iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: III Month of publication: March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67288

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

Experimental Study on the Stabilization of Expansive Soil using Gypsum Hemihydrate

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Abstract: An expansive soil is a type of soil that expands or contracts as a direct consequence of variations in water volume. Expansive soils have low bearing capacity, large settlement, and excessive water absorbability as their physical properties. They have inadequate bearing capacity due to high water content, and causes consolidation settlement. This makes them problematic for civil engineering construction. Various issues in the buildings or construction projects may arise as a result of expansive soil's swelling and contracting behaviour such as crucible damage to roads and walkways and other lightweight structures, wall and ceiling cracks, excessive settlement etc. Hence, before beginning any construction projects, checking for the presence of expansive soil and implementing an appropriate treatment strategy are critical. The consequence of swell- shrink nature of expansive soils can be reduced by using a number of techniques such as replacement of soil by controlling compaction, moisture controlled; surcharge loading; use of geosynthetics. The best way for controlling expansive soil volume changes is to stabilise the soil with the addition of admixture which can restricts volume changes or alters characteristics of expansive soil. The goal of soil stabilisation is to enhance soil shear strength, decrease permeability, increase durability of soil mass, and strengthen the load carrying capacity of foundation soils. In this study, gypsum hemihydrate (Plaster of Paris) is used as a stabilising agent for stabilisation of soil. Gypsum hemihydrate is added to the soil in proportions of 3 to 12 percent. Effect of gypsum hemihydrate on Atterberg's limits, unconfined compressive strength, free swell index, pH and conductivity, consolidation properties are determined. The use of gypsum hemihydrate successfully strengthens the soil while minimizing the swelling.
Keywords: Expansive Soil, Free Swell Index, Gypsum hemihydrate, Unconfined Compressive Test, Conductivity

I. INTRODUCTION

Engineering soils are manly classified into: silt, clay, fine aggregates (sand) coarse aggregates (gravel). An expansive soil is a type of soil that expands or contracts as a direct consequence of variations in water volume. Expansive soils have low bearing capacity, large settlement, and excessive water absorbability as their physical properties. When the soil required for a project is not suitable for the intended purpose, soil stabilisation is done. The primary goal of soil stabilisation is to increase soil strength or stability while decreasing construction costs by utilizing locally accessible materials. The goal of soil stabilisation is to enhance soil shear strength, decrease permeability, increase durability of soil mass, and strengthen the load carrying capacity of foundation soils. There are two different techniques for stabilizing soil. The first method involves mechanically stabilizing soil by applying physical processes such compaction, drainage, external loading, and consolidation. The other option is to enhance the soil by adding chemical additives that bind soil particles together through chemical processes such as cement hydration or pozzolanic reactions. Cement is the most extensively used substance for chemical soil stabilisation, but because to its numerous environmentally unfriendly characteristics, such as greenhouse gas emissions, its usage as a sustainable substance is constrained. Gypsum hemihydrate is a soft white hydrated chemical substance. $Ca_2SO_4.0.5H_2O$ is the chemical formula for Plaster of Paris also known as Gypsum hemihydrate. The gypsum hemihydrate is produced by burning gypsum rock at temperatures ranging from 1200 to 1800 degrees Celsius. Gypsum loses three to four times as much water as it needs to crystallise when heated, causing the formation of Plaster of Paris. In this study, gypsum hemihydrate (Plaster of Paris) is used as a soil stabilising agent. The following are the objectives of the study:

1) Evaluation of plasticity characteristics of the Gypsum Hemihydrate treated soil.
2) Detailed investigation on swelling characteristics of Gypsum Hemihydrate treated soil.
3) To evaluate the curing effect on strength of Gypsum Hemihydrate treated soil.
4) Evaluation of some chemical properties of the Gypsum Hemihydrate treated soil.
5) Evaluation of consolation properties of the Gypsum Hemihydrate treated soil.

