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Influence of $CaCl_2$ on Compaction and CBR Characteristics of Gypsum ($CaSO_4.2H_2O$) Stabilized High Plastic Clay

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Abstract. Lightweight structures that are constructed on clay would experience the uplift and settlement due to changes in moisture content. Soil with high plasticity could cause problems to the structures. Good numbers of options are available to stabilize the highly plastic clays. One such option in the recent past is utilization of Gypsum in soil stabilization. Gypsum can be derived from demolished building sites as waste. This paper presents the behavior of clay stabilized with gypsum, and also the effect of $CaCl_2$ on the improvement of CBR and shear characteristics. The tests such as of Standard compaction, California Bearing Ratio (CBR), Free Swell Index (FSI) and Direct shear are conducted. The proportions of Gypsum used in the study are 0%, 2%, 4%, 6% and 8% by dry weight of soil. A 2% $CaCl_2$ is added to the clay which is stabilized at 6% Gypsum in order to see the improvement in soil behaviour. The results revealed that as % Gypsum increases from 0% to 8% initially, there was an increase in the maximum dry density (MDD) up to 4% Gypsum content and thereafter it showed little decrease in MDD. The CBR of high plastic clay stabilized with gypsum showed marginal improvement. Free swell index of gypsum treated clay is reduced to almost 50% at 8% Gypsum. For the Gypsum stabilized clay when 2% $CaCl_2$ is added, resulted in a further increase in CBR and MDD. The 6% Gypsum and 2% $CaCl_2$ addition to the high plastic clay resulted in improvement in strength and CBR values.

Keywords: OMC. MDD, CBR, FSI, shear characteristics

1 Introduction

Soils have either occurred naturally or made artificially. High plastic clays are found to be the most troublesome soils. These soils are generally clayey, deep, impermeable, and are formed by lava basaltic rocks. These soils have high swelling and shrinkage potential, when exposed to moisture changes. Swelling and shrinkage nature of these soils lead to occurrence of cracks in the soil mass. Structures require a stable and steady foundation for their sustainability. The engineering properties of the soil also differ from place to place and depend mainly on soil mineral deposits, water table and soil water relationships. The improvements and changes in the soil can be made either by modification or by stabilizing the soil or by using both. Soil modification is done by the compaction and grouting methods. Soil Stabilization may be defined as the technique adopted to improve the engineering properties of weaker soil by using different stabilizing agents. Improvement of soil properties by using waste or inexpensive materials is considered to be eco-friendly. Gypsum from the demolished building sites is considered to be waste material and it can be used in the soil stabilization as stabilizing agent.

Gypsum stabilized clay samples showed an improvement in the stability, strength and durability when cured in short periods of 3 and 7 days as compared with the 28 days cured samples. The water absorption and soil deterioration are significantly reduced with the admixture content and soaking time. The volume change of clay stabilized with gypsum showed less than 0.15% of soaked sample and it is noticed as insignificant [10]. Addition of paddy husk did not improve the clay soil strength and CBR, but when 2% gypsum is added to clay at its OMC revealed 18% increase in UCS and 33% increase in CBR. Clay soil stabilized with paddy husk even showed reduced values of UCS and CBR as compared to untreated clay soil [9]. The bentonite samples tested corresponding to gypsum mixes such as 2.5%, 5%, 7.5%, and 10% by dry weight revealed a noticeable change in the plasticity, swell percent and strength parameters. It was mentioned that the gypsum can be used as a stabilizing agent for expansive clay soils [1].

Generally to prevent the solubility of gypsum and to improve the durability of clay samples, the cement or lime is used as admixtures in soil [8]. Good amount of research work had revealed that the use of lime or cement as a stabilizer would enhance the strength of soft soil [7]. Shear strength of cement-treated soil is influenced by the type of cement, amount of cement, physical properties, chemical properties, curing period and mixing process. Generally the type of cement and its amount to be used to stabilize the soil are most considerable parameters [5, 6].

