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Arvind Kumar Agnihotri
Krishna R. Reddy
Ajay Bansal *Editors*

Recycled Waste Materials

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Preface

The ever-increasing population growth has resulted in a tremendous load on the natural resources. Added to this, the rapid industrialization and urbanization activities are making the situation grim. All these developments have been at a heavy cost in terms of deteriorated environmental conditions. An adverse impact on the environment has drawn the attention of technocrats and researchers to look for technologies that are sustainable. As a consequence of a huge domestic and industrial waste and deteriorating environmental conditions in general, statutory regulatory bodies have become more active and the pollution-related norms have become more stringent than ever before. We are running a race against time to look for technologies with sustainable viability. The recycling of waste materials is one of the key features of sustainability.

The growing quantities and types of waste materials, shortage of landfill spaces, and lack of natural earth materials highlight the urgency of finding innovative ways of recycling and reusing waste materials. Additionally, recycling and subsequent reuse of waste materials can reduce the demand for natural resources, which can ultimately lead to a more sustainable environment. The construction industry is a massive consumer of natural resources and a huge waste producer as well. The high value of raw material consumption in the construction industry becomes one of the main factors that causes environmental damage and pollution to our mother earth and the depletion of natural and mineral resources.

Waste material has been defined as any type of material by product of human and industrial activities that has no lasting value. The amount of waste material is increasing day by day with an increase in population. It is a general practice to dump these waste materials on lands, which creates environmental and social problems. The reuse of these waste materials is one of the effective ways of minimizing such problems. The bulk use of wastes like pond ash, rice husk ash, fly ash, and tire wastes as admixture is now becoming popular in the construction of geotechnical structures. Researchers have shown that these materials can be used in the subgrade of roads, embankments of roads, as fill materials in retaining walls, etc.

The greatest challenge before the processing and manufacturing industries is the disposal of the residual waste products. Waste products that are generally toxic, ignitable, corrosive, or reactive have detrimental environmental consequences. Thus, the disposal of industrial wastes is a major issue for the present generation. This major issue requires an effective, economic, and environment-friendly methods to tackle with the disposal of the residual industrial waste products. One of the common and feasible ways to utilize these waste products is to go for the construction of roads, highways, and embankments. If these materials can be suitably utilized in the construction of roads, highways, and embankments, then the pollution problem caused by the industrial wastes can be greatly reduced.

Recycling waste materials is beneficial in many ways.

- Recycling helps protect the environment. This is because the recyclable waste materials would have been burned or ended up in the landfill. Pollution of the air, land, water, and soil is reduced.
- Recycling conserves natural resources. Recycling more waste means we do not depend too much on raw (natural) resources, which are already massively depleted. Recycling saves energy.
- It takes more energy to produce items with raw materials than from recycling used materials. This means we are more energy efficient, and the prices of products can come down.
- Recycling creates jobs. People are employed to collect, sort, and work in recycling companies. Others also get jobs with businesses that work with these recycling units. There can be a ripple of jobs in the municipality.

This book covers a variety of such multidisciplinary articles which will be very useful for students, working professionals, practitioners, and researchers.

Jalandhar, India — Arvind Kumar Agnihotri
Chicago, USA — Krishna R. Reddy
Jalandhar, India — Ajay Bansal

Contents

About the Editors

Arvind Kumar Agnihotri is Professor of Civil Engineering at NIT Jalandhar. He completed his Ph.D. from University of Roorkee (1998), M.Tech. from NIT Kurukshetra (1989) and B.E. from Panjab University Chandigarh (1987). He possesses a work experience of around 29 years in research, teaching and academic administration, with several years spent holding key leadership positions. His areas of interest are Geotechnical and Geo-Environmental Engineering, Reinforced Earth (Geo-Synthetics and Geofibers), Ground Improvement and Soil-Structure-interaction. He has supervised nine Ph.D. Thesis and seven more are in progress. He has guided 45 M.Tech. dissertations. He has published more than 100 papers in international and National journals and conferences. He served as Head of Civil Engineering, Dean Academic, Dean (Planning and Development) at prestigious Dr. B. R. Ambedkar National Institute of Technology, Jalandhar. He is fellow/member of many professional organizations like ASCE, IGS, ISTE, Institution of Engineers, International Society of Soil Mechanics and Geotechnical Engineering and Indian Roads Congress. He is reviewer of many international journals of repute.

