Journal of Engineering and Computer Sciences, Qassim University
Vol. 13, No. 1, pp. 1-14 (Jan. 2020 /Jumada Al-Awwal 1441H)

Improving Geotechnical Properties of Expansive Soil Using Palm Fronds Ash

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(Received 13/04/2020, accepted for publication 16/05/2020)

Abstract. Expansive soils exist in large areas around the world, especially in the arid and semi-arid regions. In different areas around Kingdom of Saudi Arabia, this problematic soil exists in form of layers especially in the newly developed regions of the country. Construction activities on such soil requires considering precautionary measures in order to avoid and/or minimize the risks associated with this problematic soil. Different research studies proposed measures to improve construction conditions where expansive soil exists. These measures utilize one of two techniques, either the full replacement of expansive soil layers or mitigating the expansive soil with a wide range of additives. In the current study, a new mitigating agent is introduced to be mixed with expansive soil aiming at improving its geotechnical properties; which shall be reflected in its engineering behavior under construction loads. The mitigating agent is the form of Palm Fronds Ash [PFA].

Palm Fronds [PF] is an agricultural waste that is being hugely produced every year in Saudi Arabia as a byproduct of cultivating millions of palm trees. The typical process of disposing such a waste is through open air burning, which causes serious environmental hazards to Saudi communities. In the current study, the PFA is utilized as a stabilizing agent through mixing it with the expansive soil. Remolded samples of expansive soil samples mixed with 4%, 8% and 12% PFA are prepared and tested in order to assess the improvement, if any, in its geotechnical properties. The results of the experimental program conducted on this soil mixture showed improvement of the geotechnical properties of the expansive soil; Atterberg limits, maximum dry density

(MDD), unconfined compressive strength (UCS), and the swelling pressure (SP). This study showed that at a 10% content, by weight, of PFA in the expansive soil samples, the soil Liquid Limit is reduced by almost 40%. The MDD increased by almost 5% and the UCS increased by an average value of almost 26% while the swelling pressure decreased by almost 88%. Moreover, a preliminary empirical equation is presented to estimate the percentage of reduction in swelling pressure as function of the percentage of PFA mixed with the expansive soil.

Keywords: Expansive soil, Palm Fronds Ash [PFA], Unconfined Compressive Strength, Swelling Pressure.

1. Introduction

Expansive soil is among a group of problematic soils which may be found in many project sites where civil engineers face difficulties since it widely exists worldwide. Expansive soil has a high clay content and is rich in montomorillonite. It has very high ability in absorbing water and usually its liquid limit is more than that of ordinary clays (above 90%). Expansive clay swell upon absorption of water and shrink when dried [1], and that is why structures founded in expansive soil are more likely to be exposed to severe damage.

In order to minimize the problems expected by expansive soil, many techniques have been developed by researchers in order to stabilize the expansive soil. Soil stabilization can be accomplished by several methods, all these methods fall into two broad categories namely mechanical and chemical stabilization. Mechanical stabilization is a physical process that involves altering the physical nature of native soil particles by either induced vibrations or compaction or by incorporating other physical properties such as barriers and nailing. Chemical Stabilization depends on initiating chemical reactions between stabilizers (usually cementitious material) and soil minerals (pozzolanic materials). This usually leads to achieving the desired effect of improving the soil properties that are of interest to engineers; volume stability, strength, compressibility, permeability and durability [2, 3, and 4]. Techniques such as belled piers [5], granular pile-anchors [6], chemical stabilization with lime and fly ash [5, 7, and 8], and increasing coarse fraction in expansive soil [9] have been proposed for mitigating heave problems associated with expansive soil.

Researchers have also been looking to ways for improving the geotechnical properties of laterite clay. Laterite clay is known to contain a substantial amount of clay minerals and therefore its strength and stability under loads are questionable especially in the presences of moisture; similar to expansive soil behavior [10]. Improving the geotechnical properties of laterite clay such as unconfined compressive strength and maximum dry density have been investigated by researchers.

