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

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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 clay soil 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 Compresibility 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

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.

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.

RESULTS AND DISCUSSION

GENERAL

This chapter discusses the experimental results of parameters such as maximum dry density (MDD) and the corresponding optimum moisture content (OMC) of Soil 1, Soil 2, and Soil 3 with admixtures of quarry dust (QD)and fly ash (FA) with ratios of 90:10, 80:20, 70:30, and 60:40. These parameters were analyzed by standard Proctor compaction test as per BIS: [2720 (Part 7) - 1980] shown in Figures 5.11– 5.15. Higher dry densities were obtained from the experiments on Soil 2 with QD (70:30) and Soil 3 with QD (80:20) Further, the above ratios were used toanalyze the time- swelling, swell pressure, load settlement, and Californiabearing ratio (CBR) under soaked condition. The time-swelling behaviour of Soil 1, Soil 2, and Soil 3 alone; and Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20), with single- and double-layer geogrid are shown in Figures 5.16–5.18.

Swell pressure tests were conducted in the laboratory upon completion of swelling of Soil 1, Soil 2, and Soil 3 alone; and Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20), with single- and double-layer geogrid, are shown in Figures 5.19–5.22.

The load settlement of Soil 1, Soil 2, and Soil 3 alone; and Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20), with single- and double- layer geogrid are shown in Figures 5.23–5.24.

The CBRs of Soil 1, Soil 2, and Soil 3 alone; and Soil 1, Soil 2 withQD (70:30), and Soil 3 with QD (80:20), with single- and double-layer geogrid were also determined for the above conditions and plotted in Figures 4.25–4.26.

THE STANDARD PROCTOR COMPACTION TEST ON SOIL1, SOIL 2 AND SOIL 3 WITH VARIOUS ADMIXTURES

The following section discusses the different soils, i.e. Soil 1, Soil 2, and Soil 3 mixed with admixtures QD, MP, and FA with ratios of 90:10, 80:20, 70:30 and 60:40.

Influence of Maximum dry density of Soil 1 with Quarry Dust

Figure in 5.1 shows, Soil 1 with quarry dust 90:10, 80:20, 70:30 and 60:40 through which the quarry dust mixture with 70:30 proportion of Soil 1 provided highest maximum dry density of 1.52g/cc corresponding optimum moisture content is 19%. It is due to the sharp, rough and angular particles of quarry dust (Onyelowe Ken *et al.* 2012). The increase in strength from 1.42 g/cc (Soil 1 without admixture) to 1.52 g/cc after the addition of QD. 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.

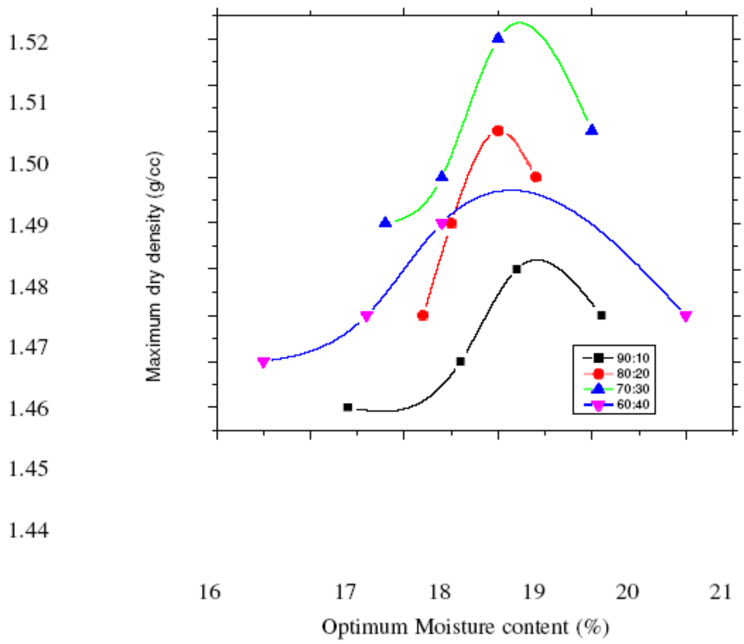

Figure 5.1 Variation of OMC-MDD for Soil 1 with quarry dust

Influence of Maximum Dry Density of Soil 1 with Fly Ash

Figure 5.3 shows Soil 1 with FA in the ratio of 90:10, 80:20, 70:30 and 60:40 out of which the ratio of 60:40 has the higher MDD of 1.35 g/cc corresponding optimum moisture content is 15.2%. The increase of clay minerals and reduction of inert materials show the increase in OMC. Due to the addition of fly ash to black cotton soil, compaction characteristics gets affected and pozzolanic reaction occurs in the soil mass contributing to shear strength improvement Black cotton soil was mixed with FA and QD in the ratio of 1:2, the dry mass of soil increases up to 75%. Adding FA and QD to the dry mass of soil from 0% to 25% with the increment of 5% and then 0% to 50% with the increment of 10% to the soil: fly ash: quarry dust (70:10:20) resulted in the increase of MDD and corresponding OMC decreased by enhancing the percentage of addition of these mixes (Akshaya Kumar Sabat & Bidula Bose 2013).

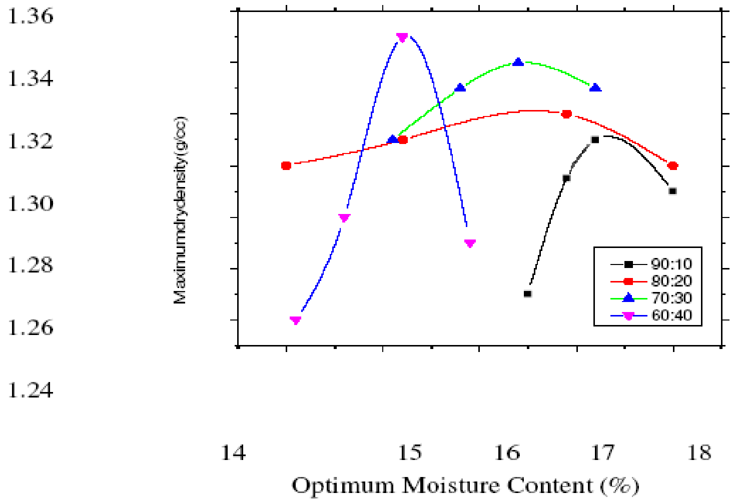

Figure 5.2 Variation of OMC-MDD for Soil 1 with fly ash

Influence of Maximum Dry Density of Soil 2 with Quarry Dust

Figure 5.4 shows the maximum MDD of 1.63 g/cc and OMC of 22 % with the ratio of 70:30 for Soil 2 with QD. It is observed that with the other ratios of 90:10, 80:20, and 60:40 have lower values 1.621 g/cc, 1.62 g/cc, 1.61g/cc respectively. Due to the addition of stabilized soil mixtures like soils stabilized with other cementitious admixtures like quarry fines have the potential for a time- dependent, increase in strength and therefore with additional curing time, further strength is increased.

The mechanism of compacted soil involves capillary effects and osmotic effects. Suction is related with breakage, are very distinct in rockfill materials. The clayey soil reinforced with QD at different ratios of 0%, 15%, 25%, and 35% showed that QD is a good geotechnical material with high shear strength and improved permeability characteristics that prevent water content from seriously affecting geotechnical properties (Vinod Sonthwal2016).

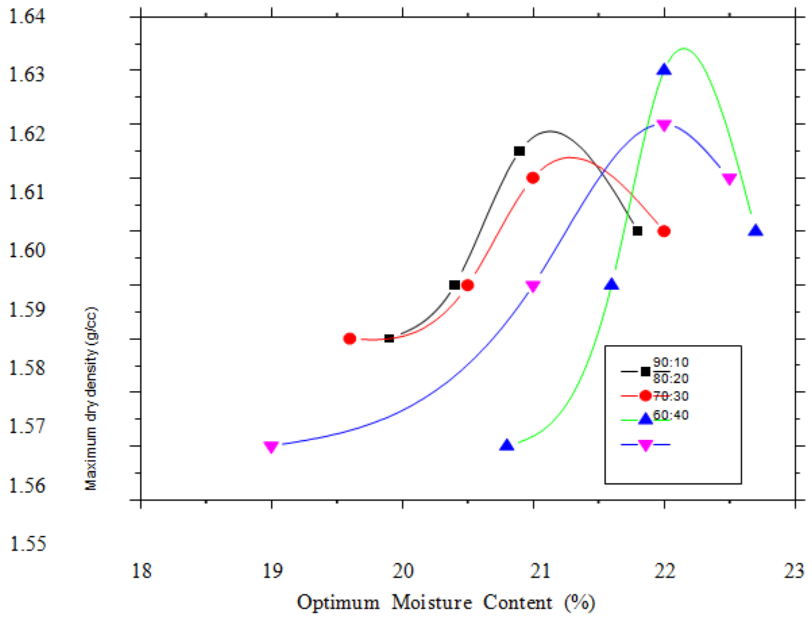

Figure 5.3 Variation of OMC-MDD for Soil 2 with Quarry Dust

Influence of Maximum Dry Density of Soil 2 with Fly Ash

Figure 5.6 shows Soil 2 with FA at the ratio of 60:40 provides the maximum dry density of 1.51 g/cc corresponding optimum moisture content is 18%. The other proportions reacted much faster with water than dry density. The cation exchange, flocculation reaction and soil additive pozzolanic reaction are due to the mechanism of soil with admixture. The chemical composition of soil and fly ash influences the quality and quantity of the reactions resulting in the soil fineness, moisture content, reaction temperature and amount of stabilizer which also enhanced the geotechnical properties of the soil. Soil and FA considered in the range of 10–30% resulted in strength enhancement approximately to 11%.

