Case Studies in Construction Materials 10 (2019) e00223

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Short communication

Experimental study on properties of natural soils treated with cement kiln dust

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ARTICLE INFO

Article history:
Received 28 November 2018
Received in revised form 19 January 2019
Accepted 24 January 2019

Keywords:
Engineering properties
Unconfined compressive strength
Natural soil
Cement kiln dust

ABSTRACT

Soil improvement by the addition of chemical or cementitious additives is emerged as a remarkable solution to provide a suitable ground for infrastructure construction. Previous studies have used several additives together with the cement kiln dust (CKD) worldwide. Using CKD as an additive would also lower the solid waste problem in cement industry, thus CKD can be used effectively as a sustainable solution. To illustrate the efficacy of CKD in soil improvement, this study treated two natural soils with several proportions of CKD for various curing periods. Extensive laboratory tests were carried out to depict the variation of unconfined compressive strength by treating the natural soils with CKD at various proportion. Samples were prepared for natural soils with and without CKD. Similarly, tests were carried out in dry and immersed conditions. The sum of results highlights that significant increment in the unconfined compressive strength is achieved when CKD is used as an additive in natural soil.

1. Introduction

Due to ever increasing demand of cement worldwide, quantity of cement kiln dust (CKD) is being collected in record high quantity in recent years. In most of the countries, CKD is considered as a solid waste; however, in some other countries alternative use is already in practice. Previous studies by Al-Homidy et al. [1] Ahmed et al. [2] Osmanovic et al. [3] El-Attar et al. [4] Arulrajah et al. [5] Al-Rezaiqi et al. [6], among others highlight the use and properties of CKD when mixed with other construction materials. Arulrajah et al. [5] studied the efficacy of CKD along with fly ash as binder focusing on the durability. Similarly, Ahmed et al. [2] observed significant increase in the compressive strength of CKD bricks when such bricks are treated with industrial wastewater. On the contrary, El-Attar et al. [4] focused on the recyclability of CKD itself to assure sustainability. Ismail and Belal [7] performed an analysis of engineering properties of soils using 5, 10, and 20% CKD and observed that the plasticity index decreased due to such addition. They further noted that the optimum moisture content increased with increasing the percentage of CKD. Similarly, Sariosseiri and Razavi [8] conducted series of tests to investigate the contribution of cement and CKD and found that optimum moisture content increases when CKD is added to soil samples. They further concluded that the dry unit weight of soil decreases with the addition of CKD. Mosa et al. [9] performed showed that adding 20% of CKD with curing for 14 days led to an increase in the CBR value from 3.4% in untreated soil to 48% in treated soil. Similarly, Arulrajah et al. [5] Yoobanpot et al. [10], Miller and Azad [11], Amadi [12], Amin and Hashem [13], Hashem

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https://doi.org/10.1016/j.cscm.2019.e00223

et al. [14], Salahudeen et al. [15], Amadi and Eberemu [16], Sadek et al. [17], Baghdadi and Rahman [18], Jimoh et al. [19]; among others conducted experimental works to identify the contribution of CKD in soil stabilization as well as improvement of engineering properties in various kinds of soils. As of now, sustainability concept is gradually surpassing the conventional design and construction scenarios. Thus, durability, recyclability, toxicity, among others are crucially considered when accounting with the industrial by-product like CKD. As can be seen from the existing literature search, notable attention has been paid in the global scale, however, to the best of authors' knowledge, no works have been done in Nepal.

Poor soil conditions can result in inadequate support to the structure and reduce the structure's life as well. Soils may be improved by the addition of chemical or cementitious additives. These chemical additives range from waste products to manufactured materials that include lime, Class C fly ash, Portland cement, cement kiln dust and proprietary chemical stabilizers. These additives can be used with a variety of soils to help improve their native strength characteristics. Different types of structures such as highways, airport runways, embankment, and dams require satisfactory engineering properties of soil. Soil is a naturally formed complex material having the engineering properties which is often partially or entirely unsuitable for a particular need. When such soil is met at the construction site, its strength characteristics should be enhanced as per site requirement. Soil stabilization deals with physical, physio-chemical and chemical methods to make the stabilized soil serve its purpose as construction material. Undesired properties of soil have been a continuing problem for structures constructed on it. A firm soil layer is an essential component of the structure. Its engineering properties, viz., strength and modulus, have an influence on the overall performance of a structure since cement kiln dust is a byproduct during cement production and its environmentally friendly disposal is itself an issue. If CKD can be used to treat soil to improve its properties than both the problem of disposal and soil stability can be solved at the same time. This will in turn provide economic benefits as well. To assess the efficacy of the CKD as an additive in Nepal, this study considers borrow pit soils from Kathmandu valley be treated with CKD. The compaction characteristics and unconfined compressive strength parameters are studied for various proportions and time interval. Similarly, this study aims to compare the strength characteristics of untreated and CKD treated soil samples using laboratory test results.

