

Research Article

Investigation into Effectiveness of By-pass Cement Dust as Soil Stabilizer in Road Construction

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Abstract

By-pass cement dust (BPCD) is produced in large amounts during the process of cement manufacturing and renders the cement industry classified as highly pollutant. Nonetheless, because of its physical characteristics and chemical reactivity, BPCD has been used in several industries and construction works. This paper discusses the effectiveness of BPCD as a soil stabilizer in road construction works. The effectiveness is evaluated in terms of results of the modified Proctor test and California Bearing Ratio (CBR) test conducted on soils mixed with different contents of BPCD. The presented results and discussions indicate that BPCD is effective in stabilizing soils that are commonly used in road construction works in Egypt. For the test soil and the range of BPCD content considered in this investigation, BPCD could increase the maximum dry unit weight and CBR value of the test soil by approximately 18.9 and 90.0%, respectively. On the basis of the obtained results, two good correlations that can be used in designing BPCD-stabilization works could be established. The first correlation shows that the maximum dry unit weight increases exponentially with the increase in BPCD content. However, the other correlation reveals that the CBR value increases linearly with the increase in BPCD content.

Keywords: *By-pass cement dust, Soil stabilization, Road construction, Maximum dry unit weight, CBR value.*

1. Introduction

Cement industry is one of the important and large industries in Egypt and worldwide. However, this industry is considered environmentally as highly pollutant mainly because of the large amounts of by-pass cement dust (BPCD) that is produced during the process of cement manufacturing (El-Didamony, *et al*, 2001), (Abd El-Aleem, *et al*, 2005). Past studies have estimated the amount of BPCD in Egypt as 8.0–10.0% of the cement production (El-Demirdash, *et al*, 1999), (Abd El-Aleem, *et al*, 2005). Though efforts have been made to decrease the amounts of BPCD, the actual amounts produced at present are still very large.

BPCD is a very fine material and chemically considered a very reactive material. Therefore, it has been used in different industries and construction works, such as production of cement (Bhatty, 1985), (Hawkins, *et al*, 2003), production of rubber (Kryszafkiewicz and Maik, 1984), production of glass (Min'ko and Ermolenko, 1992), stabilization of waste (Rahman, *et al*, 2011), (Mostafa, 2012), construction of roads and highways (Rahman, *et al*, 2011), (Khodary, *et al*, 2013), and manufacture of masonry and concrete

blocks (Ravindrarajah, 1982), (Adaska and Taubert, 2008). The use of BPCD in the field of soil stabilization has been a major interest (Bhatty, 1986), (Abdel-Ghani and El-Sakhawy, 1994), (Huang, *et al*, 1994), (Mohamed, 2002), (Pierce, *et al*, 2003), (Katz and Kovler, 2004). Past studies have shown that BPCD, for instance, improves the physical and chemical properties of soils (Napeierala, 1983), improves the mechanical properties and increases the unconfined compressive strength of soils (Santagata and Bobet, 2002), and decreases the plasticity index of soils (Miller and Azad, 2000).

The investigation reported in the current paper aimed at evaluating the effectiveness of BPCD as soil stabilizer in road construction works. The effectiveness is evaluated in terms of results of the modified Proctor test and California Bearing Ratio (CBR) test conducted on soils mixed with different contents of BPCD. The paper starts with a description of the materials used in the investigation. Then, the adopted testing program is explained. Finally, the results of the performed tests are presented and discussed.

2. Test materials

The effect of using BPCD in the construction of base and sub-base layers of roads and highways is evaluated

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herein through testing a soil after being mixed with different contents of BPCD. The virgin soil was obtained from the area of Qift-Quseir in the South Valley Governorate of Egypt. This soil is commonly used in actual construction of base and sub-base layers of pavement in Egypt. The grain size distribution of the soil as shown in Fig. 1 indicates a well-graded soil with low content of fines. Its specific gravity, mean particle size, and uniformity coefficient are approximately 2.65, 13 mm, and 3, respectively.