Two different types of clay such as expansive and non-expansive clay soil are highly plastic and improved the percentage of FA in the soil resulting in the maximum MDD and OMC values (Phanikumar *et al.* 2007). The shape of the grains, the uniformity of grain size, and the conditions of sedimentation depends upon the void ratio of soils. The void ratio and porosityare free from moisture at maximum whereas the void ratios and porosity is minimum in bulk density under compaction. Normally for all soils the dry density reduces in water content till the optimum point of moisture content beyond which the increase in water content decreases dry density (Prabakara *et al.* 2004).

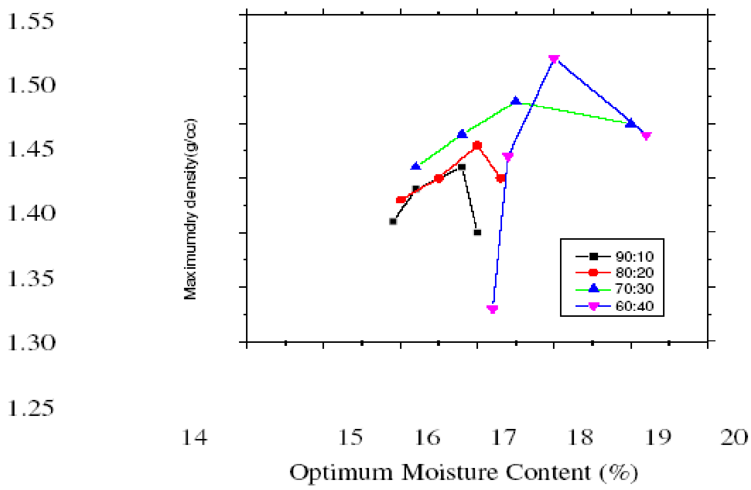

Figure 5.4 Variation of OMC-MDD for Soil 2 with fly ash

Influence of Maximum Dry Density of Soil 3 with Quarry Dust

Figure 5.7 shows the MDD value of 1.72 g/cc corresponding optimum moisture content is 24.1% in the ratio of 70:30 in Soil 3 with QD in comparison with other ratios such as 90:10, 80:20 and 60:40. This is because of reduction of soil plasticity and linear shrinkage when blended with these dust.

In the laboratory tests, such as compaction, specific gravity, and CBR on expansive clays with various proportions of stone dust by dry weight of soil and the addition of stone dust to black cotton (BC) soil increases MDD, decreases OMC, and increases CBR to approximately 50% (Naman Agarwal 2015). The effect of QD mixed with various percentages of modified and unmodified expansive soil by laboratory tests such as consistency limits, compaction and CBR test increases the MDD and decreases OMC.

The liquid limit and plasticity index of unmodified soil is decreased by 26.86% and 28.48%, respectively. With the addition of 40% of QD, MDD increased by 5.88% and OMC decreased by 36.71%, and also yielded higher CBR valueof 4%(Kumar & Kiran B Biradar 2013). Addition of 20% stone dust and 9% lime to stabilized BC soil increased the MDD, UCS, and CBR, and further increase of the stone dust decreased the MDD, UCS, and CBR.

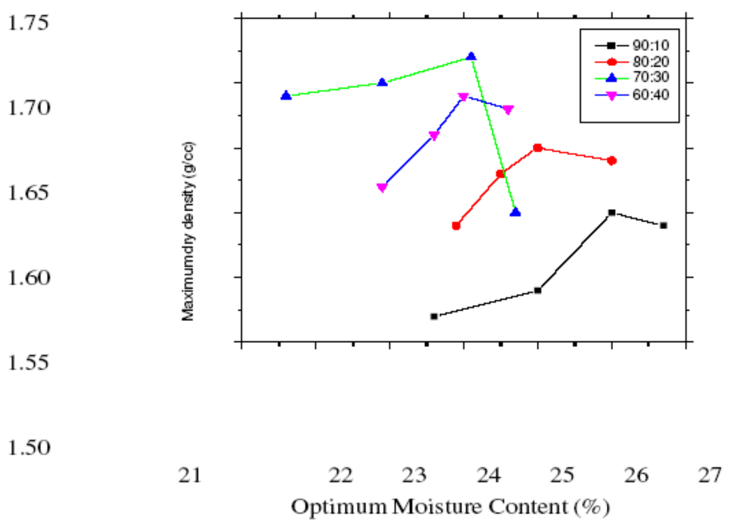

Figure 5.5 Variation of OMC –MDD for Soil 3 with quarry dust

Influence of Maximum Dry Density of Soil 3 with Fly Ash

Figure 5.9 shows that the ratio of Soil 3 and FA (60:40) has higher value of maximum dry density, 1.61 g/cc whereas all other proportions (90:10, 80:20 and 70:30) have lower MDD of 1.57 g/cc,1.58 and 1.59 respectively and corresponding OMC value of 60:40 is 23% and 22%, 23.4%,23% . The addition of soil with FA (70:30) decreased the liquid limit, plasticity index, and MDD but increased the OMC with increasing FA content**.**

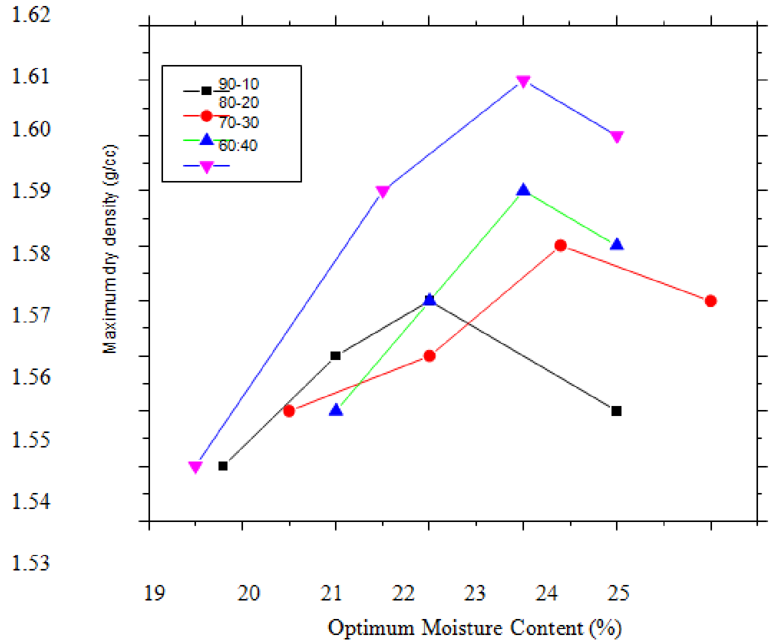

Figure 5.6 Variation of OMC-MDD for Soil 3 with fly ash

BEHAVIOUR OF SOIL 1, SOIL 2 AND SOIL 3 WITH QUARRY DUST AND FLY ASH ON MDD

The following sections discuss the behaviour of different soils, i.e. Soil 1, Soil 2, and Soil 3 with various proportions of admixtures QD and FA. The plots are given for the maximum value of the ratios of 90:10, 80:20, 70:30, and 60:40 vs. MDD and OMC

Influence of MDD of Soil 1 with Admixtures for the Ratios of 90:10, 80:20, 70:30 and 60:40: Figure 5.10 shows Soil 1 with QD (90:10, 80:20, 70:30) in increasing order but decreases with the ratio of 60:40. Soil 1 with MP and FA shows the same trend up to 70:30, with the dry density maintaining the ratio 60:40. This results owing to the augmentation in soil aggregation, modification of the effect of clay minerals, development of swelling properties and reduction in water absorption of the soil.

The addition of fly ash to the soil played a vital role in augmenting shear strength parameters. While increasing the amount of fly ash, the value of cohesion also increases. 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(Prabakara *et al.* 2004).

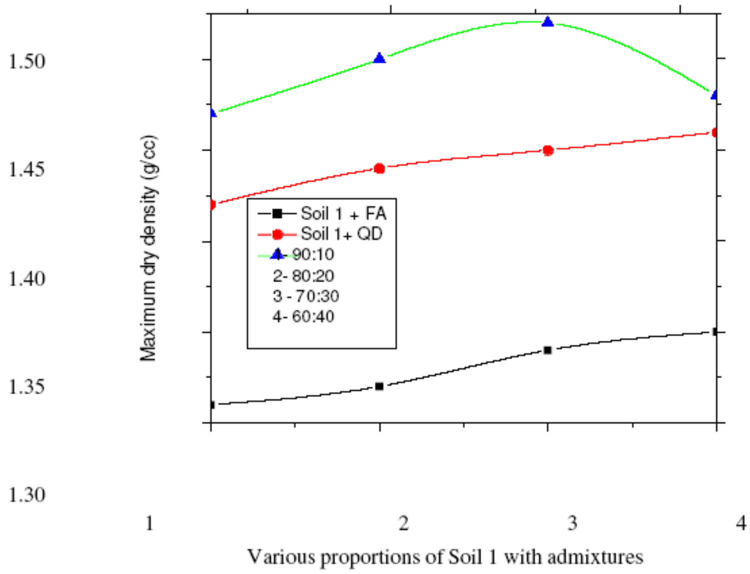

Figure 5.7 various proportions of soil 1 with maximum dry density

Influence of MDD of Soil 2 with Admixtures for the Ratios of90:10, 80:20, 70:30 and 60:40:

Soil 2 combined with admixtures for proportions such as 90:10, 80:20, 70:30 and 60:40 are shown in Figure 5.11. It is noted that the addition of QD to Soil 2 did not significantly increase the MDD for all the proportions.It is due to reduce the clay content of the soil and improve its strength. The initial density value is 6.38% for FA and MP, and the final density is 3.3%. Compared with FA and QD, the initial density is 14.5% and the final densityis 7.28%. The addition of crusher dust to the soil increases the MDD of soil to8%. With further increase in the percentage of crusher dust, due to the reduction of clay content, the coarser particle increases (Amulya Gudla 2017).

