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Evaluation of strength of expansive soil using nano-material oxide

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ABSTRACT

The application of nanomaterials on the improvement of quality and durability of road infrastructure is reported herewith. Laboratory experiments were conducted to examine the changes in the fundamental geotechnical properties after using nanomaterials with construction materials. The engineering of the construction materials (clay soils), used in road pavements, with improved performance characteristics in compare to their normal geotechnical properties, are demonstrated here. In this work, the performance of nano silicon dioxide on pure bentonite soil has been studied at room temperature. The research shows that the effect of nano SiO_2 in bentonite depends on its concentration and 0.2% nano SiO_2 powder was found to be an optimum concentration exhibiting positive impact on rheology of the soil. The selected optimum nano silica treated system shows good cutting transport efficiency.

Keywords: **Nanomaterials, Bentonite, Nano SiO_2, Expansive soil**

1. INTRODUCTION

Expansive soils (expansive clays) contain minerals such as smectite clays that are capable of absorbing water. The more water they absorb, the more their volume increases. Expansions of ten per cent or more are not common. This change in volume can exert enough force on a building or other structure to cause damage. Cracked foundations, floors, and basement walls are typical types of damage done by swelling soils.

Expansive soils will also shrink when they dry out. This shrinkage can remove support from buildings or other structures and result in damaging subsidence. Fissures in the soil can also develop. These fissures can facilitate the deep penetration of water when moist conditions or runoff occurs. This cycle of shrinkage and swelling places repetitive stress on structures, and damage worsens over time. This damage is done slowly and cannot be attributed to a specific event. The damage done by expansive soils is then attributed to poor construction practices or a misconception that all buildings experience this type of damage as they age. The American Society of Civil Engineers estimates that one-fourth of all homes in the United States have some damage caused by expansive soils. Insurance companies pay out millions of dollars yearly to repair homes distressed by expansive soils.

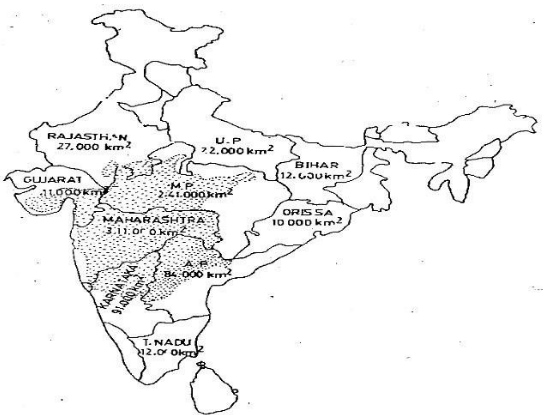

Figure 1. Map area covered by expansive soils in different states of India

The maps Figure 1show the generalized geographic distribution of soils that are known to have expandable clay minerals which can cause damage to foundations and structures. It also includes soils that have a clay mineral composition which can potentially cause damage. In this research the essential aspects of bentonite soil and its use with nanoparticle will be discussed. Bentonite is the commercial name of a whole range of natural clays with a high water absorption capacity causing it to expand and swell. Bentonite predominantly consists of montmorillonite: a clay mineral belonging to a class of phyllosilicates called smectites Montmorillonite is an aggregate of lamellar platelets, packed together by electrochemical forces and containing interposition water. Each platelet consists of 3 sandwich-arranged layers: a central octahedral alumina layer, and two tetrahedral silica layers (Figure 2).