The physical properties of BPCD vary from cement plant to another depending on the used raw materials and the adopted manufacturing process. The specific gravity of BPCD typically ranges from 2.6 to 2.8 (Collins and Emery, 1983) and its specific surface area is approximately 3,180 cm²/gm (Amer, *et al*, 1991); the specific surface area of the Portland cement is approximately 3,500–3,800 cm²/gm (Neville, 1996). BPCD has a typical loose unit weight of approximately 4.8 kN/m³ and can be compacted to approximately 13.5–15.0 kN/m³ (Todres, *et al*, 1992). The BPCD used in this investigation was provided by Misr Cement Company in Qena, Egypt. The chemical composition of this BPCD was determined using the X-ray fluorescence (XRF) technique. The results show the chemical composition in Fig. 2 and Table 1 and reveal that Calcium, Silicon, and Iron are the main constituents of BPCD. This indicates that BPCD is potentially effective in stabilizing base and sub-base soils used in road and highway construction.

3. Testing program

The effect of using BPCD as an agent for soil stabilization is evaluated in terms of results of the modified Proctor test and the California bearing ratio test. The BPCD was mixed with the virgin soil in different percentages. The Egyptian Code of Practice specifies that the content of fines in the soils used in base and sub-base layers should not exceed 15%. Therefore, the maximum content of BPCD was limited to 15% in the current investigation. Four test soils with BPCD contents of 0.0, 5.0, 10.0, and 15.0% by weight were prepared and tested. The soil with zero-BPCD content was considered for use as a control soil for the purpose of comparison with the other soils mixed with BPCD.

The preparation of the test samples was made in the following order:

- 1) The virgin soil was oven-dried.
- 2) The dried soil and the BPCD were carefully weighed for a predetermined content of BPCD.
- 3) The weighed soil and BPCD were thoroughly mixed together for 15 minutes to provide for a sufficiently homogeneous mixed soil.
- 4) Samples were taken from the mixed soil for the modified Proctor test and the California bearing ratio test.

This procedure was followed in preparing all the test samples. The only variable was the content of BPCD.

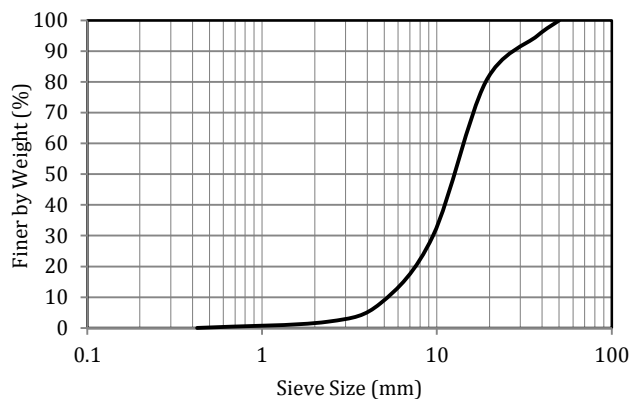


Fig. 1 Grain size distribution curve of virgin soil

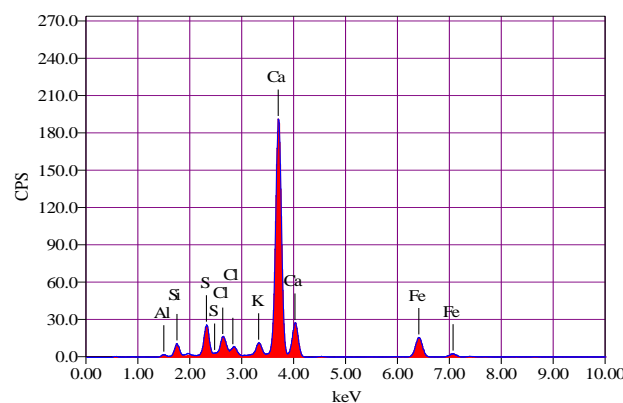


Fig. 2 Results of X-ray fluorescence test on used BPCD

Table 1 Chemical composition of used BPCD

Element	Weight (%)	Element	Weight (%)
Al	1.4316	Al ₂ O ₃	2.2106
Si	3.5232	SiO ₂	6.0844
S	3.4154	SO ₃	6.7123
Cl	2.837	Cl	2.1778
K	3.4095	K ₂ O	2.9873
Ca	79.3455	CaO	74.6209
Fe	6.0378	Fe ₂ O ₃	5.2067

