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A Study on Utilization of Admixtures for the Stabilization of Swelling Soils: A Review

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ABSTRACT

Rapid urbanization along with the development of large-scale industries has created numerous environmental problems. With the reduction of buildable ground, the construction sector has to move to areas with claysoil for expansion, which require soil stabilization. Any construction work over subgrade clay soil is expensive since treatment with various admixtures is required. Civil engineers, structural engineers, architects, and builders have tried many ways to avoid the damaging effects of expansive soils.

This study shows that admixtures help reduce the costs of construction on expansive soil as well as the disposal of industrial wastes. Technological advances have made it possible to introduce new technologies in civil engineering; for instance, geosynthetics are embedded in the soil to reduce the height of replacement soil. The purpose of this study is to critically evaluate the methodologies for improving the geotechnical properties of clay soil. Three different types of soils were collected from Bhopal (M.P.). Based on their physical-chemical parameters, these were classified as Low Compressibility of soil (CL), Medium Compressibility of soil (CI), and High Compressibility of soil (CH) according to IS standards, respectively.

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The different admixtures QD, MP, and FA, which are abundantly available in quarries and thermal industries, were collected and their physical and engineering properties were determined. Three soil samples were mixed with the admixtures at different ratios and their maximum dry density and optimum moisture content were determined. The trials were conducted with the addition of admixtures ranging from 10% to 40% by weight to Soil 1, Soil2, and Soil 3, and the dry density was obtained.

The experimental results showed that the dry strength of Soil 1: QD(70:30) is higher than that of Soil 1 with other admixtures of different ratios. The experimental results showed that the dry strength of Soil 2: QD (70:30) is higher than that of Soil 2 with other admixtures of different ratios.

The experimental results showed that the dry strength of Soil 3: QD (80:20) is higher than that of Soil 3 with other admixtures of different ratios.

Regarding the Optimum Moisture Content (OMC), the variations in OMC for Soil 1, Soil 2, and Soil 3 are 21%, 24%, and 26%, respectively. Soil 3 has greater OMC to achieve the corresponding Maximum dry density (MDD). Water was adsorbed on clay minerals based on the percentage of clay content. Since Soil 3 has higher clay content, the OMC was higher to attain the MDD. From the test results, the best soil and admixture with the best ratio was identified. The best admixture QD was mixed with soil samples, but the proportion was reduced. Then, experiments were carried out by introducing single- and double- layer geogrid.

The swell behaviour of soil, the time settlement, swell pressure, load settlement, and California bearing ratio (CBR) of the soil with QD at the best reduced ratio were analyzed. The swelling values controlled by the placement of double-layer (DL) geogrid (GG) are approximately 38.5%, 58%, and 80% for Soil 1, Soil 2, and Soil 3, respectively, compared with Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20) + geogrid double layer (GG (DL). The swelling was controlled 80% through mixing of admixture (QD- 80:20) with placement of geogrid in double-layer. The percentage reduction of swell pressure for Soil 1, Soil 2, and Soil 3 with admixture, single-layer geogrid and double-layer geogrid are 40%, 60% and 80% respectively. It is clearly shown that pressure gradually increased with the addition of admixtures. The provision of the double-layer geogrid increased the pressure by 257.14% compared to Soil 1 alone.

The same soil and admixtures, with and without single- and double-layer geogrid, were used to test the subgrade strength in terms of CBR value. For soil alone, the CBR value are less than 2%; with the addition of admixtures this gradually increased to 12%; and with the provision of single- and double-layer geogrid increased to 16% and 18%, respectively.

Thus, any type of expansive soil exhibits swelling behavior; with the addition of admixture, dry density increases and OMC remains constant regardless of clay content. The results showed that the best admixture for Soil 1, Soil 2, and Soil 3 is QD. The ratio of the admixture with and without geogrids, and ways to improve the stabilization of clay soil were discussed.

KEYWORDS: *Rapid urbanization, geogrid in double-layer, CBR value, Optimum Moisture Content, Maximum dry density, different admixtures, Compressibility of soil*

INTRODUCTION

GENERAL

Rapid population growth, industrialization, and urbanization have created unprecedented demand for infrastructure development throughout the world, which has led to a tremendous increase in construction projects. Earlier, residential buildings and other construction projects were built on suitable lands. Nowadays, urban and rural areas are moving closer, creating a shortage of buildable lands for roads, highways, railways, and airports. Hence, the construction sector is forced to implement construction projects on whatever and wherever land is available. Limited land space, tight construction schedules, environmental issues, high maintenance costs, and continuous stability needs demand for innovation to enhance the soil characteristics. In the southern regions of India, 40% of the surface area is covered by clay soil, and 20% of this soil is expansive in nature. The soil mainly consists of montmorillonite, kaolinite, and illite, which are highly swelling in nature.

for expansive soil and that the significant advances have been made with regard to theories on the behaviour of expansive soil. classified the factors that influence swelling characteristics such as physico-chemical, environmental, and geological engineering. The research investigated the pre- wetting method, an obsolete one, which increases compressibility, reduces the shear strength of soil and is time consuming. The moisture barrier method failed to arrest the water percolation owing to heavy rains and the water table. This research has been widely carried out on the factors influencing the magnitude of the swelling behaviour of soil and their control measures.

SOIL STABILIZATION

Soil stabilization has been a challenge for geotechnical engineers to find innovative and cost-effective techniques to improve the engineering performance of expansive soils such as increasing soil strength (shearing resistance) and durability (wearing resistance), reducing swelling potential and stiffness (resistance to deformation) and other desirable characteristics. Chemical or mechanical treatments are intended to improve the shear strength, sustainability, reduce compressibility, and control the water absorbing capacity of treated soil.

This research examines the potential of such treatments to improve expansive soil and investigates the changes that occur in the engineering properties of soil by modification or improvement of the properties of expansive soil without any admixture (mechanical process) and with admixture (chemical process).

Chemical stabilization is the addition of one or more external agents to expansive soil to improve its mechanical and geochemical properties. Chemical additives accelerate consolidation settlement under embankments and prevent sliding failure of embankments. The utilization of chemical admixtures is aimed at increasing the strength, improving swelling or squeezing characteristics, reducing compressibility, and increasing the durability of the soil.

Soil Stabilization with Solid Waste

The rising environmental consciousness towards pollution due to chemical stabilizer's utilization, identifying the impact of potential solid wastes in soil stabilization demands the researchers to work on quantifying the environmental footprint. Various methods for effective utilization of solid wastes are being identified and serious research is being conducted on the impact of these materials. Fly ash, quarry dust, marble dust, cement kiln dust, coconut coir, sugarcane, bagasse waste, rice husk ash, saw-dust and eggshell powder are some of the industrial and agricultural wastes that have been researched, accepted, and successfully adopted for soil improvement.

Swell Control

Swell prediction methods can be categorized into three: consolidation theory-based methods, water content-based methods and suction-based methods. Each method has its own strength and limitations. Thus, it is up to the geo technologist to select simple, economical, and efficient methods to predict the moisture movements of expansive soil over time. Effective treatment of expansive soil can reduce or clear up its swelling properties and improve the shear strength index.

Clay soils exhibit cyclic swelling and shrinkage phenomena with respect to seasonal moisture fluctuations. During swelling, the soil softens and loses its strength. Swelling is influenced by geological, environmental and engineering factors. Swell and shrink leads to low bearing capacity when wet and when it is dry severe cracking occurs.

STABILIZATION WITH ADDITIVES

Many researchers have considered industrial wastes like quarrydust, marble dust fly ash, furnace slag, and agricultural wastes (e.g., rice husk,sugar cane, etc.) to stabilize the soil. recommended that double objectives like waste disposal with improvement of weak soil could be achieved by appropriate blending of admixtures with the soil. evaluated soil characteristics and stabilization improvement with various additives.