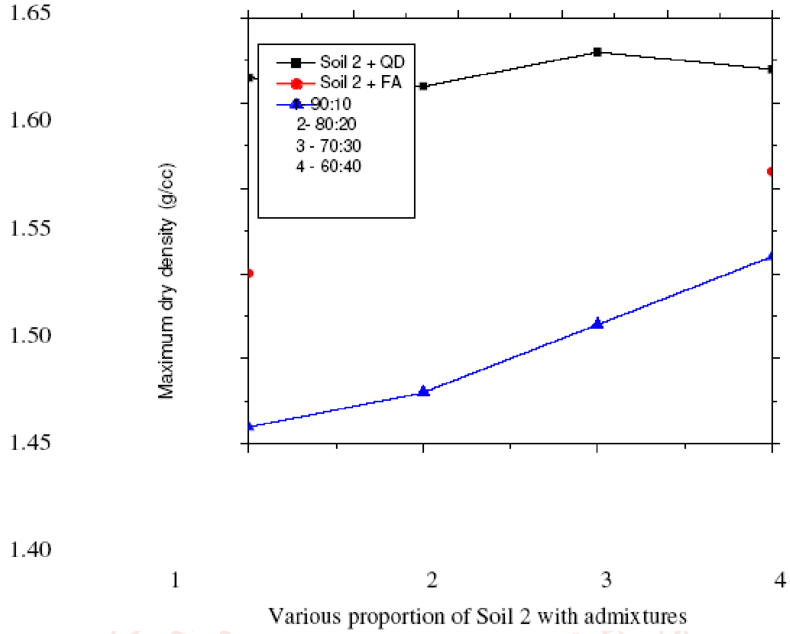

Figure 5.8 various proportions of soil 2with maximum dry density

Influence of MDD of Soil 3 with Admixtures for the Ratios of90:10, 80:20, 70:30, and 60:40:

Figure 5.12 shows the increase of different ratios such as 90:10, 80:20, 70:30 and 60:40 of Soil 3 with FA,Soil 3 with FA, QD increased the density. The initial dry density increased to approximately 2.5%for FA and MP, and 3% for final density; whereas for FA and QD is approximately 1.9% and 6.8% at the initial and final stages, respectively. This shows that the strength increases with increasing plasticity index.

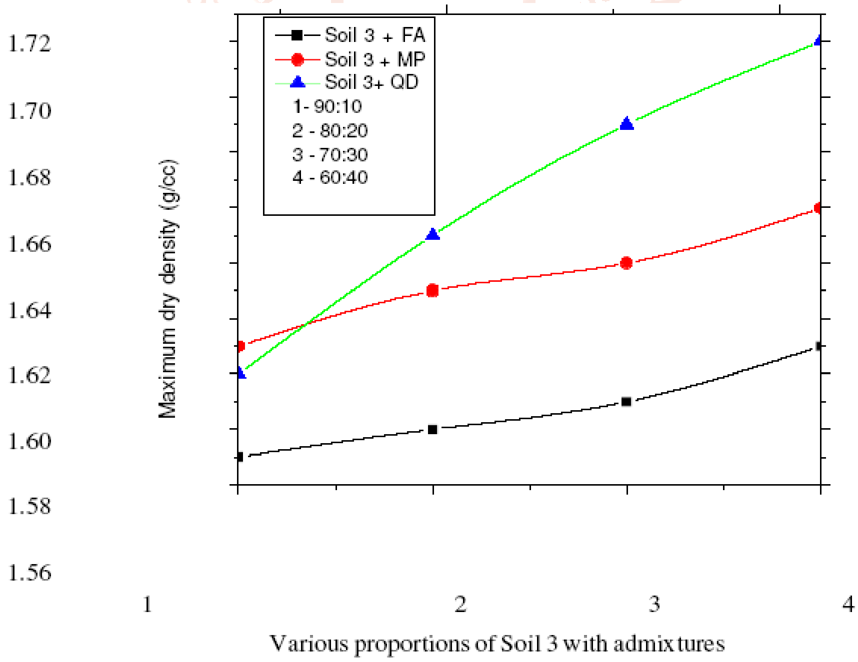

Figure 5.9 various proportions of Soil 3 with maximum dry density

Influence of Optimum Moisture Content of Soil 1 with Admixture

Figure 5.13 shows the various proportions of Soil 1 with OMC of the ratios of 60:40, 70:30, 80:20, and 90:20. The ratios 90:10, 80:20, and 70:30 are constant while the ratio 60:40 is lower than the other ratios. OMC increases due to the continuous decrease in the particle size.

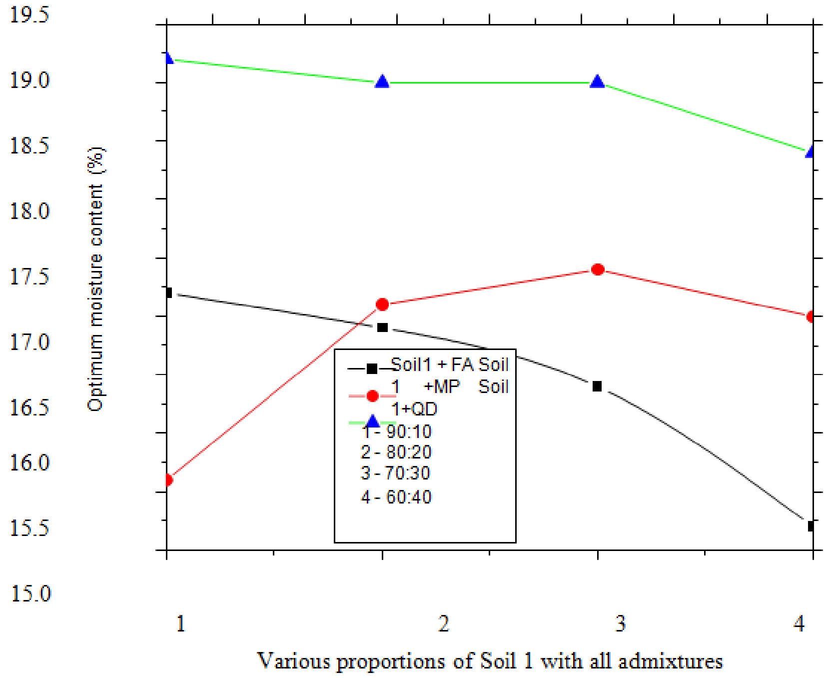

Figure 5.10 various proportions of Soil 1 with OMC

Significant change in the behavior of expansive soils may be attributed to the physical characteristics such as grain size, shape and particle size distribution of various additives are usually quite distinct. The efficiency of the stabilization process is dominantly influenced by the chemical reactionssuch as pozzolanic reactions, cation exchange capacity, carbonation and cementation, and microfiller effects and largely controlled by particles composition of additives (Gangadhara Reddy & Janardhan Tahasildar 2015). Clayey soil stabilized by the addition of crusher dust decreased the claycontent; the OMC was reduced to 27.5% and the coarser particles increased Influence of Optimum Moisture Content of Soil 2 with Admixtures

Figure 5.14 shows the OMC of Soil 2 with admixtures for the different ratios. Smaller is the ratio of the admixture; maximum is the ratio of OMC and vice versa. The mechanisms of soil with admixtures resulted in the decreased liquid limit and swell characteristics of the soil.Tensile strength is often considered as a material constant or part of the shear strength for soils that are either completely dry or saturated.Tensile strength is known as a role of suction and significantly depends on water content for soils under partially saturated conditions(Ning Lu *et al.* 2007).Water contents is relatively limited on the tensile strength within a broader range of compaction.(Chao-Sheng *et al.* 2015) . When waste ceramic dust (WCD) was added 0–30% to the soil, the liquid limit decreased from 71% to 35%; when waste marble dust (WMD)was added to the soil at the same ratio, the liquid limit also decreased from 71% to 38%. The swell decreased from 111% to 36% and 111% to 39% for WCD and WMD respectively. This clearly indicates that the WCD is the moststabilizing agent

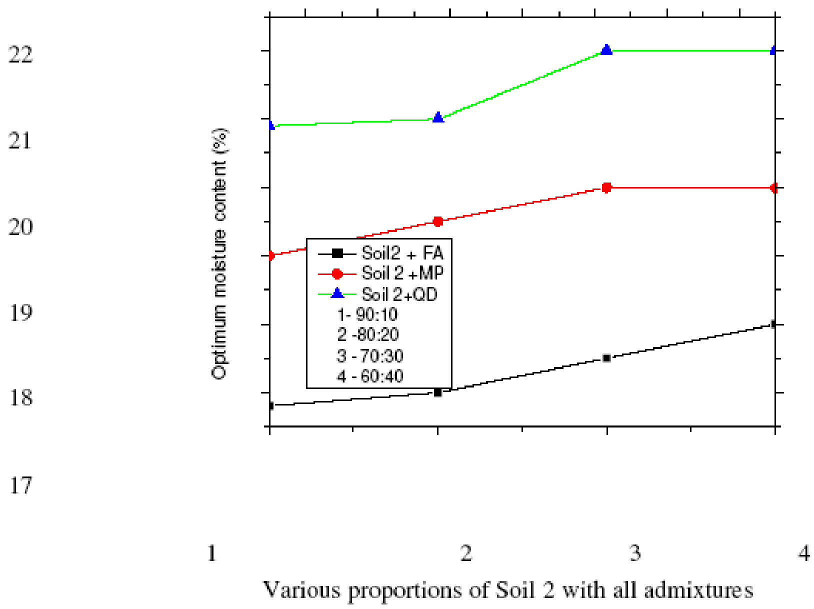

Figure 5.11 various proportions of Soil 2 with OMC

Influence of Optimum Moisture Content of Soil 3 with Admixtures

Figure 5.12 shows that the variations in moisture content, which increase in the order 60:40, 70:30, 80:20, and 90:10, prove that when clay content continuously increases, the OMC value is higher and achieves MDD. Chayan Gupta & Ravi Kumar (2014)concluded that for the stabilization of expansive soil, stabilizing agents such as MD, FA, and sand have been used. BC soils and (70:30) increases the MDD, and further increasing sand with BC soil increases the composite material. FA added to BC soil-sand in the ratio of 60:40 decreased the MDD since the FA is a lightweight material, finer, and round in shape. BC soil: sand: FA: marble dust in other ratios, reduces better MDD: 52.36%:22.44%:13.20%:12%, respectively. By adding these mixtures, the CBR value increases from 2.69% to 8.07%. Thus, it can be concluded that these mixtures can be used for subgrade, flexible pavements in areas with low traffic rural roads etc.