3.1 Modified Proctor test

The modified Proctor test is one of the important tests used to determine the relationship between water content and dry unit weight of soils. In this investigation the modified Proctor test was performed according to the ASTM Standards (ASTM D 1557). A soil sample at selected water content was placed in five layers into a standard test mold. Each layer was compacted with a 10.0-lbf (44.5 N) rammer that was dropped freely from a height of 18.0 inches (457 mm). The dry unit weight (γ_d) was calculated on the basis of the wet unit weight (γ) and water content (w) of the sample according to the following expression:

$$\gamma_d = \frac{\gamma}{1 + w} \tag{1}$$

For each test soil of a given BPCD content, five samples of different water contents were tested to establish a relationship between the water content and the dry unit weight (compaction curve). The values of optimum water content and corresponding maximum dry unit weight were determined from the obtained compaction curve.

3.2 California bearing ratio (CBR) test

The California Bearing Ratio (CBR) test is a penetration test commonly used to evaluate the potential strength of pavement subgrade, subbase, and base course materials for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods; the CBR test results are used with empirical curves to determine the thickness of pavement and its layers. In the current investigation the CBR tests were conducted in accordance with the ASTM Standards (ASTM D 1883). Four samples were taken from the four test soils; a single sample was taken from each test soil. Every sample was then compacted, according to ASTM D 1557, to a dry unit weight of 18.928 kN/m³. The CBR test was performed by subjecting a sample to penetration by a cylindrical rod. Results of penetration stress versus penetration depth were recorded and plotted. The CBR value was determined from the penetration stress-penetration depth curve using the following expression:

$$CBR = \frac{x}{y} \cdot 100 \tag{2}$$

where x = penetration stress at 0.1 in. (2.54 mm) or 0.2 in. (5.08 mm) penetration, and y = standard stress of 1,000 psi (6.9 MPa) for the 0.1 in. (2.54 mm) penetration or 1,500 psi (10.3 MPa) for the 0.2 in. (5.08 mm) penetration.

4. Results and discussion

4.1 Effect of BPCD on compaction characteristics of soil

The effect of adding BPCD on the compaction characteristics of soil is evaluated in this section. Figure 3 and Table 2 show the results of the modified Proctor tests performed on the four test soils. It is seen that adding BPCD to the soil resulted in significant changes in its compaction characteristics; it should be noted that all the test samples in the performed modified Proctor tests were subjected to exactly the same compactive effort. The use of BPCD resulted in significant increases in both of the optimum water content and the maximum dry unit weight. The increasing water content, as intuitively expected, is essentially attributed to the increasing BPCD content, which results in a finer test soil and thus necessitates more water to reach the maximum dry unit weight.

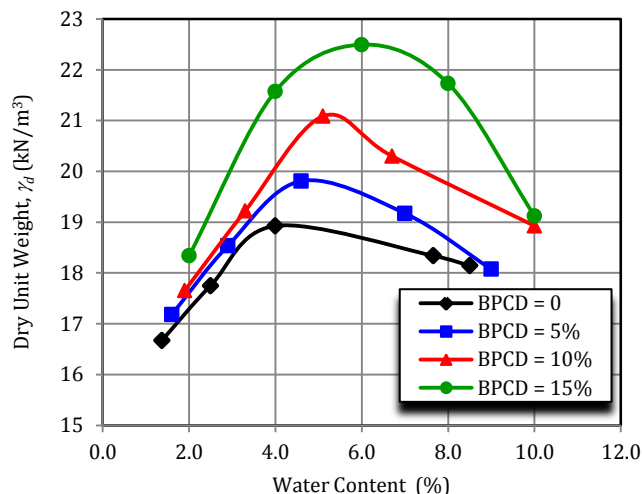


Fig. 3 Results of modified Proctor test on four test soils with different BPCD contents

