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Experimental Evaluation of Stabilising Potential of Brick Dust in Clay Soils

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Abstract

Construction on clayey soil is one of the biggest challenging tasks for engineers as this soil exhibits unpredictable behavioural changes due to its formation from chemical weathering. Soil stabilization is one of the solutions that are useful in augmenting the soil properties by adding different additives in it. From economic perspective, brick dust is a cheaper alternative to conventional materials. India is the second largest manufacturer of brick and tons of brick waste generated each year goes in unplanned way. This waste occupies arable land creating environmental concerns. The problems could be solved by using this material as a soil stabilizer. In this study, the effect of brick dust (introducing in various percentages) on permeability, shear strength and consolidation characteristics of clayey soil is investigated. In addition, laboratory experiments like consistency limit tests, compaction test, unconfined compressive strength test and CBR tests are also performed with an objective to reach for better results and conclusions. Laboratory examination of soil was carried out and laboratory experiments were carried out on soil mixed with varying percentages of brick dust (i.e., 0%, 10%, 20%, 30%, 40% and 50%). The results obtained shows that addition of brick dust as additive is satisfactory when mixed with clayey soil.

Keywords: Clayey soil, stabilization, brick dust, consolidation, shear strength, permeability characteristics.

Introduction

Over several years, innumerable reasons have amplified the rate of migration of flocks to large cities. Consequently leaving these big cities overcrowded that have somehow resulted in the urbanization and construction of big engineering structures[1]. With this unexpected growth of population, suitable lands for civil engineering activities have become a major necessity. This can only be accomplished when the soil in that area is competent enough to bear the load impacted on it. Generally, the soils are classified as clayey and sandy type. The latter formed by physical weathering barely poses any threat, whereas clay formed by chemical weathering, is considered as a problematic soil because of its unpredictable behavioural changes[2,3]. Construction on clayey soil is the major problem faced by geotechnical engineers. Numerous studies have been done in the past to bring out a sustainable solution to this issue[4]. The solution they have come up with is soil stabilization which is augmenting the soil properties by adding different additives in it.

Design and construction of civil engineering structures in such soils undergo foundation problems, which lead to a reduction in the life span of such structures[5]. Encountering such problems is a herculean task for civil engineers and the solutions of such problems include unearthing and replacing a layer of clay with a certain fill to minimize moisture changes[5]. The cited solutions are uneconomical as it necessitates the removal of significant amount of inferior materials and the soil with good engineering properties has to be hauled from a long distance[5]. Global demand for energy and good quality of construction materials constrain engineers to make use of stabilization techniques on the locally available soil so as to curtail down the cost of project[6]. Thus, geotechnical engineering design requires the use of potentially cost effective materials that are locally available in order to augment the engineering characteristics of the deficient soils[3].

Brick dust is such eco-friendly material which is locally available in brick kilns, loading or unloading and construction sites[7]. India is the second largest manufacturer of brick[8]. The annual production of bricks in India is around 150-200 billion bricks that are manufactured in more than 100,000 brick kilns[8]. Thousands tonnes of brick waste is produced every year much of which is discarded inadvertently. The waste generated in brick kilns occupies space as well as creates environmental problems[7]. The problems could be reduced by using this waste material as a soil stabilizer. From economic perspective, application of brick dust in the stabilization of soil provides a cheaper alternative to conventional materials[6]. Environmentally, using a vast amount of brick dust in stabilization of soil and other engineering construction not only leads to greener construction material but also helps in reducing wastes in the environment[7].

The main purpose of this study is to analyze the modifications in the geotechnical characteristics of soil when stabilized adding brick dust. This investigation attempts to explain the effect of brick dust on selected soil when mixed in percentages varying from 0 to 50% (*i.e.*, 0%, 10%, 20%, 30%, 40% and 50%) in order to predict the alterations in its strength, permeability, compression characteristics and consistency.

Material and Methods

The following materials were used for laboratory investigation: i. Soil, ii. Brick Dust.

Soil: Soil sample was procured from Crop Research Centre (CRC) - Block D_1 (Area 6.0 ha) Pantnagar, Uttarakhand, India. For classification of the soil, determination of index properties of the soil were determined following IS codes. Properties of the local soil utilized in further tests are briefed in Table-1.