2. Materials and methods

For this study, disturbed natural soils from borrow pit and different proportions of cement Kiln dust were used experimental materials. The natural soil samples were collected from Satdobato area (soil A) and from Tokha (soil B) neighborhoods of Kathmandu valley, Nepal. Disturbed soil samples were collected from the depth of excavation of about 2.5 m and were immediately kept into plastic bags to prevent from the contamination with other materials. The samples were brought to the Central Material Testing Lab of Institute of Engineering, Pulchowk Campus and were carefully stored. The CKD, which is used as an additive for this study, was collected from Shivam Cement Factory Hetauda, Nepal. The properties of CKD were identified from laboratory analysis are presented in Table 1.

Both the soil samples were air dried about 10 days in shade at room temperature of about 25 °C–30 °C and then crushed with wooden hammer. Sample passing through sieve no. 4 ASTM was used for compaction and unconfined compressive strength tests. The dry material was mixed with CKD thoroughly until a uniform color was observed. Formation of clumps was avoided when water was added to soil-CKD mixture. Samples were prepared at optimum water content and maximum dry density. The various properties which would be considered as index properties are the grain size of particles, specific gravity, and Atterberg limits. They were determined using usual method as specified by ASTM standards.

A 500 gm of soil sample was wet and sieved through sieve no. 200 to separate coarse and fine fractions. The fractions passing through the sieve no. 200 was analyzed using hydrometer and 75 gm of soil sample passing through sieve no. 200

Table 1
Properties of the CKD used as an additive.

Constituents	Percentage
Chemical Analysis	
Silicon Dioxide, SiO_2	17.62
Aluminum Oxide, Al_2O_3	4.90
Iron Oxide, Fe_2O_3	2.58
Calcium Oxide, CaO	62.09
Magnesium Oxide, MgO	1.93
Sodium Oxide, Na_2O	0.56
Potassium Oxide, K_2O	3.76
Sulfur Trioxide, SO_3	5.79
Moisture content	0.07
Loss of Ignition	4.94
Available Lime Index, CaO	33.7
Water-Soluble Chlorides, CL	–
Physical Analysis	
Retained on No.325 sieve (%)	16.9
Specific Gravity	2.95

was taken and treated with the dispersing agent for 18 h. Dry sieving was done on soils retaining in the sieve no. 200. Atterberg limit is used to classify the soils. To find the liquid limit, Casagrande device was used to determine the number of blows and plastic limit was determined by rolling 3 mm diameter threads of soil until they started cracking longitudinally. The test was performed on natural air-dried soil samples passing through sieve no. 40. The Unified Soil Classification System (UCS) was used to classify the soil in this study. The UCS allocates a two-letter symbol to represent a particular soil type based on the particle size analysis and the Atterberg limits. Among two types of classification procedures: the visual-manual procedure and the more rigorous testing-based procedure, the second is used in this research. As specific gravity is necessary to determine the compaction characteristics. The specific gravity of soil solid was determined in lab using Pycnometer. Optimum moisture content and maximum dry density of untreated and treated soil samples were determined using standard proctor compaction test. Optimum moisture content and maximum dry density of the CKD treated soils was also determined using Harvard Miniature compaction apparatus. Soil sample passing through sieve no. 4 was used for this purpose. The Unconfined compressive strength (q_u) and undrained shear strength ($S_u = q_u/2$) was obtained by unconfined compressive strength test. This test was carried out using Unconfined Compression Testing Machine. For this test, sample was extracted from Harvard miniature apparatus. This test is used globally for rapidly measuring shear strength of soil and can only be done if the soil is intact and has cohesion. Since the test is quick, water is not allowed to drain out of the sample.

