

Experimental Study on Effect of Gypsum and NaCl in Improvement of Engineering Properties of Clayey Soil

S.Peddaiah^{#1}K.Suresh^{#2}

[#]Assistant Professor, Dept. of Civil Engg.CMR College of Engineering & Technology, Hyderabad.

^{*}Professor and Head Dept. of Civil Engg.CMR College of Engineering & Technology, Hyderabad.

¹s.peddaiahgeomtech@gmail.com

²Sureshkandru78@gmail.com

Abstract---Soil stabilization is a process generally which improves the engineering properties of weak soil such as compaction characteristics, bearing capacity etc. and this can be achieved by controlled compaction or addition of suitable stabilizers like cement, lime fly ash etc. But the cost of these additives has also become expensive in recent years which opened the door widely for introducing the other kinds of soil admixtures like gypsum and Sodium Chloride (NaCl). The objective of this research paper is to investigate the effect of gypsum and NaCl on the engineering properties of clay soil with high compressibility (CH).Gypsum is a source of calcium which has major mechanism that binds soil organic matter to clay in soil which gives stabilizes the weak soil. This study involves the investigation of the effect of gypsum and NaCl on clayey soil for which a series of Compaction tests and California Bearing Ratio (CBR) tests performed on both virgin soil and reinforced soil with varying percentages of gypsum and NaCl (3%, 8% and 13%). The results reflect that with increase in the percentages of both gypsum and NaCl, engineering properties of soil such as Maximum Dry Density (MDD) and CBR value are also increased significantly comparing with the properties of natural soil.

Key Words: Soil Stabilization, Gypsum, NaCl, Maximum Dry Density, CBR Value.

I. INTRODUCTION

In general, large areas of plain terrains associated with the soils having high clay content which have very low shear strength, bearing capacity etc. If adequate support does not provide to these weak soils they create a problem at the time construction of earthen embankments, roads etc.In order to provide proper stability to the earthen embankments and to provide roads for sustaining for such a long time, it is necessary to add stabilizers like cement, fly ash, lime etc to those weak clay soils. The cost of introducing these additives are also increasing day by day and which in return opens door for use of other additives to improve the engineering properties of soil. This work involves in the soil stabilization of soil using gypsum and Sodium Chloride with different percentages. A series of laboratory tests such as standard proctor test and CBR test on both virgin soils as well reinforced soil with gypsum and Sodium Chloride.

Gypsum is a naturally occurring mineral that is being made of calcium sulphate and water ($\text{CaSO}_4+2\text{H}_2\text{O}$) and this is sometimes also known as hydrous calcium sulphate. It is the mineral calcium sulphate with two water molecules attached and by weight it is having 79% calcium sulphate and 21% water. Gypsum has 23% calcium and 18% Sulphur and its solubility are around 150 times that of limestone, hence it is a natural source obtained from plant nutrients. Gypsum naturally occurs in sedimentary deposits from ancient sea beds. Gypsum is mined and made into many products like drywall used in construction, agriculture and industry. It is also a by-product of many industrial processes. So considering the properties of gypsum, this can be effectively used as stabilizer of improvement of engineering properties of soil.

Soil water salinity generally affects the soil physical properties by causing fine grained particles to bind together and to form an aggregate structure. This process is named as flocculation and is being beneficial in terms of improving the required engineering properties of the clay soil. Considering the abundance of salt and economic viability, the use of sodium chloride is most preferable method for soil stabilization. Sodium has the effect of salinity on soils. The forces responsible to bind clay particles together are disrupted when too many sodium ions come between them. When this separation process occurs, these clay particles get expand, leading the clay particles to swelling and soil dispersion. Soil dispersion leads clay particles to plug soil pores which resulting in reduced permeability of soil. So soil stabilization using these gypsum and sodium chloride is an alternative method for improving sub grade and stability of earth embankments. This new technique of soil stabilization can be effectively used to meet the challenges of society and to reduce the cost of constructions over expensive methods of soil stabilization.