Table 2 Optimum water content and maximum dry unit weight for four soils tested by the modified Proctor test

Test Soil #	BPCD Content (%)	Optimum Water Content (%)	Maximum Dry Unit Weight (kN/m ³)	Increase in Maximum Dry Unit Weight (%)
1	0	4	18.928	0
2	5	4.6	19.81	4.7
3	10	5.1	21.085	11.4
4	15	6	22.497	18.9

BPCD contents of 5.0, 10.0, and 15.0% increased the maximum dry unit weight by 4.7, 11.4, and 18.9%, respectively (Table 2). Increasing the unit weight improves the engineering properties of soils. In other words, it can be said that increasing the unit weight of soil results in higher shear strength, lower compressibility, higher CBR value, and lower permeability which respectively imply greater stability, less settlement under static load, less deformation under repeated load, and less hydraulic conductivity. These are important engineering properties and performance criteria for soils in different earth structures.

The results in Fig. 3 and Table 2 are re-plotted in Fig. 4 to show the variation of the maximum dry unit weight with the content of BPCD. It is interesting to note that the plotted results reveal a good correlation between the maximum dry unit weight and the content of BPCD; $R^2 = 0.9939$, where R is the correlation coefficient. This correlation indicates that the maximum dry unit weight increases exponentially with the content of BPCD and can be represented by the following expression:

$$\gamma_{d\max} = 18.823 e^{0.0116D} \tag{3}$$

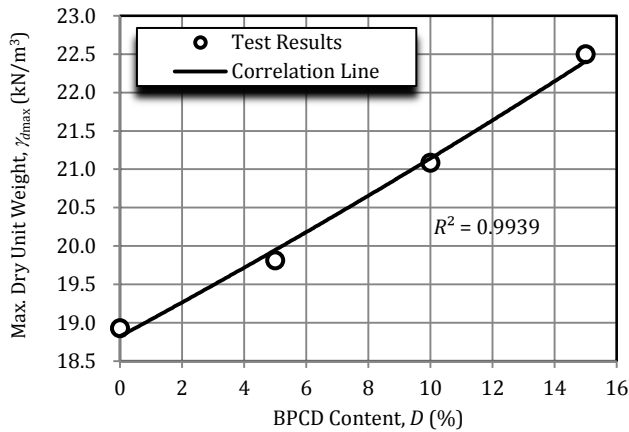


Fig. 4 Correlation of the maximum dry unit weight of test soil with BPCD content

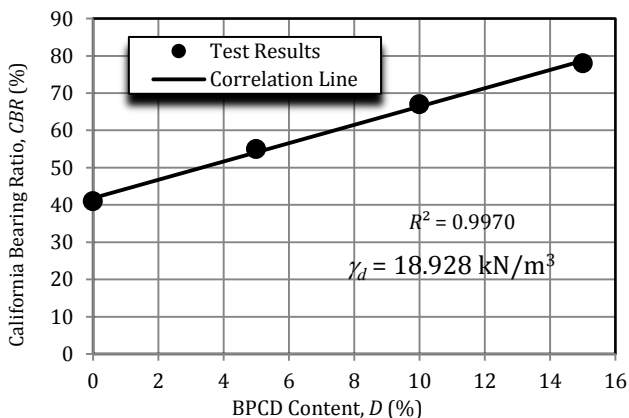


Fig. 5 Results of CBR test on four soil samples of different BPCD contents, and correlation of CBR value with BPCD content; all samples were compacted to a dry unit weight of 18.928 kN/m³ prior to CBR testing

where D = the content of BPCD. This correlation provides a practically important guideline as it can be used for the design of BPCD-stabilization works and estimating the BPCD contents for given target compaction criteria.