Once the engineering properties of the natural soils were determined, specimens were prepared at optimum water content and maximum dry density for each mixture (0, 2.5, 5, 7.5, and 10% CKD content) using the Harvard Miniature Apparatus. For each CKD content, two sets of specimens were prepared. One set was wrapped in plastic bag and was put in an air tight container with a wet sponge placed upon it and tested after 7, 14, and 28 days. The other set was wrapped in a plastic bag and placed in an air tight container with a wet sponge, then immersed in water after one day for curing for 7, 14, and 28 days test samples.

3. Results

3.1. Index properties of soil samples

The two soil samples were found to be ML (sample A) and CL (sample B) per the UCS classification system. Figs. 1 and 2 show the grain size distribution curve for soil A and soil B respectively used for the laboratory tests. Fig. 1 shows that 54.5% of particles are smaller than 0.075 mm (Sieve no. 200) and hence the soil A is fine grained (ML); on the contrary, for soil B, 80% of particles are smaller than 0.075 mm (Sieve no. 200) so the soil B is also fine grained (CL).

By Pycnometer analysis, the specific gravity of soil A is found to be 2.675 and that for the soil B is found to be 2.63. The results of Atterberg limit tests for the soils are shown in Table 2. Soil A is found to be Silt of low plasticity when plotted in USCS Casagrande plasticity chart and Soil B is found to be clay of low plasticity.

For soil A the maximum dry density and optimum moisture content from standard proctor test were found to be 14.56 K N/m^3 and 21.79% respectively. The Harvard Miniature Test depicted the maximum dry density was obtained as 14.60 K N/m^3 at the optimum moisture content of 22%. For soil B, the maximum dry density and optimum moisture content

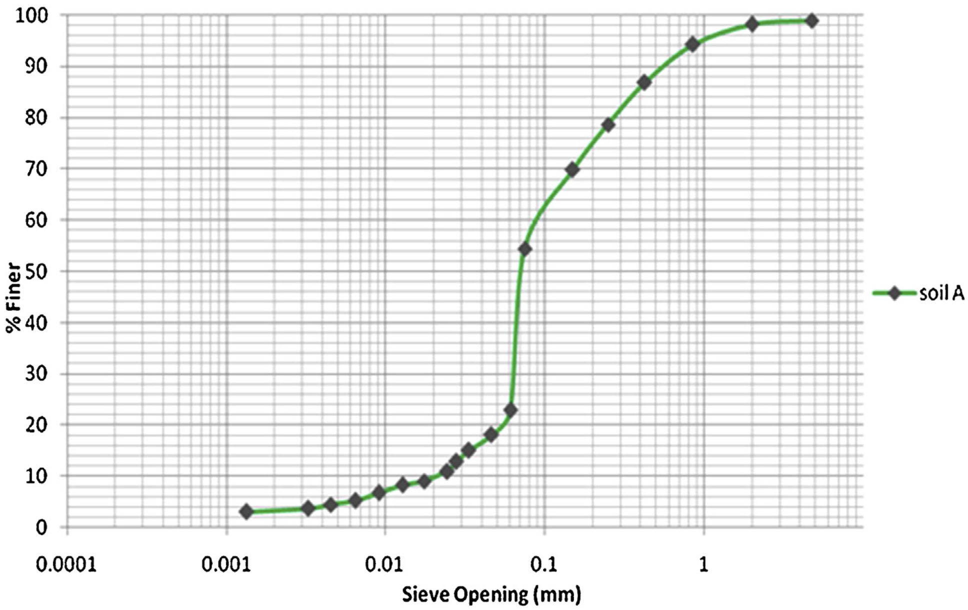

Fig. 1. Grain size distribution curve for soil A.