Quarry Dust

Quarry dust (QD) is a cohesion less and non-plastic material. As natural sources of sand are getting depleted, more regulations are given by the government for sand mining. Quarry Dust is formed during primary and secondary crushing and screening. Owing to the increase in construction projects such as roads, rail, buildings and concrete works, the demand for crushed stones has increased. To cope with the demand, crusher units were multiplied and the crusher dust generated leads to environmental pollution problem. The bulk density of quarry products vary according to the type of rock processed. Quarry Dust yields high California bearing ratio (CBR) which defines the behaviour of good sub-base material. Quarry Dust - sand mixtures have been used in embankments, backfills, and sub-base materials. Quarry Dust increases the strength of subgrade soil (Pradham *et al.* 2014). The shear strength of Quarry Dust -soil mixtures is less sensitive to moulding water content around the optimal moisture content (OMC). In this research, QD was obtained from stone quarries in Thattaparai, Thoothukudi Tamilnadu State, India, and used for investigations with expansive soil in ratios 90:10, 80:20, 70:30 and 60:40 respectively.

Fly Ash

Fly ash (FA) is one of the by products generated when coal is used as fuel in thermal power plants. The fine-grained fraction, collected from exhaust gases by electrostatic precipitators, is classified as class C depending on the source of the coal. Class F has maximum silica of approximately 70% and low calcium content of nearly 10%. Class C contains 50% silica and high calcium content between 30% and 40%.

When FA is mixed with expansive soil, both short- and long-term reactions occur (Diamond *et al.* 1965). During short-term reactions, ion exchange takes place, which leads to agglomeration and flocculation on the expansive soil, causing immediate swell, shrinkage, and plasticity index. Long- term reactions slowly increase the strength of the treated soil, which can take a few weeks to several years (Nicolson *et al.* 1993). The improvements in the strength characteristics of expansive soils in terms of CBR, shear, unconfined compressive strength (UCS), and volume change were analyzed. In this research, FA was taken from a thermal power plant in Thoothukudi, Tamilnadu, India, and utilized in tests with expansive soil; the maximum dry strength was determined with ratios of 90:10, 80:20, 70:30, and 60:40, respectively.

GEOGRID

Geogrids are made from polyethylene. This technological innovation and increased environmental regulations have prompted researchers to establish alternative soil stabilization methods/techniques. The first geogrid application was developed in 1970 and various applications have emerged since the early 1980s. The initially extruded geogrid were uniaxial and biaxial. Later, triaxial geogrid were developed and implemented. Uniaxial geogrid are punched in one direction, whereas biaxial geogrid are punched in two orthogonal directions. Welded geogrid are manufactured by fusing the junction of polymers and strips. Geogrid reinforcement prevents or reduces rutting caused by bearing capacity failure of the base course or sub grades as well as the lateral movement of base or subgrade materials. One of the latest techniques developed in the last few decades is the use of geosynthetics. The functions performed by geosynthetics are separation, filtration, drainage, and reinforcement. The reinforcement mechanism has improved bearing capacity and lateral restraints.

The most effective location for single-layer geogrid is at the upper one-third of the base course. Proper aperture size and high tensile strength of geogrid play vital roles in producing vertical deformation depth.

The behaviours of reinforced soil have been studied by several geotechnical researchers. The conventional solution to improve the bearing capacity of clay soil is to remove part of the existing soil and replacing it with granular soil. Sometimes, the greater height of the soil needs to be replaced, which increases the cost of the project. As an alternative, geosynthetic reinforcement is recommended. The last two decades have seen the dramatic development of the geosynthetics industry. Innovation, testing methods, and geosynthetic specifications form the crux of this development.

geogrid as a geosynthetic material consisting of connected, parallel sets of tensile ribs with apertures of sufficient size to allow soil, stone, or other geotechnical materials. Geogrids are mostly used in soil reinforcement, soft ground improvement, and construction. According to geogrids can be categorized into three: i) uniaxial geogrids provide tensile stiffness and strength in one planar direction; ii) biaxial geogrids provide higher strength in both longitudinal and lateral direction; and iii) triaxial geogrids provide stiffness and strength more uniformly on the geogrid plane.

When the geogrid is buried in soil, it embeds into the soil. The geogrid provides stiffness, which retains the lateral displacement of soil particles. It increases the aggregate compaction and favours both longterm and short-term performance in roadways. Most research considers the interaction parameters between synthetic and granular soil, whereas few studies have focused on the interaction between geosynthetics and cohesive soils. The mechanisms involved in improving the performance of subgrade soil by geogrids include prevention of local distribution through the base course reduction of shear stress and tensioned membrane effect. In this study, a geogrid was obtained from a local agency in Coimbatore, Tamilnadu State, India. Improvement of expansive soil by QD addition: Soil 1, Soil 2 + QD with ratio of 70:30 and single- and double-layer geogrid, and Soil 3 + QD with ratio of 80:20 and single- and double-layer geogrid was analyzed by different laboratory tests.

NEED FOR THE STUDY

- Owing to increased population, urbanization, and industrialization in countries like India, agricultural and infertile lands have been utilized for construction purposes. A geotechnical engineer has to overcome these problems and turn unsuitable land into useful land in various civil engineering applications. Hence, necessary actions are required for stabilization to improve soil strength with admixtures.
- To analyze the effective utilization of admixtures derived from various industries to minimize the storage area.
- To develop state-of-the-art techniques through the introduction of geogrid over fill material, thereby improving the shear of cohesive soils.

SIGNIFICANCE OF THE STUDY

Rapid urbanization and industrialization has created an unprecedented demand for infrastructure development. As long as the land is suitable for construction activities, it is economical. However, when the situation changes, e.g. moving construction projects to unsuitable land, the land must be developed or stabilized using sound and cost-effective techniques. In our study, the effect of QD, a waste product of crusher units, is used as admixture for the stabilization of local expansive soil.

This research has manipulated the addition of QD and FA to expansive soils and investigated the maximum dry density (MDD) and OMC for various proportions, i.e. 90:10, 80:20, 70:30, and 60:40; explored the volume change of expansive soil; and evaluated the amount of swell; swell control, and strength properties of expansive soil with single- and double-layer geogrid.

ORGANIZATION OF THE STUDY

The analysis of investigational work in the present study is organized into five chapters:

Chapter 1 gives the introduction of the present study.

Chapter 2 presents the literature review for the research.

Chapter 3 presents the identified problems and objectives of the study

Chapter 4 deals with the materials and methods adopted to carry out the investigation.

Chapter 5 analyses the results obtained from laboratory experiments.

Chapter 6 forms the conclusion for the present work.

LITERATURE REVIEW

Katti *et al.* (2020) observed that. in Indian expansive soils. the depth of active zone is confined only to the top 1.0 to I.2m and that there will nut he my chmge in the dry density corresponding to changes in moisture content. Rhandnri rt al (1987) observed that, in csrlnin areas, the depth of active zone might extend upto 4.5 to 5.0 nl also. Two important terms related to swelling soils need to he introduced and defined here. They are swelling potential and swell pressure.

Swelling potential: Swell potential is the ratio of the incrcasc in thickness to thc original thickness of soil sample in a consolidation ring. compacted at optimum moisture content. soaked in water under a surcharge of 6.9 k Pa (1 psi). 'I'his is cxpresscd as a prcaitagc. % swell is the ratio of the increase in thickncss to tile initial thickncss expressed as a percentage of an undisturbed soil when inundated under water under a surcharge equal lo the field overburden pressure. Swellpressure: The pressure required to be applied on the soil specimcn corresponding to zerovolume change.