Table-1: Properties of local Soil.

Parameter		Value
Specific gravity (G)		2.35
Particle size distribution	Sand (%) (4.75 – 0.075mm)	37.72
	Silt (%) (0.075– 0.002mm)	39.89
	Clay (%) (<0.002mm)	22.39
	IS Classification	CL
Consistency limits	Liquid limit, w_L (%)	22.52
	Plastic limit, w_P (%)	8.15
	Plasticity Index, I_P (%)	14.37
	OMC (%)	16.0
	MDD (kN/m^3)	16.28
CBR Values	Un-soaked (%)	3.77
	Soaked (%)	3.18

Brick Dust: Brick dust was collected from Gurunanak Brick Supplier, Kalinagar Village, Rudrapur, Udham Singh Nagar (Uttarakhand) and was brought in sack to the laboratory. The properties of brick dust have been studied by performing laboratory tests that are sieve analysis and Atterberg's limits tests. The index properties of the additive brick dust are listed below in Table-2.

Table–2: Index properties of Brick dust.

Parameters	Value
Specific gravity (G)	2.70
Particle size distribution:	
Sand (%)	81.0
Silt and Clay (%)	19.0
IS Classification	SP
Consistency limits:	
Liquid limit, w_L (%)	NP
Plastic limit, w_P (%)	NP
Plasticity Index, I_P (%)	NP

Methodology Adopted: The testing programme was executed in two stages: i. In the first stage, geotechnical properties of soil samples were studied by performing specific gravity test, grain size sieve analysis; consistency limits test, permeability test, CBR test, compressibility tests (compaction and consolidation), UCS test and triaxial shear test. ii. In the second stage, the soil mixed with various proportions (*i.e.* 10%, 20%, 30%, 40% and 50%) of brick dust was tested to determine the modification in the soil properties.

Results and Discussion

In this section, the outcomes are presented which are based on the various laboratory tests carried out on the natural soil and the soil mixed with various proportions of brick dust (BD).

Results on Geotechnical Properties of Soil: Specific Gravity: The specific gravity of soil was determined according to IS: 2720 (Part III)-1980. Three tests on identical samples were conducted and average of them was reported as specific gravity of the soil comes out to be 2.35.

Grain Size Analysis: In order to find out the particle size distribution of local soil, grain size analysis was performed as per IS: 2720 (Part IV) - 1985. Figure-1 presents typical plot of grain size distribution of tested soil.

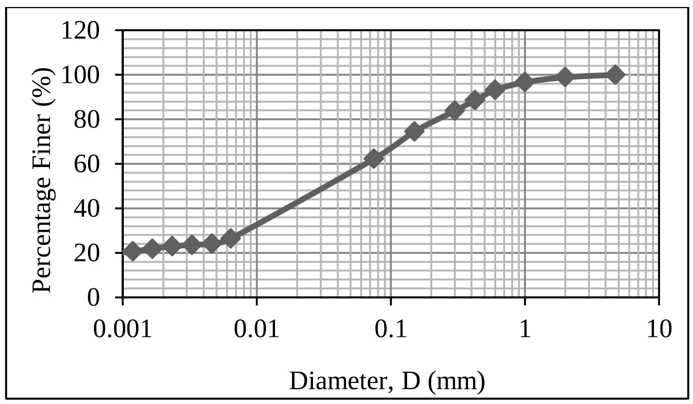

Figure-1: Curve showing particle size distribution of local soil.

Consistency Limits: Consistency limits play a significant part in the identification as well as the classification of the soil. To attain this objective, consistency limit tests were performed on soil as per IS: 2720 (Part V) - 1985. The liquid limit of soil was 22.52%, plastic limit was 8.15% and plasticity index of soil was 14.37%.

Outcomes of Geotechnical Properties of Soil Mixes: Specific Gravity: The soil was mixed with various proportions of brick dust (*i.e.,* 10%, 20%, 30%, 40% and 50%). Average value of three tests samples were taken as specific gravity of soil mixtures. Table-3 presents the values of specific gravity of mixes and Figure-2 shows variation of specific gravity of local soil with increasing percentage of brick dust.