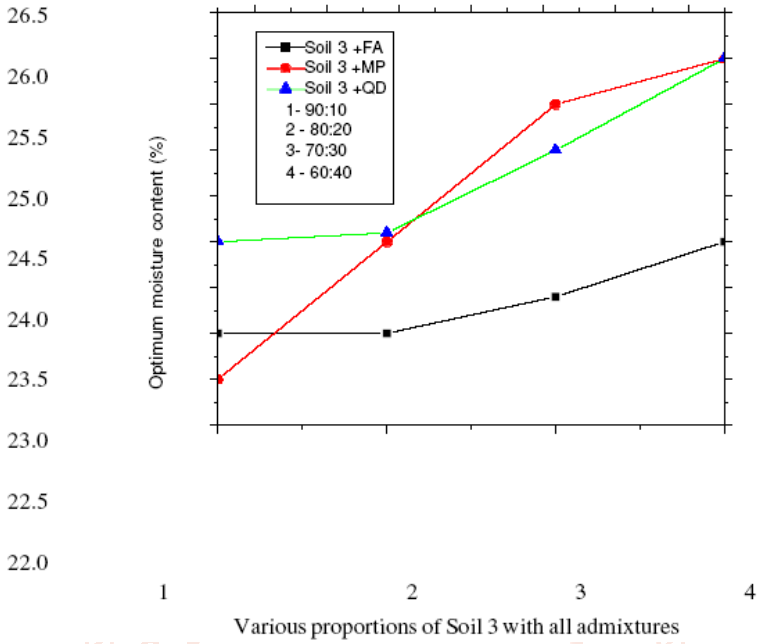

Figure 5.12 various proportions of Soil 3 with OMC

SWELLING BEHAVIOUR OF SOIL 1, SOIL 2 AND SOIL 3 WITH ADDITION OF ADMIXTURES, GEOGRID SINGLE AND DOUBLE LAYER

The following sections discuss the different types of soils, i.e. Soil 1, Soil 2 with QD (70:30) and Soil 3 with QD (80:20) and Soil 1, Soil 2 and Soil 3 with single and double-layer geogrid.

Swelling of Soil 1, Soil 2 and Soil 3

It is observed that the experimental results show that Soil 3 has higher swelling than Soil 1 and Soil 2. Comparison of Swell percentage of Soil 2 and Soil 3 with reference to Soil 1 is shown in Table 5.1. Compared with Soil 1, Soil 3 and Soil 2 have approximately 148% and 100% higher swelling respectively.

This is because the stone dust does not show affinity to water. It merely acts as a fill material within the pore space of the soil mass. A difference in density of particles between additive and parent soil is also created. The performance of non-cementitious additive like stone dust indropping Swell and Swell potential are also observed to be low when compared to its counterpart additives. (Gangadhara Reddy & Janardhan Tahasildar 2015). Soil swelling can be controlled by tensile geogrid and geogrid reinforcement compared with conventional methods of improving soilstrength. Stiffness of geogrid increased with continuous swell reduction. As the stiffness value was directly obtained from the manufacturer, the increased surcharge was not considered Raid R Al-Omari & Faris J Hamodi (1991).

Table 5.1 Comparison of Swell percentage of Soil 2 and Soil 3 with Soil 1

Descriptions	Free Swell index (%)	% of Swell
Soil 1	39	-
Soil 2	78	100
Soil 3	97	148.71

Swelling of Soil 1, Soil 2 and Soil 3 with Admixture

The addition of QD (70:30) to Soil 1 and Soil 2 results in lower value of swelling compared with Soil 3 with QD in the ratio of 80:20. It is observed that the Quarry Dust (80:20) by addition of geogrid double layer with Soil 1 shows the control of maximum swell about 80%. Similarly Soil 2 with QD (70:30) and Soil 3 with Quarry Dust (80:20) by addition of geogrid double layer control the maximum swell of 80%. The soil can improve the particle bond between clay grains and control the swelling and shrinkage of the soil. (Bin Shi et al 2002).

Swelling of Soil 1, Soil 2 and Soil 3 with Admixture and GG(SL)

The experimental results show that for Soil 3 with QD (80:20) and single-layer geogrid has higher swelling than Soil 1 and Soil 2 with QD (70:30) and single-layer geogrid. It is evidently seen that irrespective of any type of clay soil QD (70:30) with Soil 1, Soil 2 and QD (80:20) with Soil 3 controls the swell of 38.5%, QD (70:30) with GG (SL) 58% and QD(80:20) with GG (DL) is 80%as shown in Table 5.2, 5.3 and 5.4.

Since the difference between current and saturation states of diffuse double layers are more significant, samples with larger matric suction at OMC show greater swell potential. (Botao Lin &Amy B Cerato (2012)

Since the volume of clay particles were reduced by the addition of admixture, the swelling was reduced. The contact area of fibre and the tension prevailed in the geogrid was influenced in the reduction of swelling.

Table 5.2 Control of Swell in % by addition of admixture, geogridsingle and double layer with Soil 1

riptions	Swell index (%)	% of Swell
1	39	-
1 + QD (70:30)	24	38.5
1 + QD (70:30) + GG(SL)	16	58.97
1 + QD (70:30) + GG (DL)	8	79.5

Table 5.3 Control of Swell in % by addition of admixture, geogridsingle and double layer with Soil 2

Descriptions	Free Swell index(%)	% of Swell
Soil 2	78	-
Soil 2 + QD (70:30)	48	38.5
Soil 2 + QD (70:30) + GG(SL)	33	57.69
Soil 2 + QD (70:30) + GG (DL)	15	80.76

Swelling of Soil 1, Soil 2 and Soil 3 with Admixture and GG(DL)

The addition of QD (70:30) to Soil 1 and Soil 2 with double-layer geogrid has lower value than Soil 3 with QD (80:20) and double-layer geogrid. It is evidently seen that irrespective of any type of clay soil QD (70:30) with Soil 1, Soil 2 and QD (80:20) with Soil 3 controls the swell of 38.5%, QD (70:30) with GG (SL) 58% and QD(80:20) with GG (DL) is 80%.

Cyclic wetting– drying process has to be increased to reach the balance state and due to the inter- aggregate porosity and macrostructure void ratio of the soil, the soil would accrue swelling deformation. (Gang Wang & Xing Wei-2014).

Table 5.4 Control of Swell in % by addition of admixture, geogrid single and double layer with Soil 3

Descriptions	Free Swell index (%)	% of Swell
Soil 3	97	-
Soil 3 + QD (80:20)	61	37.11
Soil 3 + QD (80:20) + GG(SL)	39	59.79
Soil 3 + QD (80:20) + GG (DL)	20	79.38

TIME-SWELLING BEHAVIOUR OF SOIL 1, SOIL 2 AND SOIL 3 WITH ADMIXTURE, GEOGRID SINGLE AND DOUBLELAYER

The following sections discuss the swelling behaviour of Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20) with single- and double- layer geogrid. The percentage increase and reduction of swell with respect to time for Soil 1, Soil 2, and Soil 3 were analyzed.

Time-Swelling behaviour of soil 1, with Admixture, Geogrid Single and Double Layer

Swelling was enhanced after three days and the asymptote of the swelling ends in 31 days. Figure 5.16 shows the maximum amount of swelling and durations are presented in Figure 5.16. The time vs swelling behaviour of Soil 1, Soil 1 + QD (70:30), Soil 1 + QD (70:30) + GG (SL), and Soil 1 + QD (70:30) + GG (DL). The maximum swelling was observed for Soil 1. The addition of QD (70:30) decreased the height of swelling to approximately

38.5 %. Further, the addition of single- layer geogrid reduced the swelling to approximately 58.97%. The swell was completely reduced by the addition of double-layer geogrid to the soil and admixture.

During swelling the significant change in the volume of clay soil is a function of plasticity index and the quantity of colloidal clay particles present in soil. The overall behavior of swelling such as specific gravity admixture, particle size and shape of admixture, chemical reaction between fly ash and kerosene, particle interlocking forces are due to a number of phenomenon (Prabakara *et al.* 2004).