Rozhan Sirwan Abdullah *et al.* (2020) investigated CH and CL soil and included MP in percentages of 10, 20, and 30 by weight of the soil. When the percentage of MP was increased, the WL, Wp, IP and swell potential got decreased for the CH & CL soil taken from Bastora & Ebil Airport. The addition of marble powder decreased the swelling percentage by the decrease of liquid limit, plastic limit and plasticity index. Muthu Kumar & Tamilarasan (2015) considered the behavior of clay soil by using marble powder with the percentage of 0 to 25% at an increment of 5%. As a result, it indicates that at 15% of marble powder, the maximum UCS of the clay is 215KN/m^2. The expansive soil was modified into low plasticity and silty behavior.

Choudhary *et al.* (2019) analyzed the subgrade strength by using multiple layers of reinforcement viz. geogrid and jute geotextile. When the soil is reinforced with single layer the expansion ratio decreases and goes on decreasing with an increase in number of reinforcing layer. The inclusion of reinforcement controls swelling of the soil as is evident from the decrease of jute geotextile and marginal in the case of geogrid. With increase in number of reinforcing layers, the CBR value also increased. studied the improvements in the clay soil with inclusion of geogrid by conducting CBR of the sub grade with and without geogrid. It was reported that the soaked CBR value for without geogrid was 2.9% and when the geogrid was placed at 20cm from the top, the CBR increased to 9.4%. It was also concluded that 0.2H from top gives the improvement in CBR value and shows the stress strain characteristics of the soil.

Arunkumar & Kiran B Biradar (2019) identified that quarry dust to the soil reduces the clay content and thus increases the percentage of coarser particles, it is also identified that addition of 40% of quarry dust yielded high CBR value. The addition of QD increased the MDD by 5.88% at 60:40 ratios reduced the liquid limit by 26.86%, IP by 28.48% and OMC by 36.71% compared to the unmodified soil. Amulya Gudla (2017) studied that the addition of crusher dust to the soil collected at Rajivnagar, near Warangal, Andhra Pradesh, reduced OMC of soil to 27.5% with increased in percentage of crusher dust. The addition of crusher dust to the oil increased MDD of soil to 8% with increase in percentage of crusher dust. The CBR value increased to about 64.17% with addition of 30% crusher dust.

Sridharan (2018) presented the improved compressibility characteristics of expansive soil with fly ash which resulted in the decreasing of liquid limit, OMC and swell pressure. used class F flyash and zycosil in soaked and unsoaked condition to determine the CBR value. used lime and flyash with expansive soil and reported the increment in WL, WP, OMC and reduction in IP and MDD. Similar experiments were conducted for embankment settlement. swell pressure, swell potential and differential free swell index. considered the various percentage of geogrid such as 1%, 2%, 2.5% and 3% with weak sub grade soil and soft murrumincreased the CBR value.

Parte Shayam Singh *et al.* (2018) examined the impact of MP on black cotton soil by varying the percentages from 0 to 40. A huge change was observed in consistency limit. The WL reduced from 57.67% to 33.9%. The IP reduced from 28.35% to 16.67% and shrinkage limit increased from 8.06 to18.39% with the addition of MP. The differential free swell decreased from

66.6 to 20%. The addition of MP increased the UCS value and varied from 110.86KN/m^2 to

175.46 KN/$m^{2.}$ When 40% of MP was added to black cotton soil, the CBR value increased from 1.81 % to 4.17%.

Arvind Kumar & Sivapulliah (2017) dealt with number of trials to explore the effects of different Fly Ash contents on the physical and also rigidity developments in soil. In order to find out whether it is capable for use in the presence of gypsum, lime treated soil and lime treated gypsies soil wereused. To evaluate the engineering properties of soil, Atterberg limit, Free Swell Index, Compaction Tests, and Unconfined Compressive strength tests etc were conducted to obtain the rigidity developments at different time interval up to 1 year. On conducting PH tests and detailed micro analysis changes in Alkalinity, Mineralogy and Microstructure were observed. Atterberg Limits for all proportions of soil were determined and Optimum Lime Content (OLC), Maximum Dry Density, Optimum Moisture Content and UCS tests etc were also performed.

Jitendra Singh Yadav (2016) presented the outcome of the study carried out for stabilization of the clay by mixing Pond Ash and Cement and treated coir fiber. At the same time, various laboratory tests were performed to observe the strength parameters such as Unconfined Compressive strength (UCS), Split Tensile Strength etc with various mix proportions. When the Pond Ash and cohesive soil are mixed (5%, 10% etc) together for stabilization, it was observed as cost effective and also eco - friendly. Increased usage of waste materials would reduce the proportion of cement, which leads to greenhouse emissions (Co2, CH4) and also save energy. This technique of stabilization exhibited the improvement and good appearance for the structure viz. Buildings, Foundations, Pavement etc. For determining the Tensile strength of soils bending tests, Direct Tensile, Split Cylinder Test and Double Punch Tensile tests were performed. On performing Proctor Compaction test on the various mixtures of pond ash, cement and treated coir fiber, Maximum Dry Density (MDD), Optimum Moisture Content (OMC) were evaluated.

It was concluded that, the unreinforced soil with cement stabilization with these mixtures improved the axial stress and axial strain by nearly two times and decreased the cost. By inclusion of coir fibers, brittleness may lead to sudden decrease in post peak strength and thereby increases the ductility. In fiber content more than 1%, decrease in stability has been obtained. The combination of these mixtures was replaced up to 20% which results in best improvement.

Gudo *et al.* (2016) carried out a series in - situ tests using geogrids on rectangular and square footings. conducted their experiments on sand reinforced geogrid to determine the critical path of the reinforcement and the dimension of the geogrid layers. performed an extensive work on monotonically loaded footings and investigated the improvements in the bearing capacity and settlement characterizes of footings. studied the effects of aperture openings of the basal geogrid. It conducted experimental studies on circular footing on geocell reinforced sand and soft clay with a series of tests by varying the width and height of geocell mattress.

Aref Al Swaidani (2016) The objective of this paper is to identify the micro structural improvement and to analyze the chemical composition of the examined lime stabilized clayey soil after adding natural pozzolana. Number of tests such as consistency, compaction, CBR, linear shrinkage properties were examined using Scanning Electron Microscope (SEM) which was fitted with energy dispersive X-Ray spectrometer.

Plasticity index decreased with increase in natural pozzolana which denotes the increase of strength, reduced swelling and compressibility to convert the clayey soil from CH to MH classification, the use of natural pozzolana and 4% lime has to be added. By adding natural pozzolana to lime stabilized clay soil instead of adding 20% natural pozzolona affected the MDD and 8% of lime was obtained.

Dharmapal N.Shingade *et al.* (2016) studied on the basis of L9 orthogonal array strength Characteristics and input parameters were developed by regression analysis. For predication of Swelling Pressure Strength in terms of Fibre percentage and length of fibres, mathematical model for Swelling Pressure of Expansive Soil - Fly ash Mix Reinforced with Nylon Fibres were developed. It is observed that difference between predicated and observed value of Swelling pressure is lies within 10%, the suitability of developed mathematical model were tested by conducting different experiments.

Vinod Sonthwal *et al.* (2016) explored the feasibility of using QD to investigate the possibility of improving the strength of clay soil. By conducting modified proctors laboratory test and concluded that the optimum replacement of quarry dust was 25%. It was reported that the increased value of MDD is due to the increase in percentage of quarry dust with higher specific gravity than clay. Thirumalai *et al.* (2017) conducted experiments on the black cotton soil with QD to modify the soil with mechanical means and tested for WL, OMC, and MDD. It was observed 20% of the QD improved the UCS and WL decreased from 21% to 17%. It was concluded that the increase of the specific gravity of black cotton soil with the addition of quarrydust is due to plasticity character of soil

Mohamad *et al.* (2015) studied the effect of mixing straw ash and crusher fines on UCS of silty soil of Kurukshetra, India. The covered Atterberg's limits, modified proctor compaction test and UCS in various proportions from 2%, 4%, 6%, 8% and 10%. It was concluded that the crusher sand effectively improved the soil property. Indiramma *et al.* (2016) conducted laboratory experiments on expansive soil with the addition of QD different percentage to check the improvements in the soil properties. The results from Atterberg's limits, compaction characteristics, different free swell index and UCS concluded that the clay soil has reduced swelling and increased MDD.