Consistency Limits: The consistency limit tests were carried out on soil samples with percentage of brick dust varying from 0-50% (*i.e.,* 0%, 10%, 20%, 30%, 40% and 50%). The consistency limit test values *i.e.* for liquid limit (w_L), plastic limit (w_P) and plasticity index (I_P) values are presented in Table-4 for the discussed soil samples. The curves showing variation in consisitency limits and plasticity index (I_P) of soil with varying percentage of brick dust is presented in Figure-3.

Table-3: Specific gravity values of soil with varying proportions of Brick Dust.

Mix	Specific Gravity
Soil + 0% BD	2.35
Soil + 10% BD	2.39
Soil + 20% BD	2.42
Soil + 30% BD	2.46
Soil + 40% BD	2.49
Soil + 50% BD	2.53

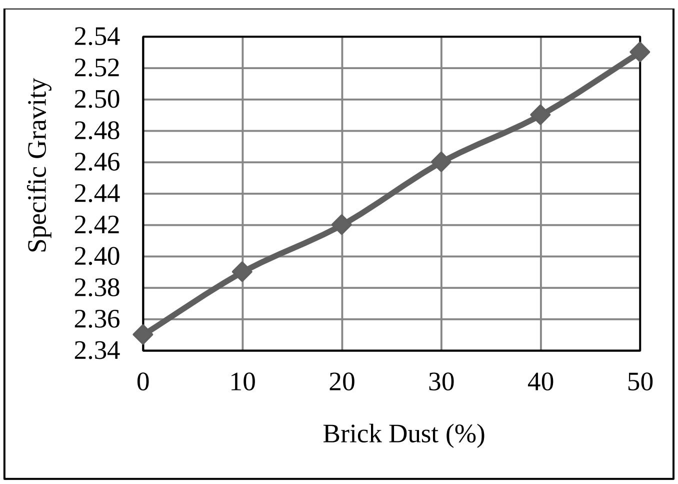

Figure-2: Variation curve of specific gravity of soil with increasing percentage of BD.

Table-4: Consistency limits values of soil with varying proportions of Brick Dust.

Mix	Liquid Limit (w_L) (%)	Plastic Limit (w_P) (%)	Plasticity Index (I_P) (%)
Soil+0% BD	22.52	8.15	14.37
Soil+10% BD	21.21	7.62	13.59
Soil+20% BD	17.17	4.70	12.47
Soil+30% BD	16.45	4.10	12.35
Soil+40% BD	11.64	3.19	8.45
Soil +50% BD	10.67	NP	-

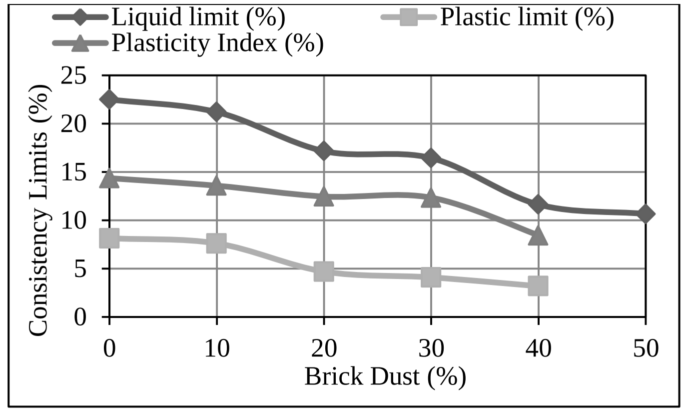

Figure-3: Variation curve of consistency limits and plasticity index of soil with increased percentage of BD.

From the results shown above, it is evident that liquid limit shows a decreasing trend *i.e.* it decreases from 22.52% to 10.67% on increasing the percentage of brick dust from 0-50% (*i.e.,* 0%, 10%, 20%, 30%, 40% and 50%). Further, the typical plot of variation of plastic limit of soil with brick dust mixes shows a decreasing trend. The plastic limit decreases from 8.15% to 3.19% on increasing the brick dust from 0% to 40% while on increasing the brick dust content to 50%, plastic limit could not be determined as a true non-plastic behaviour was observed. Plasticity Index (I_P) reduced from 14.37% to 8.45% with increase in brick dust percentage from 0% to 40% while on increasing the brick dust percentage to 50%, plasticity index could not be determined due to non-plastic behaviour of soil. The reason behind the lessening of plasticity characteristics of soil is the decrease in clay content of the soil because of replacement of finer particles with brick dust[9]. Soils with higher Ip re less desirable for sub-grade or base course than those having lesser indexes.