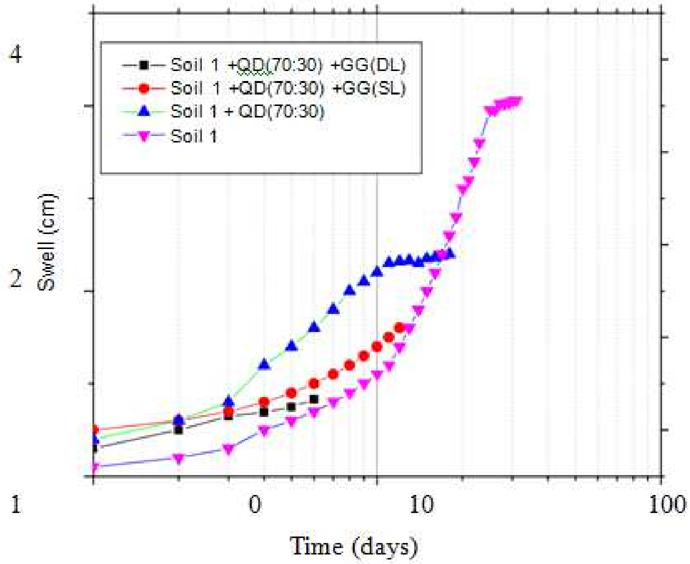

Figure 5.13 Time –swelling behavior of Soil 1 with admixture, single and double layer geogrid

Time-Swelling behaviour of Soil 2, with Admixture, Geogrid Single and Double Layer

Figure 4.17 shows the time vs. swelling behaviour of Soil 2, Soil 2 + QD (70:30), Soil 2 + QD (70:30) + GG (SL), and Soil 2 + QD (70:30) + GG (DL). The maximum swelling occurred for Soil 2; the addition of QD (70:30) decreased the height of swelling to approximately 38.5%. Further, the addition of single-layer geogrid reduced the swelling to approximately 57.69%. The swelling was completely reduced with the addition of double- layer geogrid to the soil and admixture. Reduction in particle size can be considerably reduced based on the increase in swelling and reduction of swelling pressure due to swelling in the clay samples. (Dinesh R Katti & Shanmugasundaram (2001).

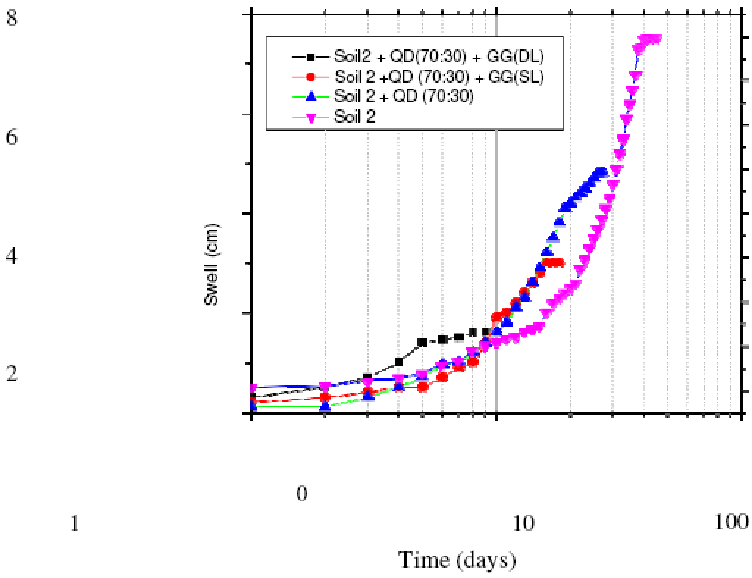

Figure 5.14 Time –swelling behavior of Soil 2 with admixture, single and double layer geogrid Time-Swelling behaviour of soil 3, with Admixture Geogrid Single and Double Layer

Figure 5.18 shows the time vs. swelling behaviour of Soil 3, Soil 3 + QD (80:20), Soil 3 + QD (80:20) + GG (SL), and Soil 3 + QD (80:20) + GG (DL). The maximum swelling was observed for Soil 3. The addition of QD (80:20) decreased the height of swelling to approximately 37.11%. The addition of single-layer and double layer geogrid reduced the swelling to approximately 59.79% and 79.38%. The swell completely decreased with the addition double- layer geogrid to the soil and admixture. The aggregates would swell when water content changes unlike sand or silt grains. The deformation of expansive soils is due to the relocation of the granular-like skeleton created by the aggregates and the self deformation of the aggregates. (Gang Wang & Xing Wei2014). The inter particle porosity increases with the decrease of suction denotes swelling of the aggregates (David Masin & Nasser Khalili 2014).

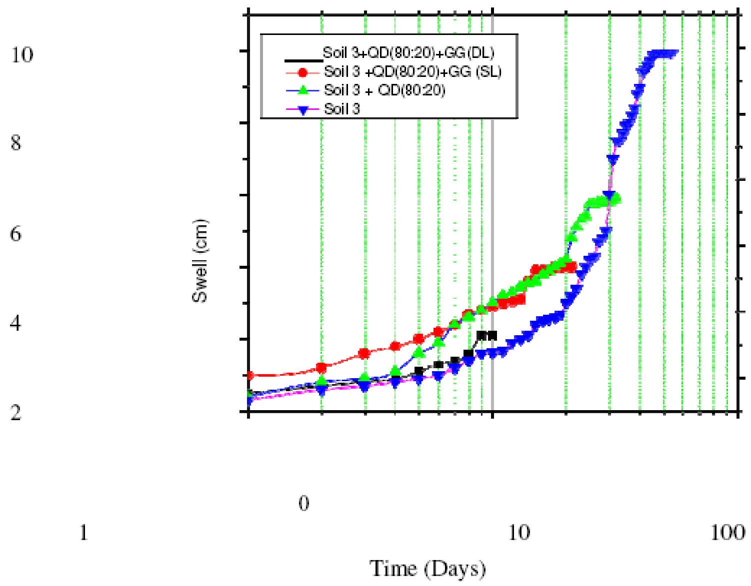

Figure 5.15 Time –swelling behavior of soil 3 with admixture, single and double layer geogrid

The initial water content is not important for when the soil below the shrinkage limit is used for the purpose of swelling and swells pressure. The initial density, swell potential, and swell pressure are superior. The high values of initial density, swell, and swell potential owing to the activity plays a vital role (El-Sohby & Rabba 1981). The maximum swelling and amount of swell can be determined using a hyperbolic equation. Initially, swelling with time is slow, but increases sharply with asymptote value, depending on the changes in the percentage of bentonite and non-swelling time. With increased swelling rate, the bentonite value also increased (Agus Setyo Muntohar & Roslan Hashim (2015).

5.6 SWELL PRESSURE FOR SOIL 1, SOIL 2 AND SOIL 3 WITH ADMIXTURE, GEOGRID SINGLE ANDDOUBLELAYER

The following sections analyze the percentage increase and reduction of swell and swell pressure for Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20) and with single- and double double-layer geogrids.

Swell pressure for Soil 1, Soil 2, and Soil 3:

Soil 1, Soil 2 and Soil 3 were compacted at 95% of the corresponding maximum dry density in the California Bearing Ratio (CBR) mould and kept inside the water chamber allowed to maximum swell. Soil 1 is observed that the maximum swell of 12.5 cm to 16.4cm and the net value of about 3.9cm. The initial height reached to the corresponding applied pressure considered as swell pressure, when a constant pressure is applied gradually over the swelled sample. Figure 4.19 shows the swell pressure for Soil 1, Soil 2 and Soil 3 alone. The swell pressure and corresponding compacted height of the Soil 1, Soil 2 and Soil 3 as shown in Table 5.5.

Due to the decrease in dry unit weight, clay percent, and an increase in the initial water content, initial applied pressure on the soil the volume is decreased. (Adnan A Basma 1995). Soil swelling pressure and side friction controls the soil layer due to the mechanism of soil swelling, soil collapse, and interaction between the soil layers. (Simona Saba & Yu-Jun Cui2013).

Table 5.5 Swell pressure and corresponding compacted height of theSoil 1, Soil 2 and Soil 3

Descriptions	Initial height (cm)	Final height (cm)	Net height (cm)	Swell pressure(kPa)
Soil 1	12.5	16.4	3.9	54
Soil 2	14	21.8	7.8	160
Soil 3	15.5	25.2	9.7	435

At swell pressure greater than 600 kPa, the minimum water content was determined with various swell pressures using clay soil obtained from city of Barranquilla, Colombia, at constant volume, and equations were developed. When water content rises above 40%, the swell pressure suddenly decreases to approximately zero (Víctor Cantillo *et al.*2017).

Many researchers have calculated the swell pressure of different soils using properties such as liquid limit, plastic limit, plasticity index, and consistency limit to estimate the swell pressure is water content base method.

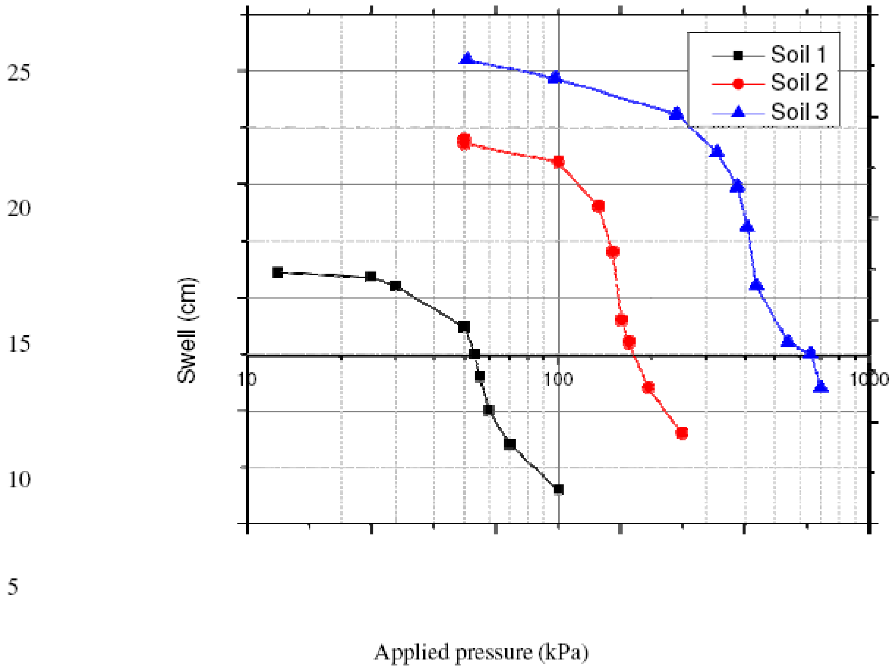

Figure 5.16 Applied pressure Vs swell for Soil1, Soil 2 and Soil 3

Swell pressure for Soil 1, Soil 2, and Soil 3 with Admixture, Geogrid Single and Double Layer

It is observed that the swell pressure from Figure 5 .20, 5 .21and 5.22 of Soil 1, Soil 2 and Soil 3 with admixtures given in Table 5 .6,5.7 and5..8. Soil 1 + QD (70:30) + GG (DL) has decreased in swell of 80% compared with Soil 1 alone. The same trend was seen for Soil 2 QD (70:30) and Soil 3(80:20) with the addition of geogrid single and double layer.

