive strength values in accordance with ASTM D 2166.

Swelling Characteristics:

A series of tests are carried out using consolidometer. Procedures adopted for determining swelling percent and swelling pressure are listed below. To find the influence of various percentages of Bentonite and admixture combination of silica fume-clay on swelling percent and swelling pressure of clay soils. These specimens were compacted at dry density equal to (17.13 kN/m^3) and optimum moisture content is (17.5%).

Preparation of specimens

The preparation of specimens is carried out as described by Head (1984). For all tests mentioned above the same procedure for preparation of specimens and static compaction were used. A predetermined amount of oven-dried soil with (105-110°C) in accordance with (BS 1377; 1975, Test 1(A)) was placed on a flat glass plate. The required amount of additives computed as a percentage of the oven-dried weight of the soil, were weighed out to the nearest 0.01gram and mixed with soil by a palette knife for about 3 minutes in order to achieve a well- blended mixture. The required quantity of de-ionized water is then added. It was calculated on the basis (soil plus additives).After the process of mixing is completed by adding the water to the mixture of soil-additives and mixing thoroughly by hand, and then the mixture was placed in the oedometer ring. The specimen was compacted to its initial dry density using the static compaction method and it was immediately wrapped in two plastic bags. Then it was stored for 24 hours before testing to allow equalization and dissipation of any excess pore pressures set up by the compression process [Head (1984)].

Static compaction method:

To prepare specimens for swelling, the static compaction procedure was carried out using the hand operated loading frame of the unconfined compression machine. The ring mold was placed in a holding device consisting of two steel plates that were placed at top and bottom of the ring. The specially designed compressor piston had a disc of metal. This disc diameter is 1 mm less than the internal ring diameter and 5 mm thickness. The holding device and ring mold assembly were then placed in a compression testing machine, **Plate 1**. The static compaction was applied at a slow rate until the lip on the upper end of the disc was at the same level with the top rings, i.e. the specimen height is less than the height of the consolidation ring, a difference is 5 mm so as to keep the specimen laterally confined during swelling process and the required volume was reached. In the preparation of all specimens for swelling, the load was maintained on the specimen for five minutes after reaching the required height, to prevent the occurrence of rebound after static load removal. Finally, measurement of height of the specimen at several points using a dial gage mounted on a compactor stand was done to check the sample size.

Percent Free Swell Determination

The amount of swelling that may occur following saturation of a specimen while it is under a normal load depends greatly on the initial moisture content, amount and type of additive .The prepared samples were divided into two apportions, the first apportion includes the specimens of clay soil containing different percentages of Bentonite. The second apportion includes the specimens of clay soil containing different percentages of Bentonite with silica fume. After preparing the test sample using the same procedure as described in sections 5.1 and 5.2, the specimens were then placed into the consolidation apparatus following standard method described by Head (1984). A seating pressure of 6.9 kPa was first applied to the sample and the dial gauge was adjusted to zero reading, de-ionized water was then added to the sample, and the expansion of the volume of the specimen (that is, height of the specimen; the area of cross section is constant) is measured until equilibrium is reached. The percent of swell may be expressed as a ratio [Swell (%) = (ΔH/H) x100].

Presentation and Discussion of Test Results:

Effect of Bentonite on the Properties of Natural soil:

Effect of Bentonite on Specific Gravity:

The effect of Bentonite on the specific gravity of the natural soil is presented in Figure 2 and summarized in Table 3**.** Figure 2 shoes that as the Bentonite content increases, the specific gravity of soil decreased. This indicates that the soil-Bentonite mixture is lighter than that of the natural conditions because the Bentonite fills the voids between soil particles. The G.S of the untreated soil was (2.69) decreased to (2.55, 2.47 & 2.39) as Bentonite content increased to (30%, 50% & 70%) respectively.

Effect of Bentonite on Consistency Limits:

The effect of adding Bentonite in different percent on the consistency limits (LL, PL and P.I) of the natural soil are shown in Figure 3 and summarized in Table 3. It can be observed a highly increase in liquid limit, plastic limit and plasticity index with increasing percentage of Bentonite. This behavior is due to Bentoinite is classified as highly plastic clay when mixed with soil, Bentonite can develop cementation bonds, this a good agreement with the results obtained by Rahil, 1992.

Effect of Bentonite on Compaction Parameters:

Figure 4 presents relationship between dry unit weight and moisture content for untreated soil, soil treated with 30% Bentonite, 50% Bentonite and 70% Bentonite respectively and values were summarized in Table 3. From figure and Table it can be noticed that maximum dry unit weight decrease gradually with an increase of Bentonite content. The reduction in dry density is a result of flocculation and agglomeration of fine grained soil particles which occupies large space leading to corresponding drop in maximum dry density. It is also the results of initial coating of soils by bentonite to form large aggregate, which consequently occupy large spaces. On the other hand, the optimum moisture content of soil increases with increase in Bentonite content, because these admixtures were finer than the soil. the more fines means more surface area, so more water is required to provide well lubrication. The increase of water content was also attributed by the pozzolanic reaction of the mixes with soil. Similar results were obtained by Rahil, 1992 and by Manikandan and Moganraj, 2014.

Effect of Bentonite on Swell and Swell pressure:

Figures 5, 6 and 7 present the effect of Bentonite in different percentages on the free swell% and swell pressure of the natural soil. From these figures it can be observed that the free swell and swell pressure highly increase with increasing percentages of Bentonite, which confirms the work of other investigators. Soils with higher clay content and higher plasticity indices generally have a greater volume of water and thus are more prone to large volumetric shrinkage strains. The measured values of the swelling pressure were 24 kPa for untreated soil increased to (84 kPa, 104 kPa and 219 kPa) as increasing Bentonite to (30%,50% and 70%) . the free swelling percentages increase from 1.4% for untreated soil increased to (6.7%,7.9% and 14.5% as increasing Bentonite to (30%,50% and 70%).Table 4 summarized all results. The similar conclusion was obtained by Rahil, 1992.