4.2 Effect of BPCD on CBR of soil

Figure 5 shows the results of CBR tests performed on the test soils. The four data points in the figure represent the CBR values for the samples of 0.0, 5.0, 10.0, and 15.0% in BPCD content; it should be noted that each sample, after being thoroughly mixed with the pre-determined amount of BPCD and prior to CBR testing, was compacted to a dry unit weight of 18.928 kN/m³. It is seen that the use of BPCD resulted in large increases in the CBR value. BPCD contents of 5.0, 10.0, and 15.0% resulted in increases in the CBR value by approximately 34.0, 63.0, and 90.0%, respectively. The CBR value represents the strength of the tested soil. It is therefore concluded that BPCD is effective as an agent for stabilizing soils in road construction.

The obtained results of CBR test, as shown in Fig. 5, indicate that the CBR value as a representative of the

gained strength increases with the increase of the BPCD content and that the CBR value can be correlated with the content of BPCD. The line in Fig. 5 reveals that a practically linear correlation can be established between the CBR value and the BPCD content; $R^2 = 0.9970$. This correlation can be represented by

$$CBR = 2.46 D + 41.8 \tag{4}$$

Practically speaking, this correlation provides a useful guideline for estimating the content of BPCD for a given target CBR value; this correlation corresponds to a soil with dry unit weight of 18.928 kN/m³. However, to establish a generalized guideline that can be used to determine the effect of BPCD content on the CBR value for soils of different types, properties, and dry unit weights, further investigation is warranted. Until such a generalized guideline is established, the correlation given by the expression in Eq. 4 should be used prudently when applied to soils that are different from the soil used in the current investigation, or alternatively, reasonable corrections should be made.

Conclusions

In this paper, the results of modified Proctor tests and California bearing ratio (CBR) tests conducted on soils mixed with different contents of by-pass cement dust (BPCD) are presented and discussed to evaluate the effectiveness of BPCD as a soil stabilizer in road construction works. On the basis of these results and discussions, the following conclusions can be made:

- 1) BPCD is effective as a stabilizer of soils used in road construction.
- 2) The improvement of soil in terms of the increases in the maximum dry unit weight and CBR value because of BPCD increases with the increase in BPCD content.
- 3) For the considered soil and range of BPCD content, which is 5.0–15.0%, BPCD could increase the maximum dry unit weight and CBR value of the test soil by approximately 4.7–18.9 and 34.0–90.0%, respectively.
- 4) The increases in the maximum dry unit weight and CBR value have good correlations with the content of BPCD. The maximum dry unit weight increases practically exponentially with the increase in BPCD content as given by Eq. 3. The CBR value increases practically linearly with the increase in BPCD content as given by Eq. 4. These correlations can be used in the design of BPCD-stabilization works for given target degree of compaction and/or CBR value.
- 5) Further investigation is needed to quantitatively evaluate the effect of BPCD on the maximum dry unit weight and CBR value for soils of types and properties different from those considered herein. Extended investigation is also warranted to evaluate the effect of BPCD on CBR value for different degrees of compaction.