The percentage reduction of swell pressure for Soil 1, Soil 2, and Soil 3 with admixtures are approximately 40%; Soil 1, Soil 2, and Soil 3 with admixtures and single-layer geogrid is 60% % and Soil 1, Soil 2, and Soil 3 with admixtures and double-layer geogrid is 80% as shown in figure 5.20, 5.21and 5.22.

Table 5.6 Percentage decrease of Swell pressure by addition of admixture, geogrid single and double layer with Soil 1

Descriptions	Swell pressure(kPa)	% decrease of Swell pressure
Soil 1	54	-
Soil 1 + QD (70:30)	32	40.74
Soil 1 QD (70:30) + GG (SL)	22	59.25
Soil 1 QD (70:30) + GG(DL)	11	79.63

Table 5 .7 Percentage decrease of Swell pressure by addition of admixture, geogrid single and double layer with Soil 2

Descriptions	Swell pressure(kPa)	% decrease of Swell pressure
Soil 2	160	-
Soil 2 + QD (70:30)	96	40
Soil 2 QD (70:30) + GG (SL)	64	60
Soil 2 QD (70:30) + GG (DL)	32	80

Table 5.8 Percentage decrease of Swell pressure by addition of admixture, geogrid single and double layer with Soil 3

Descriptions	Swell pressure(kPa)	% decrease ofSwell pressure
Soil 3	435	-
Soil 3 + QD (80:20)	261	40
Soil 3 QD (80:20) + GG (SL)	174	60
Soil 3 QD (80:20) + GG (DL)	87	80

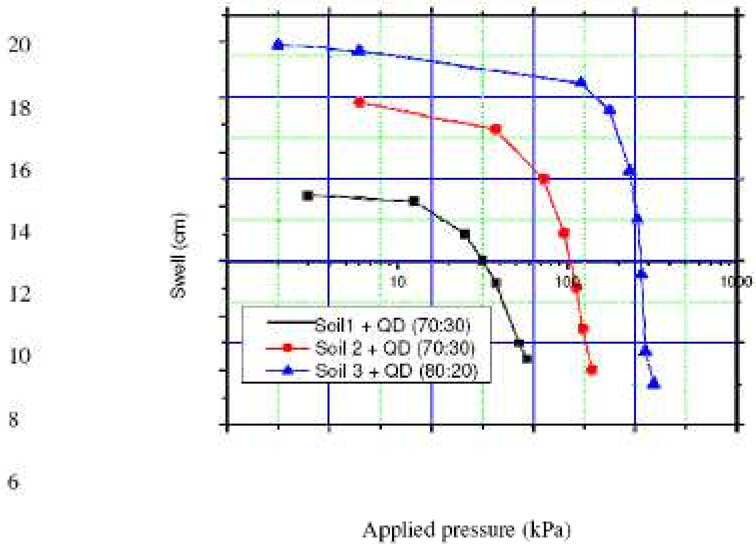

Figure 5.17 Applied pressure Vs swell for Soil1, Soil 2 and Soil 3 with admixture

Irrespective of any clayey soil to the addition of admixtures QD (70:30), QD (80:20) and geogrid single and double layer shows higher swell pressure. Reduction in the clay particles through the addition of QD (70:30), QD (80:20) have friction angle, shear strength improved and thereby it shows the higher swelling pressure, since soil is weak in tension and strong in compression. The tensile material like geogrid was placed inside the soil are capable of taking the tensile stress on weaker plane among the application of normal pressure and hence it is observed that the placement of geogrid single and double layer shows higher pressure irrespective of any clayey soil (Koerner 1999).

The soil stiffness of the zero-day stabilized soils significantly increased from the stabilization process as seen from the higher swell pressure and is indicated by the increased unconfined compressive strength. Since complete stabilization transforms the soil to non-expansive soils the specimens stabilized for 14 days show no swelling at all.

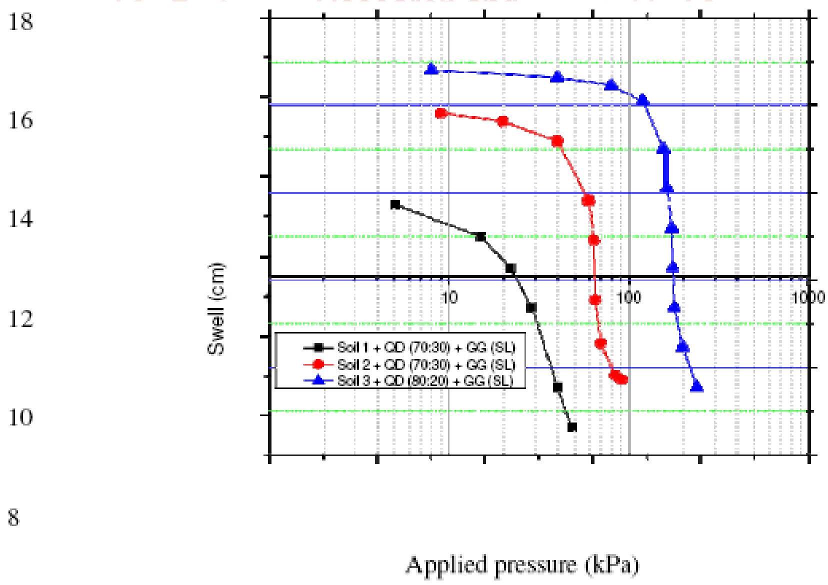

Figure 5.18 Applied pressure Vs swell for Soil1, Soil 2 and Soil 3 withadmixture and geogrid single layer

With the increase of matric suction at OMC for untreated soils, the unconfined compressive strength decreases (Botao Lin & Amy B Cerato 2012). The global dry density can be considered as the dry density of the aggregate at full saturation as the global dry density is constant during the swelling pressure test (David Masin & Nasser Khalili 2014).

The addition of reinforcement layers of geostrips or geotextiles and geogrid enhanced the ultimate bearing capacity and settlement of the foundation. This investigation is not only applicable to slope stability but also earth slope. Swell pressure was reduced mainly by the addition of admixture, which prevented the passage or movement of water inside the soil mass.

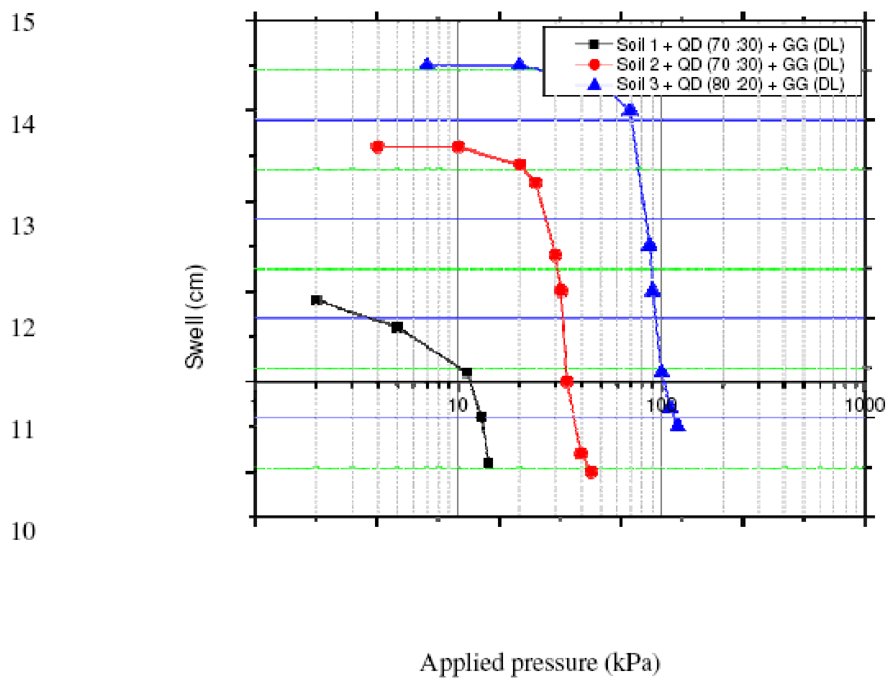

Figure 5.19 Applied pressure Vs swell for soil1, soil 2 and soil 3 withadmixture and geogrid double layer

The admixture also controlled the swelling of expansive soil. Moreover, placing single- and double- layer geogrid made of pure polypropylene fibre normally does not absorb the water and leads to thecontrol of soil movement, thus reducing the swelling (Dash *et al.* 2003; Boushehrian & Hataf 2003; El Sawwaf 2005; Alamshahi *et al.* 2009; Lee & Manjunath 2000; Abdrabbo *et al.* 2008; Yoo 2001).