Venkateswaralu *et al.* (2015) researched on the suitability of QD for the improvement of the strength of expansive soil. The decreased value of differential free swell with the increasing percentage of quarry dust to the expansive soil varied from 100% to 83% at

10% increment of QD. From the laboratory results such as shear strength parameters, soaked CBR and differential free swell on clays with different proportions of QD. It was observed that the optimum of 10% of QD resulted in the improvement of soil strength.

Satyanarayana *et al.* (2013) studied the strength characteristics of compacted crusher dust with gravel soil at North coastal districts of Andhra Pradesh, India through a series of CBR tests by varying the admixture ratio. Onye lowe ken et al (2012) analyzed the QD properties and exposed the application of QD during soil improvement and for a more economic approach. It was reported that the addition of QD to the expansive soil would make it more porous, reduce cohesion etc. Since the structure of the QD is rough sharp and angular particle, the clay soil gains the strength from these particles.

Sabat et al. (2013) investigated the effect of QD + FA mixture in different ratios on engineering properties of the expansive soil. With the increased percentage of FA and QD, the CBR & MDD, OMC and swell pressure decreased. The optimum FA& QD mix was found to be 45%. Sabat et al. (2012) conducted different tests for Atterberg's limit, compaction characteristics; shear strength parameters with expansive soils mixed with optimum percentage of QD (45%). When the percentage of lime was increased, the liquid limit, plasticity index, maximum dry density decreased whereas plastic limit, shrinkage limit, cohesion and angle of internal friction ,OMC of the soil-QD mixes increased.

Evangelin Ramani Sujatha et al. (2012) proved that the strength of weak soil was improved by geogrid reinforcement. CBR tests were conducted on soil with geogrid placed at different depths within the sample, in single, double and triple layer. When geogrid is placed at 2/3 distance from the base it exhibited best performance in the single layer. The CBR value of triple layer of geogrid is higher than single layer but lesser than the double layer. It was concluded that both in soaked and unsoaked condition the geogrid increased the strength of the subgrade soil. Therefore it was proved that strength of the soil increased with the geogrid reinforcement provided in a single or multilayer to the subgrade and reduced the thickness of the pavement.

collected the experimental samples at Annanagar, Chennai and conducted the load test swollen sample and the required density was achieved by static compaction. It was observed that when the geosynthetic was placed vertical, orientation caused higher swell reduction. The soil with two layers of geogrid has 2.5 times higher value than swollen clay without geosynthetics materials as load carrying capacity.

Brook *et al.* (2011) conducted the experiments too find free swell index, swell potential, plasticity index, compaction and strength characteristics on expansive soil with flyash by varying its percentage from 0 to 20. In this finding, as the percentage of flyash increased, the MDD increased, OMC decreased, the shear strength increased and the conductivity decreased. Bin Shafique (2010) found significant increase of UCS, decreasing of plasticity and swell potential. The similar result was reported and also included lime in his studies.

Ali & Koranne (2011) used FA and QD in the ratio of 1:1 up to 50% of an expansive soil and determined the WL, WP, compaction characteristics, UCS, FSI and soaked CBR values. Strength was reported to be in increased trend. Ankur Mudgal *et al.* (2014) has studied the effect of stone dust on black cotton soil and concluded that MDD of lime stabilized 9% black cotton soil increased up to the addition of 20% stone dust and further increase of the agent decreased the value. Similarly for UCS and CBR the strength increased up to 20 % addition of stone dust in lime stabilized soil. This effect is due to the pozzolanic reactions of lime with the clay in the soil and with stone dust.

Agarwal & Gupta (2011) reported that with the addition of QD to the expansive soil to improve the stability results in improvement for the high way sector. performed Atterberg's limit tests, linear shrinkage test, and free swell index and modified proctor test on black cotton soil and marble dust from Gandhinagar. It was evaluated that the swelling potential of the soil in its natural state as well as mixed with varying proportions of MP increased from 30 to 50%. It improved the swelling and linear shrinkage properties of the expansive soil.

conducted CBR tests on soft sub grade soil with flyash. The very poor subgrade soil has the CBR value ranging from 0to 5% or soft sub-grade. The FA increased the CBR and resilient modulus of the weak soil. Kate (1998) worked on CH soil and reported a decrease in swelling pressure from 120 Kpa to 90 Kpa by treating with 12% FA. studied the effect of class C flyash from Turkey, on the swelling characteristics of expansive soil. reported a decrease in swell potential from 19.6% to 0% by the addition of 15% class C fly ash.

Sabat & Das (2009) conducted the expansive soil with QD admixture to find the compaction characteristics, UCS, soaked CBR and swell potential. Ramdas *et al.* (2010) in his experiment on expansive soil with QD, FA admixtures with different proportions, showed that the QD increased the strength of the soil and reduced the swelling characteristics. It was found that the optimum percentage of FA and QD are 25% and 30% respectively in improving the soil strength when these additives are added, the Atterberg's limits, OMC and free swell index decreased and MDD, UCS & CBR values increased.

Soosan *et al.* (2005) studied the effect of quarry fines on red earth, Kaolinite and Cochin marine clay to improve the geotechnical characteristics in highway construction. The steady increase of CBR value with respect to the increased QD is attributed to the significant improvement in the angle of shearing resistance. The QD improved the CBR value of the soil and the optimum proportion of 40% QD with 60% of soil. Sridharan *et al.* (2005) analyzed the QD and reported that the QD showed high shear strength so that it is recommended for the beneficial use as geotechnical material. It was found that the shear strength with the addition of QD becomes less sensitiveto water content variations at OMC. Therefore compaction at dry side is more beneficial.

Zomberg & Guptha (2009) worked on the reinforcement of pavements using geogrid and reported that it minimized the development of longitudinal crack. They constructed two geogrid reinforced sections, the first on 20cm ad the second one 12.7cm thickness base course. The falling weight deflect meter testing obtained a clear evaluation of performance based on visual inspection and condition survey.

Ezekwesilieni (2009) proved that when Pyroclastic dust also known as quarry dust with varying % was added with expansive soil improved the geotechnical properties by the investigation of atterberg limit, compaction, CBR. Meanwhile plasticity index and linear shrinkage has to be reduced when added to pyroclastic dust resulted in change in water content. With the increase in dust there was a reduction in plasticity index of the soil and the workability has improved.

In a compaction test, addition of pyroclastic dust to the soil sample resulted in increase of MDD, OMC up to 8% and decreased thereafter denotes the higher compactive energy. Expansive soil has higher content of clay minerals and calcium oxide (lime) present in pyroclastic dust increased the OMC. In CBR test, the pyroclastic dust added with various ratios such as 4%, 8% & 12% resulted in increase during the curing period upto 7 days. Afterthat it revealed decrease in CBR value. Pyroclastic dust supposed to be added to 12% shows decrease in strength and increase during the curing period. Finally, it has been concluded that CBR value attained the maximum strength at 8%. Addition of pyroclasticdust has higher unsoaked CBR value compared to soaked CBR value, suggests that improving bearing capacity of soil, serves better in engineering construction. It was concluded that when pyroclastic dust, lime act as stabilizing materials there is reduction in soil plasticity and linear shrinkage when combined with dust. It binds the clay cast and fills the void of the soil.