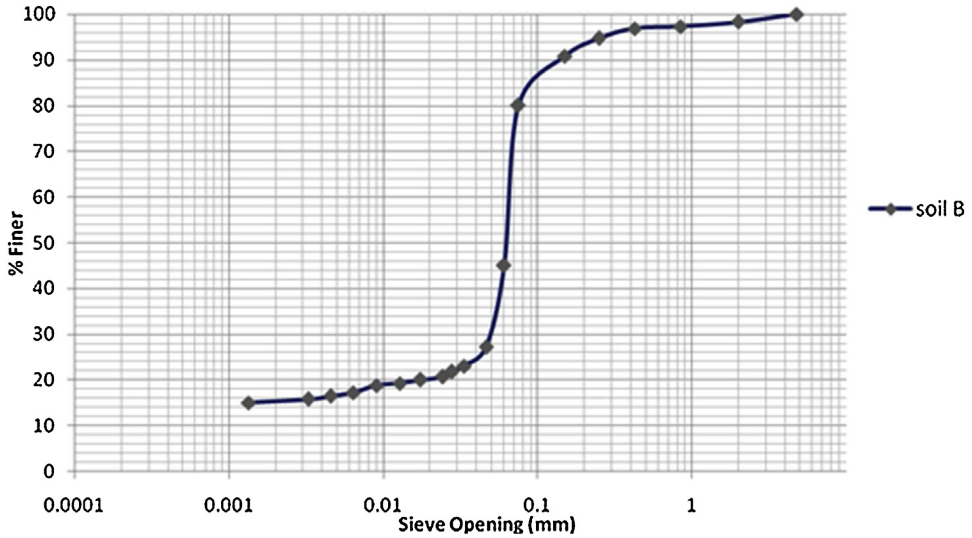

Fig. 2. Grain size distribution curve for soil B.

Table 2
Atterberg limits for the natural soils.

Soil sample	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Soil type according to USCS
A	38.06	29.00	9.06	Silt of Low plasticity
B	26.00	6.00	20.00	Clay of low plasticity

from standard proctor test were found to be 15 K N/m^3 and 22% respectively. This resulted in the maximum dry density of 15.3 K N/m^3 at the optimum moisture content of 22%. From the laboratory observations, the soil A was found to have lesser density and optimum moisture content than the soil B.

Figs. 3 and 4 show the comparison of maximum dry density and optimum water content for Standard Proctor Test and Harvard Miniature Test at various proportions of CKD for soil A and soil B respectively. Similarly, Figs. 5 and 6 show the comparison of maximum dry density and optimum water content for standard proctor test and Harvard Miniature Test at various proportions of CKD for soil B. As shown by Figs. 3 and 5, the maximum dry density of soil A was less than 16 K N/m^3 in the case of both Harvard Miniature Test as well as Standard Proctor Test; whereas the maximum dry density of soil B was found to be greater than 16 K N/m^3 for both tests. It is noted that the Harvard Miniature Test reflects higher maximum dry density for both samples when compared to Standard Proctor test results. Similarly, optimum moisture content was found to be higher in soil sample B and the higher values were reflected by Harvard Miniature Test. The motive of performing both Standard Proctor Test and Harvard Miniature Test was to compare the results from both tests.

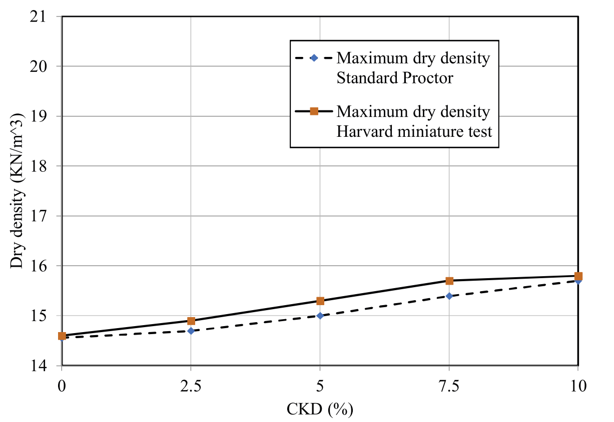

Fig. 3. Maximum dry densities for various proportions of cement kiln dust obtained by Standard Proctor test and Harvard miniature test (Soil A).

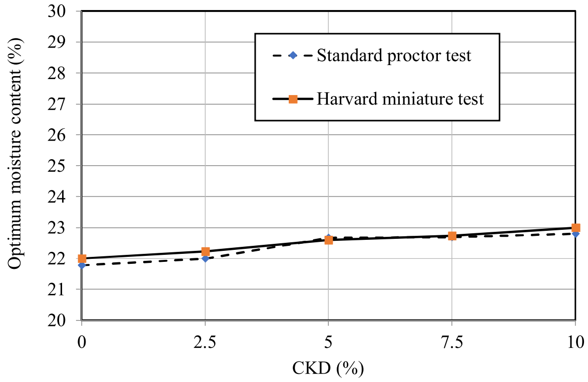

Fig. 4. Optimum moisture content for various proportions of CKD obtained by Standard Proctor Test and Harvard Miniature Test (Soil A).