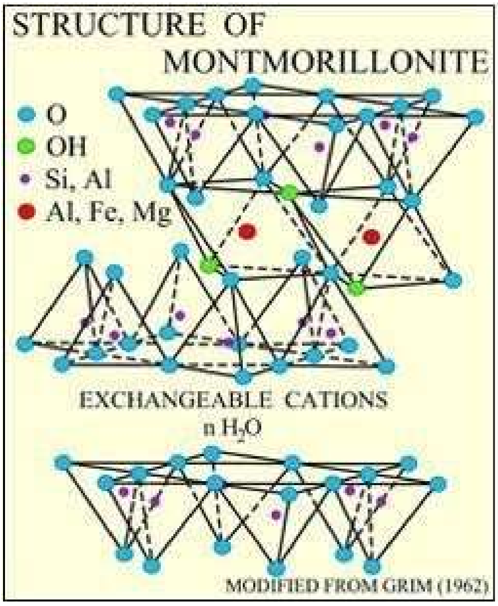

Figure 2. Structure of montmorillonite

The subgrade (in-situ material) is the compacted soil layer that forms the foundation of the pavement system. Subgrade soils are subjected to lower stresses than the surface, base, and sub-base courses. Since load stresses decrease with depth, the controlling subgrade stress usually lies at the top of the subgrade. Poor subgrade should be avoided if possible, but when it is necessary to build over weak soils there are several methods used to improved subgrade performance. Soil Stabilization, using a variety of stabilizers, is a common method used by engineers and designers to enhance the properties of soil. The use of Nanomaterial's for soil stabilization is one of the most active research areas that also encompass a number of disciplines, including civil engineering and construction materials. Soils improved by Nanomaterial's could provide a novel, smart, and eco- and environment- friendly construction material for sustainability. Soil that has been stabilized will have a vastly improved weight bearing capacity, and will also be significantly more resistant to being damaged by water, frost, or inclement conditions. Nanomaterial's have remarkable properties other than size, such as the high surface- to- volume ratio and surface energy, coordination of bonds at the particle surface. Apart from these properties, they exhibit increased reactivity compared to their bulk material, making them of great interest in a number of applications **[1].**

Application of Nano Technology in Pavement Materials deals with the major pavement materials and the ways in which nanotechnology can be utilized to enhance their performance or to develop novel materials for specific applications. Research into the behavior of clay minerals soil in the nanotechnology field **[2]** is providing new insights into the fundamental properties of clays. Application of this new knowledge may lead to alternative methods for the stabilization of the clays found in road reserves, and may thus lead to less expensive methods for using these materials in the pavement structure. The Architecture, Engineer, and Construction industry can take the advantage of applications of nanotechnology and nanomaterial's. By using these materials and nanotechnology we can save time and also energy. This is the advanced technology which can very useful in the civil and construction industry. A overall research process is demonstrated in Figure 3.

