Improvement of engineering characteristics of expansive clays by sand mixing

L'amélioration de Maniguancer les Caractéristiques de Glaises Expansives par le Mélange de Sable

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ABSTRACT

Expansive Soils are a worldwide problem that poses several challenges for civil engineers. They are considered potential natural hazard, which can cause extensive damage to structures if not adequately treated. The expansive soils have caused severe distresses to various civil engineering structures, especially to lightly loaded structures such as houses, floors, highway pavements, canal linings etc. One of the mitigation techniques of such soils is to mix them with soils which are not swelling in nature. In this paper, the results of three series of tests are presented in which a swelling clay has been mixed with sand in varying amount ranging from zero to 35%. Through these tests, the effects of sand mixing on deformation and strength characteristics of swelling clay have been investigated. For performing such tests, the swelling clay samples have been procured from an expansive soil area in Pakistan. The clay-sand samples were remolded at Modified AASHTO density and optimum moisture content with proportion of sand ranging between 0-35 percent. Three series of tests performed included, Modified AASHTO compaction, California Bearing Ratio, One-dimensional consolidation tests in addition to basic property tests. The results of the study showed that mixing of sand in swelling clay remarkably reduces swelling potential of expansive clay and improves its strength characteristics. The sample with out mixing sand content showed a swell potential of the order of 3.5 % and this reduced to about 0.5% when the clay was mixed with 35% of sand. The swell pressure for sample without mixing sand was found to be 90 kPa and reduced to about 10 kPa for sample mixed with 35% sand. The CBR values increased from a value of 4% in case of pure clay sample to a value of 8% when the clay was mixed with 30-35% sand. The Modified AASHTO density was increased from 18.2 kN/m^3 to 19.4 kN/m^3 in case of pure clay and clay mixed with 30-35% sand, respectively. These results are very promising and have application when such clays are being used as highway subgarde soil, where there is requirement of mitigating their expansive nature along with improving their strength characteristics like CBR etc.

RÉSUMÉ

Les sols gonflants constituent un problème que l'on rencontre partout sur la planète et ils posent plusieurs challenges aux ingénieurs de génie civil. Ces sols sont considérés comme responsables de potentielles catastrophes naturelles, qui peuvent causer des dégâts très importants aux structures s'ils ne sont pas correctement traités. Les sols gonflants sont la cause de nombreuses pathologies sur diverses structures de génie civil, et plus spécialement les structures légères telles les maisons, dallages, chaussées d'autoroute, revêtements en béton des canaux, etc. Un des traitements possibles de tels sols est de les mélanger avec d'autres sols non sensibles au gonflement par nature. Dans ce document, sont présentés les résultats de trois séries de tests où une argile gonflante a été mélangée avec une proportion de sable variant de 0 à 35%. A travers ces tests, les effets de l'incorporation de sable sur les caractéristiques de déformations et sur les résistances de l'argile gonflante ont été étudiés. Pour réaliser de tels tests, des échantillons d'argile gonflante ont été récupérés dans une zone de sols sensibles au gonflement au Pakistan. Avec des proportions de sable variant entre 0 et 35%, les mélanges d'argile et de sable ont été réalisés à la densité modifiée AASHTO et avec à l'optimum de teneur en eau. Les trois séries de tests réalisés comportaient, en plus des tests habituels des caractéristiques des sols, les tests suivants : compaction modifiée AASHTO, California Bearing Ratio, test de consolidation unidimensionnel. Les résultats de l'étude ont montré que l'apport de sable dans les argiles gonflantes réduit remarquablement le potentiel de gonflement des sols gonflants tout en améliorant leurs caractéristiques et de résistance mécanique. L'échantillon sans sable ajouté possède un potentiel de gonflement de l'ordre de 3.5% alors que l'échantillon avec 35% de sable réduit ce potentiel de gonflement à environ 0.5%. La pression de gonflement pour l'échantillon sans sable était de 90 kPa et est réduite à 10 kPa pour l'échantillon avec 35% de sable. De même le CBR passe de 4% pour l'échantillon sans sable à 8% pour l'échantillon avec 35% de sable et la densité modifiée AASHTO passe de 18.2 kN/m^3 pour l'argile pure à 19.4 kN/m^3 pour l'échantillon avec 35% de sable. Ces résultats sont très encourageants et pourraient trouver des applications pratiques pour des sols supports de chaussées d'autoroute, lorsqu'il y a la nécessité de limiter leur nature gonflante tout en améliorant leurs caractéristiques mécaniques comme le CBR, etc.