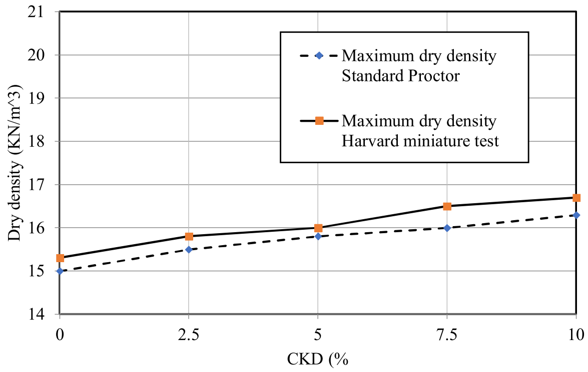

Fig. 5. Maximum dry densities for various proportions of cement kiln dust obtained by Standard Proctor test and Harvard miniature test (Soil B).

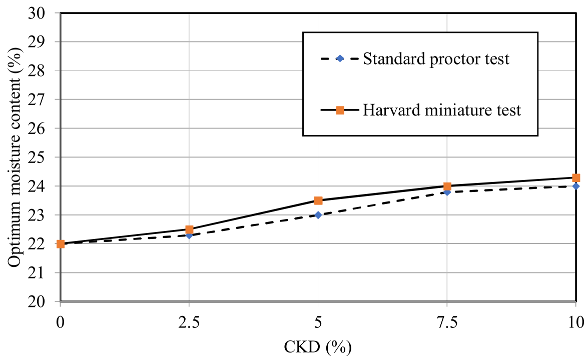

Fig. 6. Optimum moisture content for various proportions of CKD obtained by Standard Proctor Test and Harvard Miniature Test (Soil B).

3.2. Unconfined compressive strength

The tests show that the unconfined compressive strength of non-treated soil increased from 0.346 kg/cm^2 to 1.65 kg/cm^2 when kept dry for 28 days. Table 3 shows the effect of time on unconfined compressive strength of non-treated dry samples of soil A and soil B. The tests show that the unconfined compressive strength of non-treated soil increased from 0.318 kg/cm^2 to 1.53 kg/cm^2 when kept dry for 28 days. The stress-strain behavior of CKD treated soil samples for dry samples at the same day of preparation, 7, 14, 28 days are respectively shown in Table 3. The variation of unconfined compressive strength of soil sample A is presented per the time variation. A notable increment in unconfined compressive strength is observed in the first seven days as shown in Table 3. Meanwhile, the higher the content of CKD, greater strength is obtained. Apart from the dry samples, immersed samples were also tested in laboratory under various CKD mix ratios and time variation. In the same way, the stress-strain behavior of sample B was determined for the same CKD contents in the same time interval. The summary of

Table 3
Unconfined compressive strength (Kg/cm^2) for cement kiln dust treated dry samples tested at various days.

Day	Soil type	CKD % by dry weight of soil				
		Non-treated	2.50%	5%	7.50%	10%
First day	Soil A (ML)	0.346	0.761	1.053	1.310	1.670
	Soil B (CL)	0.318	0.692	0.984	1.230	1.590
7th day	Soil A (ML)	0.684	2.162	2.834	3.953	5.658
	Soil B (CL)	0.588	2.013	2.552	3.408	5.240
14th day	Soil A (ML)	1.103	3.244	3.828	5.388	7.857
	Soil B (CL)	1.048	2.999	3.554	5.119	7.521
28th day	Soil A (ML)	1.650	5.959	7.365	9.323	10.552
	Soil B (CL)	1.531	5.624	7.097	9.064	10.156

the unconfined compressive strength for both samples under various conditions is presented in Table 3. Table 3 shows that the unconfined compressive strength of the sample A (ML) is greater than sample B (CL) for all variations. For the immersed samples, Table 4 presents the summary of unconfined compressive strength of both soil samples. Table 4 also highlights that the unconfined compressive strength of ML is always greater than that of CL.