Relationship between Swell pressure, plasticity index and liquid limit :

The variations of swelling pressure with plasticity index and liquid limit for the four soil types is shown in Figure8 .It can be observed from this figure that the swelling pressure may be correlated with the liquid limit and plasticity index. From figure it can be seen that there is approximately a linear relationship exists between the swelling pressure, plasticity index and liquid limit. The same behavior was noticed by Rahil, 1992.

Effect of Silica Fume on the Properties of Prepared Soil:

Effect of Silica Fume on Specific Gravity of prepared soil:

The effect of silica fume in different percentages on the specific gravity of the prepared soils (B, C and D) is shown in Figure 9 and values were presented in Table 5. From this Figure it can be observed that specific gravity decrease with increasing percentage of silica fume. This indicates that the soil- silica fume mixture is lighter than that of the natural conditions because the silica fume fills the voids between soil particles. Similar results were obtained by Azzawi et al. ,2012 and Abbas,2013 in which lime and silica fume blend was used.

Effect of Silica Fume on Consistency Limits of prepared soil:

From Figure 10, it is observed that as the increase in silica fume content, there is a marked reduction in liquid limit whereas plastic limit is increases. From this, it can be deduced that the flow characteristics of soil samples are gradually decreasing, for soil B (30% Bentonite), liquid limit changed from 89% to lowest value of 78% with increase in silica fume content from 3% to 7% and plastic limit of these mixes are increases from 22% to maximum of 29% , for soil C (50% Bentonite), liquid limit changed from 120% to lowest value of 103% with increase in silica fume content from 3% to 7% and plastic limit of these mixes are increases from 26% to maximum of 31% and for soil D (70% Bentonite), liquid limit changed from 150% to lowest value of 135% with increase in silica fume content from 3% to 7% and plastic limit of these mixes are increases from 30% to maximum of 34%. The increase of plastic limit implies that Bentonite and silica fume treated soil required more water to change it plastic state to semi solid. This change of Atterberge limit is due to the cation exchange reaction and flocculation- aggregation for presence of more amount of Bentonite-silica fume content, which reduces plasticity index of soil. A reduction in plasticity index causes a significant decrease in swell potential and removel of some water that can be absorbed by clay minerals. Similar results were obtained by Abd El- Aziz et al., 2004 and by Abass, 2013 in which lime and silica fume was used and similar concluded by Abbawi, 2013and Al-Kubbaisy (2013). Results were shown in Table 5.

Effect of silica fume on Compaction Parameters of prepared soil:

Figure 11 shows the variation of moisture content and dry unit weight values of stabilized samples with silica fume. There are an increase in the optimum moisture content and a decrease in the maximum dry unit weight due to the addition of silica fume. The reason for increase in the optimum moisture content is due to the change in surface area of composite samples. The silica fume changes the particle size distribution and surface area of the stabilized soil samples. In the same way, the reason for decrease in the maximum dry unit weight is the addition of high amounts of silica fume with low density, which fills the voids of composite samples. The similar conclusion was observed by Pera et al. 1997, kalkan and Akbulut, 2004, Azzawi et al. ,2012 , Abbawi,2013 and Al-Kubbaisy 2013. Results were shown in Table5.

Effect of silica fume on unconfined compressive strength of prepared soil

The effect of silica fume contents on unconfined compressive strength for stabilized clay soil samples are presented in Figure 12. The unconfined compressive strength increases with increasing silica fume from 3% to 7% (increase from 200 kPa to 225kPa for soil B, from 215kPa to 235kPa for soil C and from 226kPa to 245kPa for soil D). The increase in the unconfined compressive strength is due to the internal friction of silica fume particles and chemical reaction between silica fume and soil. An increase in silica fume content in soil has made the stabilized soil sample more brittle than the natural soil sample, which is ductile as compared to all stabilized sample. The similar observation was noticed by Azzawi et al., 2012 and Al-Kubbaisy 2013. Table5 summarized all results.

Effect of silica fume on swelling of prepared soil:

It was observed that improvement in swelling pressure was obtained using silica fume contents. The swelling pressure in composite samples was decreased with increasing silica fume content as shown in Figures 12,15 and 18 for soils B,C and D respectively. The composite samples with 3%,5% and 7% silica fume content decrease the swelling pressure by 5.9%,20.2% and 40.5% respectively for soil B, for soil C, the composite samples with 3%,5% and 7% silica fume content decrease the swelling pressure by 2.9%,8.7% and 31.8% respectively and for soil D The composite samples with 3%,5% and 7% silica fume content decrease the swelling pressure by 14.2%,29.7% and 41% respectively. The amount of swelling of natural soil and composite soil samples containing silica fume is shown in Figures13, 16 &19.As can be seen in these figures, silica fume decrease the vertical swelling of soil-silica fume mixtures. The vertical swelling percentages of soil-silica fume mixtures samples decreased from 6.7% to 4% for soil B containing 0% and 7% silica fume contents, for soil C, the vertical swelling percentages of soil-silica fume mixtures samples decreased from 7.9% to 5.9% for soil containing 0% and 7% silica fume contents and for soil D, The vertical swelling percentages of soil-silica fume mixtures samples decreased from 14.5% to 12.3% for soil containing 0% and 7% silica fume contents. This behavior is due to the addition of low plastic material and the interaction between clay minerals and silica fume particles. The active silica reacts with calcium and hydroxide and forms calcium silicate hydrate gels. This chemical modification reduces clay mineral contents of composite samples. The silica fume contents decreased the cation exchange capacity (CEC) and specific surface area (SSA) values of composite samples which causes low water holding capacity and swelling. The same observation was noticed by many researchers Attom and Al-Sharif,1986, Kalkan and Akbulut,2004 , Abd El- Aziz et al., 2004, Kalkan,2009, Al-Azzawi et al.,2012 and Al-Kubbaisy (2013). Table 6 summarized values of test results.