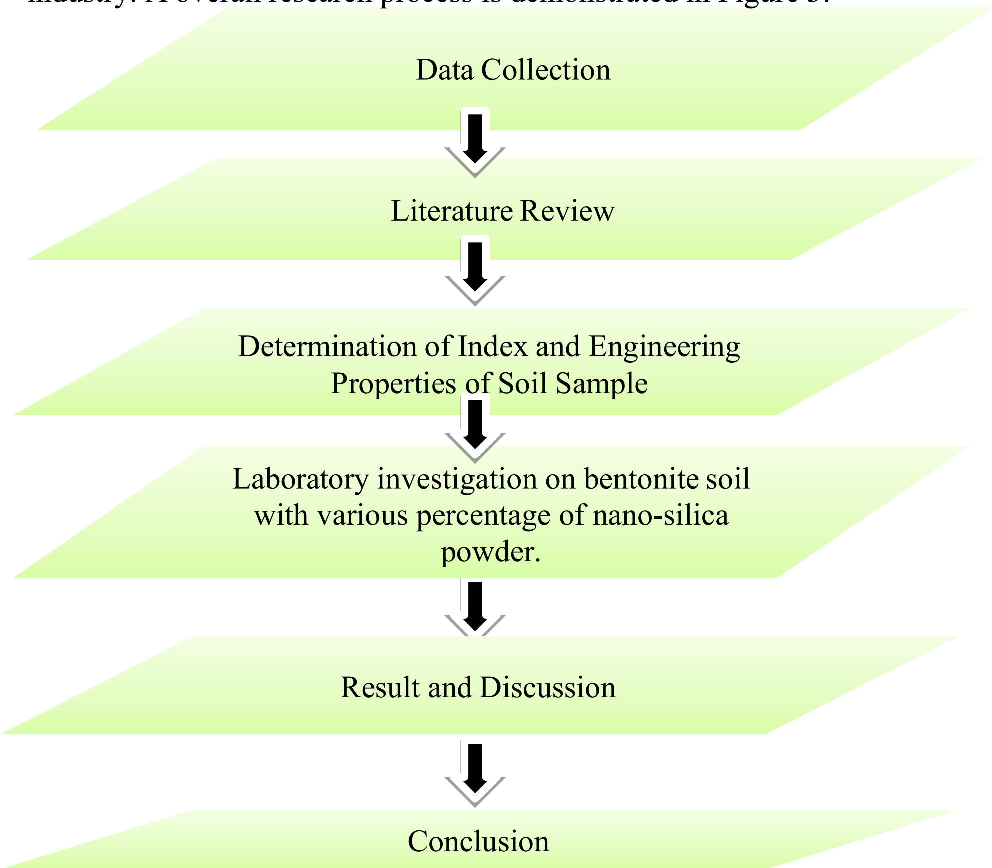

Figure 3. A flow chart demonstrating the overall research approach

2. EXPERIMENTAL VALUE

The bentonite soil purchased from Selaqui market was of large lumps in pieces which was crushed in laboratory and sieved through I.S Sieves according to Indian Standard (IS) methods used for different tests. The physical properties are presented in Table I. The nano silicon dioxide (Nanodispersion) was purchased from SISCO Research Laboratory Private Limited (SRL), a sub-branch in Dehradun (Table II). The materials are represented in Figure 4

Table I: Soil properties

Physical Properties	**Values**
Specific Gravity**[3].**	2.185
Compaction Test [4].	
Optimum Moisture Content	32.5%
Maximum Dry Density	1.262 g/cc
Consistency Limits and Indices [5].	
Liquid Limit	52.5%
Plastic Limit	35.0%
Plasticity Index	17.5%
USCS Classification	CH
Typical Soil Classification	Clay Soil with highly Plasticity
Swelling Index	126.086%
UCS (100%) Soil	0.093%

Figure: 4 Crushed bentonite and nano silicon dioxide powder

Table II: Nano Silicon Dioxide Powder (Hydrophilic) Properties

Test Parameters	**Results**
Content	25g
Appearance (Colour)	White
Appearance (Form)	Powder
Molecular Weight	60.08
APS	15nm
Assay	99.5%
SSA	$650m^2/g$
Molecular Formula	SiO_2 amorphous