II. LITERATURE REVIEW

The review of literature has been presented for studies related to soil stabilization using gypsum and gypsum hemihydrate. Yilmaz and Civelekoglu (2009) performed stabilization of swelling clay soil using gypsum. Standard compaction experiments were carried out to determine the optimum moisture content (OMC) for the bentonite soil. To achieve the highest water content, different amounts of gypsum such as 2.5%, 5%, 7.5%, and 10% were added to swelling soil and compacted. Both treated and non-treated samples were compared for Atterberg's limits, free swell, and unconfined compressive strength. The study discovered that treated and non-treated samples had different plasticity, swell percentage, and strength characteristics. The study and findings suggest that gypsum can be employed successfully as a stabilising agent for clay soils like bentonite. Vasu et. al., (2017) compared the stabilisation of peat soil utilizing gypsum and quick lime with fly ash. In their study, index or physical and geotechnical properties of the peat soil is determined. The peat soil sample received additions of fly ash with gypsum and fly ash with quick lime ranging from 5 to 30% and 2 to 8%, respectively, for curing times of 7, 14, and 28 days. On stabilised soil samples with the above percentages, the unconfined compressive strength (UCS) test was performed. When the results of two additives were compared, the UCS experiment results increased significantly as the percentage addition of all stabilising agents increased, with the rise in the curing periods. Bhardwaj et al., (2019) performed soil stabilization using gypsum and calcium chloride. The study investigated the strength characteristics of naturally clayey soil with the addition of different amounts of gypsum and a set amount of calcium chloride as a binding agent. The different percentages of gypsum added on the soil were 2%, 4%, 6%, and 8%. The amount of calcium chloride added was 1%. Laboratory test performed were California bearing ratio (CBR) test, free swell index (FSI) and Standard proctor test. The study concluded that adding gypsum and calcium chloride to clayey soil has a significant effect on compaction parameters and soil bearing capacity. Vaijwade et al., (2020) conducted expansive soil stabilisation using Crumb Rubber and Gypsum. The study aims at improving soil properties and stabilising them with crumb rubber powder (CRP) and gypsum. With a fixed ratio of Gypsum of 2%, the proportion of CRP is 5%, 10%, 15%, and so on. Laboratory tests such as Atterberg's limit test, CBR test and Standard Proctor test were also performed on treated and non-treated soil. The study discovered that using CRP and gypsum improved geotechnical properties of soil. Purwanto et al., (2020) conducted an experiment based on soil improvement using a mixture of gypsum plafond waste (GPW). The different amounts of GPW used in the experiment were 5 %, 10 %, 15 %, 20 %, and 25 % so on. Soaked CBR and Unsoaked CBR laboratory tests were performed. According to the findings of the study, the utilization of GPW as a mixture increases the bearing capacity of the red soil. Singh et al., (2020) performed clayey soil stabilization using Gypsum and Calcium Chloride. On both treated clayey soil and non-treated soil, a series of Standard Proctor tests and CBR were performed. 2%, 4%, 6% and 8% of gypsum were added to the soil and a fixed percentage of calcium chloride (0.75%) was added to the soil. The properties of raw clayey soil, soil mixed with gypsum, and soil mixed with gypsum and calcium chloride were compared. It was concluded that costly soil stabilisation methods such as cement, fly ash, and so on can be replaced with gypsum and calcium chloride as an alternative method to improve the weak clayey soil properties. Chetna et al., (2021) presented clay soil stabilisation using Gypsum hemihydrate (Plaster of Paris) and Cement. The study used gypsum hemihydrate as a stabiliser to enhance the swelling property of the soil. Different amounts of gypsum hemihydrates were added to clayey soil, such as 3%, 5%, 7%, and 10%, in addition to a small amount of cement, 1% to 3% by dry weight of the soil. On treated and non-treated samples, Atterberg's limit and strength tests were performed. The study found that adding 7% gypsum hemihydrate to the soil reduces the liquid limits and plastic limits. At 5% gypsum hemihydrate in the soil, the OMC and MDD were acceptable. The strength parameters in soil were substantially enhanced at 7% Gypsum hemihydrate addition. The value of UCS tends to increase when 7% gypsum hemihydrate and 1% cement are added to the soil. The UCS value increased when the amount was increased to 3% cement.

III.MATERIALS AND METHODOLOGY

1) *Expansive clayey soil* - An expansive soil is a type of soil that expands or contracts as a direct consequence of variations in water volume. Kaolinite, Montmorillonite, illite group of materials makes up the majority of expansive soil type. Expansive soil primarily has low bearing capacity, high settlement, and high absorbability as their physical properties. While expansive soil's high water content causes consolidation settlements in areas of loaded grounds, their inadequate bearing capacity makes them problematic for civil engineering constructions. Shear failure is typically caused by their poor shear and compressive strength. Pavement, building foundations, embankments, and irrigation system all suffer damage as a result of the expansive soil's tendency to swell. The expansive clayey soil is collected from a place which is 200 km away from Guwahati.