II. LITERATURE REVIEW

Işık Yılmaz, , Berrin Civelekoglu (2009) studied the effect of the gypsum as an stabilizer for treatment of the expansive clay soils by means of swell potential and strength. Maximum dry density and optimum moisture content for bentonite soils was determined by standard compaction test. Different quantities of gypsum such as 2.5%, 5%, 7.5%, and 10% by mass are added to bentonite. A series of compaction tests, Atterberg limit tests are performed to see the changes in the plasticity, swell percent and strength parameters of treated and untreated samples. Results indicated that gypsum can be used as a stabilizing agent for expansive clay soils effectively.

Aly Ahmed, Usama H.Issa (2014) has studied the stability of soft clay soil stabilized with recycled gypsum in a wet environment. The recycled gypsum was mixed with cement and lime in different ratios in the dry state, and different amounts of admixtures were mixed with the tested soil to explore the effect of the wet environment on the stability and durability of the stabilized gypsum clay soil. The results show that increasing the content of both types of admixtures had a positive effect on the improvement of stability and durability for the tested soil in a wet environment, while the increase in the admixture ratio had a slightly negative effect on both the stability and the durability of the samples subjected to soaking.

Dina Kuttah, Kenichi Sato (2015) reviewed on the effect of gypsum content on soil behavior. They added the varying percentages of gypsum to the soil. Form the results, it is reviewed that addition of gypsum content to the soil, the properties of soil are also increased significantly.

Tamadher et.al (2007) investigated the stabilization of soft soils like silty clay using salts of chloride like NaCl, MgCl₂ and CaCl₂. Three amount percentage of salt (2%, 4% and 8%) were added to the soil to study the effect of salts on the compaction characteristics, Atterberg limits, and unconfined compressive strength. The results showed that the increase in the percentage of each of the chloride salts increased the maximum dry density and decreased the optimum water content. The liquid limit, plastic limit, and plasticity index decreased with increasing salt content. Also the results showed that the unconfined compressive strength increased when the salt content increased too.

Swarna Kolaventi et.al (2016) studied the stabilization of black cotton soil using salts and their comparative analysis. To investigate the effect of adding different chloride compounds including (NaCl, CaCl₂) on the engineering properties of black cotton soil. Various amount of salt (2%, 4%, 6%and 8%) were added to the soil to study the effect of salts on the compaction characteristics, consistency limits and compressive. The main findings of this study were that the increase in the percentage of each of the chloride compounds increase the maximum dry density and decrease the optimum moisture content. The liquid limit, plastic limit and plasticity index decreased with the increase in salt content. The strength increases as the salt content increases.

III. SCOPE OF THE STUDY

The scope of work includes addition of gypsum and NaCl to the given locally available weak clay soils to see the effect on the engineering properties. The work presented in this paper aims to investigate the improvement of soil properties such maximum dry density (MDD) and CBR values by adding gypsum and NaCl. A series of laboratory tests are conducted on both virgin soils as well as on reinforced soil with gypsum and NaCl to compare the improvement of soil properties. List of experiments conducted in laboratory as per IS Codes are given in Table 1.

IV. MATERIALS AND METHODOLOGY

4.1 Natural Soil

In this section, the results for various tests such as specific gravity test, grain size analysis, liquid and plastic limit tests, standard proctor test and CBR test are performed on natural soil. The results for properties of natural soil obtained from these experiments are shown in Table 2. Natural soil used in this study is collected from the plain of Hyderabad (TS) near CMR College of Engineering & Technology (CMRCET).