Employing numerical limit analysis and using cement treated soil characteristics such as shear strength and unit weight of various stabilized soils, the Monte Carlo simulations were developed for the undrained bearing capacity of a surface strip foundation. It is very well valid for practical purposes [4]. The swell percent, swell pressure and UCS of lime, gypsum and lime with gypsum mixtures of compacted soil with curing revealed that the swell percent and swell pressure have reduced with increased additive, while the strength was increased over a period of time. The lowest improvement ratio was reported for gypsum alone added to clay soil. For high plastic clay stabilization point of view, the optimum lime content 6% can be proposed [3].

The variation in strength of soil with curing are due to the cation exchange, flocculation and binding of particles with cementitious compounds formed after curing. The early accelerated strength is due to formation of compacted structure with growth of entringite needless within the voids. Clay matrix rearrangement and suppression of sulfate effects with formation of cementitious compounds are the main responsible factors for gaining the strength. Addition of 1% gypsum to soil – fly ash – lime, the strength was seen accelerated after 14 day curing [2]. From the above review, it is noticed that still there is a need to understand the behaviour of high plastic clay when stabilized with Gypsum and also the influence of $CaCl_2$ on Gypsum stabilized soil. The results pertinent to the geotechnical characteristics of high plastic clay which is treated with Gypsum are presented and discussed in the following sections.

2 Experimental Investigation

2.1 Materials used

Clayey soil . Clayey soil was collected from Ibrahimpatnam area in Hyderabad, TS, India from a clear ground at a depth of 0.3m from the surface. Collected soil was processed and stored in the containers in the laboratory. The basic characteristics of soil are presented in Table 1. The soil has liquid limit and plasticity index are 68% and 37% respectively.

Table 1. Basic characteristics of soil

S.No.	Property	Value
1	% Fine fraction	70
2	% Sand	27
3	% Gravel	03
4	Liquid Limit (%)	68
5	Plastic Limit (%)	331
6	Plasticity Index	37
7	Free Swelling Index (%)	90
8	Specific Gravity	2.69
9	Maximum Dry Density (kN/m^3)	14.35
10	Optimum Moisture Content (%)	20.8
11	California Bearing Ratio (%)	6.50
12	Undrained Cohesion (kPa)	14
13	Angle of Shearing Resistance (Deg)	5.0
15	Unconfined Compression Strength (kPa)	81

Gypsum. Gypsum is made up of 79% of $CaSO_4$ and 21% of H_2O. Gypsum is a byproduct of many industrial processes. It was collected from the demolished building sites and processed in the form of fine powder material and stored in the containers under controlled conditions in the laboratory.

Calcium chloride. Fused Calcium chloride ($CaCl_2$) available in the powder form was purchased from the local market. It was stored in air tight bottles under controlled temperature and moisture conditions.

2.2 Tests conducted

The laboratory tests conducted are listed in the Table 2 below along with the Bureau of Indian Standard (BIS).

Table 2. Tests conducted

S.No.	Name of the test	BIS Code
1	Specific gravity	BIS 2720: Part 3 (1980) [11]
2	Grain size analysis	BIS 2720: Part 4 (1985) [12]
3	Atterberg limits	BIS 2720: Part 5 (1985) [13]
4	Light compaction	BIS 2720: Part 8 (1983) [14]
5	Direct shear	BIS 2720: Part 13 (1986) [15]
6	California Bearing Ratio	BIS 2720: Part 16 (1987) [16]
7	Free Swell Index	BIS 2720: Part 40 (1977) [17]

3 Results and Discussion

3.1 Free swell index

Fig.1 shows the variation of free swell index (FSI) with the varied Gypsum content. From this figure, it is noticed that as the gypsum increases from 2% to 8%, there is considerable decrease in the FSI. This decrease is about 50% for the clay which is treated with 8% gypsum. For the Gypsum contents 6% and 8%, the FSI has reached a level equal to almost 40%. It can be evidenced from the figure.