Nnochiri and Aderinlewo [11] investigated improving the geotechnical properties of lateritic soil stabilized with the ashes of oil palm fronds. They concluded that the Oil Palm Frond Ash (OPFA) can be classified as a pozzolanic material. The compaction reults, California Bearing Ratio (CBR) and unconfined compressive strength tests indicated that the highest values were obtained at 4% OPFA content. They also concluded that the OPFA could be used as a stabilizing agent if added in the right quantity. Tingle and Santoni [12] conducted a laboratory experiment to evaluate the stabilization of high-plasticity clay soils with nontraditional chemical or liquid stabilizers to investigate its moisture–density compaction behavior. They concluded that the lime was relatively ineffective in stabilizing the high-plasticity clay based on the strength improvement criteria. The dry unconfined compressive strength (UCS) test results were significantly greater than the wet UCS test results for all specimens tested.

Sabat [13] studied the effect of using polypropylene fibers on maximum dry density (MDD), optimum moisture content (OMC), UCS, and swelling pressure of an expansive soil stabilized with rice husk ash and lime. He concluded that the addition of rice husk ash and lime decreases the MDD and increases the OMC of the expansive soil and increases the UCS of the expansive soil. With the addition of polypropylene fiber to rice husk ash-lime stabilized expansive soil, the UCS increases up to 1.5 % addition of polypropylene fiber, and decreases with further increase in polypropylene fiber content. Kennedy et al. [14] investigated the engineering properties of expansive lateritic soil with the inclusion of cement-lime and bush sugarcane fiber ash (BSFA) to improve its properties for use in subgrade and construction works. They concluded that BSFA proved to have a good pozzolana effect on expansive soil stabilization. The study results showed improvement in the compaction and strength tests results. Bush sugarcane fiber ash (BSFA) has a close nature to the Palm Frond Ash (PFA) waste material proposed for use in the current study. Saudi Arabia is one of the world largest producers of Date Palm trees. Recently, researchers in Saudi Arabia started to look at alternatives of the burning technique in disposing such agricultural waste [15]. Al-Kutti et al. [15] investigated the potential use of PFA material in an experimental study of the mechanical, durability and microstructural performance of PFA material in mortar and concrete samples. The results of the study indicated that the 10% dosage of PFA in mortar and concrete samples was optimum and improved the overall quality of concrete. Abbey et al. [16] investigated the effect of high plasticity on swell potential, swelling pressure and micro-structural characteristics of kaolinite-bentonite mixed clays. The study showed that doses of 5% and 8% cement reduced the maximum swell strain for investigated soils, irrespective of plasticity index, after 7 and 28 days of curing due to the cementation effect and reduction in void spaces.

2. Materials and Methods

2.1 Tested soil

Expansive soil samples collected from two different sites near AlQassim region, Saudi Arabia, were used for the laboratory-testing program. The physical and engineering properties of the two soil sets were measured, according to the American Society for Testing and Materials (ASTM) standards, and the results are shown in Table (1). The expansive soil samples are classified as CH (clay with high plasticity) and designated as Soil (1) and Soil (2) as shown in Table (1). The results of the lab tests in Table (1) show that the two soils have the potential to be highly expansive. Figure (1) shows the gradation of the two soils used in the in the mixtures.

Table (1): Properties of the two sets of soil used in the study

Properties	Soil (1)	Soil (2)
Specific Gravity, G_s	2.68	2.71
% of Gravel	0	0
% of Sand	16	13
% of Silt	22.6	21.5
% of Clay	61.4	65.5
Liquid Limit (%)	94.4	109.8
Plastic Limit (%)	22.5	32.4
Plasticity Index	71.9	77.4
Activity	1.17	1.18
Unified Soil Classification System (USCS)	CH	CH
Maximum Dry Density (MDD)	1720 (kg/m^3)	1830 (kg/m^3)
Unconfined Compression Strength (UCS)	195 (kPa)	207 (kPa)
Swelling Pressure (SP)	440 (kPa)	580 (kPa)