Table 1: List of Experiments performed in the study

S.NO	Natural Soil	Reinforced Soil with Gypsum and NaCl
1	Specific Gravity of Soil Solids (IS:2720-Part 3-1980)IS:2720-Part 3-1980	--
2	Particle Size Analysis (IS:2720-Part 4-1985)	--
3	Atterberg Limits (IS:2720-Part 5-1985)	--
4	Compaction Test (IS:2720-Part 7-1980)	Compaction Test
5	California Bearing Ratio Test (IS:2720-Part 16-1987)	California Bearing Ratio Test

Table 2: Index and Engineering Properties of natural soil

S.NO	Properties of Natural soil		Value
1	Specific Gravity (G_s)		2.78
2	Particle Size Distribution	Gravel (4.75mm-20mm)	0%
		Sand (4.75mm-0.075mm)	15%
		Silt (0.075mm-0.002mm)	25%
		Clay (<0.002mm)	60%
3	Atterberg Limits	LL	53%
		PL	27%
		PI	26%
4	Compaction Properties	MDD	1.25g/cc
		OMC	18.4%
5	Un-Soaked CBR Test	CBR	3.28%

Dry sieve analysis is performed on dry soil to determine the percentages of coarse grained soil and hydrometer analysis is conducted on the soil sample to determine the percentages of silt and clay. From Table 2, it is observed that the percentage of soil passing through 0.075mm is more than 50%, so soil is classified as fine grained soil. As per IS 1498-1970 soil classification if $LL > 50\%$ and $PI > 17\%$, then the soil is classified as Clay with high compressibility. From Table 2 it is observed that liquid limit and plasticity index are found to be 53% and 26% respectively. Based on this the given soil is classified as Clay with High Compressibility (CH). To find Maximum Dry Density and Optimum moisture content of given soil, Standard Proctor compaction test is adopted. As per IS standards, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of fine grained soils are less than 19g/cc and greater than 15% respectively. From the Table 2, it is noticed that MDD and OMC are within the limits for clayey soil as per standards (MDD=1.25g/cc, OMC=18.4%). Un-soaked CBR test was conducted on given natural soil and the CBR value is found to be 3.28% and is within the limits as per IS code for fine grained soils.

4.2 Gypsum and NaCl

The various percentages of gypsum and NaCl are added to the given clayey natural soil and the laboratory tests are performed. While mixing gypsum and NaCl in soil, care should be taken such that all ingredients mixed throughout the soil sample uniformly by making soil sample partially wet. Quantity of Gypsum and NaCl (W_{gn}) to be added to a given amount of natural soil is obtained using the following formula given in Eq. n (1)

$$W_{gn} = (a) \times W_d \tag{1}$$

Where $a = 3\%$, 8% and 13% of Gypsum and NaCl

$W_d =$ Quantity of Dry Natural Soil (gm.)

4.3 Experimental Procedure

A series of laboratory tests are conducted on both virgin soils as well as on reinforced soil with gypsum and nacl. List of experiments conducted in laboratory with IS codes and equivalent ASTM codes are given in Table 1. The results and discussions for natural soil are discussed in the following sections. In this section, procedures for conducting the tests on both natural soil and reinforced soil with gypsum and NaCl are discussed.

Compaction Test

From compaction test, water content-dry density relationship of soil with varying percentages (3%, 8% and 15%) of gypsum and NaCl is obtained. A series of Standard Proctor Tests are conducted on reinforced soil with gypsum and NaCl as per (IS-2720 Part-VII) Procedure. First, the amount of gypsum and NaCl (W_{gn}) needed to be mixed with given natural soil ($W_d = 2500\text{gm}$) is calculated for particular percentage of gypsum and NaCl (a) as given by the Eq. (1). Gypsum and NaCl thus obtained are added to natural soil after making dry soil into partially wet soil by adding sufficient amount of water to ensure soil sample uniform and paste could be formed. Gypsum, NaCl and soil are mixed thoroughly until mix becomes uniform and homogeneous. As per Standard Proctor Test procedure, reinforced soil sample is filled in the mould by three equal layers and each layer is being given with 25 blows of 2.6 kg hammer from height of 30 cm. Water contents and dry densities are evaluated from the test data and are shown in Table 3 in Results and Discussion section. The test is performed for all soil specimens containing different percentage of gypsum and NaCl.

