Confining Effects on Subgrade Properties of Surface Sand

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***Abstract* - Dry surface sand is not usually used for the foundation of buildings and for the foundation of roads in the form of subgrade because of no confinement or cohesion. Although it is rich with interparticles friction angle (phi). According to Terzaghi formula for bearing capacity of soils, the bearing capacity of surface sand is zero because cohesion (c) and depth of footing base (D) are both zero. To enhance the confinement effect, some cohesion is added to the sand mixing it with cement of 3% to 7% by dry weight of sand and cured for 7 days in water not to allow it to get hard. Direct shear and CBR tests are conducted in the laboratory on these samples of cemented sand. Results show enhanced cohesion from zero kPa of pure sand to about 700kPa for 7% cement mixed sand with drop of angle of internal friction from 35º of pure sand to about11º for 7% cemented sand. The CBR value increases from about 22% of pure sand to about 50% for 7% cement mixed sand. The category of the composite upgrades from that of subgrade to that of sub base.**

Keywords: Surface sand, cement mixing, enhanced confinement, increased CBR value. Category upgrade.

I. Introduction

Surface dry sand is difficult to compact through conventional method for the purpose of building foundation or road foundation called as a subgrade. The process of compaction becomes useless and ineffective when this dry surface sand is uniformly graded. It can be observed for dry state of sand on the surface that it just slips out the walking steps because of no cohesion the presence of which causes an internal confinement. On the other hand when it is moist or saturated as on beaches, it becomes stiffer, when one walks on it, due to suction forces left by expelling water. But it regains its displaced water when unloaded. When the dry sand on the surface is encountered for the construction of foundation, its bearing capacity (q_u) is almost zero due to lack of cohesion © and depth of surcharge / overburden (D). This is supported by Terzaghi's by Meyerhof [1], ultimate bearing capacity of a strip shallow footing is given by Eq. 1.1.

$$q_u = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma \quad \ldots\ldots\ldots\ldots\ldots \quad (1.1)$$

Where c is the cohesion of soil, D is the depth of foundation base from ground surface, γ is the unit weight of soil, B is the breadth of footing or foundation and Nc, Nq and N_γ are Terzaghi bearing capacity factors which are functions of angle of internal friction ϕ of soil (see figure 1.1).

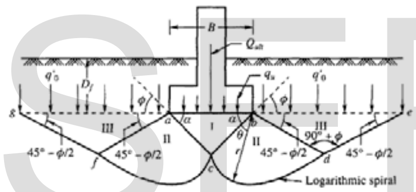

Figure 1.1: Terzaghi ultimate bearing capacity of foundation on soil model.

Such a problematic soil is encountered in Mianwali where 374km motorway from Islamabad to Dera Ismail Khan is being construction under the CPEC project. The sandy soil subgrade in that area is confined between side embankments upon which pavement is constructed by Chinese. To impart some cohesion to the dry sand, it has to be treated with the methods of soil stabilization or soil improvement by mixing cement or other chemicals which have come into being with the help of ongoing research in this area. For this purpose, ordinary Portland cement is chosen for mixing with dry sand in the presence of reasonable amount of water and curing as is practiced by Caltrans by Jones [2]. It is the aim of this study to quantify the amount of cohesion measured by direct shear tests and the strength gained and measured by 3 – point California Bearing Ratio (CBR) tests in the laboratory for the evaluation of this new composite with respect to its subgrade function.

II. Literature Review

A. ubgrade

ISSN 2229-5518

According to Jones et al., [2] subgrade is defined as "the foundation of the pavement that carries overlying load bearing members like riding surface / wearing course / asphalt cement concrete, base and subbase. The subgrade may be soil or rock, Figure 2.1.

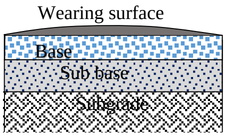

Figure 2.1: Typical cross section sketch of a flexible pavement.

This subgrade may change its characteristics over the length of route or pavement, some where it may be uniform or variable. The role of subgrade is very important with respect to the overall thickness of the pavement. If it is weak, the overall thickness of the overlying components will be more will be more or otherwise. It is this thickness which transfer the induced stresses from the traffic loads to the subgrade. In some situations, the type of pavement design is governed by strength of the subgrade i.e. instead of flexible pavement, a rigid type of pavement is resorted to. According to Yoder and Witzack [3], knowledge of basic soil mechanics for the choice and design subgrade is important as it is the main component of the system that supports the overall service of the pavement.