Krishna R. Reddy is a Professor of Civil and Environmental Engineering, the Director of Sustainable Engineering Research Laboratory and also the Director of the Geotechnical and Geo-Environmental Engineering Laboratory in the Department of Civil and Materials Engineering at the University of Illinois at Chicago. He is the author of three books: (1) *Geo-Environmental Engineering: Site Remediation, Waste Containment, and Emerging Waste Management Technologies*, (2) *Electrochemical Remediation Technologies for Polluted Soils, Sediments and Groundwater*, and (3) *Sustainable Remediation of Contaminated Sites*. He is also author of 182 journal papers, 15 edited books, ten book chapters, and 170 full conference papers. Dr. Reddy has given 160 invited presentations in the U.S.A. and 15 other countries. He has served or currently serves as an Associate Editor or Editorial Board Member of over ten different journals, including the ASCE and ASTM Journals, among others. He has received several awards for excellence in research and teaching, including the ASTM Hogentogler Award, the UIC Distinguished Researcher Award, the University of Illinois Scholar Award, and the University of Illinois Award for Excellence in Teaching. He is a Fellow of the American Society of Civil Engineers, a Diplomat of Geotechnical Engineering, and a Board Certified Environmental Engineer.

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Evaluation of Compressibility and Drainage Characteristics of Highly Plastic Clay Stabilized with Fly Ash and Stone Quarry Dust

Himanshu Yadav, Haidar Ali and V. P. Singh

Abstract Approximately, one-fifth parts of the soil deposit in India is covered with high compressible clay (i.e., Black cotton soil); due to high volume change behavior on changing moisture and poor drainage condition, such soil is classified as problematic soil and requires suitable modification before using it as a soil support. In this study, fly ash and stone quarry dust were used as stabilizing admixture to improve the mechanical behavior of soil, which reduce the waste disposal problem and the environmental pollution, and save the natural material (soil). Here, soil sample was collected from SH 102, B.P. Road, Allahabad and classified as CH. Fly ash was collected from Prayagraj Thermal Power Plant, Bara Allahabad (660 MW), and stone quarry dust was obtained from Shankargarh crushing unit, Allahabad. Three different types of samples were prepared in which soil was mixed with fly ash, stone quarry dust, and both in equal proportion in different percentages (i.e., 4, 8, 12, 16, 20, 25, and 30%) by dry mass separately. After proper mixing and aging of samples, standard consolidation test was carried out on each sample. The calculated values of compressibility characteristics (c_c, c_v) and permeability (k) have reflected considerable and justified results, in which coefficient of compressibility decreasing, coefficient of consolidation, and permeability increase with increasing mix proportion of differently used admixtures with different rates. The optimum percentages for all three different mixes have been determined and compared by considering a triple bottom line of the sustainability.

Keywords Consolidation · Compressibility characteristics · Stabilized soil · Fly ash · Quarry stone dust

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1 Introduction

High volume change behavior on changing moisture content and poor drainage of expansive soils caused severe damages to the foundation and the structure over it. Aim of the study is to improve the volume change behavior and drainage behavior with the utilization of waste materials. Soil stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to commercially available admixtures that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (IRC: SP: 89-2010). In this study, fly ash and quarry stone dust are used as stabilizing material. Fly ash itself has little cementitious value but in the presence of moisture it reacts chemically and forms cementitious compounds and attributes to the improvement of strength and compressibility characteristics of soils (Bhuvaneshwari et al. 2005). Stone quarry dust is a waste material produced from aggregate crushing industries, disposal of which involves high cost and proper knowledge. Various researchers have reported significant improvement in properties of expansive soil when mixed with fly ash and stone quarry dust. Compression index, c_c, decreases with increase in various percentages of admixtures (i.e., Rice husk ash, fly ash, and quarry stone dust). Coefficient of consolidation c_v decreases with increase in loading for various percentages of admixtures (Jain and Puri 2013a). Coefficient of consolidation also increases with increase in the fly ash content. Compression index decreases appreciably with addition of fly ash indicating improvement in consolidation characteristics (Mir and Shridharan 2014).

