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USE OF CEMENT BY-PASS DUST IN SOIL STABILIZATION

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ABSTRACT

Cement by-pass dust (CBPD) or cement kiln dust (CKD) is a by-product of the manufacture of Portland cement. It is generated during the calcining process in the kiln. Lime (CaO) constitutes more than 60% of CBPD composition. Other compounds include SiO_2, Al_2O_3, Fe_2O_3, K_2O, Na_2O, Cl^-, etc.

Oman Cement Company generates about 25,000 to 30,000 tons of CBPD every year. Some CBPD is used as a filler for road asphalting. The remainder of the CBPD is disposed of on-site without any further reuse or reclamation. As such, research was carried out to investigate beneficial reuses of CBPD in the Sultanate of Oman.

This paper presents the results of a study that investigated the use of CBPD in the stabilization of an expansive clay. The soil was stabilized with 0, 3, 6, and 9% CBPD. Mixtures were subjected to the following tests: (1) Atterberg limits, (2) pH, (3) compaction, (4) California Bearing Ratio (CBR), (5) swell percent, and (6) swell pressure.

Results indicate that as cement by-pass dust content increases, the swell percent and maximum dry density decrease while the pH and CBR values tend to increase. Thus, CBPD could potentially act similar to lime or cement in improving the properties of clayey or silty soils.

1. INTRODUCTION

Cement by-pass dust (CBPD) is a by-product generated during the production of Portland cement. As the raw materials are heated in the kiln, dust particles are produced and then carried out with the exhaust gases at the upper end of the kiln. These gases are cooled and the accompanying dust particles are captured by efficient dust collection systems.

The composition of CBPD is quite variable from source to source due to raw materials and process variations. It is primarily made up of a variable amount of fine calcined and uncalcined feed materials, fine cement clinker, fuel combustion by-products, and condensed alkali compounds [1]. The main component of CBPD is lime (CaO). Other compounds include SiO_2, Al_2O_3, Fe_2O_3, K_2O, Na_2O, Cl^-, etc.

A literature review indicated the following possible uses of CBPD:

(i) in pozzolanic base stabilization [2,3],
(ii) as a filler in asphalt concrete mixtures [4],
(iii) in wet soil conditioning and waste stabilization and solidification [5,6],
(iv) as an amendment in neutralizing acidic soils [7], and
(v) as a partial replacement for ordinary Portland cement [8,9].

There are considerable information and experience with the use of lime [10,11,12], cement [11,13,14], salt [11], and other materials [15,16] in soil stabilization. However, little research is documented on the utilization of cement by-pass dust in this application [17,18,19,20,21].

In the Sultanate of Oman, this study is a first attempt at investigating the use of CBPD in soil stabilization.

2. OBJECTIVE

The main objective of this research study was to investigate the potential use of cement by-pass dust in stabilizing expansive soils. Physical, mineralogical, chemical, and mechanical tests were conducted for this investigation.

3. MATERIALS

Cement By-Pass Dust (CBPD)

This material was obtained from the Oman Cement Company plant located in Gala. CBPD is a fine powder that is off-white to fawn or light brown in color. It has a specific gravity of about 2.56. Table 1 presents typical chemical compositions of CBPD and ordinary Type I Portland cement. Generally, CBPD is characterized by high K_2O, Na_2O, SiO_2, CaO (combined), Al_2O_3, and Cl^- contents and a higher loss-on-ignition (LOI) in comparison with Type I Portland cement.

Table 1. Chemical Compositions of Cement By-Pass Dust and Ordinary Portland Cement.

Compound	Cement By-Pass Dust (%)	Ordinary Portland Cement (%)
SiO_2	15.84	20.85
Al_2O_3	3.57	4.78
Fe_2O_3	2.76	3.51
CaO	63.76	63.06
MgO	1.93	2.32
SO_3	1.65	2.48
K_2O	2.99	0.55
Na_2O	0.33	0.24
TiO_2	0.48	0.25
Mn_2O_3	0.07	0.05
Cl^-	1.09	0.01
LOI	5.38	1.75

LOI: Loss-on-Ignition

Soil Sampling

In Oman, expansive clays are present in various regions of the country. The first case of documented structural problems due to expansive clays was reported at Sultan Qaboos University (SQU) and the Ministry of Defense [22,23]. The site selected for soil sampling is located between Sultan Qaboos University and the Married Quarter Village of the Ministry of Defense. The site belongs to the Ministry of Defense.