In case of soil, the subgrade must have California bearing ratio (CBR) value more than 10% but it is met or the soil is sandy, then stabilization or improvement of subgrade is carried out either mechanically or chemically. In some cases, removal and replacement is done. But this is the last choice to go for.

George and Waheed [4], write on the objective of pavement design that should be an economical structure with a combination of materials to take the traffic in a particular climate over the present soil conditions engineered in some fashion for a specified time. They stress on the knowledge of soil mechanics that affect the design of pavements.

B. Soil Stabilization by Cement

The method of soil stabilization of problematic soil with cement finds a very popular position in the civil engineering community. Choobbasti et al. [5], advocates that soil stabilization has become an attractive topic for engineers. A lot of efforts have been made to increase the strength of soils employing different techniques like chemical additives together with lime and cement. But cheaper and environment friendly are the search for this purpose of increasing the strength of subgrade cheaper and local materials.

Now most of the researchers go for the use of cement as a soil stabilizing agent for road construction of base, sub base and subgrade members. Ali and Youssef [6] worked on soil stabilization of a subgrade material in Saudi Arabia is intended to stabilize sandy silt. Mamun et al. [7], used this material for sand – cement stabilization. Because they say, it is more cost effective and environment friendly for the construction of sub-base pavement layer in perspective of Bangladesh.. They report that 8 to 10% cement prove to be adequate for sub-base layers of heavily trafficked roads.

III. Methodology

A. Materials

Building construction sand is collected from the local stock market and dried in the laboratory oven. Then it is kept in used cement bags for use in this study. The sand is sieved (sieve analysis), graded and classified according to unified soil classification system (USCS). One bag of Cherat cement is bought from the market. Tap water in the laboratory is used for mixing cement with sand in different proportions to prepare samples. The samples are cured in water tub for 7 days not to allow them to get much hard.

B. *Samples Preparation*

Formwork in the shape of cubical boxes from steel are fabricated of size 60mm x 60mm x 37mm. Five (5) samples of cement mixed sands of 3%, 5% and 7% each are prepared for direct shear tests and for CBR tests. Compaction of each sample is done for 10 blows, 30 blows and 65 blows in order to plot 3-point graphs. The following tests are done in this work to achieve the goal.

a) *Specific gravity*

This test is done for solids in order to find the source and mineral of sand particles. Once the mineral is known, the heaviness of the solid particle is deduced.

b) Sieve analysis

This laboratory test is carried out for gradation and classification of soil and its suitability for cement mixing and compaction. It is an index test to foresee the engineering behavior of soil in terms of its engineering properties.

c) Direct shear tests

This is also a laboratory test which is conducted on pure sand and on cement mixed samples to find the amount of cohesion imparted to the sand. This test holds good for sandy soils.

d) California Bearing Ratio (CBR) tests

This test is conducted in the laboratory as well in the field to find the strength characteristics of soils when used in foundation and roads. In this study, this test is done in the laboratory pure sand and on cement mixed sand to find the response of composite as a subgrade to the loads from the pavement. The data from the 3-points curves are used to find CBR corresponding to any dry unit weight of soil in the field.

IV. Results and Analysis

In this section, all the results are presented to arrive at some conclusion of the study presented in this paper.

ISSN 2229-5518

A. Specific gravity (Gs)

Three samples of pure sand are tested, the data of which are as shown in table 4.1. The Gs value is about 2.65 which is an indication of silica mineral, Powrie [8] and is 2.65 times heavier than water of the same volume.

Specimen number	1	2	3
W_P = weight of empty, clean pycnometer (grams)	402	402	402
W_{PS} = weight of (pycnometer + dry soil) (grams)	535	630	640
W_0 = weight of oven-dry soil in grams = W_{PS} - W_P	133	228	238
W_A = weight of (pycnometer + water) grams	1400	1400	1400
W_B = (weight of pycnometer + dry soil + water) grams	1483	1542	1548
Specific gravity of solids, $G_S = \frac{W_O}{W_O + (W_A - W_B)}$	2.64	2.65	2.64
Average value of G_s	2.647 say 2.65		

Table 4.1: Specific Gravity tests on study sand.

B. Sieve analysis

The average of the three tests is plotted in figure 4.1 which shows almost a uniformly graded fine sand of same size of grains. It is classified as SP, poorly graded sand with no fines as it does not meet the gradation criteria of uniformity coefficient and as shown in table 4.2.