2 Materials

2.1 Soil

The proposed site location for collection of soil, B.P Road, SH-102, Allahabad belongs to one of the deposits of expansive soil in Northern India. Soil sample was collected at a depth of 1.5 m from a borrow pit to avoid the organic matter.

2.2 Fly Ash

The sample collection of different types of ashes such as fly ash, bottom ash, and pond ash has different procedures. The sample of fly ash was directly collected from the storage point through a sampling pipe. Fly ash for the study was taken from Prayagraj Thermal Power Plant, Bara Allahabad (660 MW). The fly ash collected from the plant was light gray in color.

Table 1 Properties of materials (Singh et al. 2017)

Property	Natural soil	Fly ash	Stone quarry dust
Specific gravity	2.73	2.01	2.78
Liquid limit (%)	51	NA	NA
Plastic limit (%)	21	NA	NA
Plasticity index	30	Nonplastic	Nonplastic
Soil classification	CH	–	SP
Maximum dry density (gm/cc)	2.25	1.227	–
Optimum moisture content (%)	11.56	20.41	–

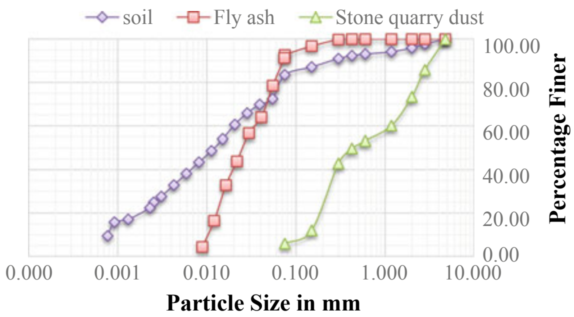


Fig. 1 Grain-size distribution curves for soil, fly ash, and stone quarry dust

2.3 *Stone Quarry Dust*

Stone quarry dust is a waste material produced from aggregate crushing industries. It was collected from the crushing units located in Shankargarh area of Allahabad which is about 10 km from the proposed site SH-102, B.P. Road, Allahabad. Index properties of the stone dust were determined as per IS codes. The stone dust is classified as SP.

The properties of materials are given in Table 1, and grain size distribution curves for materials are shown in Fig. 1.

3 Methodology

For this study, three different types of samples were made in which soil was mix with fly ash, stone quarry dust, and both in equal proportion (i.e., 4, 8, 12, 16, 20, 25, and 30%) by dry mass separately. Totally, 21 types of samples were prepared.

Table 2 Experimental program

Soil–fly ash mixes			Soil–stone quarry dust mixes			Soil–fly ash, stone quarry dust mixes			
Soil (%)	Fly ash (%)	Notations	Soil (%)	Stone quarry dust (%)	Notations	Soil (%)	Fly ash (%)	Stone quarry dust (%)	Notations
100	0	SF0	100	0	SQ0	100	0	0	SFQ0
96	4	SF4	96	4	SQ4	96	2	2	SFQ4
92	8	SF8	92	8	SQ8	92	4	4	SFQ8
88	12	SF12	88	12	SQ12	88	6	6	SFQ12
84	16	SF16	84	16	SQ16	84	8	8	SFQ16
80	20	SF20	80	20	SQ20	80	10	10	SFQ20
75	25	SF25	75	25	SQ25	75	12.5	12.5	SFQ25
70	30	SF30	70	30	SQ30	70	15	15	SFQ30

Standard consolidation tests were conducted on each sample, and consolidation characteristics and permeability of each sample were calculated. Here, admixture content is defined by the ratio of weight of admixture to the dry weight of natural clay soil expressed as a percentage, e.g., SF20 means soil with 20% fly ash by weight; and SFQ30 means soil having equal fly ash and quarry stone dust (15% fly ash and 15% stone quarry dust) (Table 2).