3.2 Standard compaction test results

Fig.2 presents the water content-dry density curves obtained from standard compaction test on clay soil treated with Gypsum of varied proportions from 2 to 8%. Calcium chloride acts as a soil flocculent and facilitates compaction. Also presents the compaction curve of clay soil treated with 6% Gypsum + 2% $CaCl_2$. From the figure, it can be noticed that as the % Gypsum increases from 0 to 8%, there is an increase in the OMC almost linearly. The MDD is increased up to 4% gypsum and thereafter it is decreasing. Overall, the range of OMC is between 20.8% to 23.2% for the gypsum content in soil from 0 to 8%. The MDD in clay at 8% Gypum is 14.10 kN/m^3, but for untreated clay its value is 14. 35 kN/m^3. The clay soil treated at 6% Gypsum + 2% $CaCl_2$ is showing the MDD of 15 kN/m^3 and it is a good improvement in MDD a compared to the clay soil treated with Gypsum alone. The increase in OMC of clay treated with 6% Gypsum + 2% $CaCl_2$ is less as compared to the clay treated with 6% and 8% Gypsum. It reveals that the addition of 2% of $CaCl_2$ along with Gypsum of 6% by dry weight of soil would result in improved MDD.

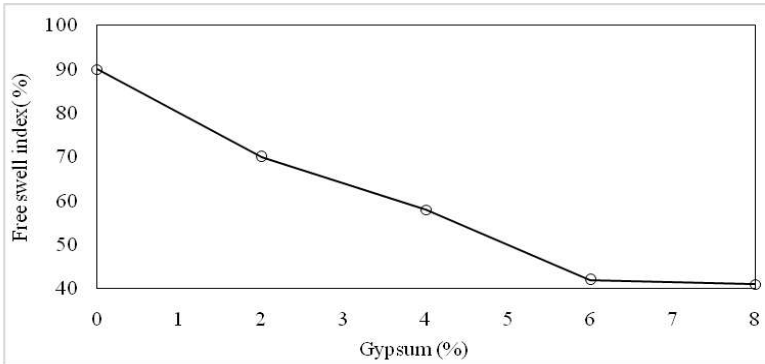

Fig. 1. Variation of Free Swell Index with % Gypsum

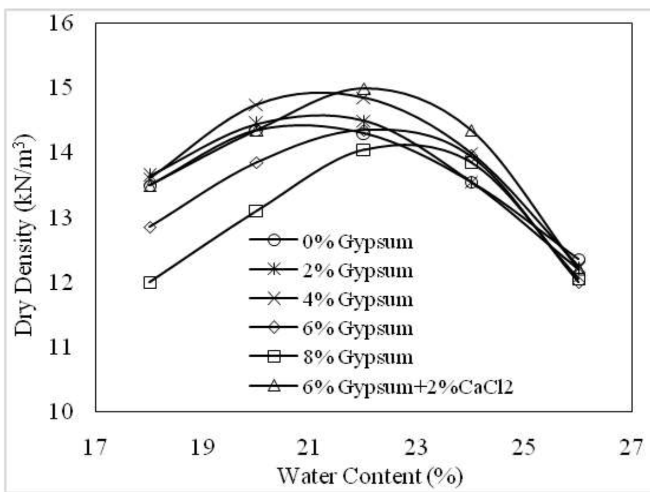

Fig. 2. Water Content - Dry Density Curves for Varied Gypsum Content

Fig.3 presents the variation of OMC with the varied content of Gypsum. As the Gypsum content increases from 0 to 8%, there is an increase in the OMC and this increase is almost linear. The increase in OMC of 8% Gypsum treated clay is found to be 11.5% as compared to untreated soil. This increase in OMC can be considered as marginal. The variation in MDD with varied Gypsum content is presented in Fig.4. From this figure, it is noticed that up to 4% Gypsum, there is an increase in MDD and this increase is about 3.5% and further addition of Gypsum from 6% to 8% resulted in decrease in MDD. This decrease in MDD at 8% Gypsum is 1.75% as compared to unthreaded soil. However, the clay treated with 6% Gypsum + 2% $CaCl_2$ showing 4.5% increase in MDD as compared to untreated soil. Hence, the effect of $CaCl_2$ addition can be felt in achieving the stabilization process of clay when compared to stabilization of clay with Gypsum alone.