Disturbed soil samples were obtained from a hole dug to a depth of 1.2 m. The superficial layer consisted of a mix of gravel and sand with traces of clay and silt. The soil samples were then brought to SQU and subjected to physical testing. A summary of the physical, mineralogical, and chemical properties of the tested soil is presented in Table 2.

Table 2. Physical, Mineralogical and Chemical Properties of the Untreated Soil.

Characteristics	Values and Descriptions
Colour	Yellowish
Depth (m)	1.2
Natural water content (%)	8.9
Field dry unit weight (kN/m^3)	17
Specific gravity	2.8
Passing No. 200 Sieve (%)	60
Clay content (less than 2μm), %	20
Liquid limit (%)	49.9
Plastic limit (%)	29.5
Plasticity index (%)	20.4
Clay activity	1.03
Unified Soil Classification System (USCS)	MH
AASHTO Soil Calssification System	A-7-6
Clay minerals (%)	43
Montmorillonite	23
Palygorskite	23
Illite	16
Kaolinite	
Cations (%)	41
Sodium (Na)	6
Calcium (Ca)	1
Magnesium (Mg)	1
Potassium (K)	
Cation exchange capacity (meq/100g)	70
PH	9.3

In general, the soil consists of 40% gravel and sand, 40% silt, and 20% clay. Based on the Unified Soil Classification System (USCS), ASTM D2487, the soil is primarily an inorganic silt with high plasticity (MH). The soil is also classified as A-7-6 soil in accordance with the AASHTO classification system. The soil showed a relatively high plasticity index of 20.4% and an activity of 1.03. Generally, the higher the plasticity index and activity of a soil, the higher the swelling potential. According to the classification systems developed by Dakshanamurthy and Raman [24] and Van der Merwe [25], the soil was classified as having high and medium swelling potential, respectively.

The soil is characterized by the presence of high content of montmorillonite clay minerals (~ 43%), high cation exchange capacity (~ 70 meq/100g), high content of sodium cation (~ 41%), and low content of calcium cation (~ 6%). The physical, mineralogical and chemical results indicate that the soil possesses a high swelling potential.

4. EXPERIMENTAL TESTING PROGRAM

The tested soil was mixed with 0, 3, 6, and 9 percent CBPD by dry weight of the soil. The mixtures were then subjected to the following tests:

(i) pH.
(ii) Atterberg limits.
(iii) Swell percent.
(iv) Swell pressure.
(v) Compaction.
(vi) California Bearing Ratio (CBR).

pH

pH is a dimensionless number that indicates the "strength" of an acidic or basic solution. Table 3 indicates that as cement by-pass dust content increases, the pH values tend to increase although not significantly. The initial increase in pH from 9.3 (untreated soil) to 10.9 (3% CBPD) is appreciable. This is primarily due to the lime presence in CBPD. All pH data of the different mixes are in the basic solution range.

It is well known that reactions between lime, water and various sources of soil silica and alumina will form cementing-type materials. These reactions are called soil-lime pozzolanic reactions. Thus, when a considerable quantity of lime is added to a soil, the pH of the soil-lime mixture will be elevated to approximately 12.4 [26]. This is when the solubilities of soil silica and alumina are greatly increased. The importance of the pH test is that soils that are reactive with lime or CBPD would produce substantial strength increases.

Table 3. Physical Properties of Cement By-Pass Dust Stabilized Soil Samples.