California Bearing Ratio (CBR) Test

A series of un-soaked California Bearing Ratio Tests are performed on reinforced soil with varying percentages of gypsum and NaCl (3%, 8% and 15%) as per IS-2720 Part 16 procedure for light static compaction. At first, required amount of gypsum and NaCl calculated from Eq. (1) and are blended with 5kg of dry soil, and then mixed thoroughly until homogeneous mix is obtained. After reinforced soil sample is prepared, sample is filled in the mould with three equal layers and each layer is being given by 56 numbers of blows by a 2.6kg rammer for light static compaction. Load required for penetrating through the reinforced soil sample up to 10mm penetration depths is noted. From the loads obtained, CBR values for all reinforced soil samples are evaluated and the results are shown in Table 3 in Results and Discussion section.

V. RESULTS AND DISCUSSIONS

In this section, detailed results for reinforced soil with varying percentages of gypsum and NaCl (3%, 8% and 15%) are presented. A series of standard proctor tests and California bearing ratio tests are performed on soil with varying percentages of gypsum and NaCl and the corresponding results are shown in Table 3.

Table 3: Test results of Reinforced soil with gypsum and NaCl

S.NO	Proportions of Reinforced Soil Sample			Compaction Properties		CBR Ratio
	Soil(%)	Gypsum(%)	NaCl(%)	OMC(%)	MDD(g/cc)	CBR(%)
1	100	0	0	18.4	1.25	3.28
2	94	3	3	16.2	1.33	10.4
	Percentage of Increment/Decrement* (%)			11.9 [#]	6.4	217.1
3	84	8	8	13.2	1.49	14.6
	Percentage of Increment/Decrement* (%)			28.2	24	345.2
4	74	13	13	12.5	1.72	16.8
	Percentage of Increment/Decrement* (%)			32.1	47	412.1

Note: *Percentage of increment/decrement in properties of soil for all percent of gypsum and NaCl contents is evaluated with respect to properties of natural soil.

Note: [#] Negative sign indicates decrement in properties of soil with respect to properties of natural soil.

Standard Proctor Compaction tests are performed on reinforced soil with gypsum and NaCl with varying soil with gypsum and NaCl with varying percentages (3%, 8% and 13%) and the corresponding results of Optimum Moisture Contents and Maximum Dry Densities are shown in Table 3. Compaction curves for both natural soil and reinforced soil with gypsum and NaCl for different percentages are depicted in Fig.1