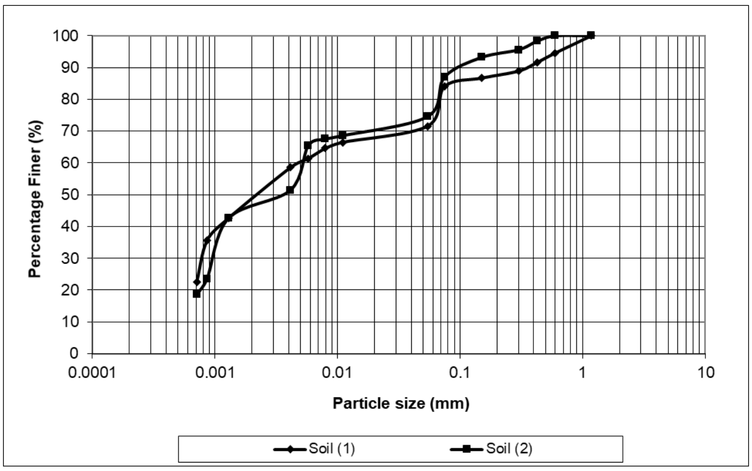


Fig. (1). Particle size gradation of the two tested expansive soils used in the study

Moreover, other geotechnical properties of the expansive soil mixtures used in the study; maximum dry density (MDD), unconfined compression strength (UCS), and swelling pressure (SP) are determined. These geotechnical properties are used as the comparison base for the soil before and after treatment in order to investigate the improvement in its engineering behavior.

2.2 PFA Material and its Chemical Properties

Figure (2) shows photos of Palm Fronds (PF) in its natural form (raw) shredded and powder after air-drying it. The fronds are then air-dried to before burning, and then the fronds were burnt into ashes and stored until used. Furthermore, the ashes were kept covered before and after use to preserve its properties.

Fig. (2). Shredded PF and its air-dried powder

The chemical composition of the PFA were determined through chemical analysis, and the results of its mineralogical composition are shown in Table (2).

Table (2): Chemical composition of the PFA material

Components (oxides)	PFA (%)
CaO	27.66
ZnO	1.09
MgO	2.93
P_2O_5	3.78
SiO_3	4.69
Al_2O_3	15.80
Fe_2O_3	6.41
SiO_2	31.70
K_2O	2.96
Na_2O	0.73

Table (2) shows that the PFA can be regarded as a pozzolana since it contains an appreciable amount of SiO_2 (31.70%). A pozzolana is a siliceous material which by itself does not possess cementitious properties but will in finely divided form and in the presence of water react with calcium hydroxide, $Ca(OH)_2$ to form cementitious compounds [17]. The PFA qualifies as a pozzolana since the percentage sum of its SiO_2, Al_2O_3 and Fe_2O_3 components (53.91%) exceeds the minimum requirement of 50% [18].

2.3 Testing Program on PFA/Expansive Soil Mixtures

Four different mixtures were prepared from each soil type shown in Table (3). The mixtures were prepared of each soil set mixed with PFA in percentages of (0%, 5, 10, and 15%) by weight. The 0% PFA is the control sample. The samples are marked as: Sample (SM-1), Sample (SM-2), Sample (SM-3), and Sample (SM-4), where SM indicates the tested soil type (1 and 2) and the numbers 1-4 refer to the percentage of the Palm Frond Ash (PFA) added (0, 4%, 8%, and 12%). Table (3) shows the samples mixtures used in the testing program.

Table (3): The soil mixtures used in the testing program

Sample (SM-1)	Sample (SM-2)	Sample (SM-3)	Sample (SM-4)
100% Soil (1) + 0.0% PFA	96% Soil (1) + 4% PFA	92% Soil (1) + 8% PFA	88% Soil (1) + 12% PFA
100% Soil (2) + 0.0% PFA	96% Soil (2) + 4% PFA	92% Soil (2) + 8% PFA	88% Soil (2) + 12% PFA

The following tests were conducted, in accordance with BS, on the prepared soil mixtures; Atterberg Limits, Compaction Tests, Unconfined Compression Tests, and Odometer Tests