Conclusion:

Based on the results obtained, the following conclusions were drawn:

A- Effect of Bentonite on Natural soil:

1- The specific gravity decrease with increasing of Bentonite percentage by 11%.
2- Bentonite increased liquid limit, plastic limit and plasticity index by 2.4%, 0.58% and 3.8% respectively.
3- Bentonite increased the optimum moisture content and decreased the maximum dry unit weights of the samples by about 17.8% and 49% respectively for all samples in the same compaction effort.
4- The free swelling percentages and swell pressure highly increases with increasing of Bentonite percentage. The swelling pressure increased from 24 kPa to 219 kPa and free swelling percentages increased from 1.4% to 14.5% when Bentonite contents increased from 0% to 70%.
5- There is a linear relationship between swelling pressure, plasticity index and liquid limits.

B- Effect of Silica Fumes on Prepared Soil:

1- The specific gravity decrease with increasing silica fume percentage from 0% to 7% to 2.49, 2.39 and 2.28 for soils B, C and D respectively.
2-Silica fume decreased liquid limits, plastic index by 12.4% and 27% respectively when silica fume increased from 0% to 7% for soil B, by about 14.2% and 23% for soil C and by 10% and 15.8 for soil D. while plastic limits increase by 32 %, 19.2% and 12% for soils B, C and D respectively.
3-Silica fume increased the optimum moisture content and decreased the maximum dry unit weights of the samples by about 50% and 13% respectively for all samples in the same compaction effort.
4- The compressive strength of clay samples increased to 12.5%, 9.3% and 8.4% with increasing silica fume contents from 3% to 7% for soils B, C and D respectively.
5- A significant improvement on free swell and swell pressure silica fume was obtained using silica fume. The swelling pressure and free swell decreased by about 40% and 23% respectively with increasing silica fume content.
6-It is concluded that silica fume is a valuable material to modify the properties of expansive soil to make them suitable for construction.

Table(1): Physical chemical properties of natural soil used and Bentonite

No.	Index property	Natural soil	Bentonite soil
1	Initial water content % (wc)	2.0	----
2	Liquid limit % (LL)	44	512
3	Plastic limit % (PL)	19	38
4	Plasticity index% (PI)	25	474
5	Specific gravity (Gs)	2.69	2.26
6	Gravel (larger than 2mm)%	0	-----
7	Sand (0.06 to 2mm)%	33.7	----
8	Silt (0.005 to 0.06)%	16.3	----
9	Clay (less than 0.005mm)%	50	----
10	Gypsum content %	13.18	----
11	SO_3 content %	6.13	----
12	Soil symbols (U.S.C.S)	CL	----

Table (2): Physical properties of Silica Fume used

Test	Oxide Composition	Oxide Content %	Test	Oxide Composition	Oxide Content %
1	SiO_2	95.95	6	CaO	1.21
2	Al_2O_3	0.02	7	MgO	0.01
3	Fe_2O_3	0.01	8	SO_3	0.22
4	Na_2O	0.00	9	L.O.I.	2.5
5	K_2O	0.07			

Table(3). Physical properties of four soil types after adding Bentonite

Type of soil	L.L	P.L	P.I	G.S	Dry unit weight (γ_{dry}) kN/m^3	Optimum moisture content %
A	44	19	25	2.69	17.13	17.5
B	89	22	67	2.55	15.11	22.7
C	120	26	94	2.47	14.73	24.2
D	150	30	120	2.39	14.08	26

Table (4): Values of swelling pressure & free swelling for treated soils

Type of soil	Swell pressure (kPa)	Free swelling
A	24	1.4
B	84	6.7
C	104	7.9
D	219	14.5

Table (5): Values of Atterbergs limits and specific gravity for treated soils

Soil type + % silica fume	L.L	P.L	P.I	GS	Dry unit weight (γ_{dry}) kN/m^3	Optimum moisture content %	Unconfined compressive strength, (qu) kPa
Soil B	89	22	67	2.55	15.11	22.7	196
Soil B+3% silica	84	27	57	2.52	14.8	25	200
Soil B +5%silica	80	28	52	2.5	14.4	28	212
Soil B +7%silica	78	29	49	2.49	13.6	35	225
Soil C	120	26	94	2.47	14.73	24.2	197
Soil C+3% silica	113	27	86	2.44	14.5	26	215
Soil C +5%silica	106	29	77	2.42	14.08	32	228
soil C +7%silica	103	31	72	2.39	13.42	38	235
Soil D	150	30	120	2.38	14.08	26	198
Soil D+3% silica	144	31	113	2.34	13.6	29	226
Soil D +5%silica	139	33	106	2.31	12.7	34	235
soil D +7%silica	135	34	101	2.28	11.2	39	245

Table (6): Values of swell pressure and free swelling values for treated soils

Soil type + % silica	Swell pressure (KPa)	Free swelling
Soil B	84	6.7
Soil B +3% silica	79	6.3
Soil B +5% silica	67	5.1
Soil B +7% silica	50	4
Soil C	104	7.9
Soil C +3% silica	101	7.6
Soil C +5% silica	95	6.7
Soil C +7% silica	71	5.9
Soil D	219	14.5
Soil D +3% silica	188	13.6
Soil D +5% silica	154	13
Soil D +7% silica	129	12.3