Compaction Characteristics: The compaction tests were performed as per IS: 2720 (Part VII) - 1980 on soil samples with brick dust percentage varying from 0-50% (*i.e.*, 0%, 10%, 20%, 30%, 40% and 50%). The results of these tests *i.e.*, optimum moisture content and maximum dry density are presented in Table-5. The variation of MDD and OMC of soil with increased percentage of brick dust are shown in Figure-4 and Figure-5.

Table-5: OMC and MDD values of soil with varying proportions of Brick Dust.

Mix	MDD (kN/m^3)	OMC (%)
Soil + 0% BD	16.28	16.0
Soil + 10% BD	16.78	13.20
Soil + 20% BD	17.17	12.0
Soil + 30% BD	18.25	11.20
Soil + 40% BD	18.44	10.12
Soil + 50% BD	18.93	10.0

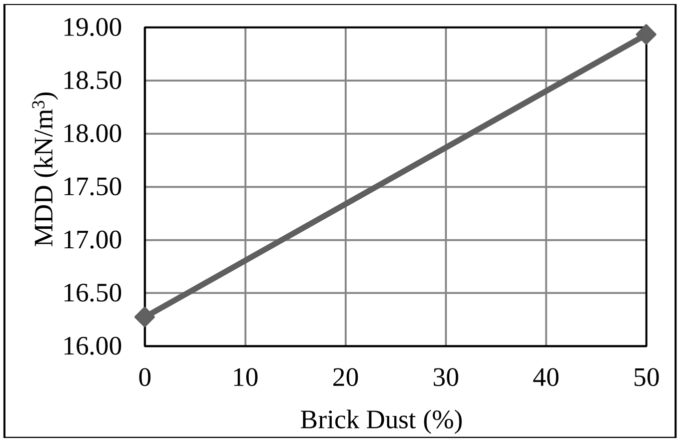

Figure-4: Variation curve of maximum dry density of soil with increased percentage of BD.

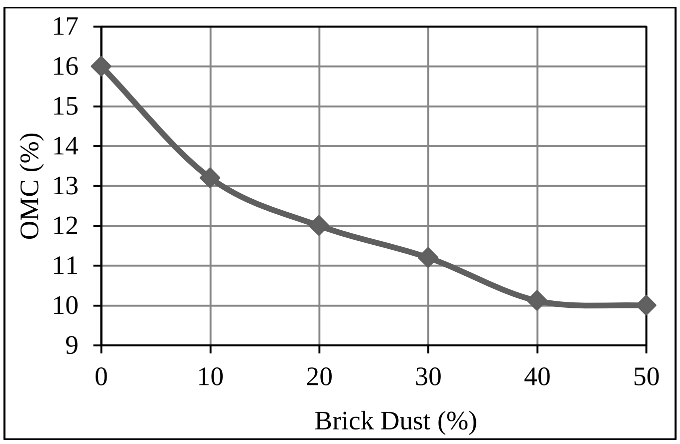

Figure-5: Variation curve of optimum moisture content of soil with increased percentage of BD.

The data summarized in Table-5 showed that maximum dry density (MDD) increases from 16.28 kN/m^3 to 18.93 kN/m^3 while optimum moisture content (OMC) of soil mixes decreases from 16.0% to 10.0% on increasing the brick dust content from 0% to 50%.

The addition of brick dust is mainly responsible for the increment in maximum dry density values as it affects the overall behaviour of the soil samples and thus reducing the ratios of inter-granular voids in soil whereas non-water absorption capacity of brick dust particles cause reduction in optimum moisture content[10].

Permeability: The falling head permeability tests were performed in accordance to IS: 2720 (Part XVII) – 1986 on different soil samples containing brick dust in various proportions (0%-50%). Table-6 shows the values of coefficient of permeability of soil samples and Figure-6 shows the variation curve of coefficient of permeability of soil with change in the percentage of brick dust content.

Table-6: Coefficient of permeability values of soil with varying proportions of Brick Dust.