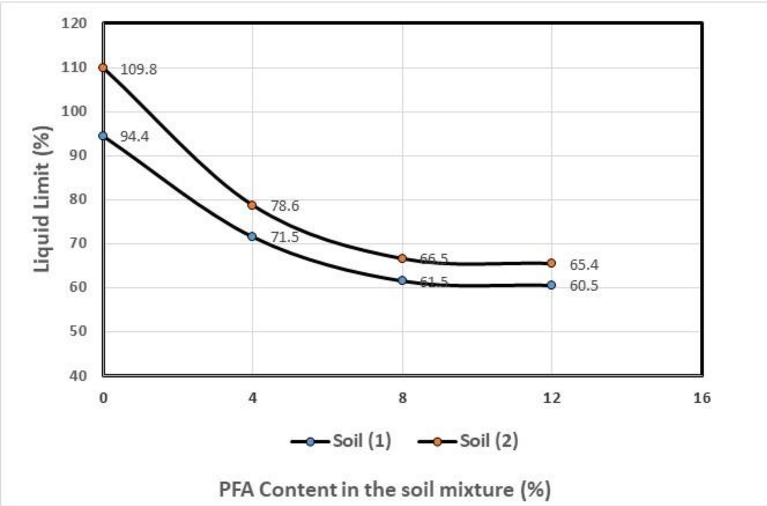
3. Results and Discussion

3.1 Atterberg Limits

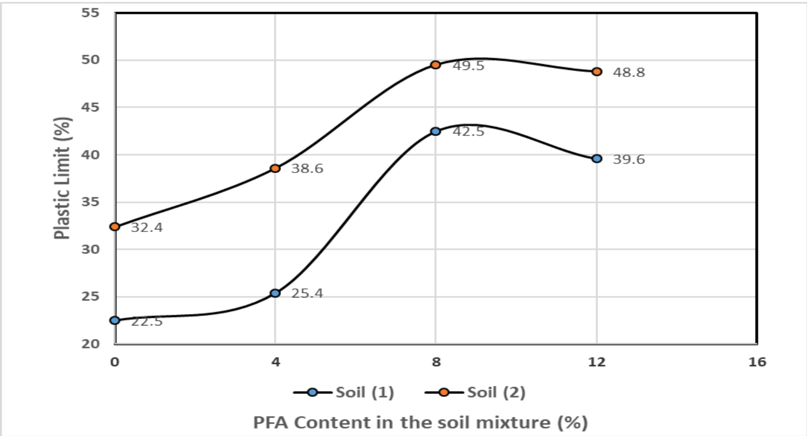
Figure (3- a & b), shows the effect of mixing the PFA material with its pozzolanic effect on the liquid and plastic limits of the expansive soil mixtures. Figure (3-a) shows that as the percentage of PFA in the soil mixture increases, the liquid limit decreases significantly. The rate of reduction in liquid limit is fast at the beginning up to almost 10 % of PFA, then the rate of reduction becomes slower. Figure (3-b) shows that as the percentage of PFA in the soil mixture increases, the plastic limit increases significantly. The rate of increase in plastic limit is comparatively faster at the beginning up to almost 10 % of PFA, then the plastic limit starts decreasing.

3.2 Compaction Test Results

Figure (4-a and b), shows the results of the compaction tests for the two sets of expansive soil mixed with the PFA material.



a)



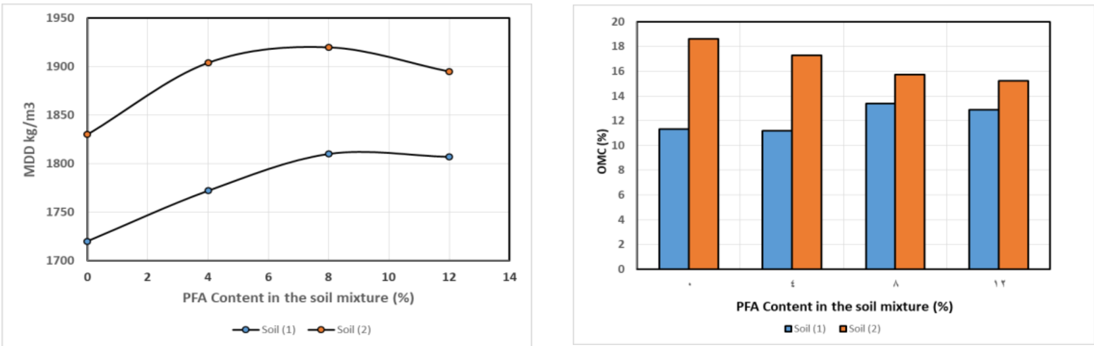
b)

Fig. (3). Effect of % of PFA content on the liquid and plastic limits results

Figure (4-a) shows that MDD improved from the initial values of 1720 and 1830 kg/m^3 for the natural soils 1 and 2 respectively to maximum values of 1810 and 1920 kg/m^3 respectively before it decreases again around the PFA content of approximately 10%. The change in OMC as shown in Figure (4-b) doesn't actually show a specific trend that could be explained scientifically which means that this point needs more research.