1 INTRODUCTION

Expansive Soils are known to cause severe damage to structure resting on it. They are considered potential natural hazard, which can cause extensive damage to structures if not adequately treated. The expansive soils have caused severe distresses to various civil engineering structures, especially to lightly loaded structures such as houses, pavements, canal linings etc. The problems with foundations on expansive soils include heaving, cracking and breaking of pavements, building foundations, slab-on-grade members, channels and reservoir linings (Chen 1988).

Expansive clays are the soils, which undergo large volume changes when their environment is changed. When saturated, they tend to heave or swell and lose shear strength. If swelling is prevented, they develop pressure. On the other hand when dried, they shrink and exhibit cracks due to volume change. Expansion or swelling is more dominant than shrinkage. It is not simply because those soils heave more than they shrink but because brittle structures are more susceptible to doming associated with heave as it puts tensile stresses into the upper parts of the walls. On the other hand, shrinkage causes dishing, throwing tensile stresses into the foundations, which can resist these stresses.

The cost of damage caused to the civil engineering structures is usually much more than the damages from other natural disasters such as floods, hurricanes, tornadoes, earthquakes etc. In the United States, it has been estimated that the losses from expansive soils exceed two billion dollars annually.

Structures constructed on expansive soils induce heave from a variety of reasons. Shrinkage from the reduction of moisture content caused by evaporation or the evapotranspiration of

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vegetation, and the subsequent increase in soil moisture content have caused heave in expansive soils. Environmental conditions of a particular area in which expansive soils are located play an important role in the behaviour of such soils. The frequency of rainfall, rate of evaporation, depth of expansive soils and the activity of the soil, are the parameters in the eventual heave of expansive soils.

Expansive soils generally occur in semi arid regions where annual evaporation and evapotranspiration exceeds the precipitation. In these areas the soils are generally very stiff and the chances of lightly loaded structures cracking due to settlement is rather remote and most of the cracking is due to the swelling of the soils. Expansive soils cover large area of the land worldwide. The countries in which expansive soils are reported include: Argentina, Australia, Burma, Canada, Cube, Ethiopia, India, Israel, Iran, Mexico, South Africa, Spain, Turkey, USA, and many other underdeveloped countries in which much of the expansive soil problems may not have been yet explored (Chen 1988).

Expansive nature of soil is generally attributed to the presence of a specific clay mineral montmorillonite. Montmorillonite has an expanding lattice structure. Water can readily be absorbed in the lattice causing it to expand. Specific surface (surface area per unit mass) of montmorillonite is also more than other clay minerals. Expansive soils generally occur in semi arid areas. In these areas soils are generally stiff to very stiff and chances of cracking due to settlement are quite unlikely especially in lightly loaded structures. Most of the cracking is due to the swelling of soils.

There are several methods that have been used to minimized or eliminate the detrimental effect of expansive soils before and after the construction of structures. These methods include chemical stabilization, soil replacement, compaction control, prewetting, moisture control, surcharge loading, mixing with non-swelling soil, and use of geosynthetics.

In Pakistan, many areas are covered with such soils which have caused severe damages to various types of structures, such as cracking of single and double storied houses, lifting of floor slabs, etc. (Farooq 1996). To treat such soils, soil replacement, chemical stabilization, moisture and compaction control and structural design methods have been used with success in various projects to overcome the problems associated with expansive soils. Another effective method to mitigate the damaging effects of such soils is by mixing these soils with non-swelling soils such as sand and other granular soils. However, the effectiveness of this technique needs to be investigated.