Mixture	pH	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Untreated Soil	9.3	49.9	29.5	20.4
3% CBPD	10.9	65.2	37.6	27.6
6% CBPD	11.0	60.4	40.7	19.7
9% CBPD	11.1	56.3	38.9	17.4

CBPD: Cement By-Pass Dust

Atterberg Limits

Liquid limit (LL), plastic limit (PL), and plasticity index (PI) data obtained on the four mixtures are presented in Table 3. Tests were conducted in accordance with ASTM D4318. The soil was initially dried and then screened through # 40 sieve. Cement by-pass dust addition to the soil seems to increase the liquid and plastic limits while the plasticity index tends to decrease. The only exception is the soil stabilized with 3% CBPD has an increase in PI value. This indicates that higher additions of CBPD will be more beneficial in stabilizing expansive soils. This is probably due to the higher release rate of Ca^{++}, Si^{++}, and Al^{+++} cations with increased CBPD usage.

Swell Percent

There is no standard procedure acceptable universally for carrying out swell percent and swell pressure testing. Each researcher adopt the testing procedure in view of the quality of samples and type of investigation. However, the loaded-swell and constant volume methods are commonly referred to for measuring swell percent and swell pressure, respectivley.

Swell percent is a measure of the vertical deformation of a soil sample, in percent, when its moisture content increases. The swell percent is usually measured under small surcharge pressures in the range of 0 to 20 kPa. An initial surcharge pressure of 25 kPa equivalent to its overburden pressure was selected for the testing program. This pressure was estimated based on the depth of one to two meters from where the soil was obtained.

To prepare remolded samples, the soil was first cut into small pieces and air-dried for twenty-four hours, and then it was pulverized repeatedly using a plastic hammer. Because of its cohesive nature, the soil was then fully soaked for another twenty-four hours. After soaking, the soil disintegrated into its individual components and additional lumps were broken by hand. The soil was then placed in an oven at 105°C for twenty-four hours to ensure complete dryness. The dry soil was further pulverized to minus number 10 sieve size. At this stage, the soil was ready for remolding.

About 167 g of dry soil was weighed and mixed with stabilizers at 3, 6 and 9% by dry weight of the soil. The water needed for a specific water content was also weighed. The soil-additive mixture was thoroughly mixed with water until a wet homogenous mixture was achieved. The wet soil-additive was then placed into the mold and compacted to exactly fit the cutting ring. Compaction was accomplished using a 4.5 kg hammer to arrive at the desired unit weight determined from the standard Proctor compaction test (ASTM D698). All remolded specimens were left in a desiccator for 24 hours before testing. This process allowed the water to be distributed uniformly within the sample without any loss of moisture.

The swell percent of each test specimen was measured using the Loaded-Swell Method [27]. The apparatus used was the standard one-dimensional oedometer. The specimen in its ring was placed between two porous stones with load plate resting on the upper porous stone. The consolidation cell was assembled in the consolidation frame. The specimen was loaded to a seating pressure of 25 kPa. The specimen was then flooded and allowed to swell under the seating load. Deformation readings were taken at 0, 0.5, 1.0, 2.0, 4.0, 8.0, 15.0, 30.0, 60.0, 120, and 1440 minutes, and then every four hours on subsequent days until no further changes in readings were observed and full swell was attained. In general, the test was run until swelling ceases. In most cases, the tests were run for two to three days.

A summary of the swell percent data is presented in Table 4. The untreated soil exhibited a relatively high swell percent (~ 11.6%). Figure 1 shows the swell percent results obtained on all four mixtures. Generally, there is a decrease in swelling as cement by-pass dust content is increased. Soil stabilized with 9% CBPD produced the least swelling (a reduction of 65%). This is primarily due to the release of more silica, alumina, and calcium oxide at the higher CBPD content.

Table 4. Swelling Potential Test Results.