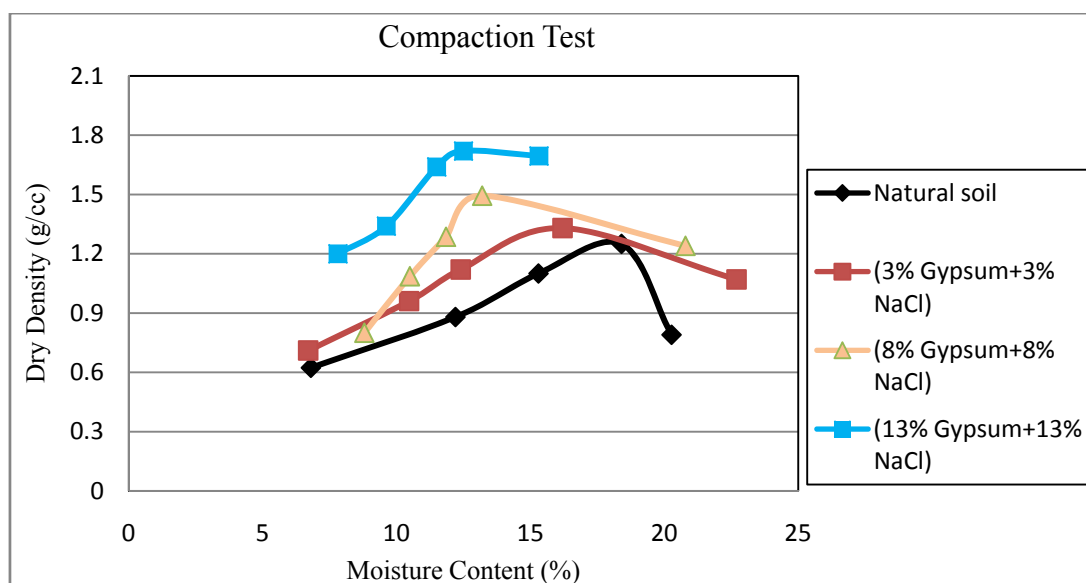


Fig.1 Compaction Curves for various percentages of Gypsum and NaCl

Based on the data obtained in Table 3 and from Fig.1, it is observed that Maximum Dry Density for natural soil is found to be 1.25g/cc and is increased to 1.33g/cc at 3% gypsum and NaCl with increment of 6.4%, further increased to 1.49g/cc at 8% gypsum and NaCl with increment of 24% comparing with MDD of natural soil. If the percentage of gypsum and NaCl is further increased to 13% then the MDD value also increased to 1.72g/cc with increment of 47% compared to natural soil. It can be concluded that, there is considerable increment in maximum dry density of soil with increase in percentage of gypsum and NaCl (shown in Fig. 2). It is also observed that, there is decrement in optimum moisture content of soil with increase in percentage of gypsum and NaCl. It is well known fact that, generally as the maximum dry density of soil increases optimum moisture content of soil decreases. From this study MDD and OMC values are analog to principles of compaction parameters.

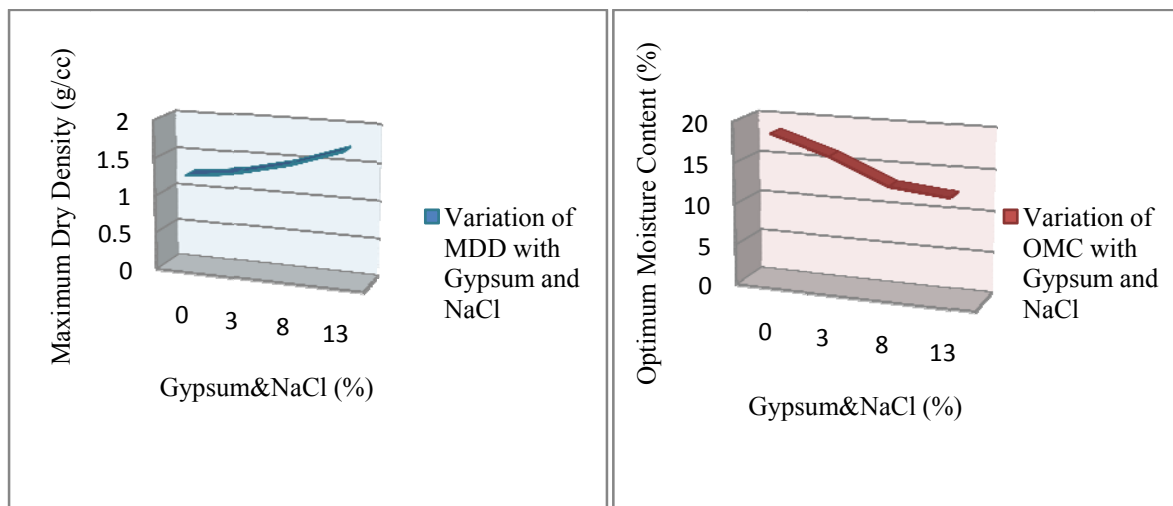


Fig.2 Effect of Gypsum and NaCl on MDD

Fig.3 Effect of Gypsum and NaCl on OMC

Increase in MDD for higher percentage of gypsum and NaCl is attributed to the fact that as the quantity of gypsum and NaCl is increased, volume of solid fraction of soil makes a very good bonding with the gypsum and NaCl. Increment in MDD of clayey soil is also due to the properties of gypsum and NaCl. Gypsum is a source of calcium which is major mechanism that binds soil organic matter to clay in soil which gives stability to the soil grains. It is also the fact that void space was filled up by the gypsum and NaCl for increase in percentage of gypsum and NaCl. This helps in further packing of soil grains with gypsum and NaCl together. In this way, compaction test on reinforced soil with gypsum and NaCl yields higher maximum dry unit weight (MDU) and lower optimum moisture content (OMC). The scientific explanation for this behavior is that the soil and gypsum and NaCl grains have a closer packing during compaction process. Generally, as the specific gravity of soil sample increases, dry unit weight also increases. With increase in percentage of gypsum and NaCl, specific gravity of soil sample also increases and dry unit weight increases. Decrement in OMC (as shown in Fig.3) of soil with increase in percentage of gypsum and NaCl may be attributed fact that, gypsum and NaCl absorbs more water during compaction process.