Mix	Coefficient of Permeability (m/sec)
Soil + 0% BD	9.52×10^{-8}
Soil + 10% BD	3.56×10^{-7}
Soil + 20% BD	6.96×10^{-7}
Soil + 30% BD	2.77×10^{-6}
Soil + 40% BD	4.85×10^{-6}
Soil + 50% BD	6.93×10^{-6}

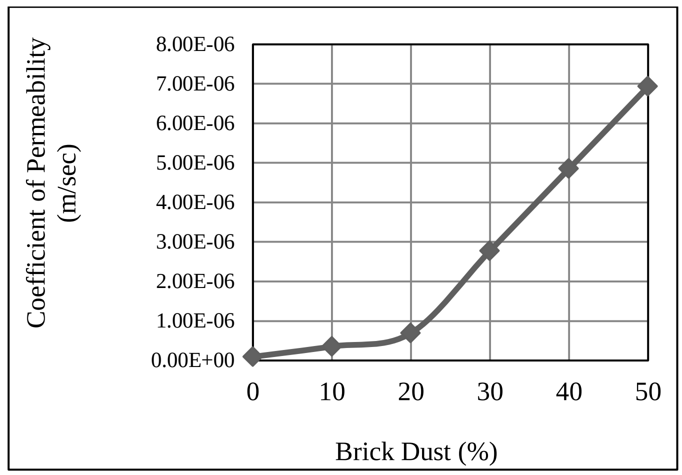

Figure-6: Variation curve of coefficient of permeability of soil with increased percentage of BD.

The coefficient of permeability increased when the percentage of brick dust was increased from 10% to 50%. From the above outcomes, it was observed that when the percentage of brick dust increases in soil, the coefficient of permeability of the soil samples increases from 9.520E-08 m/sec to 6.930E-06 m/sec.

The reason behind this is the increase in the amount of brick dust in the soil mixture which leads to reduction of the quantity of free clay and silt particles leading to the formation of coarser particles and larger voids which allow greater flow of water[11].

Uniaxial Compressive Strength: Uniaxial compression tests were carried out as per IS: 2720 (Part X) – 1991 on soil samples with brick dust percentages varying from 0-50% (*i.e.,* 0%, 10%, 20%, 30%, 40% and 50%). Stress values at failure for these samples of soil are presented in Table-7.

The variation curve of stress at failure with increasing percentage of brick dust is exhibited in Figure-7.

Table-7: Stress at failure of soil with varying proportions of Brick Dust.

Mix	Uniaxial Compressive Strength (kN/m²)			
	0 Days	7 Days	14 Days	28 Days
Soil + 0% BD	96.2	105.4	114.4	130.5
Soil + 10% BD	104.3	183.9	207.5	231.6
Soil + 20% BD	127.6	184.6	225.2	255.3
Soil + 30% BD	132.3	199.9	226.0	264.7
Soil + 40% BD	121.2	155.4	171.0	210.3
Soil + 50% BD	101.2	121.0	132.9	168.7

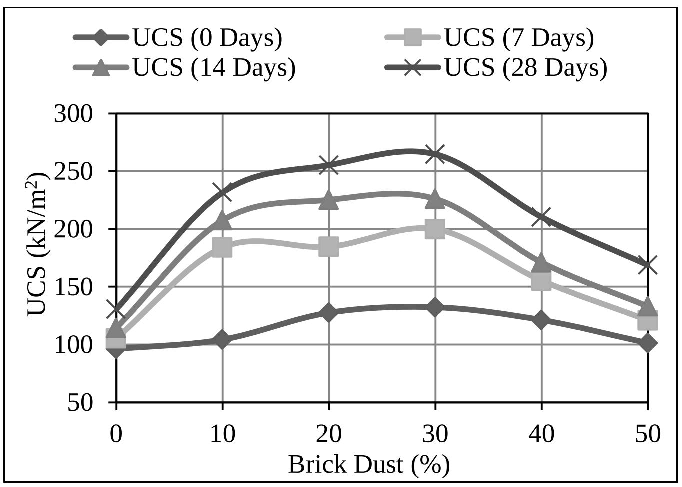

Figure-7: Variation curve of UCS of Soil with increased percentage of BD.