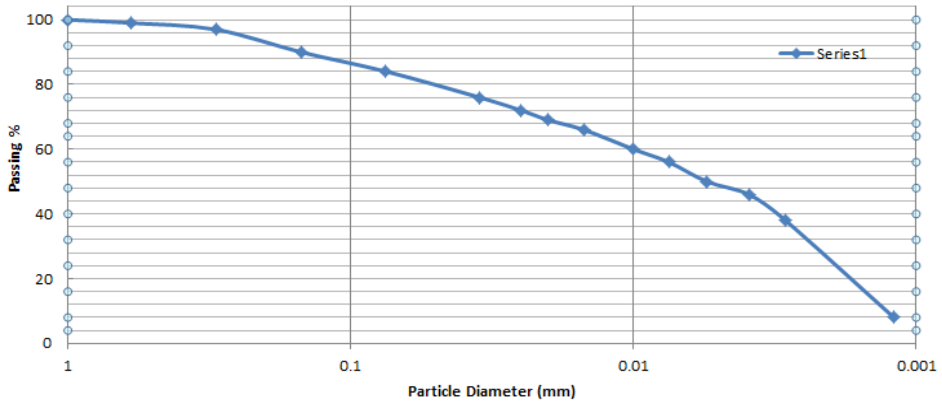


Figure (1). Grain Size of Soil Used

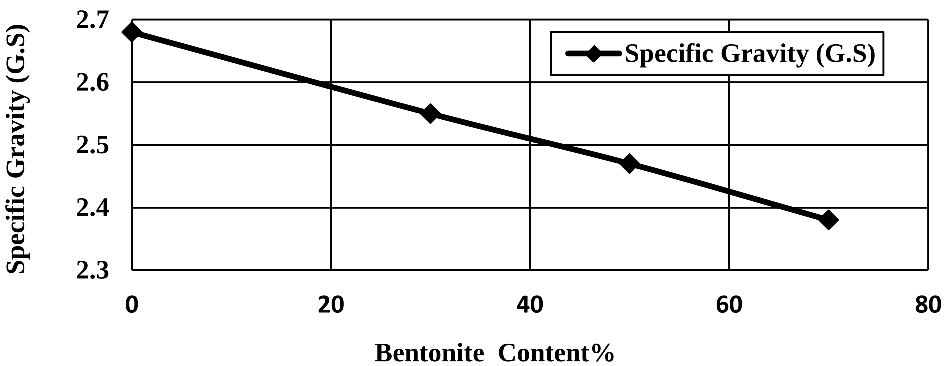
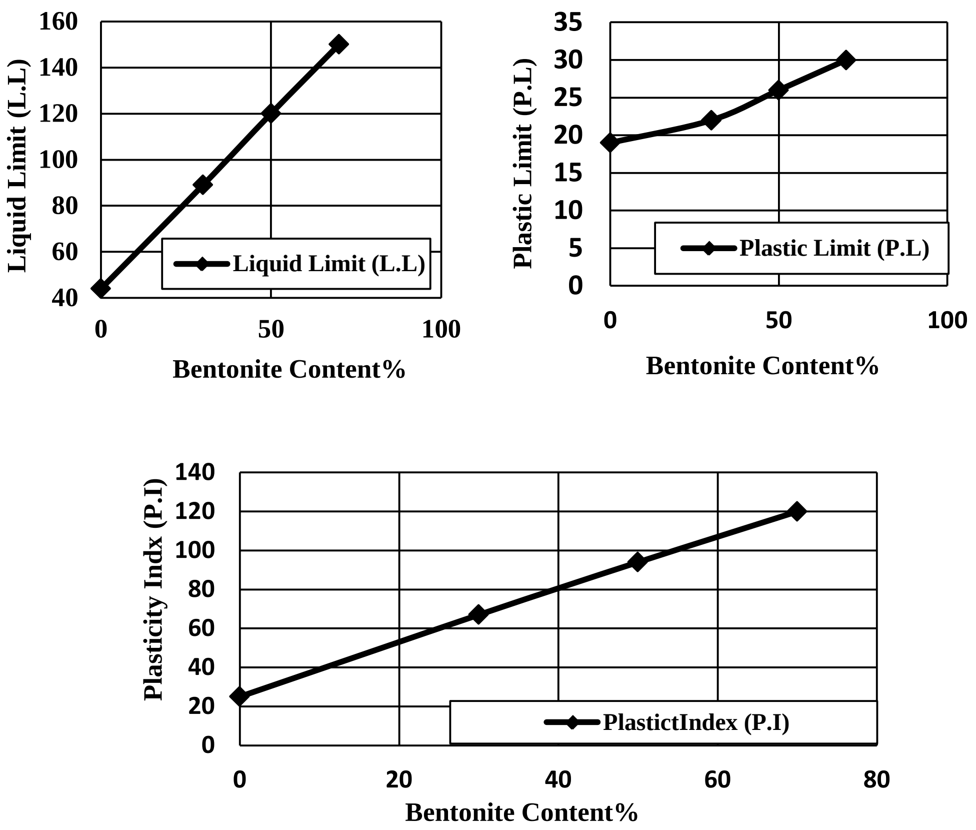