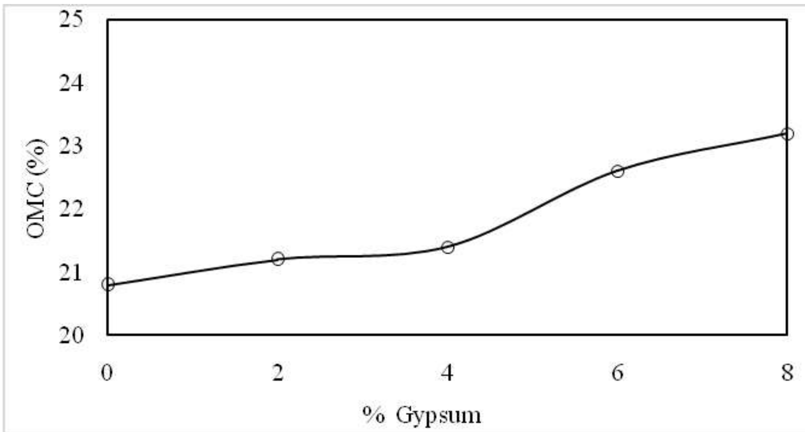

Fig. 3. Variation of OMC for Varied Gypsum Content

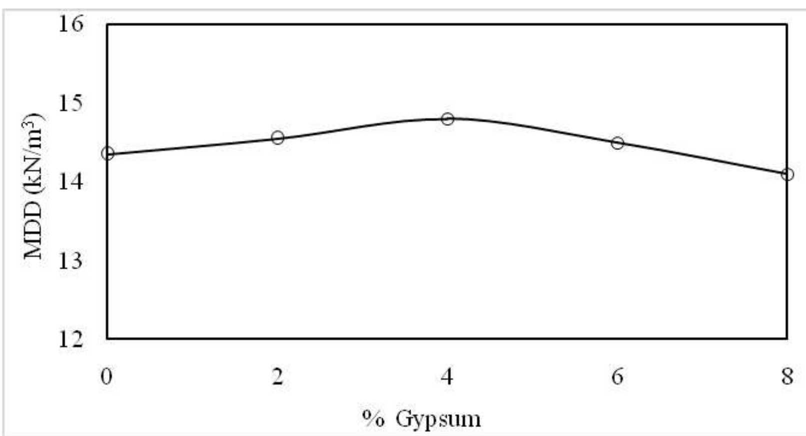

Fig. 4. Variation of Maximum Dry Density for Varied Gypsum Content

3.3 Un-soaked CBR variation with Gypsum

The variation in CBR obtained at 2.5mm, 5mm and 10mm penetrations are presented in Fig.5, with varied content of Gypsum as well as for clay soil treated with 6% Gypsum + 2% $CaCl_2$. From this figure, it is noticed that as the % Gypsum increases, there is an increase in CBR and also as penetration increase from 2.5mm to 10mm, there is decrease in CBR value. With the increase in the Gypsum content, the increase in

CBR is more at 2.5mm penetration as compared to the 5mm and 10mm penetrations. As compared to the untreated soil, the increase in CBR obtained corresponding to 2.5mm penetration is 23% and 11.5% respectively for soil treated with 6% and 8% Gypsum. The same soil when treated with 6% Gypsum + 2% $CaCl_2$ showing about 35% increase in CBR. In all the cases the higher values of CBR are noticed corresponding to the 2.5mm penetration.