Fig. 1 A Expansive Clay Soil Sample collected from Guwahati

2) *Gypsum hemihydrate*- Gypsum hemihydrate is a soft white hydrated chemical substance. $Ca_2SO_4.0.5H_2O$ is the chemical formula for Plaster of Paris also known as Gypsum hemihydrate. The gypsum hemihydrate is produced by burning gypsum rock at temperatures ranging from 1200 to 1800 degrees Celsius. Gypsum loses three to four times as much water as it needs to crystallise when heated, causing the formation of Plaster of Paris. Gypsum hemihydrate is collected from a local vendor in Guwahati.

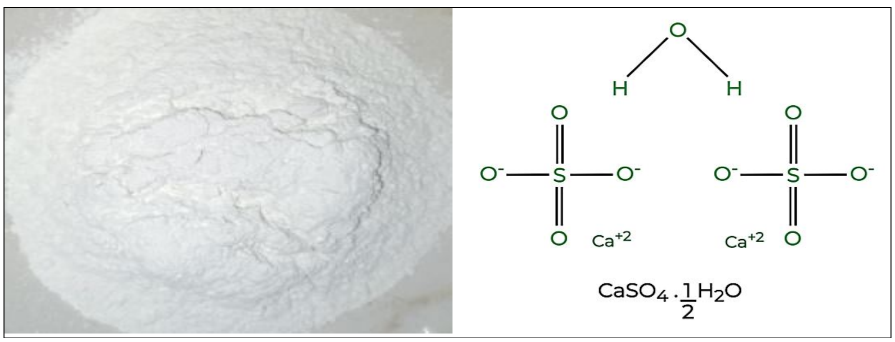

Fig 2. Gypsum Hemihydrate ($Ca_2SO_4.0.5H_2O$)

IV. MATERIALS AND METHODOLOGY

A. Methodology

1) *Sample collection and preparation:* Soil samples is collected and kept in oven for 24 hours and make it cools down. The soil was crushed into small pieces by hammer. The crushed oven dried soil sample is then sieved by using I.S. sieve 4.25 microns sieve to remove the unwanted organic materials and foreign particles.
2) *Classification of soil sample:* Soils are broadly classified as coarse-grained soils (gravel and sand) and fine grained soils (silt and clay). Classification of soil sample is done by sieve analysis i.e., dry sieve analysis and wet sieve analysis and hydrometer test. Dry and wet sieve analysis is carried out to experimentally determine the distribution of particle grain size for 75 microns of soil particles and higher as per IS: 2720(part 4)-1985. For determining the distribution of grain size, wet sieve analysis is applicable to all soils larger than 75-micron IS sieve and dry sieving is applicable only for soils which do not have an appreciable amount of clay. Hydrometer analysis is also carried out as per IS 2720(Part 4): 1985.
3) *Experimental investigation:* Gypsum hemihydrate ($Ca_2SO_4.0.5H_2O$) contains calcium cations in large amount. These calcium ions (high flocculating power) replace the sodium or potassium ions present in soil forming bulk granules (flocculation) by process of cation exchange. This process improves strength parameter of soil. In this research, Gypsum hemihydrate is added to the soil in 3%, 6%, 9%, and 12%. Effect of gypsum hemihydrate on Atterberg's limits, unconfined compressive strength, free swell index, pH and conductivity are determined based on the IS code. Atterberg's limit test is performed to test the plasticity characteristics of both gypsum hemihydrate treated soil and untreated soil based on IS code 2720- (Part 5), 1980. The MDD and OMC from standard proctor test are utilized for performing the UCS test. Unconfined compressive test is done to evaluate curing effect on the strength of gypsum hemihydrate treated soil for 0 days, 7days, 14 days curing as per IS code 2720- (Part10), 1991. Free swell index test is done to investigate swelling characteristics of Gypsum Hemihydrate treated soil as per IS code 2720-(Part 40), 1977. pH and conductivity test is also performed on untreated and gypsum hemihydrate treated soil as per IS code 2720- (Part 26), 1987 and IS code 14767- 2000. Consolidation test was conducted on both untreated soil and soil treated with gypsum hemihydrate at (3%, 6%, 9%, 12%) as per IS code 2720-(Part15), 1986.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

V. RESULTS AND DISCUSSION

Several test such as Atterberg's limit test, specific gravity test, standard proctor test, unconfined compressive test, Free swell index test, consolidation test, pH and conductivity test has been carried out as per the procedure given in the standard Indian Codes. The test results for the untreated expansive soil are given in Table 1. The particle size distribution for the soil sample is shown in Fig 3. From the test results of liquid limit and plastic limit and from the IS Plasticity Chart, the fine-grained soil is finally classified as CH (High plasticity Clay).