3.3 Unconfined Compressive Strength (UCS)

Figure (5) shows the values of the UCS of the natural expansive soil samples compared to the same soil samples mixed with the PFA material. For Soil (1), the UCS increases from 195 kN/m^2 for the natural soil to a value of 245 kN/m^2 at 12% PFA content, almost 23% increase. For Soil (2), the UCS increase from 207 kN/m^2 for natural soil to a value of 264 kN/m^2 at 12% PFA, almost 28% increase.



(a) (b)

Fig. (4). Effect of % of PFA content on compaction test results

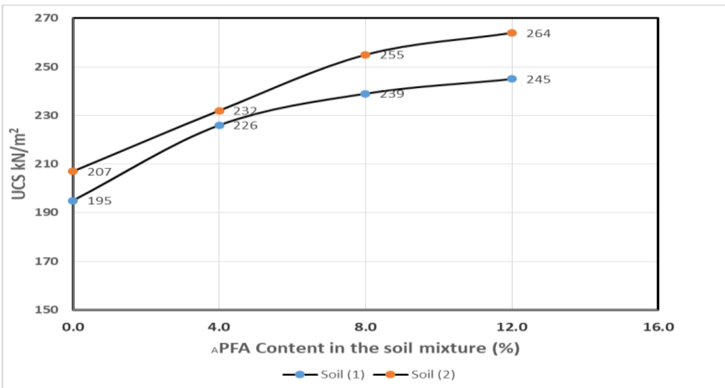
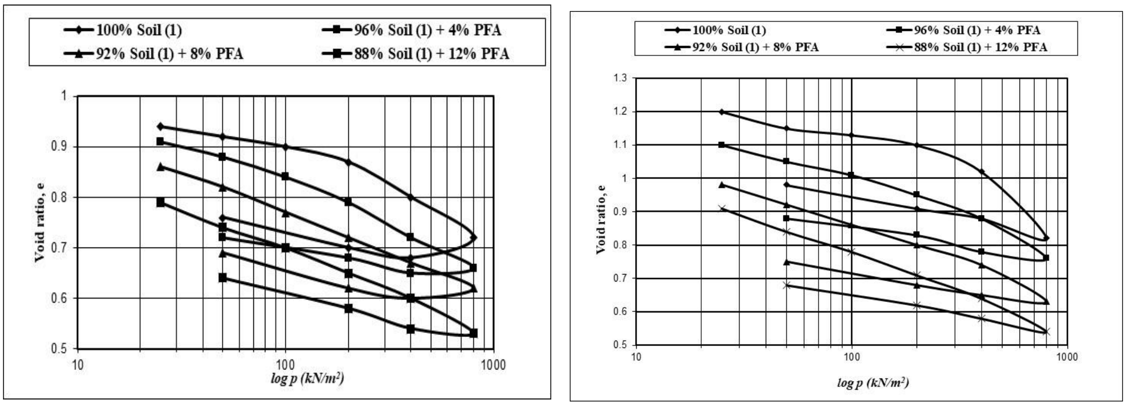


Fig. (5). Effect of % of PFA content on UCS test results

3.4 Oedometer Test Results

The results of the free swell odometer tests on the two tested expansive soil sets as well as the prepared mixtures are plotted in the form of *e vs log p* are shown for Soil (1) and Soil (2) in Figure (6- a & b), respectively. The plots show that adding the PFA material to the two expansive soils tested has significantly influenced the resulted *e vs log p* relationships; that is at the same applied pressure (*p*) the voids ratio (*e*) is significantly lower. The largest reduction was achieved at the largest percentage of added PFA (12%). The influence on the values of swelling pressure (SP) are discussed in next sections to show that for the two soils, the swelling pressure decreased significantly with increasing the content percentage of PFA mixed with the expansive soil samples.