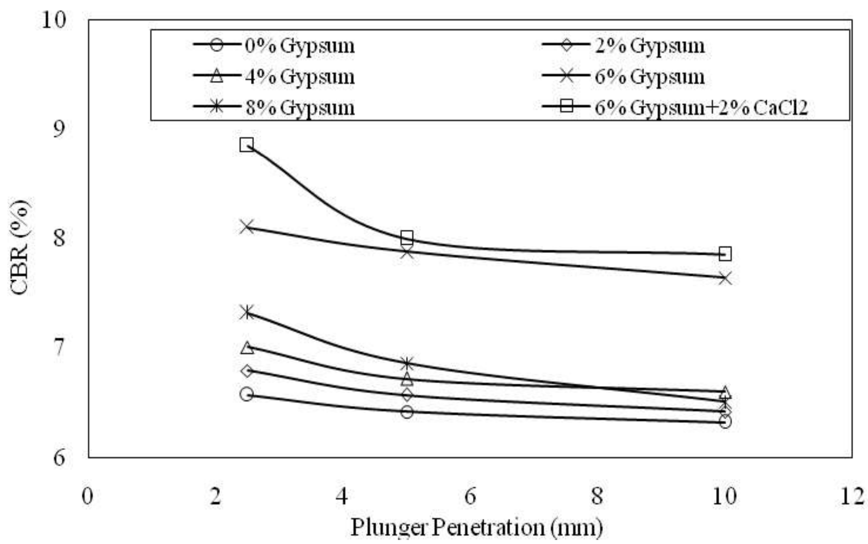

Fig. 5. Variation of CBR with Plunger Penetration for Varied Gypsum Content

Further, the CBR variation with varied content of Gypsum is presented in Fig.6. From this figure, it can be observed that up to 6% Gypsum content the CBR is increasing and for 8% Gypsum it is lower than 6% Gypsum content and its value is decreased 10% as compared to the clay treated with 6% gypsum. But, for the same soil when treated with 6% Gypsum + 2% $CaCl_2$, the increase in CBR corresponding to 2.5mm penetration is about 10% as compared to the clay treated with 6% Gypsum alone.

3.4 Shear characteristics of Gypsum treated clay

Figs. 7 to 9 presents the variation of shear stress with effective normal stress for different Gypsum contents. Fig.7 presents the strength envelops for clay treated with 0%, 2% and 4% gypsum content. Fig.8 presents the strength envelops for clay treated with 0%, 6% and 8% and Fig.9 presents the strength envelops for 6% Gypsum + 2% $CaCl_2$ and 6% gypsum for better comparison of effect of $CaCl_2$.