Figure (2). Effect of Bentonite content on specific gravity for soil used



Figure(3). Effect of Bentonite content on L.L,P.L &P.I

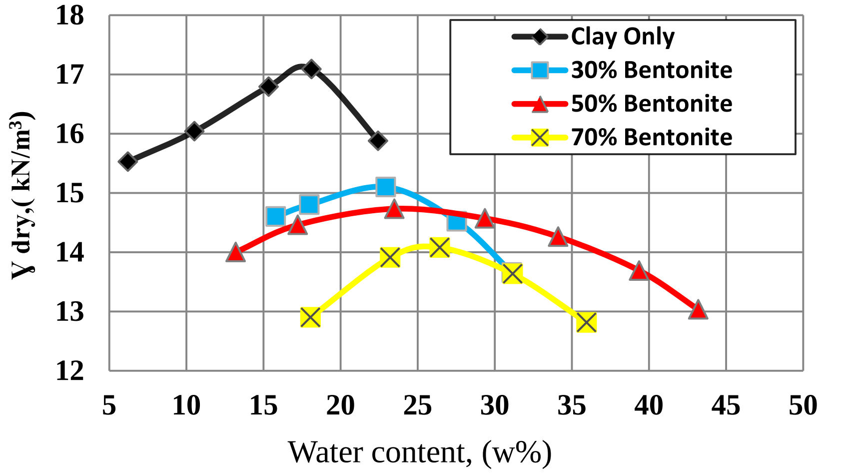


Figure (4). Relationship between water content versus dry density

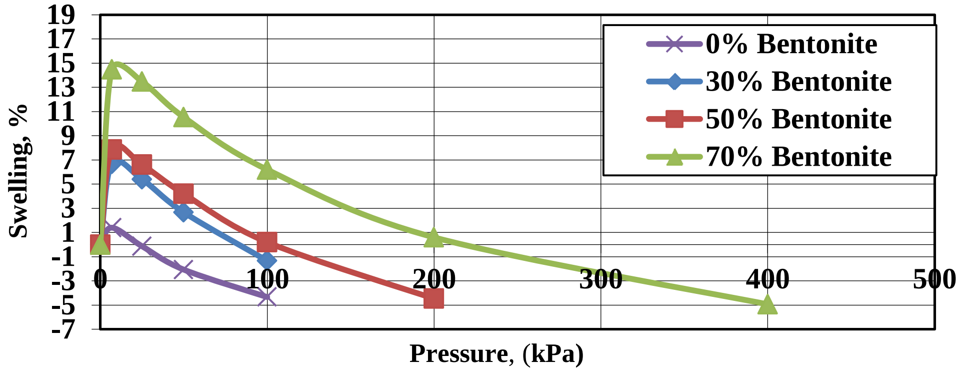


Figure (5). Swelling percent versus pressure for all types of soil used

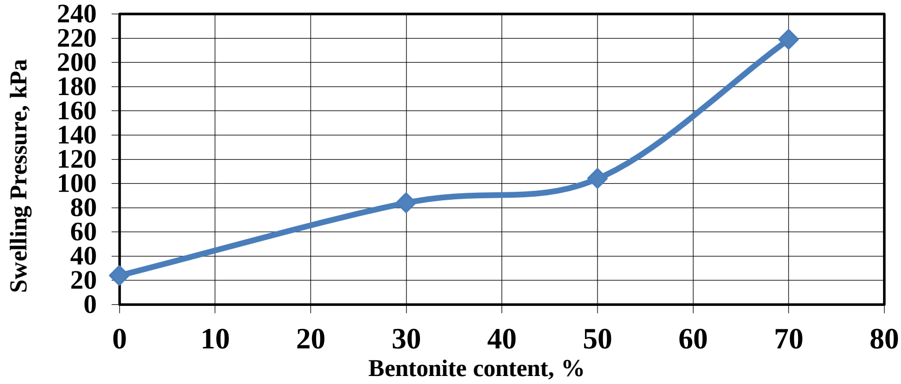


Figure (6). Swelling pressure versus Bentonite content for all types of soil

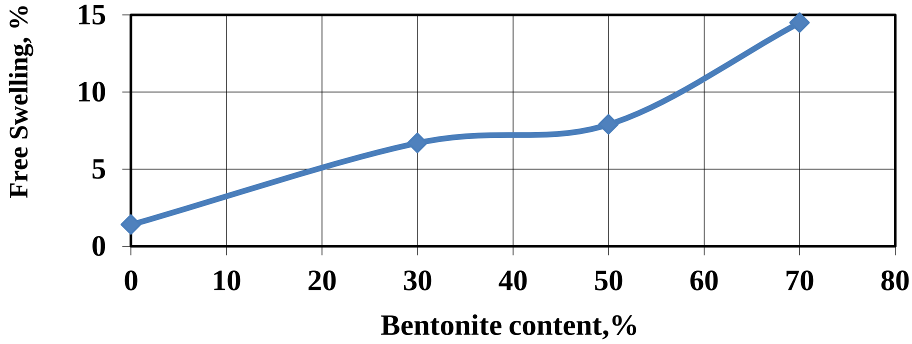