Increase in soil aggregation, reduction in water absorption, resulted in Improving swelling property and workability of the soil. Reaction between rock dust and clay has an aggregation and flocculation of particles and improvement in shear strength when rock dust increased. By the addition of 8% of pyroclastic dust to the soil improved the CBR strength of the soil

Zaho *et al.* (2007) conducted field tests in a weak subgrade of liquid retention pond, Nebraska using multilayer geogrid and calculated the requirement and compaction of clay liner which eliminated a 30cm crushed stone layer. presented a back analysis of reinforced embankments and suggested that the geosynthetics can increase the factor of safety of embankments.

Al – Sinaidi (2006) investigated the performance of multi layers of geogrid in a model and conducted isolated footing tests on soil with and without geogrid at different depths below the footing. The load settlement characteristics for each soil - geogrid configuration was observed. The influence of various related parameters on the load settlement behavior were critically appraised for their practical significance. Geogrid reinforcement helps to increase the aggregate compaction and improve both the short term and long term benefits. It has network structure and when buried inside soil, it restrains the lateral displacement of soil particles which increased the stability of the soil.

Amu *et al.* (2005) studied the effect of flyash on expansive soil and found that 3% fly ash was better than 11.2% cement in soil improvement. Kate (2005) from his experimental result, reported that the maximum swelling and swell pressure started to reduce with increased fly ash percentage. Garcher & Trivedi (2005) established a reduction in free swell index from 60% to 20% of Ghed expansive soil treated with 30% flyash. Misra *et al.* (2005) determine the laboratory experiments of UCS and CBR, they found that the samples contained flyash and weak soil gained strength during curing period. The swell potential reduced and CBR values increased with increment percentage of flyash.

Nalbantoglu (2004) reported a decrease in swell pressure from 490Kpa to 10Kpa by the addition of 25% class C fly ash to Degirmanlik expansive soil. Al Rawas *et al.* (2005) reported a decrease in swell pressure from 250Kpa to 0 Kpa by the extra addition of 6% lime. Praveen kumar et al. (2006) conducted CBR tests and static and cyclic triaxial test on flyash, QD and river sand. It was concluded that the CBR of QD was maximum than flyash has better stress-strain behavior than QD.

Gopal Ranjan & Rao (2004) reported that due to increase in density the soil is stronger, less compressible, and less permeable. At the dry of optimum and wet of optimum, soil tends to have flocculated and dispersed structure respectively. studied that the addition of fly ash to the soil played a vital role in augmenting shear strength parameters. The value of cohesion also increases by increasing the amount of fly ash. For highly cohesive soil, the cohesion value decreases and the angle of internal friction increases with the addition of fly ash might be due to the soil texture admixed with fly ash and its characteristics investigated the increase of MDD and decrease of OMC with the increasing percentage of flyash. found that the addition of lime with soil + FA mixtures decreased the linear shrinkage to a certain percentage and after that the linear shrinkage started decreasing. concluded that the similar type experiment and got the same type of result.

Zalihe Nalbantong Lu (2004) dealt with Soma Fly Ash being used as a chemical additive to modify the engineering properties of the soil, which was available from Soma Thermal Power Station in Turkey. Field tests were performed on Degirmenlik and Tuzla soil specimens were collected at a depth of 1.5m below the ground surface. Number of tests was performed on compacted soil specimens without any admixture and then the additional tests were carried out with thermal wastes added in different proportions in order to study the engineering properties of the soil Degermenlik soil revealed rapid decrease in Liquid Limit values whereas Tuzla soil exhibited increase in Liquid Limit values. Even though, the rise in Liquid Limit value was observed for Tuzla soil, the rise in Plastic Limit is large enough to set right the increase so that the maximum Plasticity Index values of Tuzla soil decreased continuously. The reduced Cation Exchange Capacity (CEC) shows that the thermal waste may cause changes inthe mineralogy of treated soils and create secondary reaction of minerals.

Kumar & Saran (2003) conducted laboratory test using strip and square footings on geogrid reinforced sand. conducted field tests on land reclaim from the ocean in Korea on a granular pad with and without geogrid reinforcement. It was observed that the layers help in redistributing the stress over a large area thereby allowed the foundation to support a larger load per square meter for a given settlement load

Agus Setyo Muntohar (2000) experimented the Engineeringproperties of clayey soil mixed with lime, RHA and laboratory experiments were conducted at varying % (2, 4…12%) and 7.5%, 10%, 12.5% for RHA. These results of mixer decreased the behavior of clay soil swell potential, plasticity index and increased CBR. Increase in lime and RHA, MDD decrease, OMC increase and decreased MDD denotes compaction energy less than the original state.

OMC increase tends to increase the lime combination; RHA improved the engineering properties of soil when effective lime mixed in the range of 6-10%. Akshaya Kumar Sabat *et al*. (2018) explored the prediction of CBR of lime and quarry dust stabilized expansive soil, ANN and SVM can be used to develop accurate models at different curing periods. The predicted and observed values highly correlated with the comparison between the observed and predicted CBR values of the stabilized soil using BRNN.

Okagbue (1999) experimented with Red tropical soil collected from South-Western Nigeria at 3 different places. Geotechnical properties were determined on their natural state and then mixed together with varying percentage of marble dust reached the good strength based on their curing period of 28 days at the temperature of 40 °C, 60 °C and 80°C. Each of three soils increased with the increase in WL, Wp and decreased in plasticity index of marble dust. Especially addition of marble dust caused decrease in MDD, increase in OMC.

PROBLEM IDENTIFICATION AND OBJECTIVES

PROBLEM IDENTIFICATION

OBJECTIVES OF THE STUDY

This study attempts to analyze the behaviour of Soil 1, Soil 2, and Soil 3 in terms of index, strength and swelling characteristics with selected admixtures such as QD, FA and single-and double-layer geogrids. As such the objectives are furnished below.

- ➢ To determine the dry strength of soil with admixtures in suitable proportions that provides the maximum dry strength.
- ➢ To evaluate the amount of swelling, time–swelling, and swell pressure of Soil 1, Soil 2, and Soil 3 with and without admixtures on single- and double-layer geogrid.

- To obtain the load–settlement curve for Soil 1, Soil 2, and Soil 3 with and without admixtures by adding single- and double-layergeogrid.
- To assess the subgrade strength of Soil 1, Soil 2, and Soil 3 under soaked condition with and without admixtures and by adding single- and double-layer geogrid.

MATERIALS AND METHODS

MATERIALS

In this research, three different types of soils were designated as Soil1, Soil 2 and Soil 3 and their properties are given in Table 4.1 .The properties of various admixtures such as Quarry Dust (QD), Marble Powder (MP) and Fly Ash (FA) are given in Table 4.2. The geogrid properties are given in Table 3.3 are placed at one–third, two –third height act as single and double layer into the standard mould.

Soil1, Soil 2 & Soil 3

Soil1, Soil 2 & Soil 3 were collected from different areas of Bhopal (M.P.), based on the consistency index and free swell test, according to BIS classification [IS: 2911 (Part-3) - 1981], soil classified as CL (Low Compressibility), CI (Medium Compressibility) and CH (High Compressibility) of high swelling nature.

Table 4.1 Properties of Soil 1, Soil 2 and Soil 3

Properties	Soil 1	Soil 2	Soil 3
Liquid limit (%)	32	48	72
Plastic limit (%)	12	23	41
Plasticity Index %	20	25	31
Free Swell Index (%)	32	44	91
Maximum Dry Density (g/cc)	1.42	1.57	1.68
Optimum Moisture Content (%)	21	24	26
Gravel (%)	00	00	00
Sand (%)	44	32	14
Silt (%)	18	22	28
Clay (%)	38	46	58
Unconfined Compressive Strength test (UCS) kN/m^2	57.1	73.41	86.70

Admixtures

The Quarry Dust (QD), And Fly Ash (FA) are by products of stone quarry and thermal power plants which leads to occupy more landfill area and waste materials. As this research, attempts to economically utilize the waste material and effectively reduce landfill area the above waste materials are used as admixtures with Soil 1, Soil 2 & Soil 3 in the proportion of 90:10, 80:20, 70:30 and 60:40.