A number of laboratory test were conducted on sets of untreated samples and samples treated with various doses of cement kiln dust (CKD) for investigating the effects on expansive soil properties. Optimum CKD dose was found as 14% of dry weight of soil. The results showed the soil treated with 14% CKD, the liquid limit, plasticity index, compressibility coefficient, expansion coefficient, and swelling ratio decreased to 57%, 14%, 21%, 11% and 9% respectively whereas CBR value increases to 828%**[6-7].** In this paper the soft soil is classified as SILT of very high plasticity based on the physical test carried out. The result showed that the optimum percentage of the bamboo ash is 15% and at 7 days of curing only. The deviator stress was found to be 292.7 kPa. However, the results would not be significant to strengthen the shear strength of soft soil mixing with bamboo leaf ash **[8].** This study deals with use of waste product bagasse ash to improve the expansive soil property. Bagasse ash is cost-free and locally available, hence is economical too. Soil is treated with bagasse ash by weight (0, 5, 10, 15, 20%) based on dry mass. From the results, the plasticity index decreased from 53.18 to 47.70%, maximum dry density increased from 1.13 to 1.24 gm/cm^3 and percentage swelling decrease from 5.48 to 3.29%. Thus, the test's outcome demonstrates that expansive soils stabilization using bagasse ash can improve the strength **[9].** Theywere studies about the improvement of strength and rigidity of Expansive Soil for Subgrade Layer with volcanic ash and lime stabilization. The various content of volcanic ash for the test was taken as 20%, 22%, 25%, 27% and 30% with lime content of 3% and 5%. The results show that, adding volcanic ash and lime, increases CBR value of soil, dry density and decreases optimum water content. The CBR value increases due to the pozzolanic reaction between volcanic ash and lime and clay resulting in mixed inter-particle bonding and changes in the morphology of clay fraction into the sand fraction, making sand stronger and more rigid **[10]** Used Black Cotton soil with micro-fine slag. Various proportions of micro-fine slag was used, i.e., 3, 6, 9, 12 and 15% to mix with BC soil. The optimum amount of micro-fine slag was approximately found to be 6-7% by the weight of soil. The test reveals that the micro-fine slag can be used as an additive to stabilize the black cotton soil **[11].** This research study the effect of adding Nano-SiO_2 on soil engineering properties with clayey soil. The soil contained clay and sand and is classified as CL according to Unified Soil Classification System (USCS). Varying contents of Nano-SiO_2 was added to soil (i.e. 0.5, 0.7, 1.0% by weight of parent soil). The results show that the optimum Nano-SiO_2 content occurs at 0.7% at which maximum increase in strength parameters are obtained **[12-13].** This paper investigates to improve the mechanical properties of clayey soils by the effect of recycled polyester fiber which is produced from polyethylene (PET) bottles, in combination with Nano-SiO_2as a new stabilizer. Different combinations of fiber-soil ratios and Nano-soil ratios were used corresponding to combination ranging between 0.1% and 0.5% in case of fiber- soil ratios and combination ranging between 0.5% and 1% in case of Nano-soil ratios. Results show that the addition of recycled fiber and Nano-SiO_2 increases the strength of soil specimens leading to improvement in both UCS and Shear strength **[14].** In this paper Black Cotton Soil (BC Soil) was tested with three different stabilizers. 1. Cement Waste dust 2. Cement Dust + Lime Powder 3. Lime Powder. The first stage include 7% of cement dust in BC soil, in second stage 8% combination of cement dust and Lime powder and last stage included 9% of Lime powder in BC Soil. Comparing the results Cement Dust proved the best agent as a stabilizer to improve Plasticity Index of BC Soil **[15].** In this study, SSA/Cement was applied as a soil stabilizer with Nano-Al_2O_3 as an additive for improving the basic properties of Soft Subgrade Soil. The mix ratio for Sewage Sludge ash (SSA) and Cement was 3:1. The soil specimen was prepared by replacing 15% of clay soil with SSA/Cement and four different volumes, namely 0, 1, 2, and 3%, of Nano-Al_2O_3were mixed with the treated soil as an additive. The results show that 15% SSA/Cement stabilizer with 1% Nano-Al_2O_3 additive fraction offered the best performance **[16].** In this paper odometer tests are performed for investigating the compression behaviour of zinc contaminated clayey soils with cement treatment. Low Zn concentration can be neglected but high Zn concentration leads to changes in the consolidation yield stress and compression index. It was found that increasing zinc concentration for given cement content, compression index and yield stress decreased. Cement contents were 12, 15 and 18% (oven-dried soil mass basis) and zinc concentrations were set as 0, 0.1, 0.2, 0.5, 1 and 2% (0ven-dried soil mass basis). Thus, the observations shows that the concentration level of zinc have significant influence on the compressibility and cementation structure of the cement treated zinc Contaminated Soils **[17].** This paper study the effect of Potassium Chloride (KCl) on swelling characteristics of 3 soil samples with plasticity indices 36, 55 and 79%. Soils were mixed with varying proportions of KCl (0.0, 2.5, 5.0 and 7.5%) by weight of dry soil. Addition of 5.0% KCl proved most beneficial in reducing the optimum moisture content, free swell, swelling pressure and increases the maximum dry density. The main findings of this study were cyclic behaviour of expansive clays. Even for extreme conditions of soils subjected to many cycles of wetting and drying the potassium ions (K^+) seem not to be removed from the soil thus resulting in lowering the swelling and shrinkage magnitudes.

Investigation of Expansive Soil

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. Specific gravity of soil solids was determined using a pycnometer **[18]** Method of test for soil test procedure was followed to determine the Specific Gravity of pure Bentonite Soil Solids by Water pycnometer. Free Swell Index test is conducted on soils which have the potential to swell. It is desirable to carry out further detailed investigation on soils with high values of free swell index such as swelling pressures under different field conditions. Indian standard code of practice (I.S.2911-Part III, 1973 Appendix A) has modified the free swell test and the modified test is known as Differential free swell test (DFS test). In this method two samples of oven dried soil passing 425 micron sieve and weighing 10 gm each are used. One sample is poured slowly in 50 ml graduated glass cylinder filled with kerosene (a non-polar liquid). The other sample is poured in another 50 ml graduated cylinder filled with distilled water. Both the cylinders are left for 24 hours and the respective volumes are noted. Swell in the pure bentonite soil was calculated. Liquid limit is determined by the mechanical method using Casagrande's apparatus by IS: 2720 (Part 5), (1985). Methods of test for soils: Determination of liquid and plastic limit. As per this method the liquid limit is defined as the moisture content at which 25 blows or drops in standard liquid limit apparatus will just close a groove of standardize dimensions cut in the sample by the grooving tool by a specified amount.