TABLE I
TEST RESULTS FOR THE UNTREATED EXPANSIVE SOIL

Sl. No.	**Parameters**		**Value**
1	Specific Gravity		2.74
2	Liquid Limit		76%
3	Plastic Limit		32.79%
4	Plasticity Index		42.21%
5	Shrinkage Limit		17.57%
6	Maximum Dry Density (MDD)		1.51g/cc
7	Optimum Moisture Content (OMC)		28%
8	Classification of the soil		CH
9	Free Swell Index (FSI)		157.14%
10	Ph		5.92 pH/mv
11	Conductivity		2.56 ms/ppt
12	Coefficient of Consolidations	0-100 kPa	0.91
		100-200 kPa	0.74
13	Unconfined Compressive Strength (UCS)		111.82 kN/m 2

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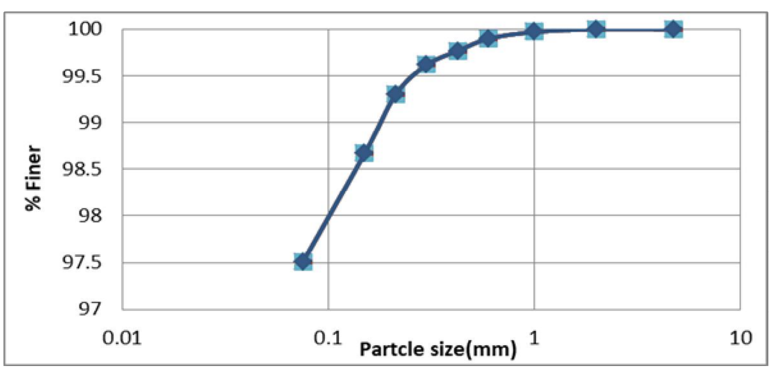

Fig 3. Particle Size Distribution

A. Atterberg's Limit Test

With the addition of 0%, 3%, 9%, and 12% gypsum hemihydrate on soil, the value obtained from plasticity index, liquid limit, plastic limit decreases with increase in the percentage addition of gypsum hemihydrate. This is due to fact that the Ca2+ ions present in gypsum hemihydrate replaced the ion present in the soil which leads to reduction in double diffuse layer of clay soils, hence decreasing plastic limit, liquid limit and plasticity index. The shrinkage limit value increases with increase in the percentage addition of gypsum due to the formation of cluster of particles by amendment of additives. The result and comparison chart is shown in figure 4.

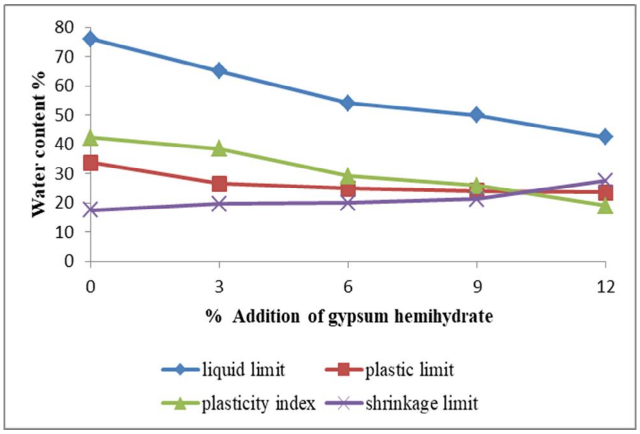

Fig 4. Atterberg's Limit Test

B. Standard Proctor Test

Standard proctor experiment was performed to determine the MDD and OMC. MDD is found to be 1.51 g/cc and optimum moisture content is obtained as 28%. The test result is shown below in figure 5.

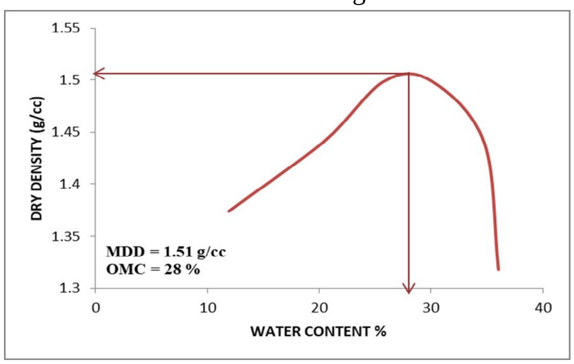

Fig 5. Test Result for Standard Proctor Test.