Mixture	Swell Percent	Total Swell Pressure (kPa)
Untreated Soil	11.6	249.0
3% CBPD	5.1	259.2
6% CBPD	6.9	261.6
9% CBPD	4.1	202.3

CBPD: Cement By-Pass Dust

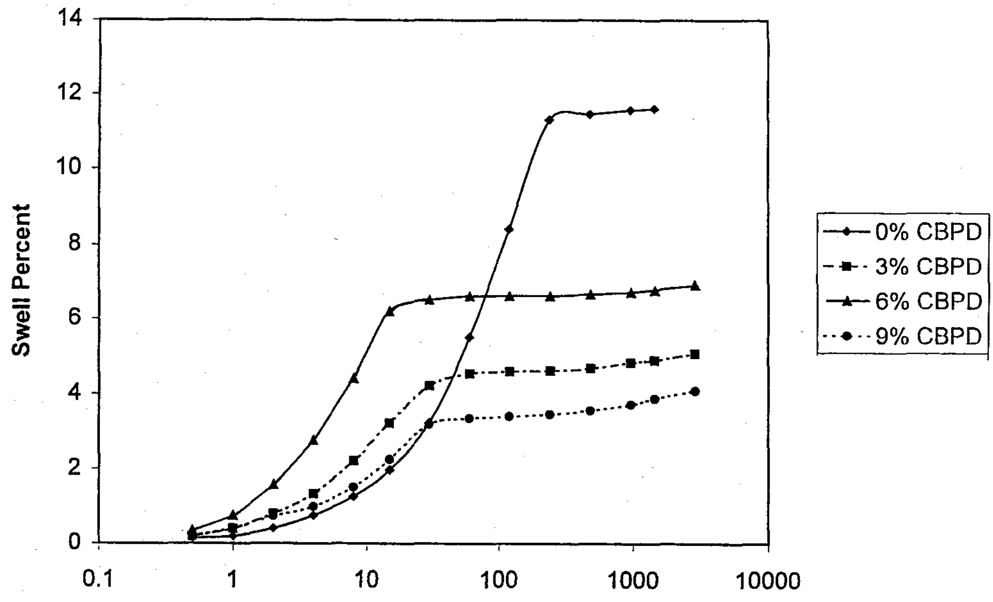

Fig. 1. Swell percent test results

Swell Pressure

Swell pressure is the pressure needed to bring the soil sample back to its original height after swelling or the pressure needed to keep the sample's volume constant when water is added to it. The swell pressure of each test specimen was measured using the *Constant Volume Method* [27]. It includes both the overburden pressure (25 kPa) and the pressure required to prevent swelling.

The specimen preparation and placement arrangement in the consolidation cell and the seating pressure were the same as in the *swell percent* test. The specimen was then given free access to water, while the volume was kept constant by continuous addition of loads at each vertical expansion of the tested specimen. Loads were applied using sand added to a plastic bag hanging from the loading arm. The addition of loads was continued until deformation ceased.

A summary of the swell pressure data is presented in Table 4. The untreated soil showed a high swell pressure (249 kPa). Table 4 further indicates that there is a slight increase in swell pressure as CBPD content increases. However, for the soil sample stabilized with 9% CBPD, the swell pressure value was lower than those soil samples stabilized with 3 and 6% CBPD and also significantly lower than the value obtained for the untreated soil.

Compaction

Modified Proctor compaction tests (ASTM D1557) were conducted on the four mixtures (Fig. 2). Generally, there is a slight decrease in the optimum moisture content and maximum dry density values with the addition of cement by-pass dust. A reduction in dry unit weight is generally expected for soil-lime mixtures when compared with unteated soils [26]. Cement by-pass dust stabilized soil exhibited a similar trend.

California Bearing Ratio

In this test (ASTM D1883), the California Bearing Ratio (CBR) of a compacted soil is determined by comparing the penetration load of the tested soil to that of a standard high quality crushed stone rock. The results are used to evaluate the relative quality and strength of a soil.

Figure 3 shows the load versus penetration data obtained for the four mixtures. A summary of the CBR and swelling results are presented in Table 5. The data indicate that as cement by-pass dust content is increased, there is an increase in the CBR and a decrease in swelling.