Sample Preparation: Heavy compaction for each mix was done as per IS 2720 (Part 8) (1987). Air-dried soil samples were compacted at maximum dry density (MDD) and corresponding optimum moisture content (OMC) in mold. The consolidation ring was penetrated into the compacted soil mold, and it was taken out and trimmed from both sides. Then specimen was assembled in consolidation cell, and test was performed for each sample similarly (IS: 2720 Part 15 1986).

4 Results and Discussion

4.1 Compressibility Characteristics

Compressibility characteristics, compression index, c_c, and coefficient of compressibility, c_v, are determined by standard procedure. Compression index determines the magnitude of settlement, while other tells about the rate of settlement.

4.1.1 Void Ratio and Compression Index

Figures 2, 3, and 4 show the void ratio (e)—effective pressure p curve for various mixes of soil with admixtures. It is also known as "e–log p curve." The compression

Fig. 2 *e*–log *p* curve for soil mixed with fly ash

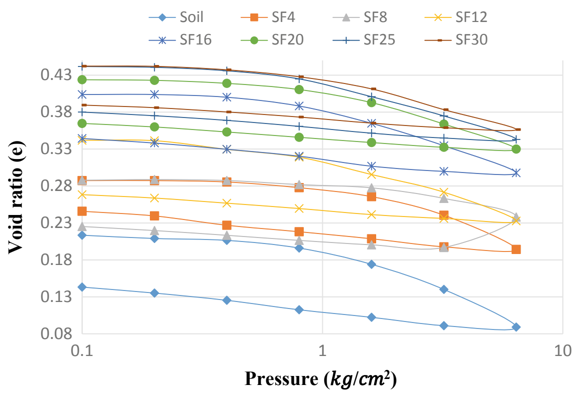
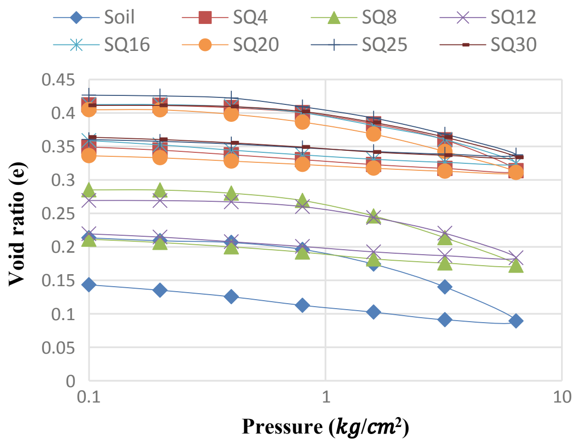


Fig. 3 *e*–log *p* curve for soil mixed with stone quarry dust



index, c_c, is the slope of linear portion of "*e*–log *p* curve" which indicates amount of settlement of soil or soil mix.

Compression index decreases with increase in admixture content and variation of compression index with different percentages of admixture (as shown in Fig. 5). The compression index, C_C, decreases with increase in percentage of fly ash and bottom coal ash (Jain and Puri 2013b).

4.1.2 Coefficient of Consolidation, c_v

Coefficient of consolidation, c_v, has been determined for different percentages of admixtures at different loading pressures (1.6, 3.2, and 6.4 kg/cm^2). Casagrande's logarithm of time fitting method was used for the calculation of t_{50} which was further used to calculate the value of coefficient of consolidation, c_v. Its value increases with increase in percentage of admixture because the soil is moving toward the courser