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References

- S.Abd El-Aleem, M.A.Abd-El-Aziz, M.Heikal, H.El-Didamony, (2005), Effect of cement kiln dust substitution on chemical and physical properties and compressive strength of Portland and slag cements, *The Arabian Journal for Science and Engineering*, Vol. 30, No. 2B, 263–273.
- K.I.Abdel-Ghani, R.R.El-Sakhawy, (1994), Soil Improvement using by-product materials, *Proceedings of the 2nd Geotechnical Engineering Conference*, Cairo University, Egypt, Vol. 1, 466–474.
- W.S.Adaska, D.H.Taubert, (2008), Beneficial uses of cement kiln dust, *IEEE/PCA 50th Cement Industry Technical Conference*, Miami, Fl.
- A.A.Amer, I.M.Helmy, S.A.S.El-Hemaly, H.El-Didamony, (1991), Aggressive attack of Sulphate bearing waters on blended cement pastes, *Indian Journal of Technology*, Vol. 29, 379–384.
- M.S.Y.Bhatty, (1984), Kiln dust cement blends, evaluated, *Rock Products*, Chicago, Illinois, USA, Vol. 88, No. 10, 47–65.
- M.S.Y.Bhatty, (1986), Properties of blended cement made with Portland cement, cement kiln dust, fly ash and slag, *Proceedings of the 8th International Congress on the Chemistry of Cement*, Rio de Janeiro, Brazil, 118–127.
- R.J.Collins, J.J.Emery, (1983), Kiln dust-fly ash systems for highway bases and subbases, *Report No. FHWA/RD-82/167*, Federal Highway Administration, Washington, DC.
- M.El-Demirdash, H.Ghorab, G.M.Ghanem, S.Fakhry, (1999), The scientific methods of reusing the cement kiln by-pass dust (CKD) inside the cement companies in Helwan industrial area, *Center of Technological Development for Researches and Studies (H.C.T.)*, Helwan University, Egypt.
- H.El-Didamony, M.Elwan, A.El-Alfife, (2001), Effect of sand and bypass cement dust as non-plastic materials on clay bricks, *Proceedings of the 7th International Conference on Mining, Petroleum and Metallurgical Engineering (MPM7)*, Asyut, Egypt, 333–342.
- G.J.Hawkins, J.I.Bhatty, A.T.O'Hare, (2003), Cement kiln dust production, management and disposal, *R&D Series No. 2327*, Portland Cement Association, Skokie, Illinois, USA.
- C.C.Huang, F.Tatsuoka, Y.Sato, (1994), Failure mechanisms of reinforced sand slopes loaded with a footing, *Soils and Foundations*, Vol. 34, 27–40.
- A.Katz, K.Kovler, (2004), Utilization of industrial by-product for the production of controlled low strength materials (CLSM), *Waste Management*, Vol. 24, 501–512.
- F.Khodary, M.S.Abd El-Sadek, H.S.El-Sheshtawy, (2013), Nano-size cement by-pass as asphalt modifier in highway construction, *International Journal of Engineering Research and Applications*, Vol. 3, No. 6, 645–648.
- A.Krysztafkiewicz, M.Maik, (1984), Waste cement dust as activating agents for rubber compound, *Cement and Concrete Research*, Vol. 14, 615–621.
- G.A.Miller, S.Azad, (2000), Influence of soil type on stabilization with cement kiln dust, *Construction and Building Materials*, Vol. 14, No. 2, 89–97.
- N.Min'ko, I.Ermolenko, (1992), Use of dust from cement plant electrostatic precipitator in glass engineering, *Steclo Keramika*, No. 3, 3–5.
- A.M.O.Mohamed, (2002), Geoenvironmental aspects of chemically-based ground improvement techniques for pyritic mine tailings, *Proceedings of the 4th International Conference on Ground Improvement Techniques*, Kuala Lumpur, Vol. 1, 113–130.
- A.H.Mostafa, (2012), Effect of cement kiln dust addition on activated sludge process without primary settling for reuse applications, *HBRC Journal*, Vol. 8, 14–25.
- R.Napeierala, (1983), Stabilization of the subsoil with the dust from the kilns of Portland cement clinker burning, *Cement-Wapno-Gips*, Vol. XXXVI/L, No.4, 127–28.
- A.M.Neville, (1996), *Properties of Concrete*, Fourth Edition, John Wiley & Sons Inc., New York.
- C.E.Pierce, H.Tripathi, T.W.Brown, (2003), Cement kiln dust in controlled low strength materials, *ACI Materials Journal*, Vol. 100, No. 6, 455–462.
- M.K.Rahman, S.Rehman, O.S.B.Al-Amoudi, (2011), Literature review on cement kiln dust usage in soil and waste stabilization and experimental investigation, *IJRRAS*, Vol. 7, No. 1, 77–87.
- R.S.Ravindrarajah, (1982), Usage of cement kiln dust in concrete, *International Journal of Cement Composites and Lightweight Concrete*, Harlow, U.K, Vol. 4, No. 2, 95–102.
- M.C.Santagata, A.Bobet, (2002), The use of cement kiln dust (CKD) for subgrade stabilization/modification, *SPR No. 2575*, Purdue University, USA.
- H.A.Todres, A.Mishulovich, J.Ahmed, (1992), Cement kiln dust management: permeability, *Research and Development Bulletin RD103T*, Portland Cement Association, Skokie, Illinois, USA.