In this paper, the results of three series of tests including compaction tests, CBR tests and one-dimentional consolidation tests were performed on clay-sand samples. In performing such tests, sand was mixed in varying proportion (0~35%) with an expansive soil in order to investigate its effects on swelling and strength properties of the clay.

2 MATERIALS AND TEST PROCEDURES

The swelling clay used in this investigation was procured from an expansive soil area along Lahore-Sialkot motarway near Daska town in Sialkot district, Pakistan. The clay samples, hereinafter known as Daska clay, were collected from a depth of about 0.25 m below existing natural surface level. The sand which was used as a blending material, has been procured from the river Ravi and referred to as Ravi sand in this paper. Table-1 shows the physical properties of Daska clay and Ravi sand samples. Figure 1 presents the gradation curves of both the samples.

In order to investigate the effect of sand mixing on compaction characteristics, Modified AASHTO (T-180) tests were performed on Daska clay samples mixed with Ravi sand in proportion ranging from 0 to 35%. California Bearing Ratio (CBR) tests were performed on Daska clay samples with sand contents varying from 0 to 35%. The CBR tests were performed in accordance with ASTM D-1883.

Table 1: Properties of Daska clay and Ravi sand

Properties	Daska clay	Ravi sand
Specific gravity	2.69	2.65
Gravel content (%)	0	0
Sand content (%)	27	97
Silt & clay content (%)	73	3
d_{50} (mm)	0.02	0.22
Liquid limit (%)	38	-
Plasticity index	20	-
Unified Soil Classification System	CL	SP
Compaction Properties		
Optimum moisture content (%)	14.0	12.5
Modified AASHTO dry unit weight (kN/m^3)	18.2	16.5

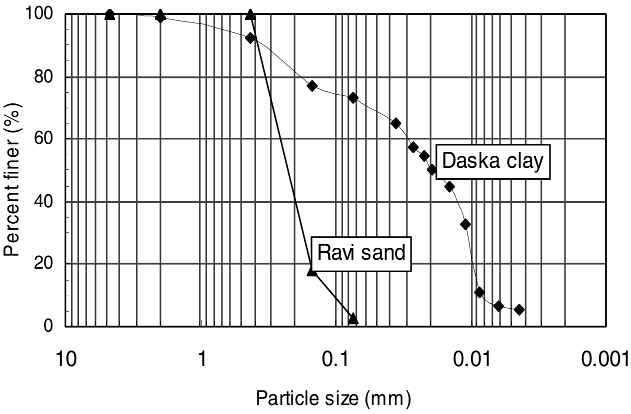

Figure 1. Gradation curves of Daska clay and Ravi sand

The effect of sand mixing on swelling characteristics of Daska clay was investigated through one-dimensional consolidation test (ASTM D-2435). Samples were mixed with sand in varying percentage from 0 to 35%. The samples mixed with sand were then compacted at optimum moisture content and maximum dry density corresponding to Modified AASHTO test.

Many researchers (Komarnik and David 1969; Mowafy and Bauer 1985) have described two parameters to evaluate the swelling properties of expansive soils, which are swell potential and swell pressure. Swell potential is defined as the percentage increase in relation to the original height of the specimen, whereas the swell pressure is designated as the pressure which is required to prevent swelling. The swell potential of each test specimen was determined by placing the remolded specimen in oedometer ring (1.5 x 0.75 inch) with porous stones placed on the top and bottom of the specimen. The oedometer ring was assembled in consolidation frame. The specimen was then loaded to a seating pressure of 7 kPa. so as to seat the loading platen on the sample properly. The specimen was then flooded with water and allowed to swell under the seating load. Deformation readings were taken at 0, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, 1440 min, and then every 4 hr on subsequent days until no further changes in readings were observed and full swell was attained. The increase in vertical height of a sample, expressed as a percentage, due to increase in moisture content is referred to as percent swell in this paper.