LOAD VS SETTLEMENT CURVE FOR SOIL 1, SOIL 2 AND SOIL 3 WITH ADMIXTURE, GEOGRID SINGLE AND DOUBLELAYER

The following sections discuss the load-settlement curve for Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20) and single- and double- layer geogrid. The percentage load carrying capacity for Soil 2 and Soil 3, with reference to Soil 1 with admixtures and single- and double-layer geogrid, is analyzed in Table 5.9.

Table 5.9 Ultimate load carrying capacity value for Soil 1, Soil 2, Soil3 with admixture, geogrid of single and double layer:

Soil Descriptions	Load(kg)	% load carrying capacitywith reference to Soil 1
Soil 1		-
Soil 2		7.14
Soil 3		42.8
Soil 1, Soil 2 + QD(70:30)		92.8
Soil 3 + QD(80:20)		
Soil 1, Soil 2 + QD(70:30) +GG(SL)		1
Soil 3 + QD(80:20) +GG(SL)		200
Soil 1, SOIL 2 + QD(70:30) +GG(DL)		2
Soil 3+ QD(80:20) +GG(DL)		2

The load - settlement curve of single and double-layer geogrid is shown in Figure 5.23. QD (70:30) was added to Soil 1 and Soil 2, and QD (80:20) to Soil 3. It is clearly shown that the increase in pressure with respect to Soil 1 is only 7.14%, 114.3% with the addition of QD, and up to 200% with the addition of QD with single- and double-layer geogrid. A steep plot of 257.14% was obtained for the provision of double-layer geogrid with Soil 3. The results were compared with Soil 1, as shown in Figure 5.24. Table 5.9 proves that, owing to the application of extended load, tensile stresses occur and enhance the geogrid.

The geosynthetic reinforcement is placed at the layer-layer interface is divided into a number of homogeneous horizontal layers. The distributed vertical load is applied at the free surface of the soil medium, bottom of the medium is assumed to be fixed at the base. At the loaded area the gravel layer is repeatedly placed at the top of soft soil to reduce settlement. This is due to increases the load transfer of gravel layer. By the addition of geosynthetic layer decrease the displacement rather than gravel layer. Multi geosyntheitc reinforcements are as efficient as a combination of single reinforced gravel layer in reducing the settlement at large displacement level (Toyoaki Nogami & Tan Yee Yong 2003).

For swollen clay soil, the load carrying capacity of double-layer geogrid is 2.5 times greater than that of swollen clay soils without geosynthetic materials. Moreover, geogrids have higher load carryingcapacity in the same soil Stalin (2010). From cyclic loading test results that adding 10% QD to the expansive soil increased its load carrying capacity. Forthe expansive soil treated with 5% and 15% QD, the total and elastic deformations decreased by 30.64%, 28.57%, and 48.38%; and 62.5%, 29.43%, and 50%, respectively Thus, adding 10% QD to expansive soil is the maximum percentage (Venkateswarlu 2015).

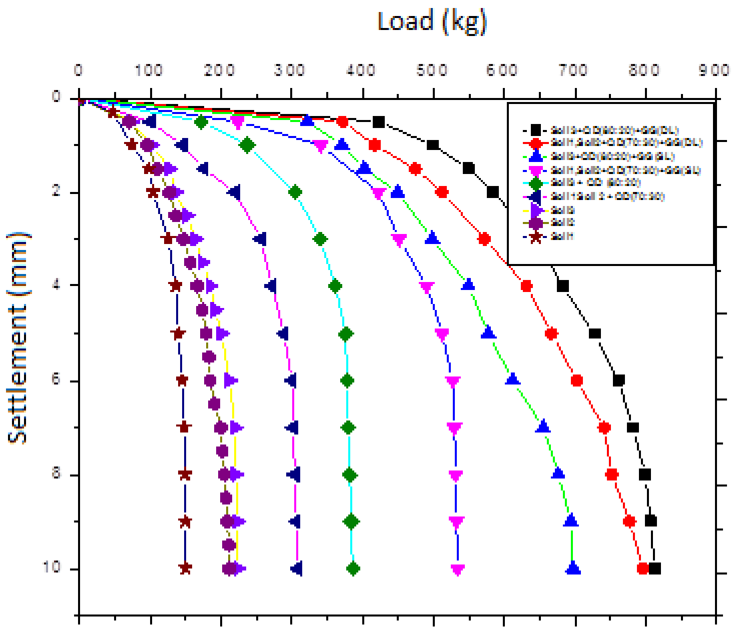

Figure 5 .20 Variation of Load Vs settlement curve for Soil 1, Soil 2, Soil3 with admixture, geogrid of single and double layer

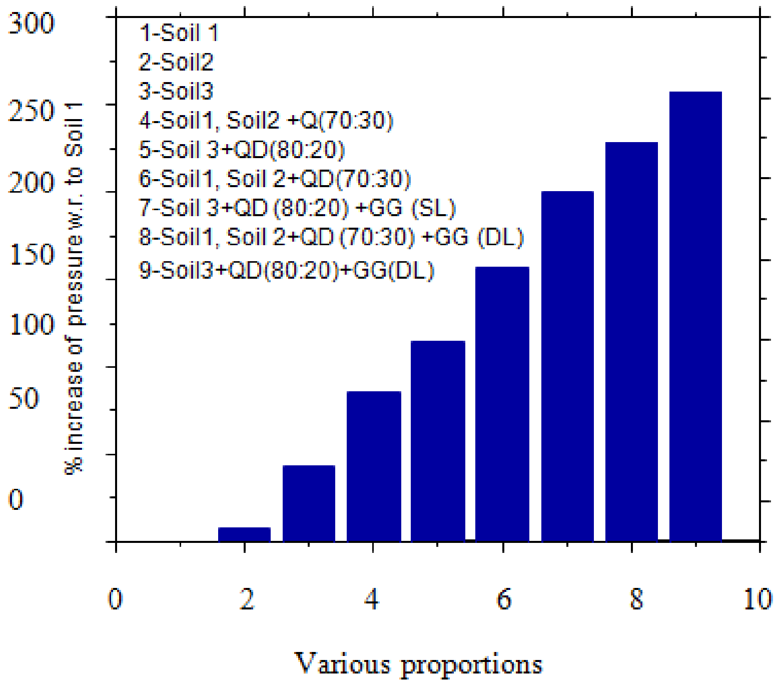

Figure 5.21 Percentage increase of pressure with reference to soil 1 VsSoil +QD+GG (SL, DL)

CALIFORNIA BEARING RATIO (CBR) FOR SOIL 1, SOIL 2, SOIL 3 WITH ADMIXTURE, GEOGRID OF SINGLEAND DOUBLELAYER

In general, the CBR measures the soil strength, and hence the pavement thickness; at low CBR, the pavement thickness is usually higher and vice versa. In this study, QD was added to Soil 1, Soil 2, and Soil 3; thoroughly mixed at 95% (ydmax), and kept under soaked condition for four days to obtain the percentage of CBR. In this experimental study, the % CBR were obtained corresponding to 2.5mm and 5.0mm penetration. The entire % CBR corresponding to 2.5mm penetration obtained higher values.

The CBRs of Soil 1, Soil 2 with QD (70:30), and Soil 3 with QD (80:20) with single- and double- layer geogrid are described in the following section. The percentage increase and CBR values for Soil 1, Soil 2, and Soil 3with QD and single- and double-layer geogrid are discussed. The CBRs for Soil 1, Soil 2, and Soil 3 are less than 2% under soaked condition, as shown in Table 4.10 and Figures 5.25 and 5.26.

Table 5.10 CBR value for Soil 1, Soil 2, Soil 3 with admixture and GG (SL, DL)

Soil Description	CBR(%) for 2.5mm penetration	CBR(%) for 5.0mm penetration
Soil 1	1.4	1.0
Soil 2	1.6	1.2
Soil 3	2.4	2.0
Soil 3 +QD (80:20)	12	11
Soil 3 +QD(80:20)+ GG(SL	16	14
Soil 3 +QD(80:20)+ GG(DL	18	15

Figure 5.25 shows that the CBR for Soil 3 + QD (80:20) + GG (DL) increased by approximately 18%.The various percentages of CBR for the soil with admixture and single and double layer geogrid are listed in Table 4.4. With increased geogrid width and decreased geogrid depth the efficiency of the sand geogrid system has increased.

The geogrid depth reduces the wetting-induced collapse settlement decreases and geogrid efficiency also enhanced. Depth of reinforcing geogrid is one-tenth of the diameter of the loaded area (0.1*D*) as suggested. Due to the capping effects of geogrid-reinforced sand pad the wetting- induced collapse settlement was considerably reduced under circular loaded area. geogrid layer of diameter equal to four times the diameter of the loaded area the settlement reduced ratio value of 95% was attained (Alawaji 2001)

The CBRs for BC with alternate of QD and inclusion of geotextile sheet at proportions such as 5%, 10%, and 15% of QD with soil. The CBR increased from 3.74% to 4.80%, 3.74% to 5.67%, and 3.74% to 6.08%, respectively. Geotextile sheets placed at depths of 50 mm, 100 mm, and 150 mm from the top of the soil increased the CBR from 3.74% to 7.92%, 3.74% to 7.33%, and 3.74% to 6.99%, respectively. It was concluded that 15% QD and geotextile sheets placed at a depth of 50 mm yields higher CBR, which greatly influences the bearing capacity of the soil (Vijay Kumar 2017).