From the observations shown in tabulated and graphical forms, it is evident that the gradation of soil has improved on addition of brick dust to soil thus increasing the interlocking between the particles of soil and brick dust. The increment of 102.77% is seen in the value of UCS for the combination of soil and 30% brick dust (28 days cured). Further addition of brick dust in soil has resulted reduction in the value of UCS of soil due to increase in non-cohesive material.

California Bearing Ratio: The CBR tests were carried out according to IS: 2720 (Part XVI) - 1987 on soil mixed with brick dust percentages varying from 0-50% (*i.e.*, 0%, 10%, 20%, 30%, 40% and 50%).

Table-8 shows the un-soaked and soaked CBR values of the soil mixes. The graphical representation of variation of CBR values of soil with increased proportions of brick dust are presented in Figure-8.

Table-8: CBR values of soil with varying proportions of Brick Dust.

Mix	California Bearing Ratio (%)	
	Un-soaked	Soaked
Soil + 0% BD	3.77	3.18
Soil + 10% BD	4.86	4.53
Soil + 20% BD	6.73	5.98
Soil + 30% BD	7.10	6.35
Soil + 40% BD	10.84	8.22
Soil + 50% BD	17.57	14.20

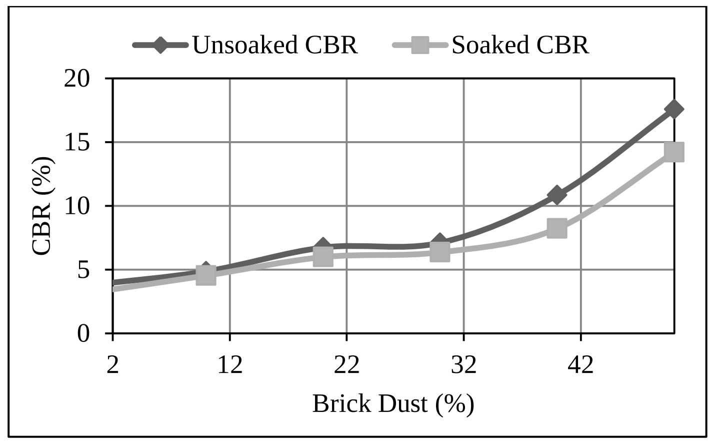

Figure-8: Variation curve of CBR values of soil with increased percentage of BD.

From the above figures and table of CBR results, it is seen that the unsoaked values of CBR of mixes increases from 3.77% to 17.57% and the soaked values of CBR of mixes increases from 3.18% to 14.20%. This increase in the values of CBR is ascribed to absence of plasticity in brick dust[12]. Under un-soaked conditions, higher CBR values were observed as compared to soaked CBR reason being additional capillary forces existing in the partially saturated samples while the lower values of soaked CBR is the result of the nullification of capillary forces acting in the soil samples immersed in the water for soaking[12]. The improved strength is attributed to minimized plasticity, improved gradation of soil and brick dust mixture comprising of coarser particles and enhanced frictional strength.

Consolidation Characteristics: The consolidation tests were performed according to IS: 2720 (Part XV) - 1986 on soil samples with percentages of brick dust varying from 0-50%. Compression parameters values for these soil samples are presented in Table-9. Figure-9 shows variation curve of Compression Index (C_c) of soil with increased brick dust percentage.

Figure-10 is a graphical representation of variation of coefficient of compressibility (a_v) and coefficient of volume compressibility (m_v) of soil with increased percentage of brick dust.

Table-9: Values of compression parameters of soil with varying proportions of Brick Dust.

Mix	Compression Parameters		
	C_c	a_v (10^{-5}) (m^2/kN)	m_v (10^{-4}) (m^2/kN)
Soil +0% BD	0.135	6.51	4.09
Soil +10% BD	0.073	3.25	2.09
Soil +20% BD	0.064	2.43	1.64
Soil +30% BD	0.036	7.03	0.499
Soil +40% BD	0.026	4.99	0.377
Soil +50% BD	0.015	2.14	0.153