The swell pressure of the specimen was determined by loading the swelled specimen in various increments. In each increment of loading, complete consolidation of the specimen was ensured by giving sufficient time after the application of incremental load. The specimen was loaded until whole of the swell of the specimen is reduced to zero and the specimen attained its original height. At this stage, the swell pressure was calculated as the load required bringing the specimen to its original height divided by the area of the specimen. When whole of the swell was recovered, the samples were then loaded in increments to a maximum pressure of 3435 kPa to investigate the effect of sand mixing on consolidation characteristics of the clay.

3 TEST RESULTS AND DISCUSSIONS

The results of Modified AASHTO compaction tests on clay-sand samples are presented in Figure 2. The figure also includes the individual compaction curves of Daska clay and Ravi sand. The other samples have been prepared by mixing Ravi sand in to the clay in proportion ranging from 5% to 35%. As evident from the figure that maximum dry density increases and optimium moisture content decreases as the sand content increases. The maximum dry density and OMC in case of pure clay is 18.2 kN/m^3 and 16.5%, respectively. However, in case of clay-sand samples, the maximum dry density gradually improves to 19.4 kN/m^3 with OMC of 9% for sample with 35% sand content.

CBR tests were also conducted on clay-sand samples with sand fraction varying from 0 to 35% and the results are summarized in Figure 3. It can be seen from the figure that CBR value increases from 4% to 8.3% for pure clay sample and sample with 35% sand proportion, respectively. This finding may be of prime importance in case of highway project where subgarde requires a CBR value of at least 7 to 8% and for poor subgarde it can be improved by mixing sand in proportion of 25% to 30%.

Figure 4 shows the results of swell (oedometer) tests which were performed on soil samples mixed with varying amount (0~35 %) of sand. The figure shows the time histories of swell percent of all the soil samples where it can be observed that sample with out sand mixing attains the maximum swell potential (3.5%) and as the percentage of sand content increases there is a decrease in the swell percent. Also seen in the figure is that the time of development of swell for all the cases is almost the same. The swell potential decreases to about 0.5% in case of soil sample mixed with 35 % sand. Figure 5 depicts the variation of swell potential with increasing sand content. The swell potential decreases gradually from a value of 3.5% for pure soil to 0.5% for soil sample with 35%.sand mixing. Figure 6 depicts the variation of swell pressure with percent sand mixing. The swell pressure value is 90 kPa for pure clay sample and reduces to a value of about 10 kPa when 35 % sand is added to the clay.

The reduction in both the swell potential and swell pressure of the soil may be attributed to the reduction of plasticity index of the clayey soil, which can be observed from Figure 7. In the figure, it can be seen that as the sand content is increased, the plasticity index (PI) decreases from a value of 21% (for pure clay sample) to 11% (with 35% sand mixing).

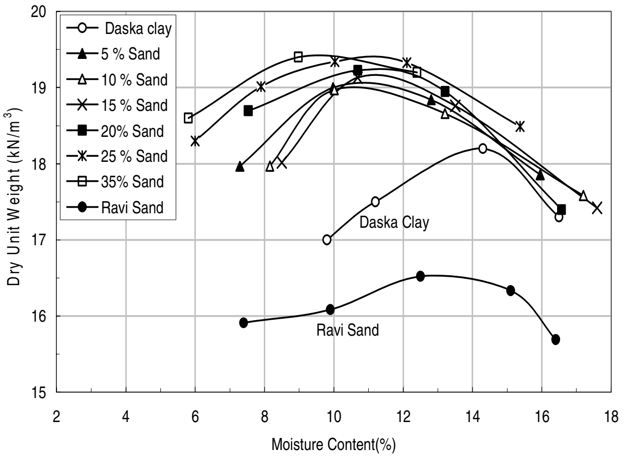

Figure 2. Compaction curves for all the samples

It has been observed (though not included in the figure) that the liquid limit (LL) reduces from a value of 38 % to 27 % for a pure clay sample and sample mixed with 35 % sand, respectively. Figure 8 summarizes the results of consolidation tests which were performed on the clay-sand sample subsequent to swell tests. The figure shows the variation of compression index (Cc) with increasing sand content. The Cc value decreases from 0.31 to 0.09 for the pure clay sample and the sample mixed with 35 % sand, respectively.