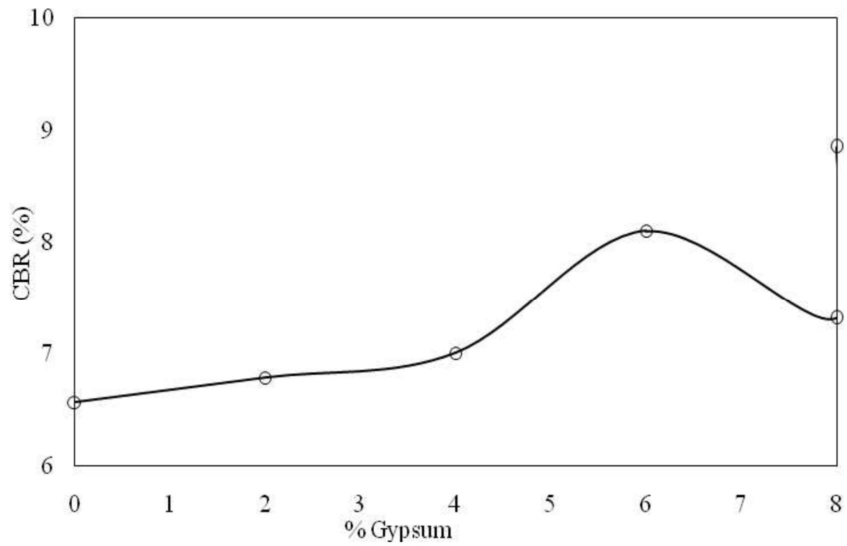

Fig. 6. Variation of CBR for Varied Gypsum Content

From figure 7, it is observed that as the effective normal stress increases the shear stress is almost becoming similar at higher normal stresses. The shear stress variation is only noticed in the initial stages of normal stress for the clay treated with 2% and 4% Gypsum. Similar such behavior is noticed in shear stress variation for clay soil treated with 6% and 8% Gypsum as shown in Fig.8. From figure 9, it is observed that as the normal stress increases, the shear stress also increasing for the cases of clay soil treated with 6% Gypsum and 6% Gypsum + 2% $CaCl_2$. The strength envelop of clay treated with 6% Gypsum + 2% $CaCl_2$ is moving almost parallel and above than the strength envelop of clay treated with 6% Gypsum. It is understand that, with the addition of 2% $CaCl_2$ to the clay treated with 6% Gypsum is causing increase in cohesion and angle of internal friction. Table 3 presents the variation of cohesion and angle of shearing resistance of Gypsum treated clay. From this table, it is clear that as the % Gypsum content increases, the cohesion of clay is decreasing, but the angle of shearing resistance is increasing. The increase in angle of shearing resistance of clay treated with 8% gypsum is 2 times more as compared to the untreated soil and its value is almost similar for both 8% Gypsum and 6% Gypsum + 2% $CaCl_2$ treated clay. The decrease in cohesion is noticed as 75% in the 8% Gypsum treated clay compared to the untreated clay. Similarly, the decrease in cohesion in the 6% Gypsum + 2% $CaCl_2$ treated clay is about 40% as compared to the untreated soil. Over all, it is observed that the clay treated with 6% Gypsum + 2% $CaCl_2$ is showing improvement in strength by increased angle of shearing resistance.

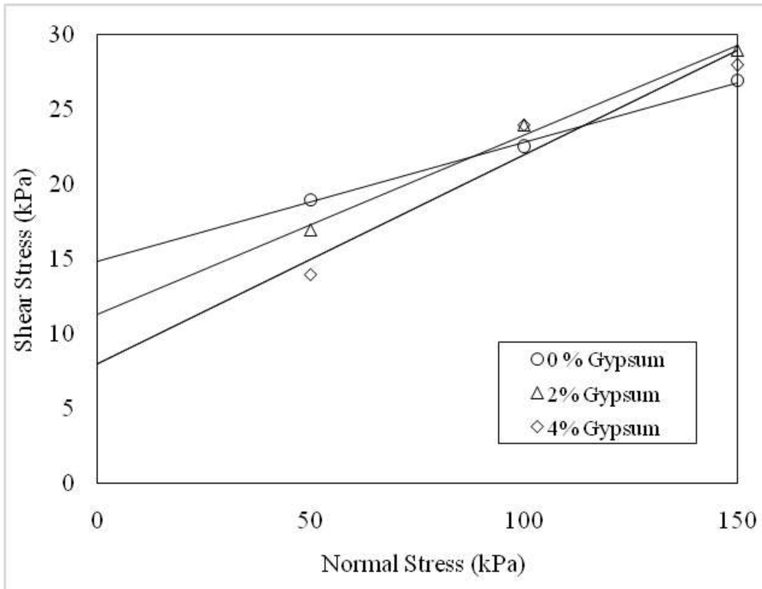

Fig. 7. Variation of shear stress with applied effective normal stress for 0%, 2% and 4% Gypsum content