4. Conclusion

Soils may be improved by the addition of chemical or cementitious additives for engineering purposes. These chemical additives range from waste products to manufactured materials and include lime, Class C fly ash, Portland cement, cement kiln dust from pre-calciner and long kiln processes, and proprietary chemical stabilizers. These additives can be used with a variety of soils to help improve their native engineering properties. One of the option could be the CKD due to the growing need of cement as a construction material which leads into massive production leaving enormous amount of cement kiln dust as a byproduct. To identify the possibility of soil improvement by this waste product, this study conducted series of experimental campaigns in dry and immersed conditions for two local soil types of Nepal. The quantity of CKD was varied for both samples and series of tests were performed. The major conclusions obtained from this study are as follows:

- As the cement kiln dust content increases, both the maximum dry density and optimum water content increase for both soil samples i.e. ML and CL, although the rate is not so high.
- The rate of increase of unconfined compressive strength for the both untreated soil samples is not significantly high as the soil A showed an increment from 0.346 kg/cm^2 on the first day to 1.65 kg/cm^2 on the 28th day. Similarly, the unconfined compressive strength of untreated soil sample increased from 0.318 kg/cm^2 on the first day to 1.531 kg/cm^2 on the 28th day. These results demand the need of additives to significantly improve the unconfined compressive strengths for both samples.
- The addition of cement kiln dust led to the increase in unconfined compressive strength for both soil samples. The unconfined compressive strength of 2.5% CKD treated soil sample (A) tested immediately after preparing the sample was obtained as 0.761 kg/cm^2, whereas the unconfined compressive strength of 10% cement kiln dust treated soil was found to be 10.552 kg/cm^2 on the 28th day. Similarly, the unconfined compressive strength of 2.5% cement kiln dust treated soil sample (B) tested immediately after preparing the sample was 0.692 kg/cm^2, whereas the unconfined compressive strength of 10% cement kiln dust treated soil sample was found to be 10.156 kg/cm^2 on the 28th day. Thus, CKD was responsible for the increment of unconfined compressive strength of soil by nearly 10 times.
- As the cement Kiln dust content increases, for dry samples, the rate of increase of unconfined compressive strength is high up to 14 days and is relatively low after 14 days.
- In the case of immersed samples non-treated and 2.5% CKD treated samples showed comparably similar results, whereas 5%, 7.5%, 10% CKD treated soil samples showed some increase in the unconfined compressive strength.

Table 4
Unconfined compressive strength (Kg/cm^2) for cement kiln dust treated immersed samples tested at various days.

Day	Soil type	CKD % by dry weight of soil		
		5%	7.50%	10%
7th day	Soil A (ML)	0.943	1.581	1.926
	Soil B (CL)	0.835	1.419	1.751
14th day	Soil A (ML)	1.030	1.562	1.962
	Soil B (CL)	0.949	1.402	1.869
28th day	Soil A (ML)	1.568	1.863	2.638
	Soil B (CL)	1.385	1.797	2.389

- As the CKD content increases, the unconfined compressive strength for both the dry and immersed samples increases but the rate of increase is relatively low in case of immersed samples for both soil samples.
- As the percentage of CKD increases, there is decrease in the reduction of unconfined compressive strength of CKD treated immersed samples with respect to CKD treated dry samples.
- Soil sample A (ML) shows slightly higher value of unconfined compressive strength than to the soil sample B (CL) for non-treated conditions.

From the behavior and the trend of obtained results, it can be concluded that CKD can be an effective additive as it improves the soil strength significantly. The results of this study are limited to 0, 2.5, 5, 7.5, and 10% addition of CKD for two soil samples in Kathmandu valley. Thus, for exhaustive understanding, more samples and addition of greater than 10% CKD is also recommended for future researches.

Conflict of interest

Authors declare that no conflict of interest of any type exists in the reported work.

Acknowledgements

The first author would like to thank Chandra Man Shrestha, Central Material Testing Laboratory, IOE, Pulchowk Campus, Ravi Acharya, Sujan Pradhan, Ramjee Shrestha, and Shivam Cement Pvt. Ltd. for their contributions during the study.

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