The soil was reinforced with geogrid for soaked and un soaked conditions. The CBR increased to approximately 2.8% and 12.2%, respectively, which corresponds to an approximately 200% increase in bearing ratio. When the OMC and MDD are 13.4% and 1.265 g/cc, the CBRs under soaked and unsoaked conditions are 0.99 and 6.11%, respectively (Kanakaraju Yadav2017). Adding 10% QD to expansive soil increased the CBR from 1.2% to 6.7% (Venkateswarlu 2015).

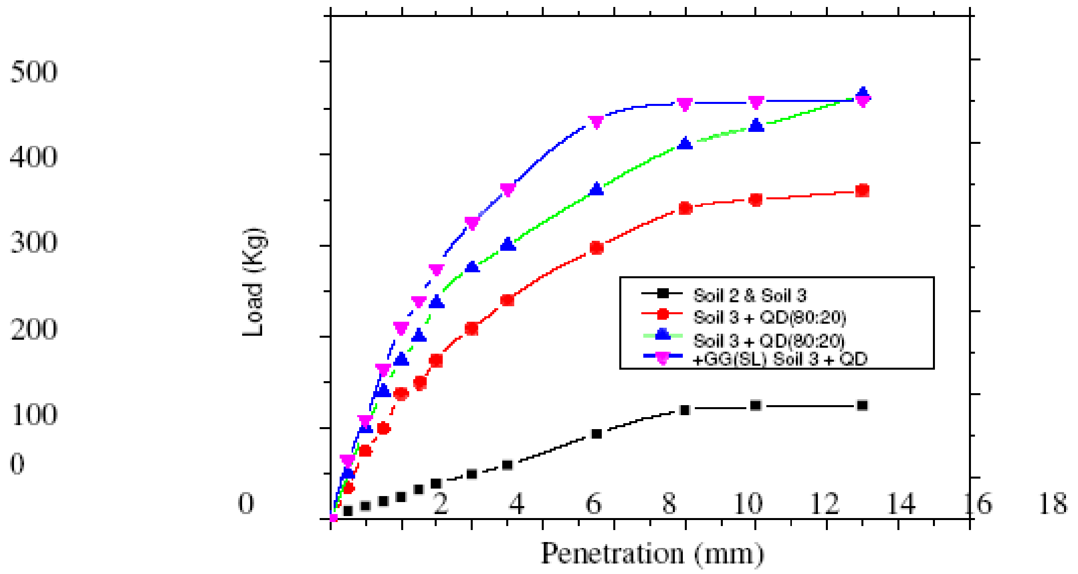

Figure 5.22 Load Vs Penetration curve for CBR for Soil 1, Soil 2, Soil 3with admixture, single and double layer geogrid

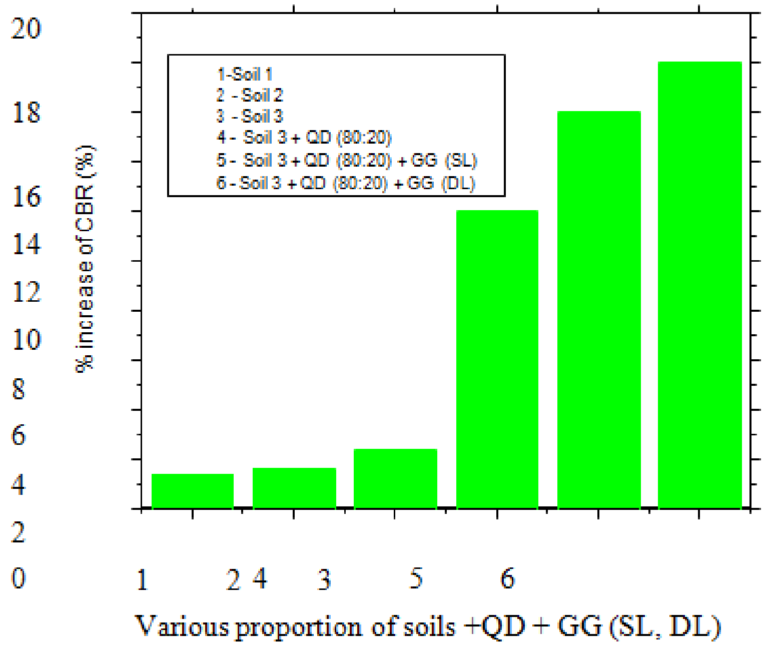

Figure 5.23 Percentage increases of CBR Vs Soil +QD+GG (SL, DL)

Weak soil was improved by geogrid reinforcement provided at various depths in single, double and triple layers. The single layer was placed two thirds from the base; the double and triple layers were placed on top of the single layer. The higher value of CBR, better performance is the single and triple layers.

Increased geogrid triple layer is less than double layer, triple layer is greater than single layer improved the sub grade strength under soaked and unsoaked conditions. The reinforcement provided in the single and multiple layers increased the strength and decreased the thickness of the pavement (Evangelin Ramani Sujatha *et al.* 2012). Increasing the MP added to BC soil from 10% to 40% decreased the free swell index value from 66.6% to 20%. Further increase in the percentage of MP increased the UCS value from 110.86 kN/m^2 to 175.46 kN/m^2,and the CBR value under soaked condition rose from 1.81% to 4.17%b (Parte Shyam Singh and Yadav R.K. 2014).

Thus, it can be observed that for improvement of Soil 3 with QD (80:20) with double-layer geogrid can control the swell

CONCLUSION AND FUTURE SCOPE OF WORK

CONCLUSIONS

Expansive soil collected from Bhopal District Madhyapradesh State, India, are weak in nature. The admixtures, QD, MP, and FA are the waste products abundantly available nearby the study area. The soil samples were classified as CL (Low Compressibility), CI (Medium Compressibility) and CH (High Compressibility) soil is termed as Soil 1, Soil 2, and Soil 3 respectively. Different proportions of admixtures were added to the samples and the dry strength was obtained, which indirectly gives higher shear strength in terms of MDD. Further, the dry strength can be improved by the placement of single- and double-layer geogrid.

Based on the results of the various experiments, the following conclusions are made.

- ➢ The dry densities of Soil 3 and Soil 2 were 18% and 7% higher than that of Soil 1, respectively. Hence, Soil 3 has greater shear strength than Soil 1 and Soil 2.
- ➢ Although Soil 3 has higher strength and free swell index (106%), these cannot be used without improvement. With the addition of admixtures ranging from 10% to 40% by weight to Soil 1, Soil 2, and Soil 3, the dry strength of Soil 1 + QD (70:30) and Soil 2 + QD (70:30) are higher than that of with other admixtures of different ratios. The experimental results of Soil 3 + QD (80:20) is higher than that of Soil 3 with other admixtures of different ratios.
- ➢ The parameters behind the increased strength in terms of MDD are:

1. Particle structure
2. Adsorption of water
3. Presence of fine particles in QD
4. Presence of other minerals like micacious
5. Shape of the particles
6. Angularity

- ➢ 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 MDD. With the addition of QD (80:20) to Soil 3, the OMC decreased compared with Soil 3 alone.

- From the time-swelling plots in Figures 4.16–4.18, the soil alone has higher value than with and without admixtures, and also with single- and double-layer geogrid. I irrespective of any type of clay soil QD (70:30) with Soil 1, Soil 2 and QD (80:20) with Soil 3 controls the swell of 38.5%, QD (70:30) with GG (SL) 58% and QD (80:20) with GG (DL) is 80%. The average swelling was also controlled, i.e. approximately 80% through provision of admixtures with double-layer geogrid. Since the volume of clay particles were reduced by the addition of admixture, the swelling was reduced. The contact area of fibre and the tension prevailed in the geogrid was influenced in the reduction of swelling.
- The swell pressure was observed in the same tank by volume decrement method. Soil 1 + QD (70:30) + GG (DL) has decreased in swell of 80% compared with Soil 1 alone. The same trend was seen for Soil 2 QD (70:30) and Soil 3 (80:20) with the addition of geogrid single and double layer as in figure 4.20, 4.21and 4.22.
- The load vs. settlement plots of the experimental values are gradually increased with the addition of admixtures as in Figures 4.23 and 4.24. The provision of the double-layer geogrid, percentage load carrying capacity increases by approximately 257.14% compared to Soil 1 alone from table 4.9.
- The subgrade strength of the same soil and admixtures, with and without single- and double-layer geogrid, 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 as in Figures 4.25 and 4.26.

Any type of expansive soil exhibits swelling behavior; with the addition of right admixture at proper ratio, dry density increases and OMC remains constant regardless of clay content.

The nature of swelling is based on the amount of clay minerals present. It has been observed that Soil 3 has high swelling nature, which is controlled through the addition of QD and provision of single- and double-layer geogrids at the spacing of one-third height from the top. It is suggested that the physical and strength characteristics of high swelling soils can be changed or altered and used as construction base materials in many infrastructures through addition of waste materials such as QD, MP, and FA, and the application of geogrid, which are normally used as tensile reinforcement to strengthen embankments and stabilize of slopes. Also, using ANN's based MATLAB decreases the number of laboratory tests so that time and cost can be saved.

FUTURE SCOPE OF WORK

Expansive soils are problematic due to the performance of their clay mineral constituent, which makes them exhibit the shrink-swell characteristics. A lot of work has been done to improve the properties of the expansive soil but there is requirement of a permanent solution which can improve the soil properties economically. In further studies waste materials from various industries can be utilized in soil for its stabilization, and these techniques will also reduce the environmental problems which are creating due to these waste materials. These waste materials can be utilized in different proportion in various types of soils for stabilization purpose. There are so many waste materials producing from various industries which are creating environmental problems, and their disposal is also difficult. Some of these waste materials have cementing properties and can behave like binding material when used with any cementing agent. This type of properties of any waste material can be very helpful for various purposes if utilized in proper manner. So in future it is very important that these materials are studied properly and their properties should be analyzed, so that they can be used for soil stabilization in environmental friendly way.

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