Figure (7). Free swelling versus Bentonite content for all types of soil used

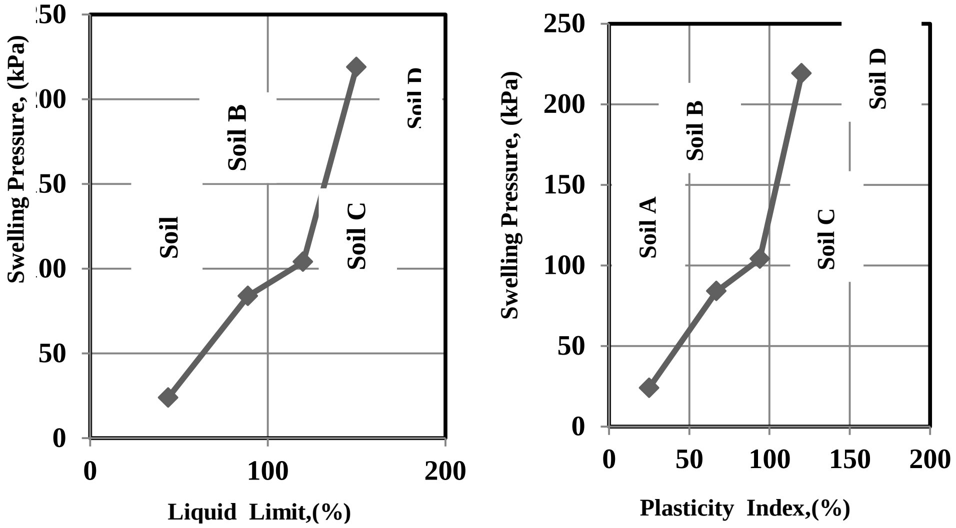


Figure (8). Effect of Liquid limit & Plasticity Index on Swelling Pressure

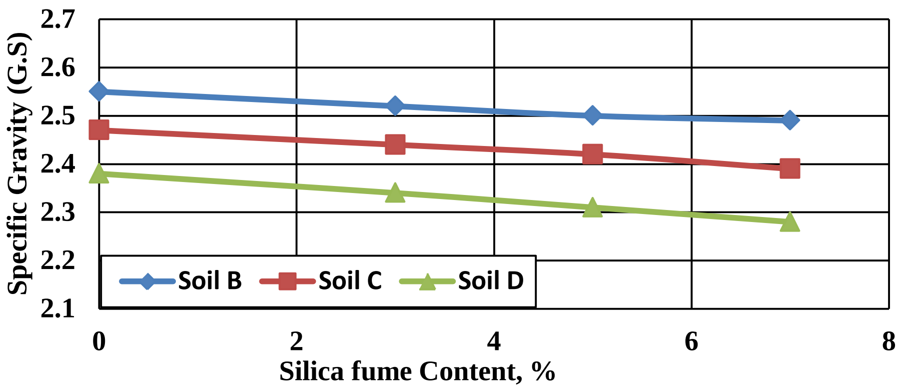
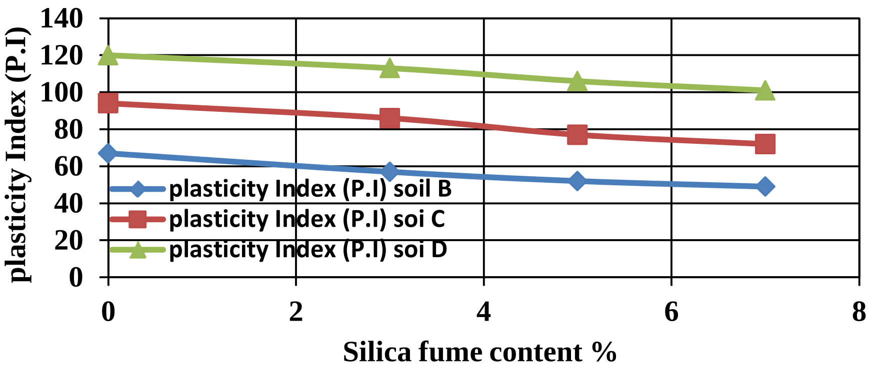
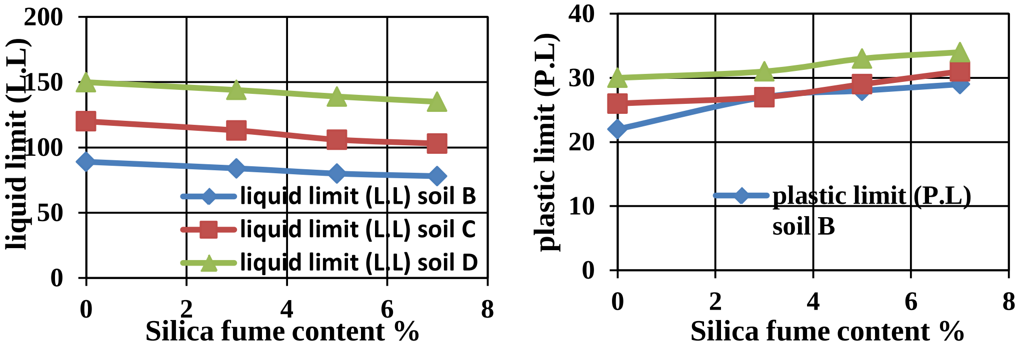


Figure (9). Effect of silica fume content on specific gravity



Figure(10). Effect of silica fume content on Liquid limit, plastic limit & plasticity



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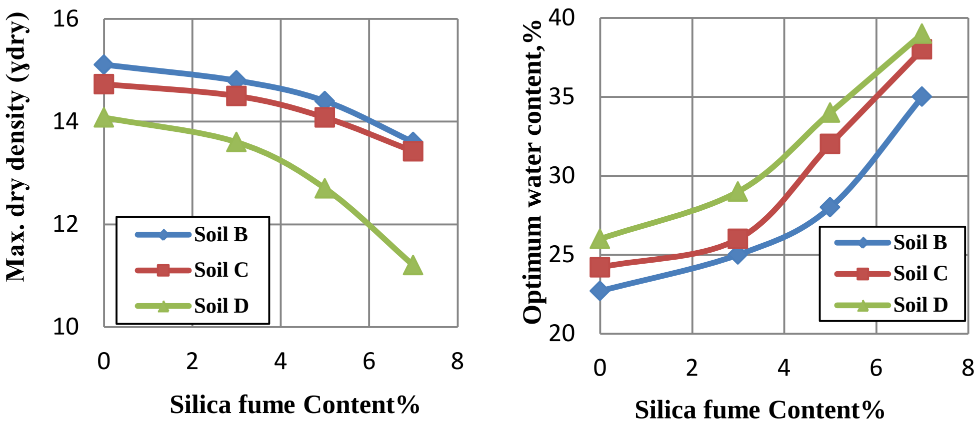