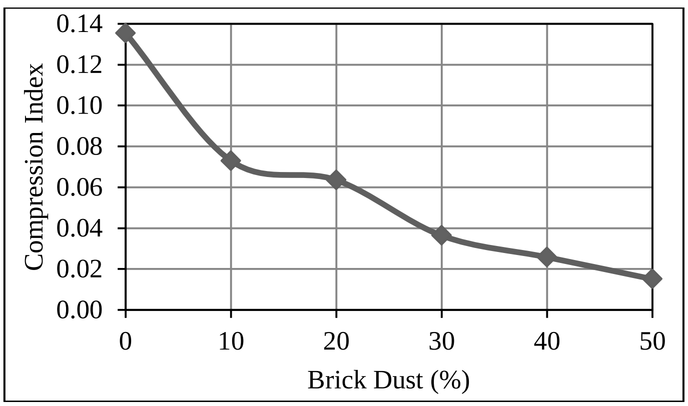

Figure-9: Variation curve of compression index of soil with increased percentage of BD.

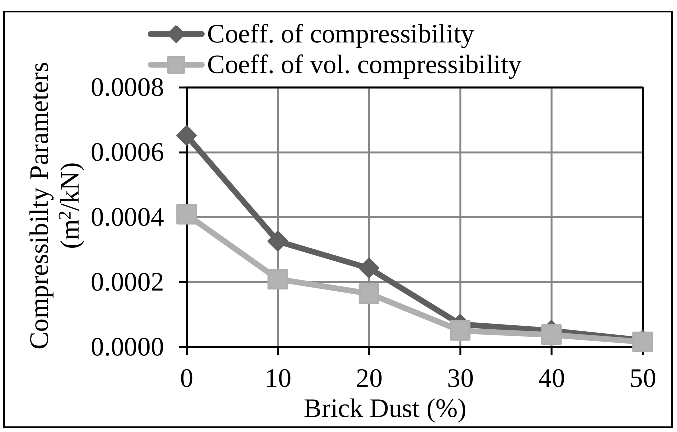

Figure-10: Variation curve of coefficient of compressibility and coefficient of volume compressibility of soil with increased percentage of BD.

From the results of compressibility behaviour of natural soil and the mixes of soil with brick dust as shown in Table-8, it can be concluded that as the brick dust percentage is increased, the compression index (C_c) decreases and this behaviour is due to the decrease in clay content making soil less plastic and decreasing the swelling and shrinkage potential and vanishing the compressibility characteristics. Coefficient of volume compressibility (m_v) reduced as brick dust percentage was increased.

Triaxial Shear Test: The triaxial shear tests were carried out in accordance to IS: 2720 (Part XI) - 1993 on soil samples with brick dust percentage varying from 0-50% (*i.e.*, 0%, 10%, 20%, 30%, 40% and 50%). The values of shear strength parameters (cohesion and internal friction angle) of soil with varying brick dust percentage are tabulated in Table-10. The curves of variation of cohesion of soil and internal friction angle of soil with increased percentage of brick dust are shown in Figure-11 and Figure-12.

Table-10: Values of shear parameters of soil with varying proportions of Brick Dust.

Mix	Tri-axial Failure Parameters	
	Cohesion (kPa)	Angle of Internal Friction (ϕ^o)
Soil + 0% BD	35.21	15.69
Soil + 10% BD	29.32	17.95
Soil + 20% BD	24.22	19.95
Soil + 30% BD	19.52	21.65
Soil + 40% BD	15.70	23.17
Soil + 50% BD	11.67	24.51

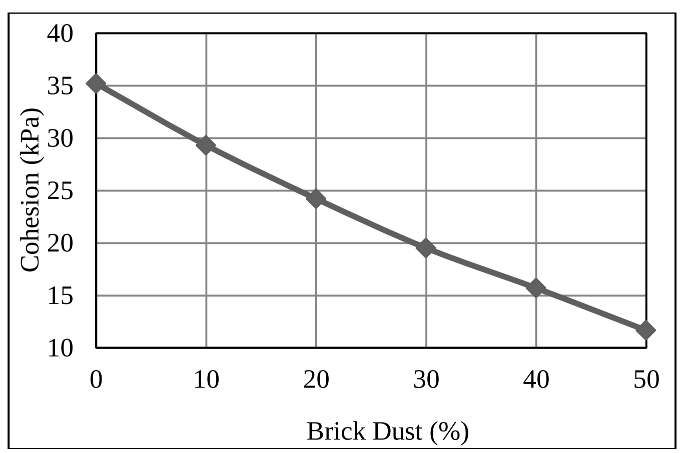

Figure-11: Variation curve of cohesion of soil with increased percentage of BD.