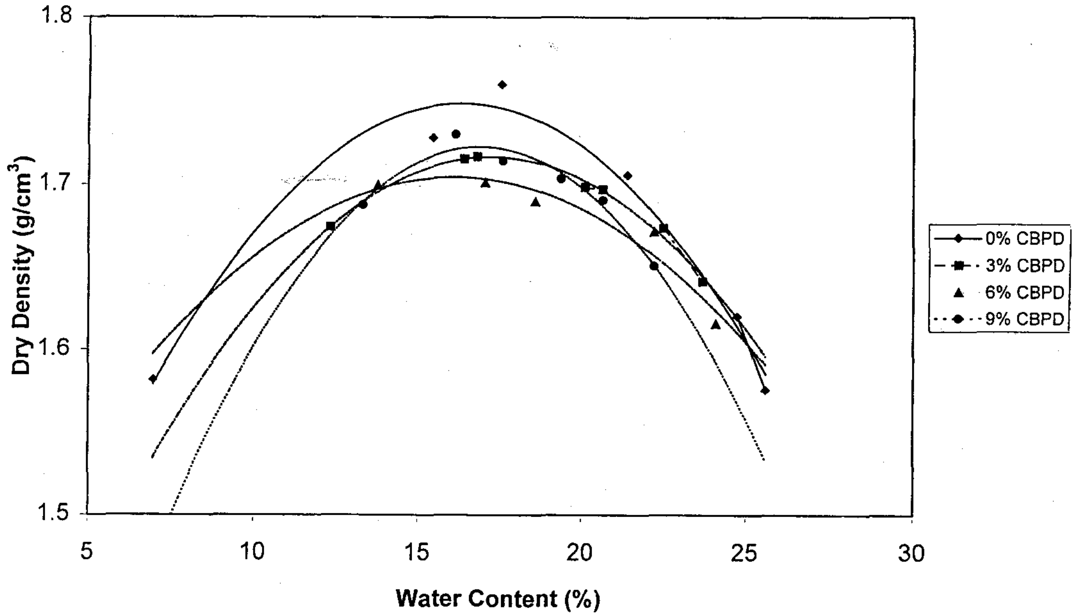

Fig. 2. Moisture – dry density relationships.

Table 5. California Bearing Ratio Test Results.

Mixture Type	California Bearing Ratio (%)	Swelling (%)
Untreated Soil	0.7	3.8
3% CBPD	4.5	2.3
6% CBPD	10.9	0.2
9% CBPD	13.1	0.1

CBPD: Cement By-Pass Dust

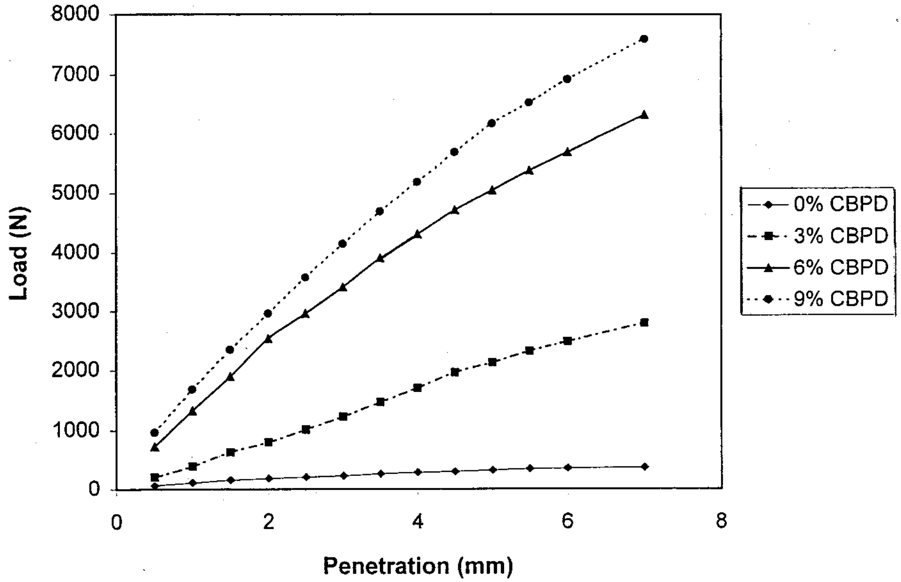

Fig. 3. Load versus penetration data obtained from a CBR test.