Figure (11). Effect of silica fume content on Compaction parameters

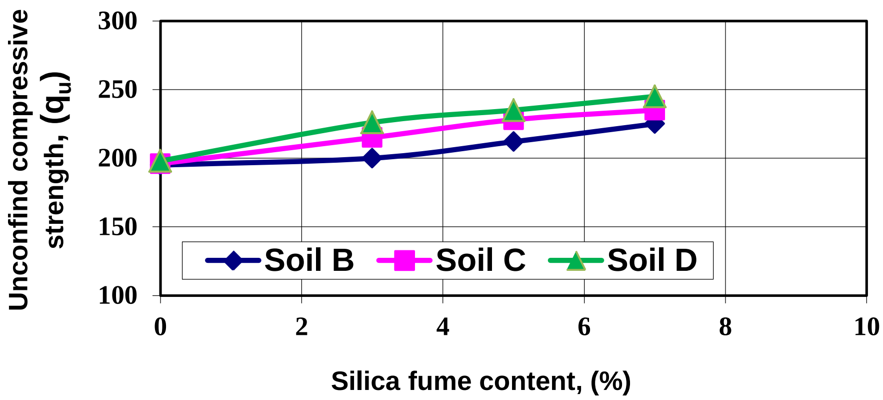
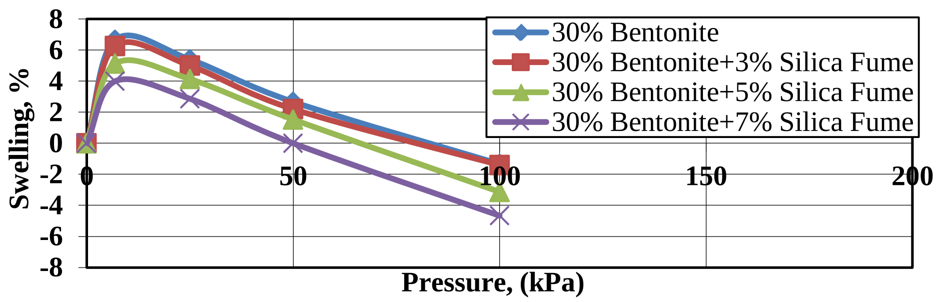
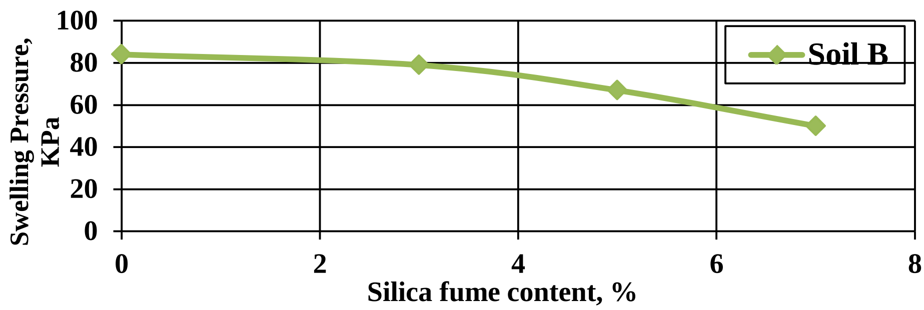


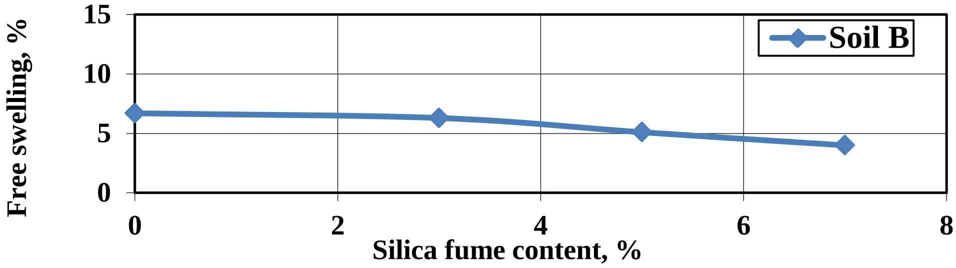
Figure (12). Effect of silica fume content on Compressive strength



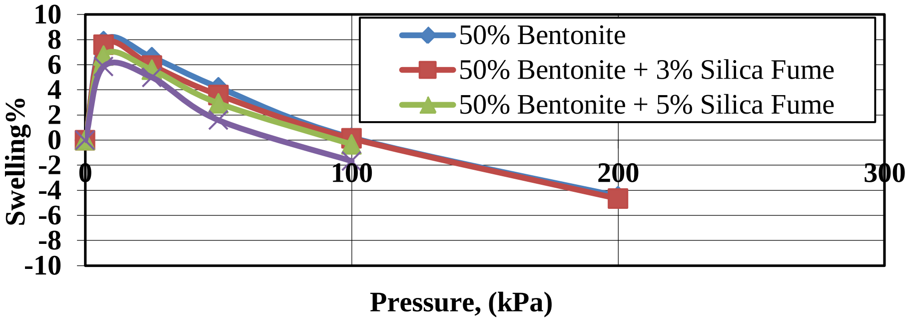
Figure(12). Swelling percent versus pressure for soil B