Quarry dust

Quarry Dust (QD) 6mm down was proportionally added with Soil 1, Soil 2 & Soil 3 has been greatly improved for engineering properties.

Fly ash

It is the waste by product that has been utilized for improving the geotechnical properties,

Table 4.2 Properties of admixtures

Properties	Quarry Dust	Fly Ash
Liquid limit (%)	Non plastic	84%
Plastic limit (%)	Non plastic	Non plastic
Specific gravity	2.65	2.09
Maximum Dry Density(kN/m^3)	16.8	13.2
Optimum Moisture Content (%)	6.5	13
Gravel	2	00
Sand (%)	96	15.20
Silt (%)	1	82.65
Clay (%)	1	2.15

Geogrid
Geogrid is the polyethylene by product purchased from retail market. In this research work, the rib thickness of 1mm biaxial geogrid was used.

Table 4.3 Properties of Geogrid (obtained from local agency)

Materials	Types and Sizes
Geogrid	Polyester biaxial geogrid
Tensile Strength (kN/m)	100
Aperture size (mm)	12
Rib Thickness (mm)	1
Junction Thickness (mm)	1.5
Elongation of break (%)	10
Unit Weight g/cc	500
Roll Dimension in m (LXB)	50x2.5

METHODS
Experiments on the various proportions of soils with and without admixture, geogrid of single and double layer have been carried out as detailed in Figure 4.1, Figure 4.2 and Figure 4.3.

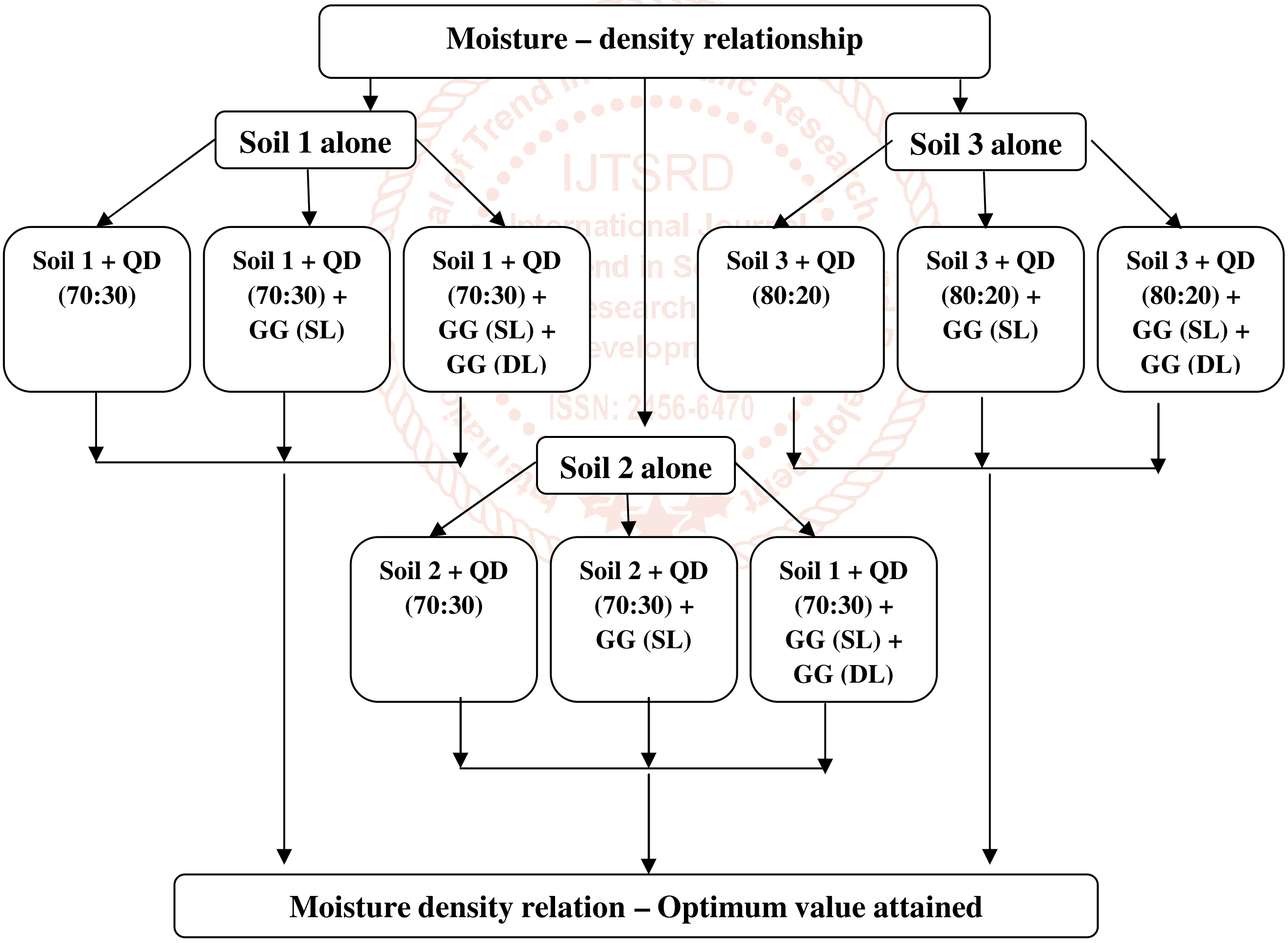

Figure 4.1 Flowchart showing the methodology for Experimental analysis of Standard Proctor Compaction tests on Soil 1, Soil 2 and Soil 3 with various admixtures

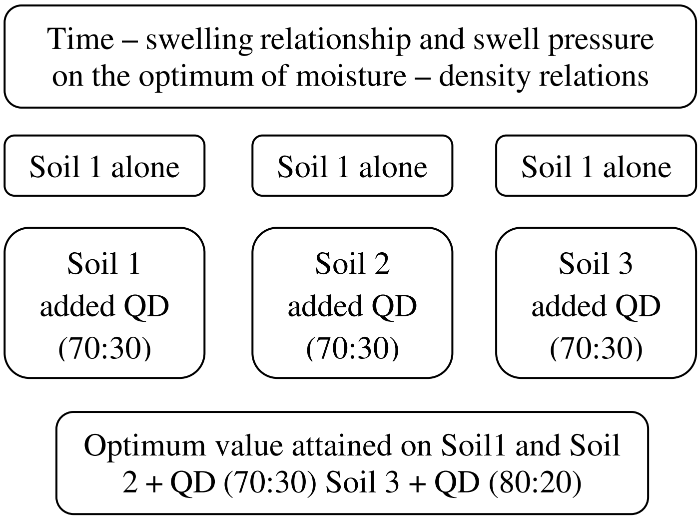

Figure 4.2 Flowchart showing the methodology for Experimental analysis for Time-Swelling& Swell Pressure on various soils + various ratios of QD