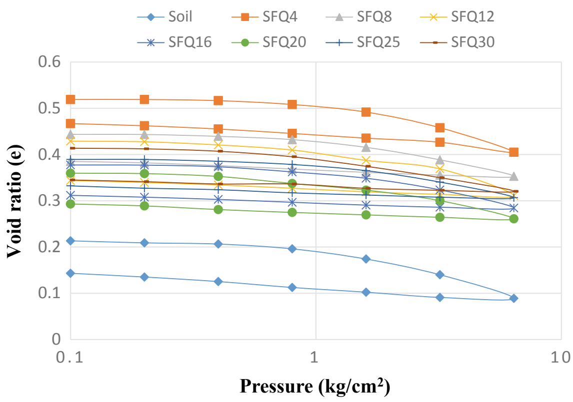


Fig. 4 *e*–log *p* curve for soil mixed with both fly ash and stone quarry dust

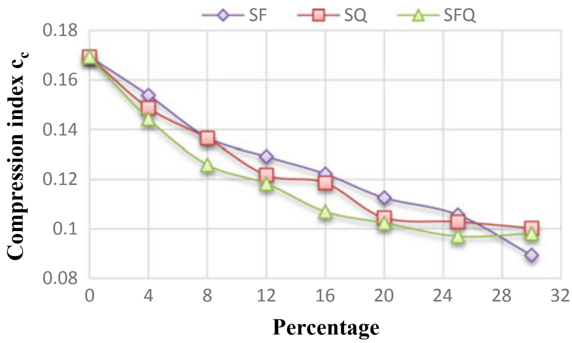


Fig. 5 Variation of compression index, c_c, with different percentages of admixture

material or turns to more granular. This will make the process of consolidation faster. Coefficient of consolidation decreases with increase in loading. It means time required for the soil to reach a given degree of consolidation will increase with increase in loading. Variation of coefficient of consolidation, c_v, is shown in Figs. 6, 7, and 8. The coefficient of consolidation, c_v, decreases with increase in loading

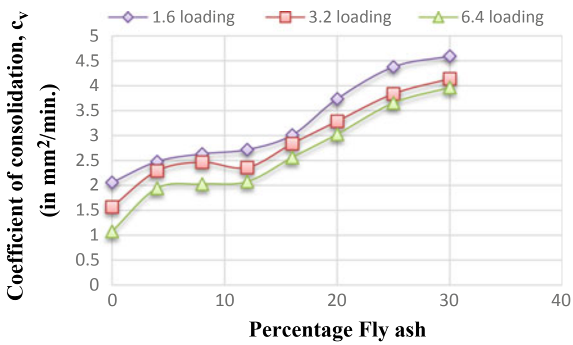


Fig. 6 Variation of coefficient of consolidation with percentage of fly ash

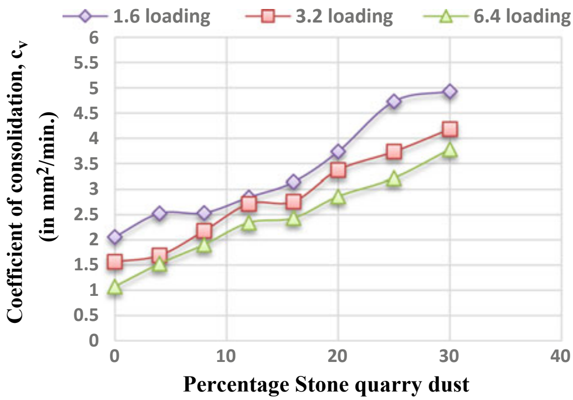


Fig. 7 Variation of coefficient of consolidation with percentage of stone quarry dust

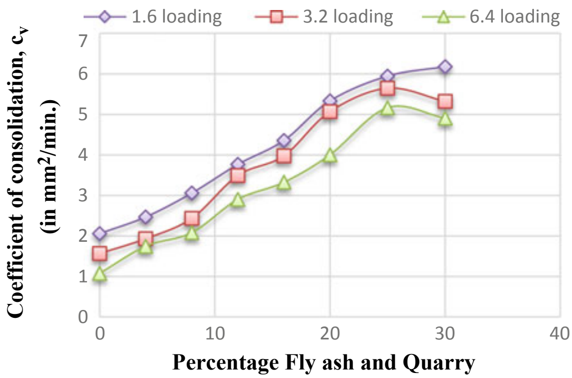


Fig. 8 Variation of coefficient of consolidation with percentage of fly ash stone quarry dust

pressure (Eberemu and Sada 2013). The coefficient of consolidation, c_v, increases with percentage of admixture increases (Narsihmarao et al. 2014).