(a) (b)

Fig. (6). Results of the odometer test for soils (1) and (2)

The swelling pressure for the tested expansive soils as well as the soil mixtures were determined. The results of swelling pressure are shown in Figure (7). The percentage of change in the swelling pressure is evaluated by comparing its value before and after soil treatment. As shown in Figure (7), an increase in the percentage of PFA mixed with the expansive soil samples from 0% to 12% significantly reduced the swelling pressure (SPR) of the two sets of tested soils. For Soil (1), SPR decreased gradually with the increase in PFA content from 440 to 50 kPa. For Soil (2), SPR decreased from 580 to 65 kPa. The rate of reduction starts to be flat around a PFA content of 10%. The reduction in SPR could be attributed to the presence of the PFA material and its pozzolana action with the swelling soil.

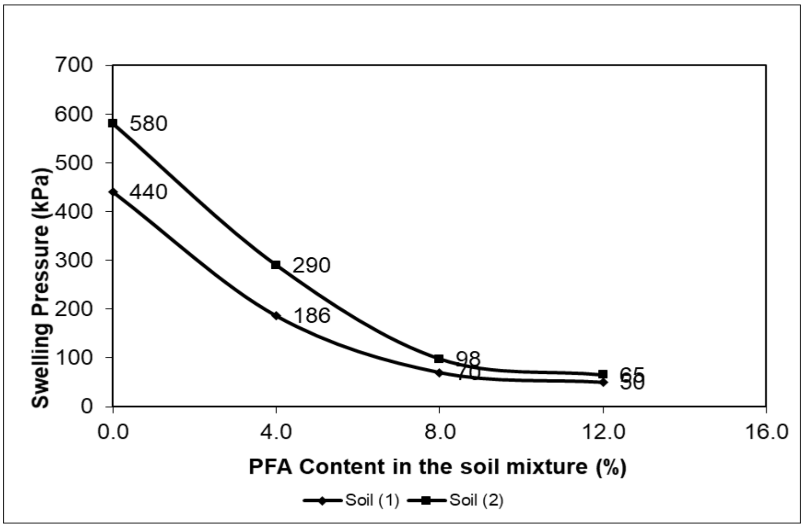


Fig. (7). Effect of % of PFA content on the SPR values

Figure (8) shows the variation of the percentage of reduction in swelling pressure (R-SPR) with the percentage, by weight, of the PFA mixed with the expansive soil. It also shows a preliminary trend line for the relationship which relates between the reduction in SPR and the percentage of PFA available in the expansive soil. The empirical relationship may be expressed as follows:

$$(R\text{-}SPR) = 7.306 * PFA\,\% + 13.773 \quad (1)$$

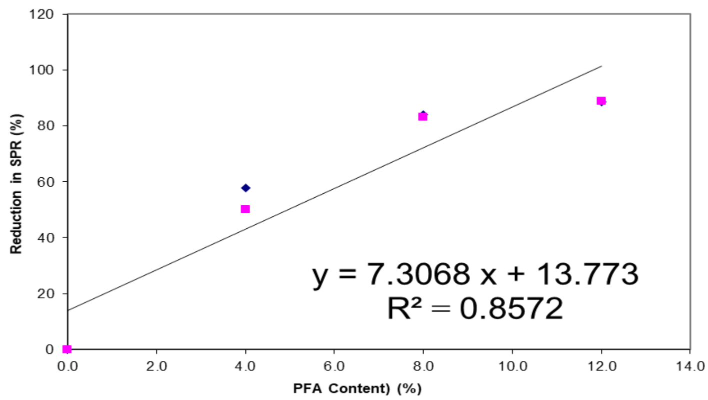


Fig. (8). Variation of the percentage of reduction in swelling pressure with the %, of PFA, by weight, added to the expansive soil.

The empirical relationship (1) could be conveniently used to predict an estimated value for the expected reduction in swilling pressure, R-SPR, of the expansive soil as a result of mixing it with a percentage of PFA. Naturally, this relationship is just preliminary and need more refinement with more experimental data in order to be widely accepted.