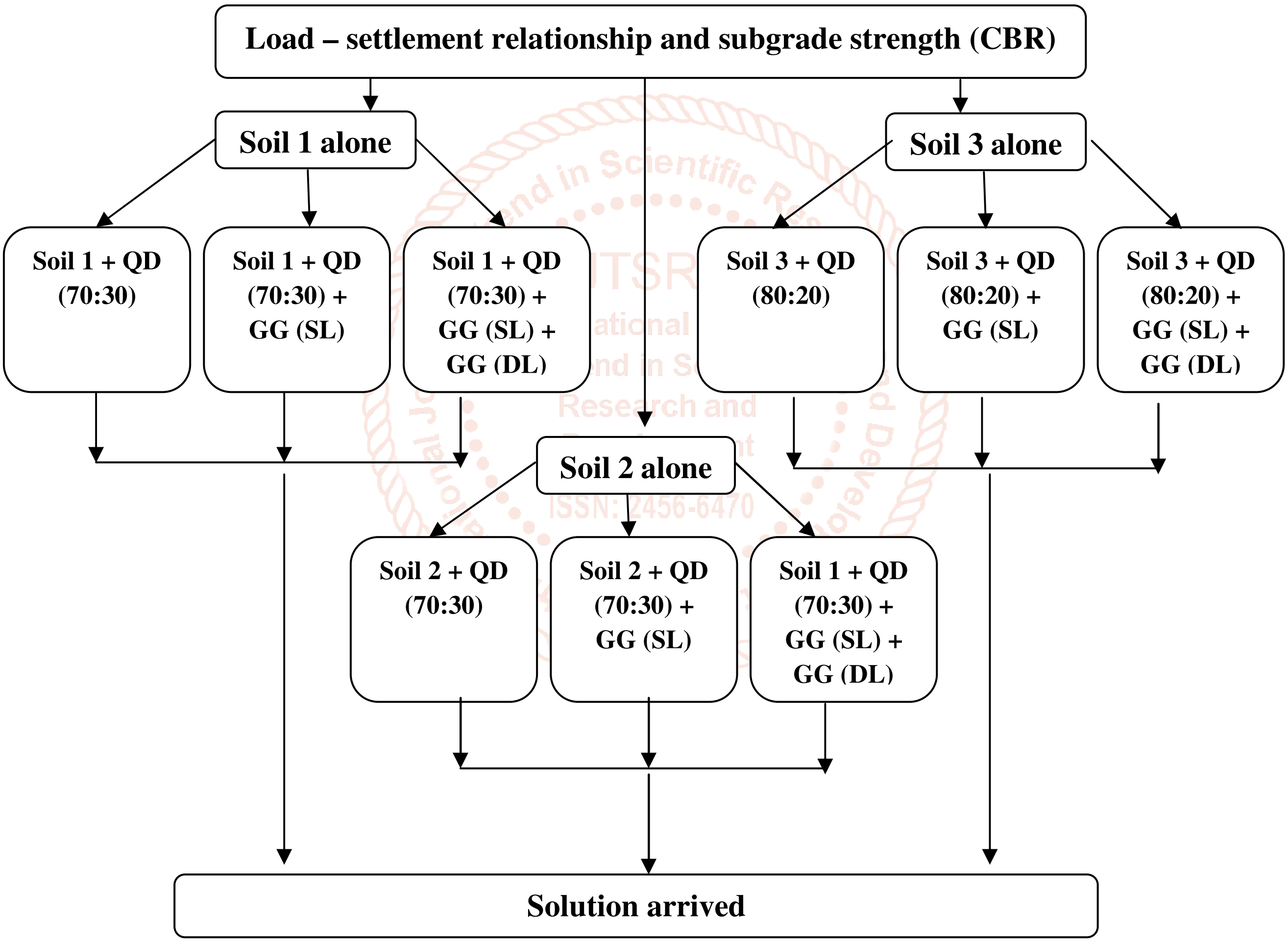

Figure 4.3 Flowchart showing the methodology for Experimental Analysis for load Vs settlement and CBR on various Soils + QD with GG (SL, DL)

Index Properties

Liquid and plastic limit tests were conducted as per IS [2720 (Part 5) -1985], the sedimentation analysis for clay soil by hydrometer method was determined as per IS [2720 (Part 4) -1985], free swell tests were carried out as per IS [2720 (Part 40) -1977] and Standard Proctor Compaction tests were conducted as per IS [2720 (Part 7) - 1980].

Free Swell Index

The two equal volumes of dry samples were taken; one sample was placed in water and the other sample immersed in a jar containing kerosene. The differences in the height between the samples in kerosene to water were expressed as free swell index. As per IS [2720 (Part 40) -1977].

Mechanical Analysis

It has been divided into two types of analysis as furnished below:

- Sieve analysis
- Sedimentation analysis

Sieve analysis is done by wet sieving method. Oven dried soil is washed through 75m IS sieve. Fraction retained was oven dried and particle size analysis carried out using sieve shaker by passing through the following IS sieve: 4.75mm, 2.36mm, 1.70mm, 1.40mm, 1.00mm, 600μ, 425μ, 100μ, and 75μ respectively 50 g of soil 75μ passing IS sieve was mixed with 3.3 g passing sodium hexa– meta–phosphate and 0.7g sodium carbonate and soil suspension prepared. Suspension was made up to 1000 ml distilled water and then shaken thoroughly. Hydrometer is immersed to a depth slightly below its floating position and then allowed to float freely. Hydrometer readings are taken at 10, 20, 30 and 45 sec, subsequently at 1, 2, 4, 8,15 and 30 minutes and finally at 1, 2, 4, 8- and 24-hour interval. Diameter of the particle in suspension at any sampling time 't' is calculated using "Stokes" formula and the percentage finer was calculated. In the semi log graph, silt and clay fractions are indicated along with coarser fractions.

Sieve analysis is useful to classify the coarse-grained soil which has the particle size greater than 75 micron and sedimentation analysis is useful for fine grained soil has the size smaller than 75 microns to 2 microns. The sedimentation analysis is based on Stokes law, the particles submerged into the water and takes time to settle. It clearly indicates the types of structure, texture in terms of CU, CC.

Standard Proctor Compaction Test

A 5kg sample of air-dried soil passing through the 19mm IS Sieve should be taken. The sample should be mixed thoroughly with a suitable amount of water depending on the soil type (for sandy and gravelly soil – 3 to 5% and for cohesive soil – 12 to 16% below the plastic limit). The soil sample should be stored in a sealed container for a minimum period of 16hrs. The mould of 1000cc capacity with base plate attached, should be weighed to the nearest 1g (W1). The mould should be placed on a solid base, such as a concrete floor or plinth and the moist soil should be compacted into the mould, with the extension attached, in five layers of approximately equal mass, each layer being given 25 blows from the 4.9kg rammer dropped from a height of 450mm above the soil. The blows should be distributed uniformly over the surface of each layer. The amount of soil used should be sufficient to fill the mould, leaving not more than about 6mm to be struck off when the extension is removed. The extension should be removed and the compacted soil should be levelled off carefully to the top of the mould by means of the straight edge. The mould and soil should then be weighed to the nearest gram(W2).

The compacted soil specimen should be removed from the mould and placed onto the mixing tray. The water content (w) of a representative sample of the specimen should be determined. The remaining soil specimen should be broken up, rubbed through 19mm IS Sieve and then mixed with the remaining original sample. Suitable increments of water should be added successively and mixed into the sample, and the above operations should be repeated for each increment of water added. The total number of determinations made should be at least five and the moisture contents should be such that the optimum moisture content at which the maximum dry density occurs, lies within that range.

The mould has 100mm diameter, 127.3mm height rammer and the rammer weight is 2.6Kg with a drop of 310mm and the capacity of 1000ml. The Soil 1 Soil 2 & Soil 3 has been compacted in three layers and the mould has been fixed to the base plate. The collar height is 60mm and 25 blows are required to compact the soil and the blows are smoothly distributed over the surface as per [2720 (Part 7) -1980]. This type of trial can be extended to three to four times till increased dry density comes into decreased manner. Soil1, Soil 2 & Soil 3 has been compacted with admixtures (QD & FA) in the ratio of 90:10, 80:20, 70:30 & 60:40 respectively. The Maximum Dry Density (MDD) corresponding to Optimum Moisture Content (OMC) are found for Soil 1, Soil 2 & Soil 3 with different proportion of admixtures and obtained the higher density values. Soil1 & Soil 2 with admixtures have obtained the value with maximum ratio of 70:30 and soil 3 has the maximum value and ratio of 80:20.