4.2 Coefficient of Permeability, k

The coefficient of permeability, *k,* was calculated for soil with different percentages of admixture at different loadings. Its value was evaluated using formula $k = c_v m_v \Upsilon_w$.

The value of coefficient of permeability increases with increase in the percentage of admixture because soil is getting converted into granular when mixed with admixture and its value decreases with increase in loading. Drainage properties, i.e., coefficient of permeability, *k,* of soil increase by 102% with the increase in the fly ash content to 30% and increases by 120% with the increase in the dolochar content to 30% (Mohanty et al. 2016). Coefficient of permeability, *k,* is directly proportional to the coefficient of consolidation, c_v. The variation of coefficient of permeability, *k,* with respect to percentage of admixture is plotted in Figs. 9, 10, and 11.

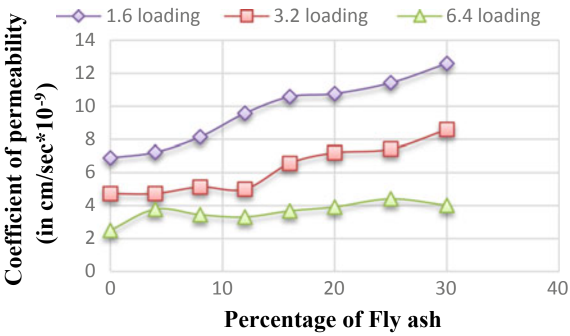


Fig. 9 Variation of coefficient of permeability, *k*, with percentage of fly ash

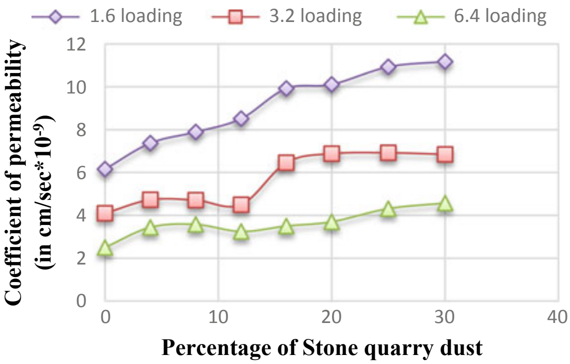


Fig. 10 Variation of coefficient of permeability, *k*, with percentage of stone quarry dust

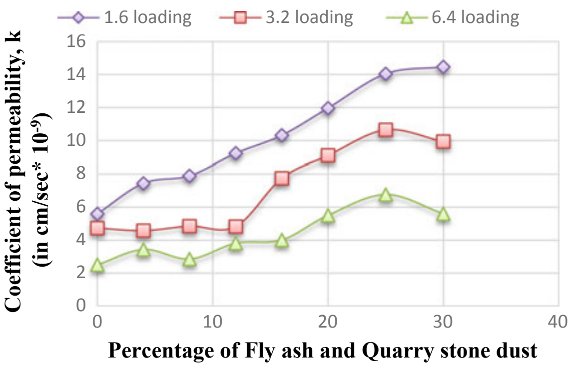


Fig. 11 Variation of coefficient of permeability, *k*, with percentage of fly ash and stone quarry dust

5 Conclusions

1. Compression index C_C decreases from **0.1694** to **0.08936** when fly ash added up to 30% and its value decreases to **0.1003** for 30% quarry stone dust. For mixture of both fly ash and quarry stone dust, its value decreases to **0.09815**.