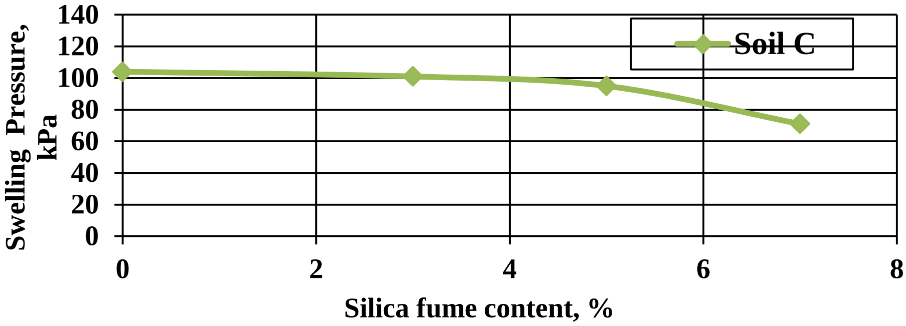
Figure(13). Swelling pressure versus silica fume content for soil B



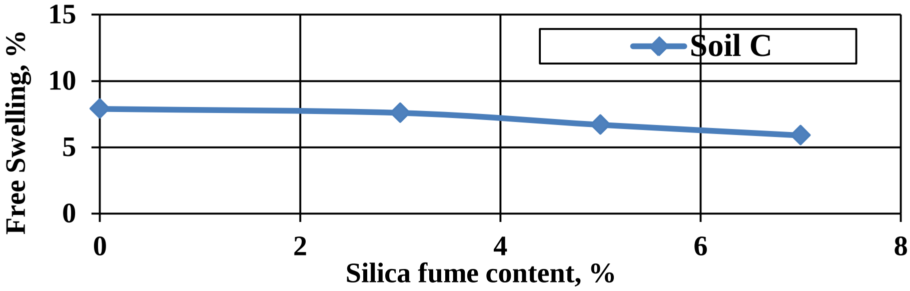
Figure(14). Free swelling versus silica fume content for soil B



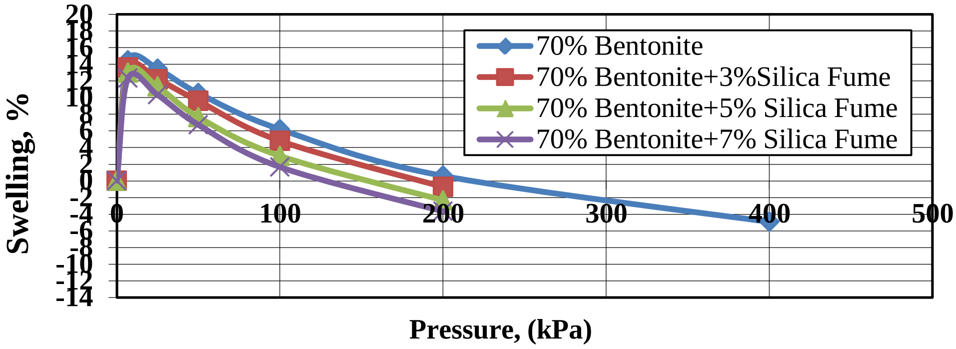
Figure(15). Swelling percent versus pressure for soil C



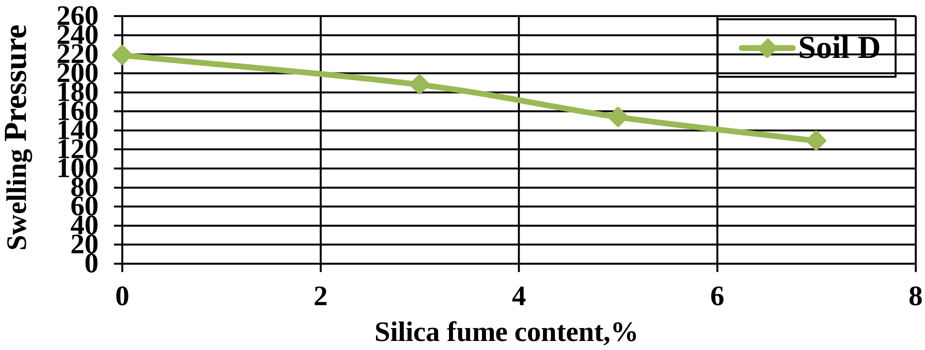
Figure(16). Swelling pressure versus silica fume content for soil C



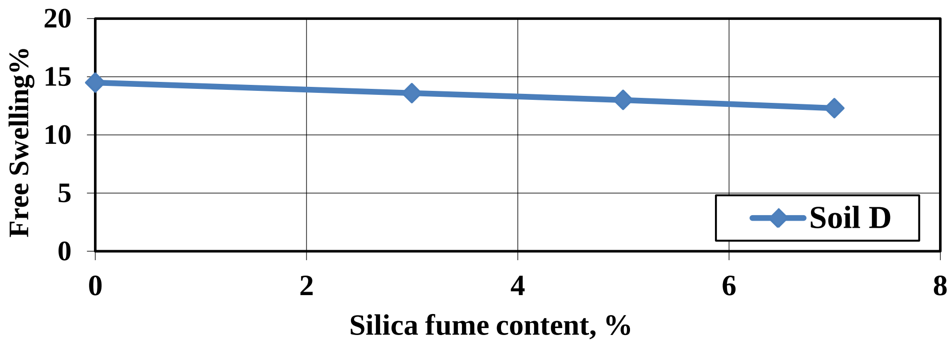
Figure(17). Free swelling versus silica fume content for soil C



Figure(18). Swelling percent versus pressure for soil D



Figure(19). Swelling pressure versus silica fume content for soil D



Figure(20). Free swelling versus silica fume content for soil D

Plate(1). Unconfined compression apparatus used for static compaction

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