4. Conclusions

An experimental study was conducted to investigate the effect of Palm Frond Ash (PFA) in the improvement of expansive soil. The lab testing program used two sets of expansive soil from two different sites near AlQassim region KSA. The expansive soils were mixed with PFA material with different percentages (4%, 8%, and 12%). For all tests the geotechnical properties; liquid limit, plastic limit, maximum dry density (MDD), unconfined compressive strength (UCS), and consolidation test results improved by different percentages. The results showed that at a 10% content, by weight, of PFA in the expansive soil samples, the soil Liquid Limit is reduced by almost 40%, the MDD increased by almost 5% and the UCS increased by an average value of almost 26% while the swelling pressure decreased by almost 88%. Moreover, a preliminary empirical equation is presented to estimate the percentage of reduction in swelling pressure as function of the percentage of PFA mixed with the expansive soil. More lab testing data are required in order to refine this empirical equation. The technique of Neural Networks could present a significant tool for researchers to develop a similar but rather more accurate relationships, which might also include the influence of other physical and engineering properties of expansive soil.

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Acknowledgement:

The authors appreciate the support received from Deanship for Scientific Research at Qassim University (QU), Saudi Arabia, for supporting this project under the Standard Research Grants funding - Applied Sciences Research center (Project no. 3583-qec-2018-1-1-14-S).

تحسين الخواص الجيوتقنية للتربة الممتدة باستخدام رماد سعف النخيل

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(قدم للنشر في 2020/04/13 وقبل للنشر في 2020/05/16)

ملخص البحث. توجد التربة الانتفاشية في مناطق كبيرة حول العالم ، خاصة في المناطق القاحلة وشبه القاحلة. في مناطق مختلفة حول المملكة العربية السعودية توجد هذه التربة ذات المشاكل في شكل طبقات خاصة في مناطق التنمية الجديدة في المملكة. تتطلب أنشطة البناء على هذه التربة النظر في التدابير الاحترازية لتجنب و / أو تقليل المخاطر المرتبطة بهذه التربة ذات المشاكل. اقترحت دراسات بحثية مختلفة تدابير لتحسين ظروف البناء حيث توجد التربة الانتفاشية. تستخدم هذه التدابير إحدى الطريقتين ، إما الاستبدال الكامل لطبقات التربة الانتفاشية أو من خلال معالجة التربة الانتفاشية بمجموعة واسعة من الإضافات.

في الدراسة الحالية ، تم إدخال عامل معالج جديد ليتم مزجه مع تربة توسعية تهدف إلى تحسين خصائصه الجيوتقنية ؛ والتي تنعكس في سلوكها الهندسي تحت أحمال البناء. العامل المخفف هو شكل رماد النخيل [PFA].

سعف النخيل (PF) هو نفايات زراعية يتم إنتاجها بشكل كبير كل عام في المملكة العربية السعودية كمنتج ثانوي لزراعة ملايين أشجار النخيل. تتم العملية النموذجية للتخلص من هذه النفايات من خلال الحرق في الهواء الطلق ، مما يسبب مخاطر بيئية خطيرة للمجتمعات السعودية. في الدراسة الحالية ، يتم استخدام PFA كعامل استقرار من خلال مزجه مع التربة الانتفاشية. يتم تحضير واختبار عينات معاد تشكيلها من عينات التربة الممتدة الممزوجة بنسبة 4٪ و 8٪ و 12٪ من PFA لتقييم التحسن في خصائصه الجيوتقنية ، إن وجدت. أظهرت نتائج البرنامج التجريبي الذي تم إجراؤه على خليط التربة هذا تحسن الخصائص الجيوتقنية للتربة الانتفاشية. حدود Atterberg ، الحد الأقصى للكثافة الجافة (MDD) ، قوة الضغط غير المحصورة (UCS) ، وضغط التورم (SP). أظهرت هذه الدراسة أنه عند احتوائه على 10٪ وزناً من PFA في عينات التربة الممتدة ، فإن الحد السائل للتربة ينخفض بنسبة 40٪ تقريبًا. زاد MDD بنسبة 5٪ تقريبًا وزاد UCS بمتوسط قيمة 26٪ تقريبًا بينما انخفض ضغط التورم بحوالي 88٪. علاوة على ذلك ، يتم عرض معادلة تجريبية أولية لتقدير النسبة المئوية للانخفاض في ضغط الانتفاش كدالة لنسبة PFA الممزوجة بالتربة الانتفاشية.