Un-Soaked California Bearing Ratio Tests are performed on reinforced soil with gypsum and NaCl with varying percentages (3%, 8% and 13%) and the corresponding results of CBR values are shown in Table 3. Load-Penetration curves for both natural soil and reinforced soil with gypsum and NaCl for different percentages are depicted in Fig.4.

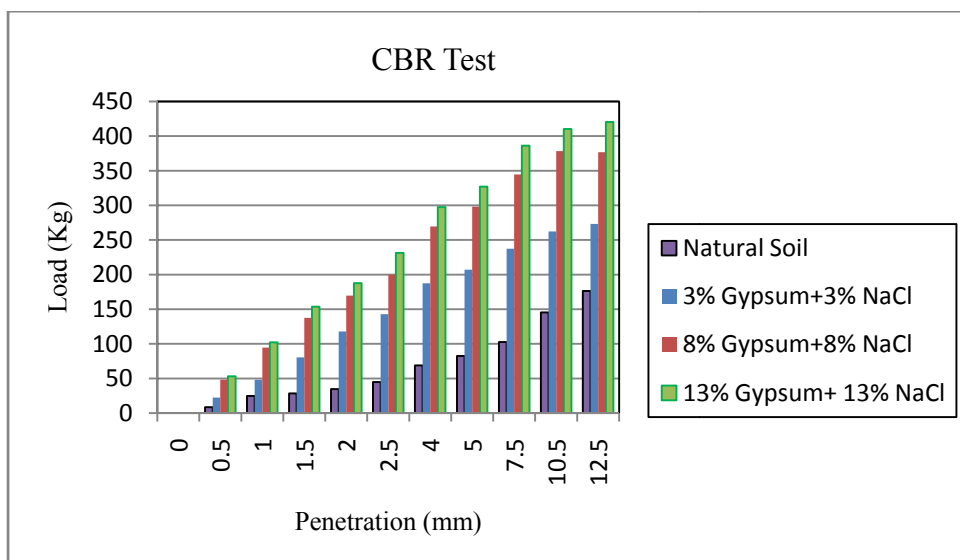


Fig.4 Load-Penetration behavior of clayey soil reinforced with Gypsum and NaCl

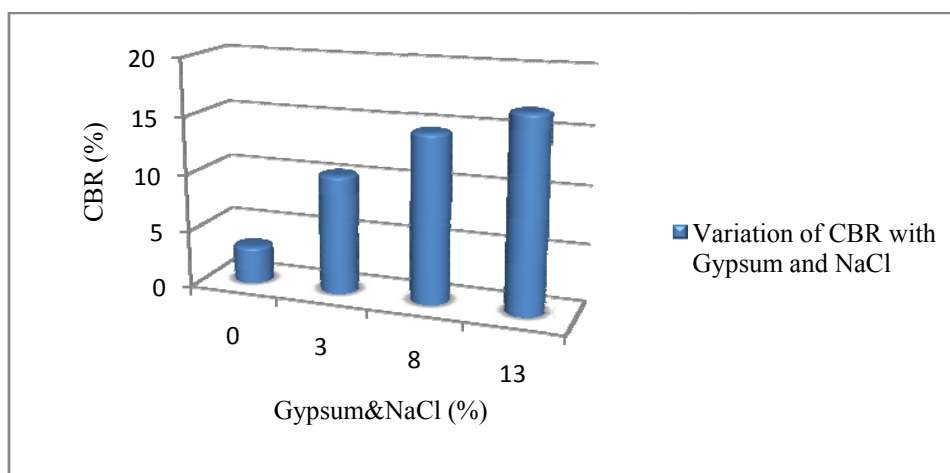


Fig. 5 Effect of Gypsum and NaCl on CBR value

Based on the data obtained in Table 3 for CBR Test and from Fig.4, it is observed that California Bearing Ratio value for natural soil is found to be 3.28% and is increased to 10.4% at 3% gypsum and NaCl with increment of 217.1%, further increased to 14.6% at 8% gypsum and NaCl with increment of 345.2% comparing with CBR value of natural soil. If the percentage of gypsum and NaCl is further increased to 13% then the CBR value also increased to 16.8% with increment of 412.1% compared to natural soil. It is clearly observed that, addition of gypsum and NaCl in soil increases CBR value considerably (As shown in Fig.5) such that thickness of sub grade can be reduced. The reduction in pavement thickness directly implies the reduction in cost of the construction of pavement. Increase in CBR value in the soil with increase of gypsum and NaCl is due to the fact that, the void space in the soil space is filled up with gypsum and NaCl and it offers higher resistance to the applied load.

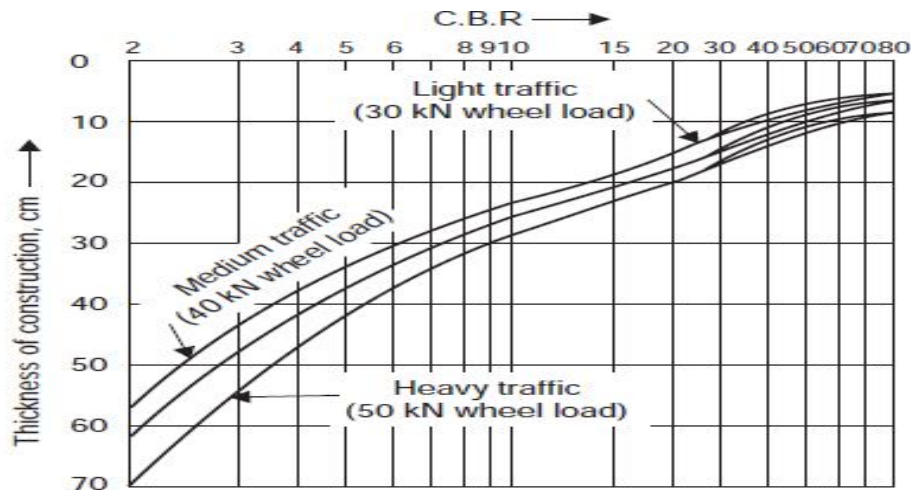


Fig.6 CBR vs. Pavement thickness curves (Venkatramaiah, 2006)