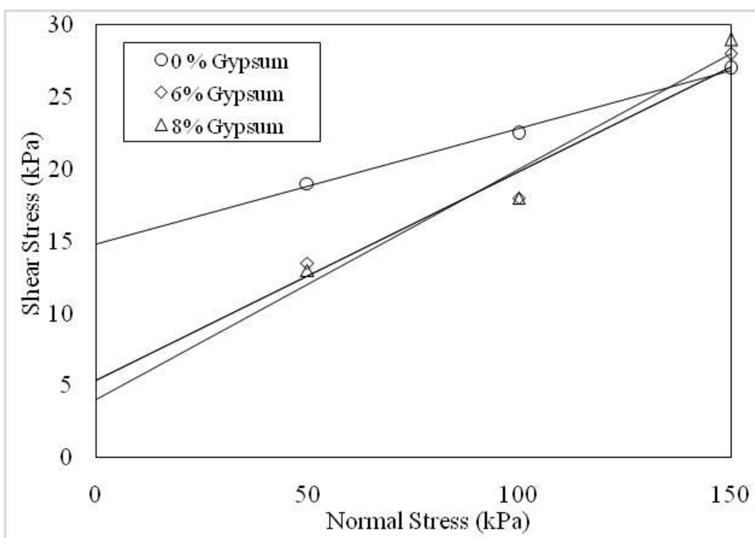

Fig. 8. Variation of shear stress with applied effective normal stress for 0%, 6% and 8% Gypsum content

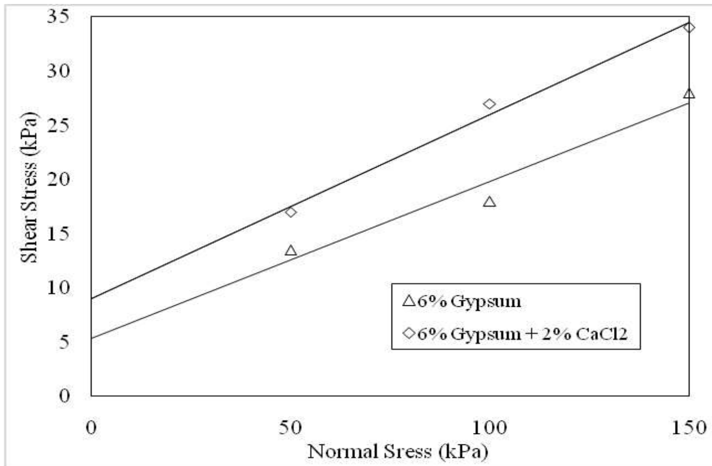

Fig. 9. Variation of shear stress with applied effective normal stress for 6% Gypsum content and 6% Gypsum + 2% $CaCl_2$

Table 3. Shear characteristics of Gypsum treated clay

S.No	% Gypsum	Cohesion (kPa)	Angle of Shearing Resistance (Deg)
1	0	15	5
2	2	11	7.5
3	4	8.0	8.85
4	6	5.35	9.25
5	8	4.0	10.15
6	6% Gypsum + 2% $CaCl_2$	9.0	10.75

4 Summary and Conclusions

The test results obtained in the laboratory on gypsum treated clay are discussed. The geotechnical characteristics such as free swell index (FSI), compaction characteristics such as optimum moisture content (OMC) and maximum dry density (MDD), Un-soaked CBR and shear chacteristics such as cohesion and angle of shearing resistance of clay treated with Gypsum and Gypsum + $CaCl_2$ are discussed. From the results discussed as above, the following conclusions are drawn.

1. The reduction in FSI is about 50% in the clay soil treated with 8% Gypsum.
2. The OMC is increased with the addition of Gypsum content and MDD is increased initially up to 4% Gypsum, thereafter it is decreased.
3. CBR of clay is improved with the Gypsum content.

4. Angle of shearing resistance of clay treated with Gypsum has increased with the increased Gypsum content, but the cohesion has decreased.
5. Overall, the clay treated with 6% Gypsum + 2% $CaCl_2$ has shown good improve ment in geotechnical characteristics.

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