A 'flow curve' plotted on semi-logarithmic graph representing water content in arithmetic scale and the number of drops on logarithmic scale. The flow curve is a straight line drawn as nearly as possible through four points. The moisture content corresponding to 25 blows is read from curve is the liquid limit of soil. Liquid limit for both pure bentonite soil and bentonite soil (100%) mixed with 0.2% SiO_2 powder is found. Plastic limit test was carried out according to Indian Standard (IS) by using ground glass plate. The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semisolid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a thread ⅛ in. (3 mm) in diameter using a ground glass plate or other acceptable surface.

The test specimen is rolled between the palm or fingers on the ground glass plate to form a thread of uniform diameter. The average of the water contents obtained from three tests specimen is computed. The plastic limit is the average of three water contents. Plastic limit of both pure bentonite soil and bentonite soil (100%) mixed with 0.2% SiO_2 powder was noted. Compaction of soil is a mechanical process by which the soli particles are constrained to be packed more closely together by reducing the air voids. Soil compaction causes decrease in air voids and consequently and increase in dry density. This may result in increase in shearing strength. Light Compaction test, designed as IS 2720 (Part 7), (1983). (This test is similar to the Modified Proctor compaction test) was performed in laboratory with 6 varying percentage of water. The wet soil was compacted in three layers and each layer was given 25 blows with 2.6 kg rammer. Using the tabulated values of moisture content and dry density, Moisture-Dry density graph is plotted with moisture content on the X-axis and dry density values on the Y-axis and a smooth curve is drawn connecting the points, which is called “compaction curve”. From the curve, the maximum dry density is noted and the corresponding value of the moisture content is taken as Optimum Moisture Content (OMC) of the pure bentonite soil. The UCS of a soil specimen is the ratio of failure load and cross-sectional area of the specimen (at the failure) when it is not subjected to any confining pressure. As during the laboratory test the rate of loading on the specimen is fast and no pore water is allowed to drain or dissipate this test is essentially an undrained test. Cylindrical specimens of diameter 38mm was prepared and tested in compressive testing machine. The UCS for pure bentonite soil; bentonite (100%) + Nano silica dispersion (1ml, 3ml and 5ml); bentonite (100%) + Nano silica powder (0.1%, 0.2%, 0.3%, 0.4%, 0.5%) was computed and optimum percentage of Nano silica for both dispersion and powder form was noted.

3. RESULTS AND DISCUSSION

Consistency Limits and Indices represent the huge difference in values of consistency limits for both the test results but the USCS Classification for both pure bentonite and modified bentonite came out to be same i.e. CH. The result indicates (Table III) represent that 0.2 % nano silica has more effective because of less plasticity index with respect to pure bentonite soil.Due to reduce the inter-particles’ spacing and nano-reinforce the soil become stronger and stiffer as a result the liquid limit fallowed by plastic limit and plasticity index decreasing in order (Figure 5).

Table III: Comparison of liquid limit, Plastic limit and Plasticity Index

Tests	Result with pure Bentonite soil	Result with Bentonite + 0.2% nano silica powder
Liquid Limit	131.8%	52.5%
Plastic Limit	92.75%	35%
Plasticity Index	39.05%	17.5%