Fig.6 shows the CBR vs. Pavement thickness curve for design of flexible pavements. From the Fig.6, it is observed that sub grade thickness for natural soil is found to be around 52 cm for heavy traffic condition (55 kN wheel load) for CBR value of 3.28% and it reduces to 28 cm for the same traffic condition for 3% gypsum and NaCl having CBR value of 10.4%. For 8% gypsum and NaCl pavement thickness is found to be around 24 cm having CBR value of 14.6% and finally for 13% gypsum and NaCl, pavement thickness is found to be around 21 cm having CBR value of 16.85. It implies that reduction in pavement thickness from 52 cm to 21 cm, quantity of aggregate materials and soil (borrowed) used in sub-grade thickness and quantity of bitumen used in base thickness is considerably decreased. Therefore, the construction cost is reduced by a considerable amount as well as the time for construction of pavements and also the improvement in soil as CBR value is increased considerably compared to natural soil.

6. CONCLUSIONS

As per data and results obtained from the experimental work on stabilization of clayey soil with varying percentages of gypsum and NaCl (3%, 8% and 13, the following conclusions can be drawn regarding the aspect of strength improvement of soil due application of Gypsum and NaCl as a mean of soil reinforcement.

Based on results and discussions from compaction test, it is observed that with increase in percentage of gypsum and NaCl, the compaction properties are also increased. The maximum dry densities are found to be 1.33 g/cc for 3%, 1.49 g/cc for 8% and 1.72 g/cc for 13% of gypsum and NaCl and it shows an increasing trend in MDD value. It is also observed that there is an decreasing trend in optimum moisture content with increase of gypsum and NaCl and this is due to the fact that, gypsum and NaCl absorbs more water during compaction process. It can be concluded that for effective soil stabilization, increase in gypsum and NaCl will give better results.