2. SQ25 and SQ30 are also having less value of compression index Cc than SQ20, but reduction in compression index Cc is quite lower and addition of higher percentage of mixture will require more cost.
3. So, **SQ20** is better than SQ25 and SQ30. Similarly, SFQ20 and SFQ25 also have less value of compression index Cc than SFQ16, but reduction in compression index Cc is very less. So, we will prefer **SFQ16** over SFQ20 and SFQ25.
4. So, SQ20 and SFQ16 are two alternatives for reduction in compression index C_C.
5. Reduction in compression index C_C increases in percentage of waste material which means there will be reduction in the settlement of soil after stabilization.
6. Coefficient of consolidation, c_v, increases with increase in percentage of admixture added and decreases with loading. It represents the rate of consolidation which means for higher percentage of admixture rate of consolidation is higher.
7. Coefficient of permeability, *k,* increases with increase in the percentage of admixture because soil is getting more granular with addition of admixture. It decreases with increase in loading pressure.

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Strength Characteristics of Clayey Soil Stabilized with Nano-silica

Abhay Malik, Shiv Om Puri, Neeru Singla and Sanjeev Naval

Abstract Due to rapid growth in urbanization and industrialization, waste utilization becomes an important aspect of the conservation of the environment. With the progression in the field of Geotechnical Engineering, waste materials like rice husk ash, fly ash, agro-industry waste, silica fume, etc. find their way in soil improvement techniques. Soil, in its natural state, at a construction site may not always be suitable for supporting structures. The constructions at a site composed of clay possess great challenge due to settlement. This research is intended to study the effect of adding nano-silica on the strength characteristics of clayey soil. A series of laboratory experiments have been conducted on the virgin soil and the soil blended with nano-silica content at 5–20% by weight of dry soil. The experimental results showed an increase in optimum moisture content with the increase in nano-silica content. It was found that unconfined compressive strength also showed an increase in the addition of stabilizing material. From the investigation, it can be concluded that nano-silica particles have a potential to improve the engineering properties of the clayey soil along with its proper utilization from the environmental point of view.

Keywords Clayey soil · Soil stabilization · Nano-silica · Compaction · UCS

1 Introduction

In India, annually huge quantities of wastes are produced and dumped at open sites or discharged into rivers which are not treated and mishandled. Consequently, available land resources for the construction of civil engineering structures are reduced. The

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remaining sites where constructions are carried on clayey soils may not always be totally suitable for supporting structures in its natural state. The usage of local soils in construction schemes is currently in limelight due to rapidly increasing prices of premium materials. These situations lead to the development of ground improvement techniques such as soil stabilization. With the development in engineering and technology, researchers have utilized the waste materials to stabilize the soils for better and improved engineering properties (Singh and Mittal 2014; Rastogi and Sharma 2012; Bachchhas and Soni 2017). The engineering properties of soils and their strength characteristics are of great concern to engineers engaged in design and construction. The improvements in parameters like Proctor compaction, shear strength, unconfined compression strength, and swell characteristics are likely to be expected for the construction of structures on unfavorable soil conditions. Recent studies define the use of waste materials like rice husk ash, sawdust ash, fly ash, coir fiber, agro waste, and even rubber tire waste for the improvement of said parameters (Butt et al. 2016; Raj and Kumar 2017; Kumar and Preethi 2014). Advancements in nanotechnology have made its way in geotechnical engineering by studying the soil structure in nanometer scale to gain better understanding of soil nature (Hareesh and Kumar 2016). Nanoparticles are used as an additive to the soil and after effects on their engineering properties are studied. A better understanding of these characteristics will enhance the usage of these materials in geotechnical engineering works, thereby making clays suitable for structures (Alireza et al. 2013). For satisfactory performance of a structure, the soil beneath must possess high strength to prevent the structure against failure. The clayey soil has high shrinkage and swelling potential; thus, the strength of the soil is relatively low. It has been witnessed by several studies that addition of nanomaterial had a positive influence on the expansive and shrinkage behavior of the soil (Taha and Taha 2012). The quality of soil has a huge effect on the structure and design of a foundation of a building or roads or earth dams. At present, development of infrastructure will encompass the areas with the types of soil which may be unsuitable for construction. The clayey soil undergoes volume changes when they originate in contact with water. Hence, it has become necessary to modify the properties of clayey soil. The improvement in engineering properties of clayey soil such as increase in shear strength, stiffness, and durability, and reduction in swelling potential of wet clayey soils can be done by soil stabilization (Puri 2012). Materials such as lime and silica fume are also being used to stabilize weak soils. These materials too had positive effects on the permeability, swelling, and compressive strength characteristics of the clayey soils (Pham and Nguyen 2014; Kalkan and Akbulut 2004; Fattah et al. 2014; Alrubaye et al. 2016; Pashabavandpouri and Jahangiri 2015). In the present work, strength characteristics have been studied for clayey soil treated with nano-silica by conducting a series of experimental test procedures (Prakash and Jain 1999).