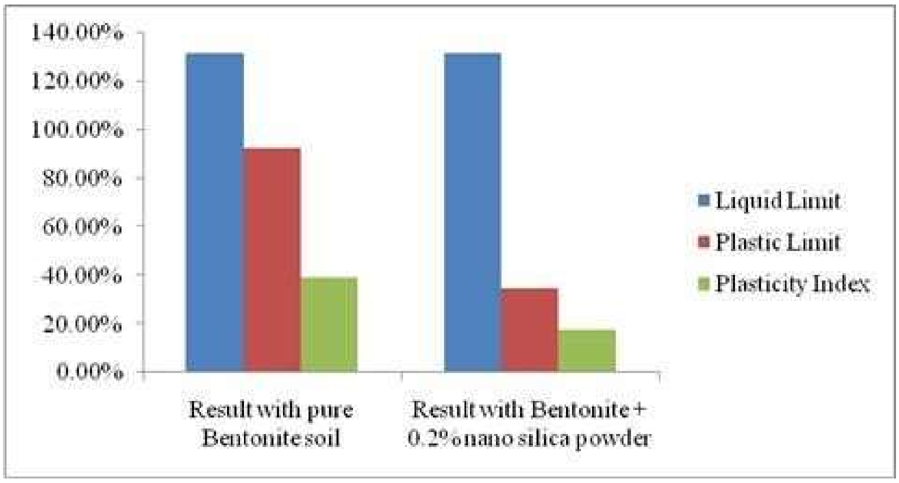

Figure: 5. Descending order of Atterbargs Index using nanosilica

The optimum value of nano silica powder from Figure 6 represents that 0.2% for which Unconfined Compressive Strength (UCS) is highest.

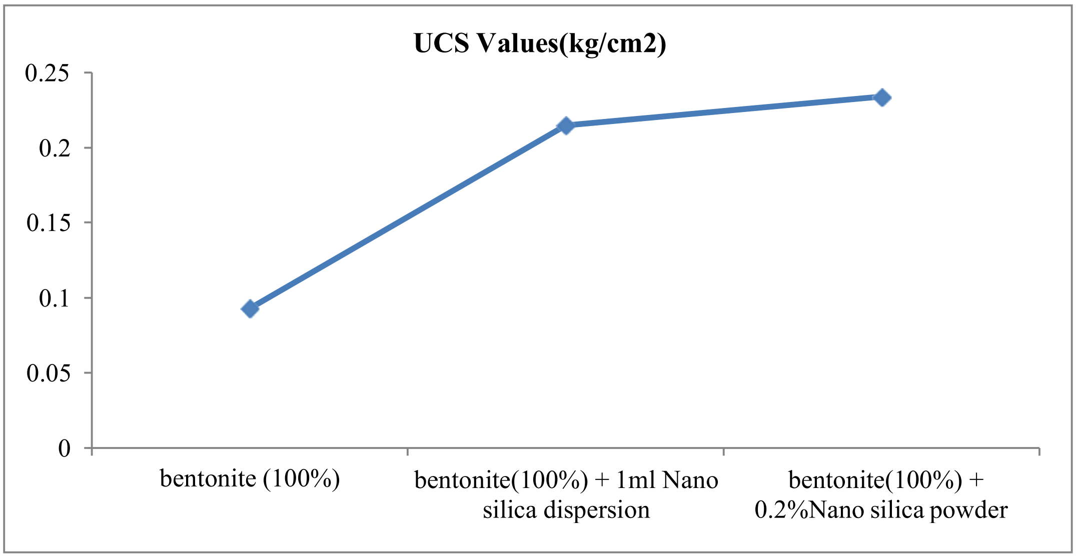

Figure 6. Comparison of Optimum UCS value

4. CONCLUSION

On the basis of the results of the present research it can be concluded that the performance of nano silica depends on its concentration during its application with construction materials. It has been inferred that that for a given system there exists an optimum concentration that works best in a sample system. The addition of 0.2% nano silica powder in the considered experimental tests influences the properties of reference mud system and shows positive impact on expansive soil treatment. The results have shown that the presence of nanoparticles in a soil has the ability to reduce the interparticles' spacing and nanoreinforce the soil, which will promote the construction of a stronger and stiffer soil skeleton matrix, therefore improving the mechanical properties of the material. From an ecological and health protection point of view, bentonite is a safe production for both the environment and human.

Following concluding remarks can be highlighted from the discussions presented in the paper.

a) The application of nanotechnology in the field of pavement engineering can potentially lead to solutions of long standing problems in this field.

b) The development of novel materials and the improvement of existing materials in response to scarcity/limitations of natural materials become a possibility through application of nanotechnology techniques on traditional pavement materials.

c) Nano-technological characterization of pavement materials improves the understanding regarding their performance.

d) Challenges such as the potential impact of nanomaterials on the natural environment around pavement should receive the required attention to ensure that solutions to pavement engineering questions do not cause new hazards to the public utilizing the natural and built environment.

e) Both the technical- and cost- effectiveness of available technologies should be evaluated as part of the evaluation of nanotechnology in engineering solutions.