Sample calculations for admixtures in soil:

Amount of soil taken by weight for conducting the standard proctor compaction test with varying proportion of admixture in soil of 90:10, 80:20, 70:30, and 60:40 are as follows.

Dimension of mould diameter = 15cm Mould Height= 17.5cm

$= \pi / 4 (d^2). H$

Volume required for sample to achieve MDD = 0.785 x 15^2 x 17.5

= 3090 cc

At 95% of MDD is maintaining the proportion of

90:10 = 3090 x (95/100) x 1.42

= 4168 gm

= 4168 x 90

Weight of soil = 3751gm

Weight of QD = 417 gm

So this weight of sample was taken for 90% moisture content

Time-Swelling Test

Based on the Standard Proctor Compaction test, the obtained 95% of maximum dry density corresponding to optimum moisture content of the soil sample was compacted and kept for CBR mould in submerged condition. The top and bottom surface of mould consists of perforated plate which has been used to enhance the swelling at any time. The soil has been compacted half of its height and the remaining height has been compacted with the same soil. Initially, the seating pressure has been considered as70Kg/cm^2. The swelling was observed initially at an interval of one hour. The readings were taken till the three consecutive dial readings were constant and the difference between initial height and final height is considered as swelling. The soils were placed on the top and the entire mould has been kept inside the water. The overall density has been maintained equal to the field density which results in controlling the swell pressure as per IS- [2720 (Part 41) - 1977]. Swell Pressure and swell percentage were found by expanding volume method. Soil 1, Soil 2 with the proportions of 70:30, Soil 3 with the proportion of 80:20 were thoroughly mixed and placed into the mould which can be compacted to achieve 95% of dry density. Addition of increased single- and double-layer geogrid improved the swell pressure with respect to time as shown in figure 4.2. Development of tensile stress could be controlled by swelling.

California Bearing Ratio (CBR)

The laboratory CBR apparatus consists of a mould 150 mm diameter with a base plate and a collar, a loading frame and dial gauges for measuring the penetration values and the expansion on soaking. The specimenin the mould is soaked in water for four days and the swelling and water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading frame. Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25 mm/min.

A load penetration curve is drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively. CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking. If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimens is reported as the CBR value of the sample.

The expansion of the soil sample on soaked condition, the penetration in the CBR mould with 150mm diameter, 175mm high separate plate and collar, 50mm plunger diameter has been used. This test is used to determine the suitability of sub base, sub grade and base course. The sub grade strength under soaked condition on Soil 1, Soil 2 & Soil 3 were mixed with QD in the proportions of 70:30 with geogrid of single and double layer with the proportion of 80:20 were evaluated. Soil 1 & Soil 2 has the same CBR value whereas Soil 3 with QD and GG (DL) has the highest CBR value obtained under same condition for 2.5mm penetration.

Load-Settlement

The California Bearing Ratio (CBR) mould was used for load- settlement characteristics of Soil 1, Soil 2 & Soil 3 with QD and single and double layer of geogrid. The test conducted as per IS1888- 1971.

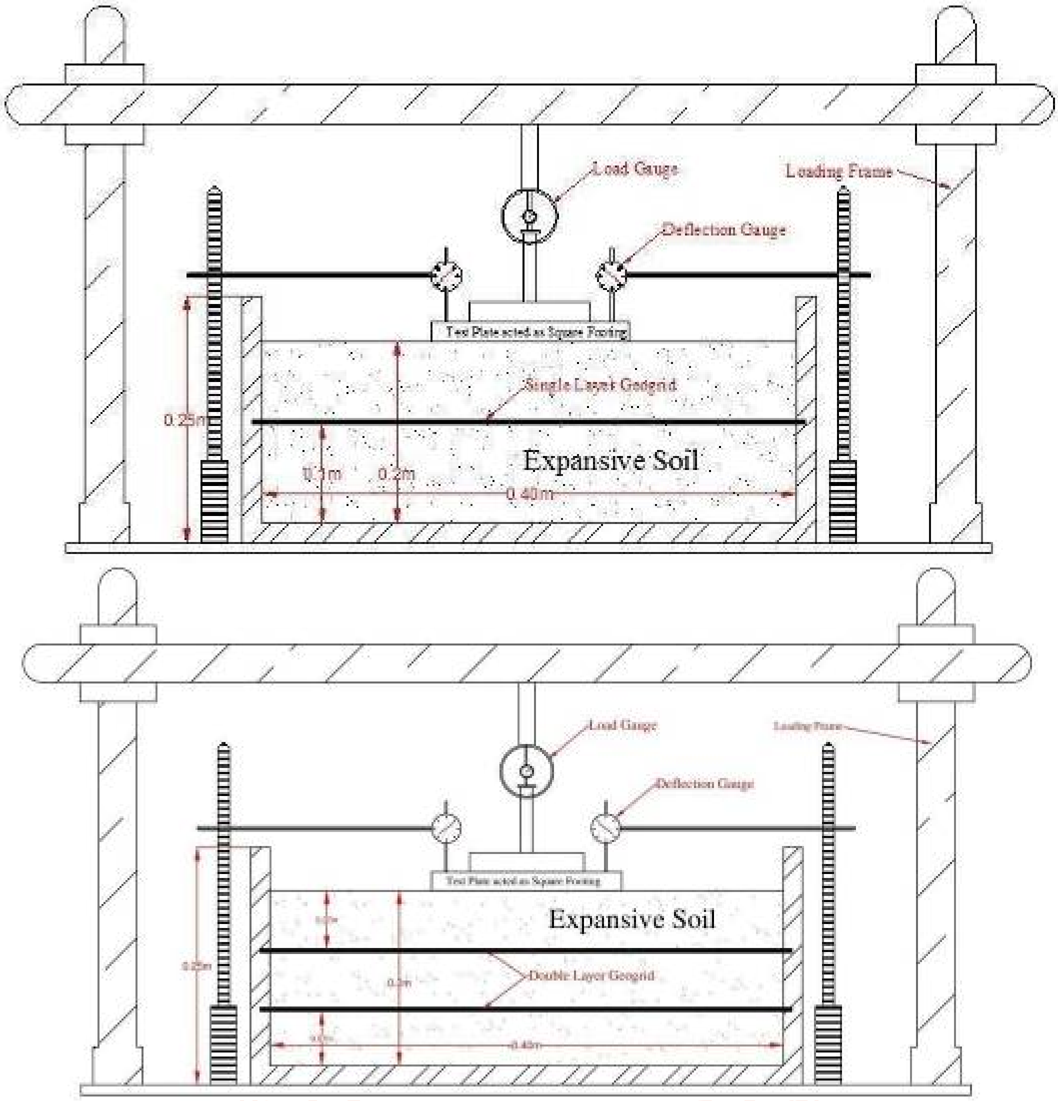

Figure 4.4 Schematic diagram for single- and double-layer geogrid

The strength and settlement characteristics of the Soil 1, Soil 2 with the proportion (70:30) of QD and Soil 3 with the ratio of 80:20 with single and double layer of geogrid have been analyzed as shown in figure 3.4. The tangents drawn for the initial and final portion of load settlement curve, the asymptode to the abscissa are considering the maximum load on each case.

Unconfined Compressive Strength (UCS) Test

The most appropriate and special type of uniaxial method for clayey soil is Unconfined Compressive Strength (UCS) which has confining pressure as zero. The maximum UCS from stress- strain curve is taken as the UCS of each sample.

The results of the moisture density relations (MDD-OMC) for the various proportion of the soil considered as target value corresponding MDD was arrived. Through the non – linear regression analysis of above methods, the regression values were arrived. Similarly, regression value of time – swell, swell pressure, load – settlement and CBR were tried.

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