A comparison between the swell percent results obtained from CBR and consolidometer tests is shown in Figure 4. The swell percent values determined in a consolidometer apparatus are much higher than those values obtained from a CBR test. This is primarily due to the testing procedure and sample preparation implemented in each test. In practice, it would be better to use the CBR test in assessing the quality and strength of cement by-pass dust stabilized soils. The data would be more respresentative of actual field performance.

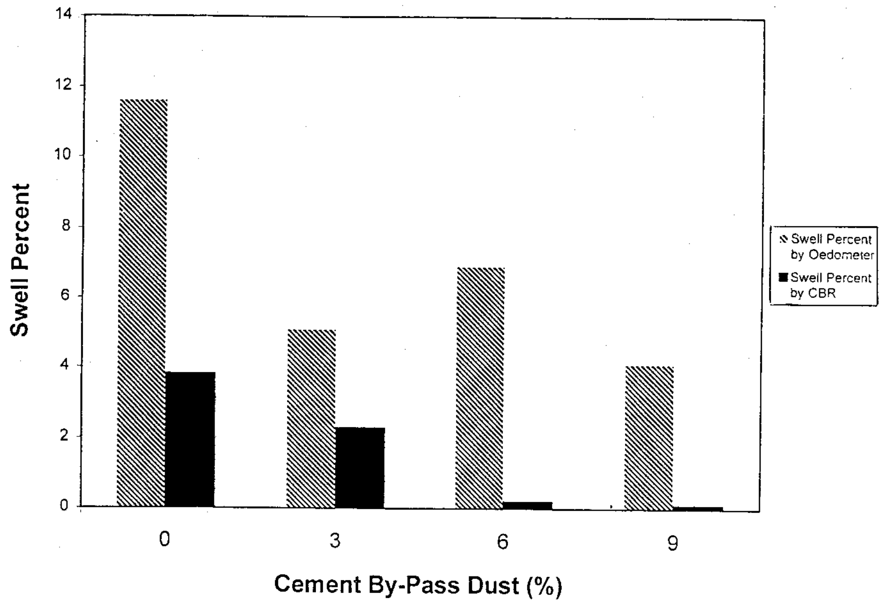

Fig. 4. Comparison of swell percent results obtained from CBR and consolidometer testing.

5. CONCLUSIONS

The main conclusions obtained from this study are as follows:

1. The soil used in the study was classified as inorganic silt with high plasticity (MH). It is characterized by the presence of high content of montmorillonite clay mineral (~ 43%), high cation exchange capacity (~ 70 meq/100g), high content of sodium cation (~ 41%), low content of calcium cation (~ 6%), high swell percent (~ 11.6%), and high swell pressure (249 kPa).

2. For any mixture and as cement by-pass dust content increases, the pH value tends to increase although not appreciably.

3. The liquid and plastic limits seem to increase while the plasticity index tends todecrease with the addition of cement by-pass dust. However, the soil stabilized with 3% CBPD exhibited an increase in plasticity index.

4. Swell percent tends to decrease with the addition of CBPD. The least swell percent was obtained in the soil stabilized with 9% CBPD (a reduction of 65%).

5. There is a slight increase in swell pressure as CBPD content increases. The soil stabilized with 9% CBPD not only produced a lower swell pressure than the 3 and 6% CBPD-stabilized soil blends but was also significantly lower than the value obtained for untreated soil.

6. There is generally a slight reduction in optimum moisture content and maximum dry density with the addition of CBPD.

7. There is an increase in the California Bearing Ratio (CBR) as CBPD contentincreases.

8. The CBR test would be more reliable in assessing the strength and swelling properties of CBPD-stabilized soil mixtures.

9. Although our testing program was limited to four mixtures (0, 3, 6, and 9% CBPD), it seems that a higher use of cement by-pass dust (greater than 9%) could be more beneficial in stabilizing expansive soils. Further testing is needed to confirm such conclusion.

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