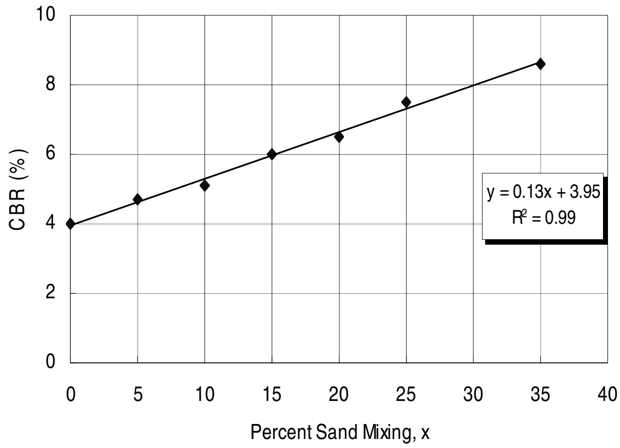

Figure 3. Variation of CBR ~ percent sand mixing

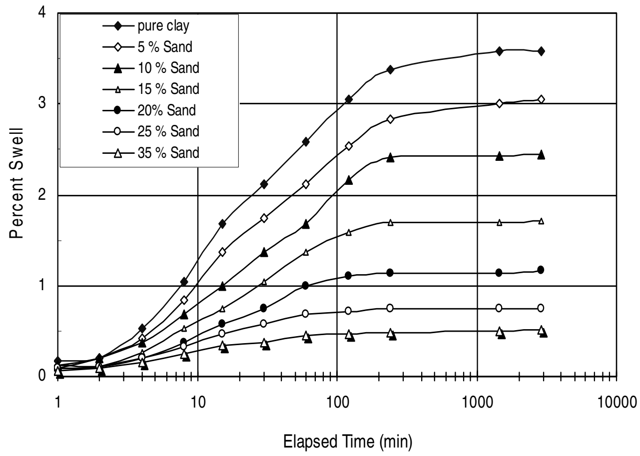

Figure 4. Time histories of percent swell for all the samples

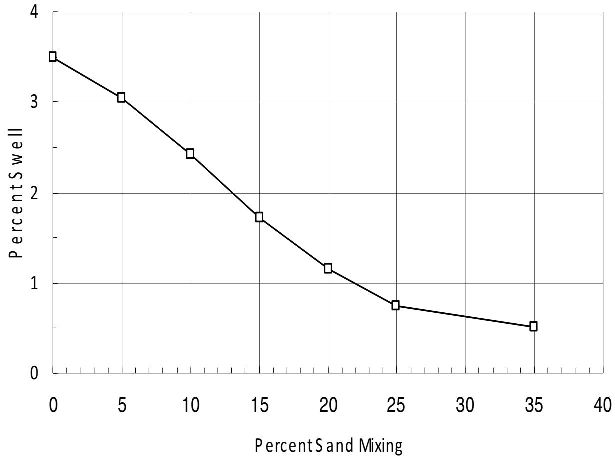

Figure 5. Variation of swell percent ~ sand content mixed

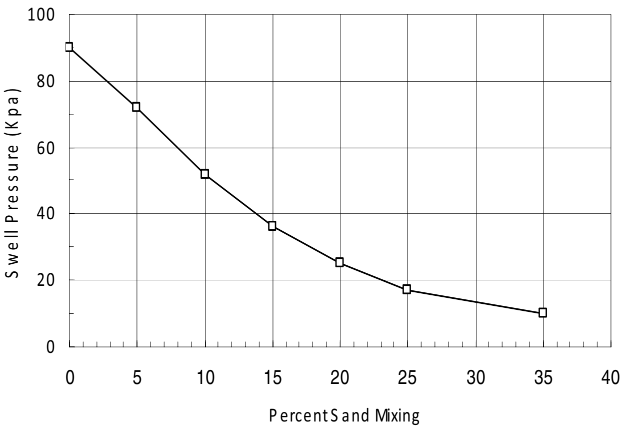

Figure 6. Variation of swell pressure with percent sand mixing

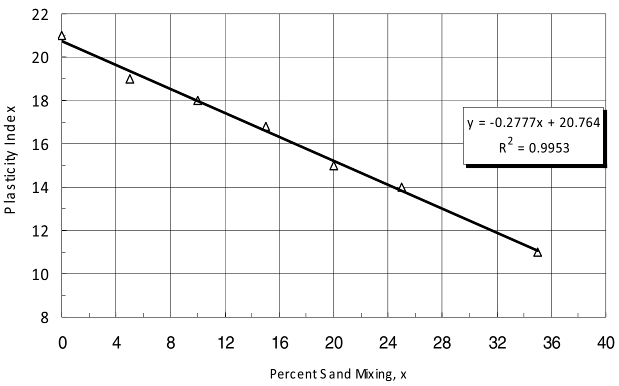

Figure 7. Variation of plasticity index with percent sand

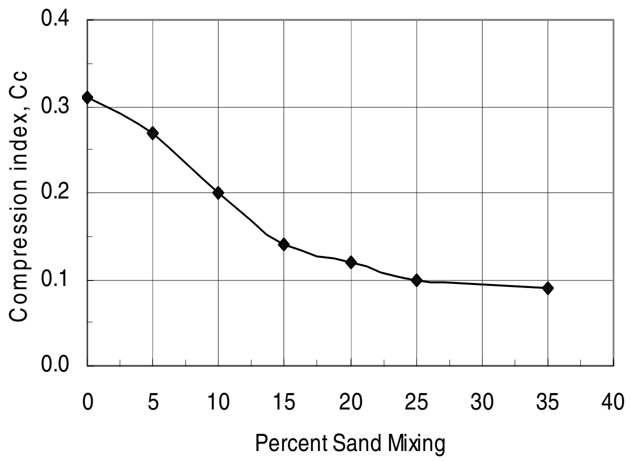

Figure 8. Variation of compression index ~ percent sand mixing

4 CONCLUSIONS

Following conclusions are drawn based on the laboratory investigation:

- Sand mixing in swelling clay improves the maximum dry density corresponding to Modified AASHTO
- from 18.2 kN/m^3 to 19.4%, for clay sample and sample mixed with 35% sand, respectively. The OMC value decreases from 16.5 to 9% for clay sample and sample with 35% sand.
- The CBR value increases from 4 % in case of pure clay sample to 8 % in case when 25% to 30% sand has been mixed into the clay sample. This finding is significant for the improvement of CBR in case of highway subgarde. The CBR can be effectively improved to the required value by the addition of 30 to 35 percent sand in clayey subgarde.
- The swell potential of Daska clay decreases from 3.5% to 0.5% for pure clay sample and 35% sand mixed sample, respectively. It shows that the deformation characteristics of the swelling clay may be improved with the addition of sand & the stiffness of the soil enhances with the addition of sand content.
- Swell pressure in case of pure Daska clay sample was found to be 90 kPa and it decreased to 10 kPa when the clay was blended with 35% Ravi sand.
- The atterberg's limits are considered to be the preliminary indicators of swelling behavior of the expansive clays. The mixing of sand into the Daska clay decreases both the liquid limit and the plasticity index. The liquid limit decreases from 38% to 27% and PI decreases from 21 to 11 in case of pure clay sample and 35% sand mixed sample, respectively.
- In summary, the strength and deformation characteristics of swelling clay have been observed to be improved by sand mixing. In practice, there appears to be a great potential of applying such technique to mitigate swelling nature of expansive clays under light structures such as floor slabs, boundary walls, foundations of single and double storied houses, pavements, canal linings etc. By applying such method in practice, the detrimental effects of swelling clays to civil engineering structures, in general, and to lightly loaded structures, in particular, can be effectively mitigated.

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