2 Materials and Methodology

For better understanding of previous trends and methodologies, an extensive review of literature was carried out. Soil stabilization paves way for improving the engineering properties of soils unsuitable for construction purposes. The materials collected from the respective sites for determination of different engineering properties are as follows.

2.1 Clayey Soil

The clay used in the experiments was collected from Samani, Traffic Police Post, GT Road, Kurukshetra, Haryana. The soil was classified as CLas per Indian Standards (IS: 1498-1970). The soil properties are given in Table 1.

2.2 Nano-silica

Nano-silica was purchased from Adinath Industries, Ajmer, Rajasthan, India. Nowadays, nano-silica has its application in various industries such as paint, plastic, ceramics porcelain, gypsum, batteries, adhesives, fiber, glass, and many other fields. The specifications of nano-silica are reported in Table 2.

2.3 Laboratory Tests

Virgin clayey soil was mixed with nano-silica at various percentages, i.e., 5, 10, 15, and 20% by weight of dry soil. Experimental tests such as Atterberg limit, specific gravity, compaction test, and unconfined compressive strength were conducted as per relevant IS code.

Table 1 Geotechnical parameters

Grain size distribution	Gravel (%)	0
	Sand (%)	7.65
	Clay + Silt (%)	92.35
Specific gravity		2.48
Liquid limit		51
Plastic limit		28
Plasticity index		23
IS classification		MH
Optimum moisture content (OMC) (%)		21.8
Maximum dry density (MDD) (kN/m^3)		14.8
Unconfined compressive strength, q_u (kN/m^2)		132.1

Table 2 Specifications of nano-silica

B.E.T. surface area	200 m^2/g
PH (4% aqueous slurry)	3.7–4.3
325 mesh residue (44 μ)	0.02% max.
Bulk density	3.0 lb/ft^3 max.
Pour density	50 g/L tap density
Loss on heating	<1.5% max.
Loss on ignition (at 1000 °C)	<2 wt%
Specific gravity	2.2 g/cm^3
Wt. per gallon	18.3 lb
Refractive index	1.46
X-ray form	Amorphous
Assay (% SiO_2)	>99.8
Oil absorption	~350 g/100 g oil
Average particle length	0.2–0.3 μ

2.4 Composition of Specimens

Specimens of parent clay and clay treated with 5, 10, 15, and 20% by weight of nano-silica particles were prepared at maximum dry density and optimum moisture content as per Indian Standards (IS: 2720-Part VII) (1974).

2.5 Compaction

Oven-dried sample at approximate water content was mixed thoroughly with and without additive at different moisture contents to determine the optimum moisture content. Soil was placed in the Proctor mold and compacted in three layers giving 25 blows per layer with 2.5 kg rammer uniformly distributed over the surface of each layer. The collar was removed, and the compacted soil was trimmed. This series was continued until a decrease in wet unit weight of compacted soil was observed.

2.6 Unconfined Compressive Strength

Specimens prepared at optimum moisture content and maximum dry density were used in unconfined compression testing machine, where a provided ring is used to measure the compressive force. There were two plates, having a seating arrangement for the specimen. The specimen was placed on the bottom plate such that it makes contact with the upper plate. The dial gauge and provided ring are set to null. Compressive load is applied to the specimen by turning the handle.