REFERENCES

[1]. Rahgozar, M. A., Saberian, M. and Li, J. (2017). Soil stabilization with non-conventional eco-friendly agricultural waste materials: An experimental study. Transportation Geotechnics, 14, pp. 52-60.

[2]. Abdulla, A.,Sharo, P. and Alawneh, A. S. (2016). Enhancement of the Strength and Swelling Characteristics of Expansive Clayey Soil Using Nano-Clay Material.Geo-Chicago, GSP 269.

[3]. IS: 2720 (Part 16), (1987). Methods of Test for Soils: Determination of Specific Gravity of soil, Bureau of Indian Standards, New Delhi, India.

[4]. IS 2720 (Part 7), (1983). Method of Test for Soils: Determination of Water Content Dry Density Relationship using Light Compaction, Indian Standards.

[5]. IS: 2720 (Part 5), (1985). Methods of Test for Soils: Determination of liquid and plastic limit, Bureau of Indian Standards, New Delhi, India.

[6]. Mosa, A. M., Banyhussan, Q. S. and Yousif, R. A. (2017). Improvement of expansive soil properties used in earthworks of highways and railroads using cement kiln dust. Journal of Advanced Civil Engineering Practice and Research, 4, pp. 13-24.

[7]. Rahman, A. S. A., Jais, I. B. M., Sidek, N., Ahmad, J. and Rosli, M. I. F. (2017). Bamboo leaf ash as the stabilizer for soft soil treatment. IOP Conf. Series: Earth and Environmental Science140 012068.

[8]. Surjandari, N. S., Djarwanti, N. and Ukoi, N. U. (2017). Enhancing the engineering properties using the bagasse ash. IOP Conf. Series: Journal of Physics: Conf. Series,909 012068.

[9]. Latifi, D. O., Rifa, A. I. and Suryolelono, K. B. (2017). Impact of Volcanic Ash and Lime Adding on Expansive Soil.International Review of Civil Ebgineering (I.RE.C.E), 8, N 5.

[10]. Shukla, R. P. andSingh, N. (2016). Stabilization of Black Cotton Soil Using Micro-fine Slag. Journal of the Institution of Engineers (India), Series –A, 97,pp. 299-306.

[11]. Changizi, F. and Haddad, A. (2015). Effect of Nano-SiO_2 on the Geotechnical Properties of Cohesive Soil.Geotech. Geo. Engg. 34, pp. 725-733.

[12]. Changizi, F. and Haddad, A. (2015). Strength properties of soft clay treated with mixture of nano- $SiO_2$and recycled polyester fiber. Journal of Rock Mechanics and Geotechnical Engineering, 7, pp. 367-378.

[13]. Changizi, F. and Haddad, A.(2016). Effect of Nanocomposite on the Strength Parameters of Soil. KSCE Journal of Civil Engineering, 21(3),pp. 676-686.

[14]. Oza, J. B. and Gundaliya, P. J. (2013). Study of black cotton soil characteristics with cement waste dust and lime. Non-Circuit Branches of the 3rdNirma University International Conference on Engineering (NUiCONE),Procedia Engineering, 51, pp. 110- 118.

[15]. Luo, H. L., Hsiao, D. H., Lin, D. F. and Lin, C. K. (2012). Cohesive Soil Stabilized Using Sewage Sludge Ash/Cement and Nano Aluminum Oxide. International Journal of Transportation Science and Technology, 1(1), pp. 83-100.

[16]. Wei, M. L., Du, Y. J. and Jiang, N. J. (2013). Compression Behavior of Zinc Contaminated Clayey Soils Solidified with Cement. Geo. Congress, ASCE 2012.

[17]. Raid, R., Saad, A. O., Ibrahim, F. and Al-Bayati, I. K. (2010). Effect of potassium chloride on cyclic behaviour of expansive clays. J. Ross Publishing, Inc. International Journal of Geotechnical Engineering, 4,pp. 231-239.

[18]. IS: 2720 (Part 4), (1985). Methods of Test for Soils: Determination of Grain Size Analysis, Bureau of Indian Standards, New Delhi, India.