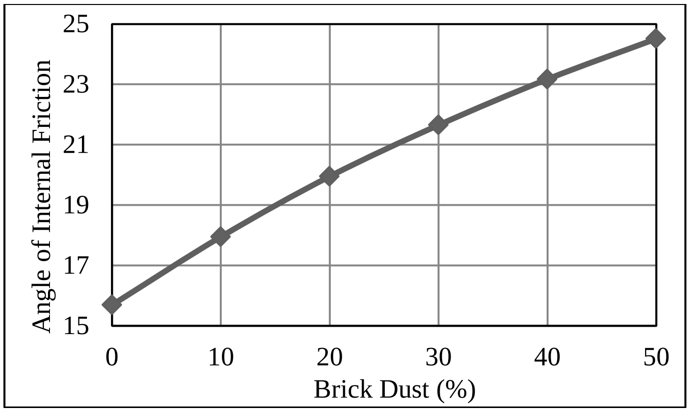

Figure-12: Variation curve of internal friction angle of soil with increased percentage of BD.

From the graphical and tabular representation, it is evident that there is decrease in value of cohesion from 35.21 to 11.67 kPa whereas increment is seen in angle of internal friction from 15.69^o to 24.51^o when brick dust percentages increases from 0% to 50%. The reason behind the increment in the values of internal friction angle and reduction in the values of cohesion is the non-cohesive behaviour of the brick dust which tends to decrease the plastic nature of the clayey soil and enhances the strength of admixed soil. The addition of brick dust to the soil makes it coarser in nature thus resulting in increment in the values of internal friction angle.

Conclusion

This study was conducted to comprehend the geotechnical behaviour of soil modified with brick dust and how this material can be useful in enhancing the engineering properties of the soil. The soil was treated with varying brick dust content in stepped concentration of 10%, 20%, 30%, 40% and 50% by dry weight of the soil. To develop an understanding of the possible variation in geotechnical properties and the mechanism involved a series of experiments on various parameters of soil were carried out, considering the obtained results and discussion following inferences can be made: i. The mass specific gravity (G) of the soil mixes increases from 2.35 to 2.53 as the percentage of brick dust increases from 0% to 50%. ii. The consistency limits of the soil samples decreases on adding brick dust to 40% and beyond 40% a non-plastic behaviour of soil was observed. iii. On studying the results of compaction tests, it is seen that the OMC of soil samples show a decrement from 16.75% to 13.25% and the MDD of soil samples increases from $16.28 kN/m^3$ to $18.93 kN/m^3$ on increasing the brick dust percentage from 0% to 50% which shows that it is advantageous to use brick dust up to 50% in civil engineering projects. iv. The permeability coefficient of soil samples increases from 9.52E-08 m/sec to 6.93E-06m/sec on increasing the brick dust percentage from 0% to 50%. v. The UCS of the soil samples increases with the increase in brick dust content but only up to 30% replacement of soil by brick dust and thereafter the UCS reduced on further addition of brick dust into the soil. vi. The values of un-soaked CBR of soil samples increases from 3.77% to 17.57% when brick dust percentage added was 0% to 50%. vii. The values of soaked CBR of soil samples increases from 3.18% to 14.20% when brick dust percentage added was 0% to 50%. viii. The compression parameters of soil samples show a decrement in the values with increase in the brick dust percentage from 0% to 50%. ix. By analyzing the results of triaxial shear tests, a decrement in the cohesion values was observed from 35.71 kPa to 11.67 kPa and the internal friction angle increases from 15.69° to 24.51° when the brick dust percentage was increased from 0% to 50%.

After examining the results, it is prominent that brick dust provides advantageous outcomes on incorporating it as an additive to the soil for modification of its geotechnical properties. The improvement in geotechnical characteristics of soil was observed at 50% of brick dust. Its application in stabilization of soil provides a cheaper alternative to conventional materials[5]. Utilization of such additive also helps in reducing the waste in the environment by proper disposal and in preserving natural soil. As a result, this study can be advantageous for design and construction of economic structures.

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