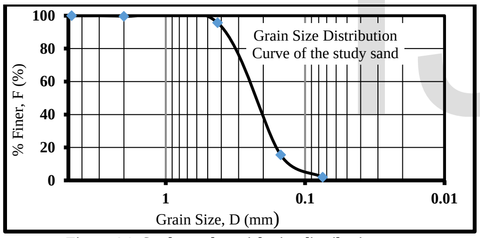

Figure 4.1: Study sand particle size distribution curve.

D-values (mm)			
Effective Size, D_{10}	*Mass-median-diameter, D_{50}	D_{30}	D_{60}
0.15	0.22	0.18	0.25
*The MMD is considered to be the average particle diameter of mass of 50% of the total.			
Coefficient Cu, Cc		**Gradation**	
uniformity Cu	Curvature Cc	USCS classification	
1.67	0.86	SP (poorly graded sand)	

Table 4.2: Gradation properties of pure sand.

C. Direct Shear Tests

a) Pure sand

Three direct shear tests are done on pure sand under normal stresses, σ_n of 125kPa, 250kPa and 375kPa to find the shear strength parameters of this fine poorly graded sand used in this study. Figure 4.2 shows the medium dense behavior of this sand in a plot between shear stress and shear displacment because the curves do not show any peak in them which is an indication of dense sand or stiff caly. The Angle of internal friction is 35º from figure 4.3 and cohesion is zero due to very less amount of fines (particles passing #200 Sieve size of 0.075mm).

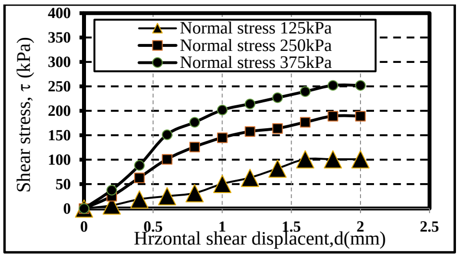

Figure 4.2: Pure fine poorly graded sand in direct shear test.

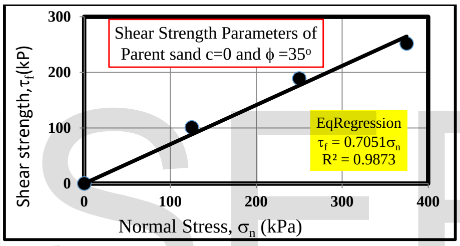

Figure 4.3: sand in direct shear test with ϕ =35º.

b) Cement Mixed Sand

Figure 4.4 shows the shear strength behavior of cemented sand with imparted cohesion of 365kPa, 453kPa and 706kPa to the 3%, 5% and 7% cement added sand respectively. This added cohesion acts as an internal confinement of soil grains. In pure sand it is zero. It is also seen from figure 4.4 that angle of internal friction (ϕ) of the coposite decreases from 35º of pure sand to about 5º to about 11º. Because the composite acts a c-ϕ soil dominantly cohesive like dry clay. Wang [9] has done such study and reports a cohesion c = 450kPa for 4.2% cement mix as compared our c = 453kPa for 5 % cement mixed sand.

ISSN 2229-5518

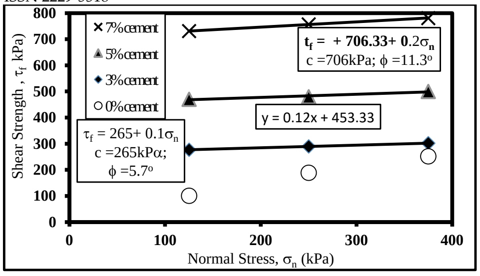

Figure 4.4: Imparted cohesion to the cemented sand.

Figure 4.5 shows the amount of imparted hohesion due to cement mixing with sand used in this study. It goes on increasing till cohision or the strength of pure cement.

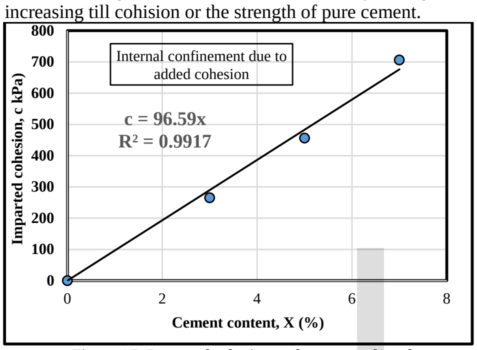

Figure 4.5: Imparted cohesion to the cemented sand.