Based on CBR test results it is observed that addition of Sodium Chloride and Gypsum as stabilizing agent produces a marked increase in CBR value. It can be concluded that, with increase in gypsum and NaCl, the CBR values are also increased considerably as CBR is found to be 16.8% for 13% Gypsum and NaCl compared to natural soil.

From the discussions, it can be concluded that addition of gypsum and NaCl to the natural soil (clay) shows the considerable effect on the compaction properties and bearing capacity of soil. It is also concluded that, expensive methods like cement, lime etc. for soil stabilization can be replaced with gypsum and NaCl as an alternative to improve the weak soil properties. Gypsum and NaCl can be used for stabilization of embankments, pavement sub-grade and other fields of civil engineering as per needs for clayey type of soil.

ACKNOWLEDGMENTS

The authors wish to acknowledge the CMR college of Engineering & Technology, Hyderabad for providing the laboratory to perform all experiments presented in this paper. The authors also express their appreciation to Mr. Bala Reddy, Lab Asst. CMRCET for his role in experiments.

REFERENCES

- [1] Işık Yılmaz, Berrin Civelekoglu, "Gypsum: An additive for stabilization of swelling clay soils". Applied Clay Science, Volume 44, Issues 1–2, April 2009, Pages 166–172.
- [2] Aly Ahmed and Usama H.Iss, "Stability of soft clay soil with recycled gypsum in a wet environment". Soils and Foundations, 2014, 54(3), Pages 405–416.
- [3] Dina Kuttah and Kenichi Sato, "Review on the effect of gypsum content on soil behavior". Transportation Geotechnics, September 2015, Volume 4, Pages 28-37.
- [4] Tamadher T, Abood, Anuar Bin Kasa and Zamri Bin Chik, "Stabilization of slity clay soil using chemical compounds" Journal of Engineering Science and Technology, 2007, Vol. 2, No. 1 Pages 102-110.
- [5] Swarna Swetha Kolaventi, Sanjay Gokul Venigalla and D.Rakesh, "Stabilization of black cotton soil using salts and their comparative analysis". International Journal of Engineering Development and Research, 2016, Volume 4 Issue 2.
- [6] C.Venkatramaiah (2006). GEOTECHNICAL ENGINEERING. New Age International Publishers.
- [7] IS: 2720-Part 3-1980, Bureau of Indian Standards New Delhi, Feb (1981).Determination of Specific Gravity of Soil Solids.
- [8] IS: 2720-Part 4-1985, Bureau of Indian Standards New Delhi, January (1986). Laboratory method for Grain Size Analysis.
- [9] IS: 2720-Part 16-1987, Bureau of Indian Standards New Delhi, May (1988) .Laboratory Determination of CBR Value.
- [10] IS: 2720-Part 7-1980, Bureau of Indian Standards New Delhi, December (1980). Laboratory method for Standard Proctor Test.

AUTHOR PROFILE

S.Peddaiah was born in Kurnool, India. He received his B.Tech degree in Civil Engineering from IIIT Kadapa, India and M.Tech degree in Geotechnical Engineering from NIT Patna, India. He is working as an asst.professor in the Dept.of civil engineering at CMR college of Engineering & Technology, Hyderabad, India. His area of interest is ground improvement techniques and soil-pile interactions.

Dr.K.Suresh was born in Guntur, India. He received his B.Tech degree in Civil Engg. From SV University, India. M.Tech in Geotechnical Engg. From JNTU Kakinada, India and Ph.D from JNTU Hyderabad India. Currently He is working as Head and Professor in Civil Dept. at CMR college of engineering & Technology, Hyderabad. He has more than 8 years of teaching experience and published more than 40 papers of international/national Journals/conferences. His area of interest includes Consolidation of soils and Innovative foundation techniques in problematic soils.