D. California Bearing Ration (CBR) Tests Results

a) Pure Sand

CBR tests are carried out on pure sand with different unit weights from compacted sand. The 3 – point CBR tests are shown in figure 4.6. They show an increase with compaction energy but mild rate. Table 4.3 shows a typical test data for 10 blows / layer energy. The three point CBR data for the tests on pure sand are plotted in figure 4.7 from CBR field value can be determined for any value field density. These values are compared in the next section for composite.

10blows/ layer)	(Ring FACTOR = 20.52 Kg.f / div, $\gamma_{d(max)}$=1.87 g/cc; 90% $\gamma_{d(max}$ =1.68 g /cc						
Time, min	0	30'	1.0'	2.0'	3.0'	4.0'	5.0'
Plunger go, h(mm)	0	0.6	13	2.54	3.8	5.08	6.35
Ring reading	0	7	11	15	20	22	29
Load, P (Kg)	0	144	226	308	410	451	595
Stress, R (Kg/cm^2)	0	7.4	11.7	15.9	21	23.3	30.8
Std Resis (Kg/cm^2)				70		105	
CBR (%)				22.72		22.2	

Table 4.3: Typical CBR data for pure sand.

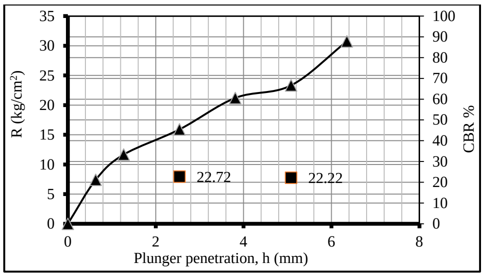

Figure4.6: CBR tests data plot for 10 blows / layer of energy.

The rest of the graphs for compaction energy due to 30 blows per layer and due to 65 blows per layer alonwith the compaction energy due to 10 blows per layer are plotted in figure 4.7. It shows that CBR increases with increase in dry unit weight of the pure sand, this increase in turn is due to increase in compaction energy. So in the field, for an approximate given compaction energy and dry unit weight, the value of CBR in percent is determined.

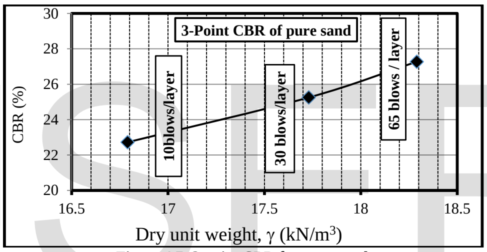

Figure 4.7: 3-point CBR for pure sand.

b) Cemented Sand

The data from the CBR tests on pure sand and on cemented sand in the ratios of 3%, 5%, and 7% are plotted in figure 4.8 for comparison. The effect of cenet on the enhanced CBR values of the cement mixed sand is very clear. These are compared with that of pure sand. This figure can be used for any value of CBR determination in the field coresponding to any value of field density of the composite. According to Iowa Highway Research Board, White [10], relative ratings of supporting strengths as a function of CBR values rates our pure sand as very good subgrade but the problem is no confinement and as per this table our composite qualifies for good subbase with 50% CBR from subgrade of pure sand with 22% CBR.

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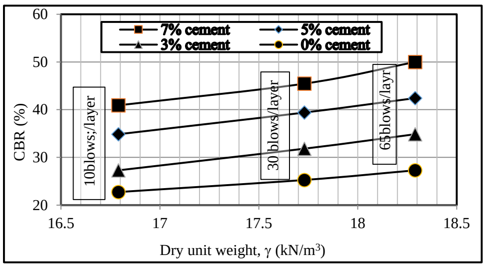

Figure 4.8: Generalized comparison of CBR properties of cemented sand with those of pure sand.

V. SUMMARY

From the results of the tests done in the laboratory in this study, it is found that:

A. The sand used is silica mineral. It is found that the sand is uniformly graded with 90% fine sand as per USCS.

B. The behavior of the sand during shear test is almost medium dense with angle of internal friction, $\phi = 35^o$.

C. The CBR value of the pure sand is 22.72%.

D. Cement addition imparts reasonable cohesion to the sand i.e. internal confinement; it increases with increase in cement content. Maximum value is 700kPa for 7% cement mix as compared to pure sand with zero cohesion.

E. CBR value of the composite reaches 50% as compared with 22% of the pure sand. This increase takes up the composite from fair pure sand subgrade to an "excellent subgrade".

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