C. pH and Conductivity Test

The result attained from the pH test for soil with the addition of 0%, 3%, 6%, 9% and 12% increases from 5.92 to 12.3. This is due to the fact that the gypsum hemihydrate reacts with water leads to the release of Ca2+ from gypsum hemihydrate increasing the pH value with increasing gypsum percentage. The release of Ca2+ makes the soil basic in nature hence increasing the pH value. The result attained from the conductivity test for soil with the addition of 0 %, 3%, 6%, 9% and 12% increases from 2.56 to 5.43. This is due to the fact that the gypsum hemihydrate reacts with water leads to the release of Ca2+ from gypsum hemihydrate increasing the conductivity value with increasing gypsum percentage. The result is shown below in figure 6.

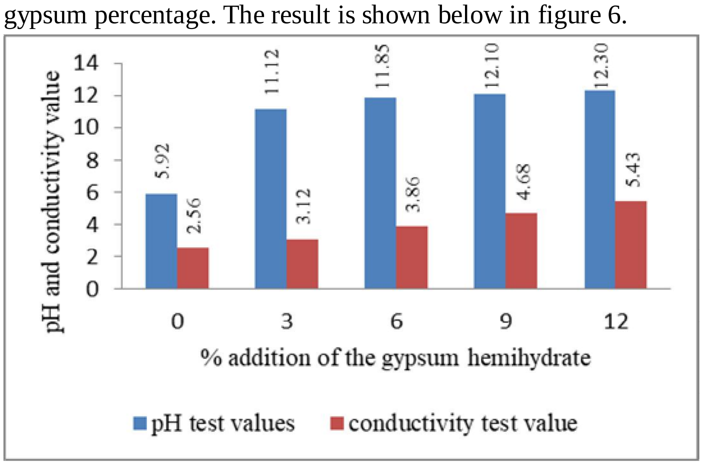

Fig 6. Test result for the pH and conductivity.

D. Unconfined Compressive Test

The compressive strength obtained from the unconfined compressive test for soil with the addition of 0%, 3%, 6%, 9% and 12% increases. This is due to the fact that the soil when mixed with gypsum hemihydrate, the alkaline cation exchange process occurs. The gypsum hemihydrate's Ca^{2+} replaces the soil's alkaline metal ions (Na^{+} and K^{+}). As a result of the soil particles being bound together by the bulk granules' growth (flocculation) and formation of binding material, the soil has a high unconfined compressive strength value. Gypsum hemihydrate reduces the likelihood of expansion and contraction in soil. The highest compressive strength is 910.31 kN/m^2 at 12 % addition of gypsum hemihydrate for 14 days curing. The strength increases with curing hence compressive strength is highest for 12 % addition of gypsum hemihydrate for 14 days curing. The test results are shown in figure 7.

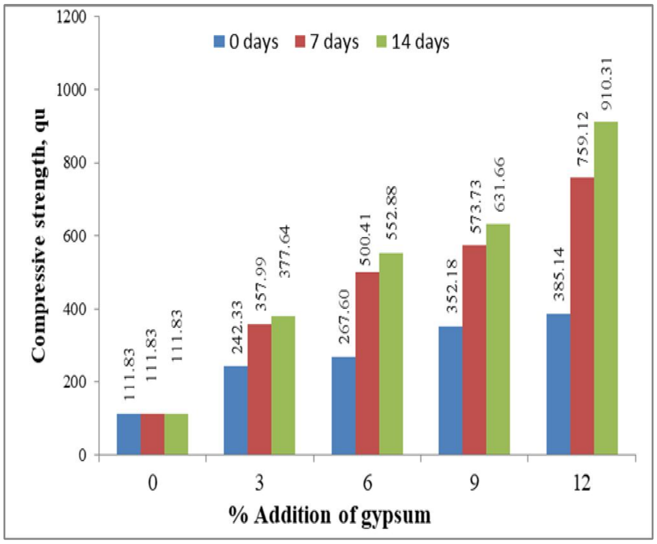

Fig 7. Test Result for Compressive Strength Test.

E. Free swell index test

With addition of 3%, 6%, 9% and 12% gypsum hemihydrate on soil, the free swell index value as well as free swell ratio decreases. When soil is treated with gypsum hemihydrate the swelling characteristics is found to be decreasing. With curing for 7 days and 14 days, the swell potential reduces. This is due to the fact that cation exchange occurs in the soil. The free swell index of non-treated soil is 157.14%. The test result for treated soil is shown in figure 8.

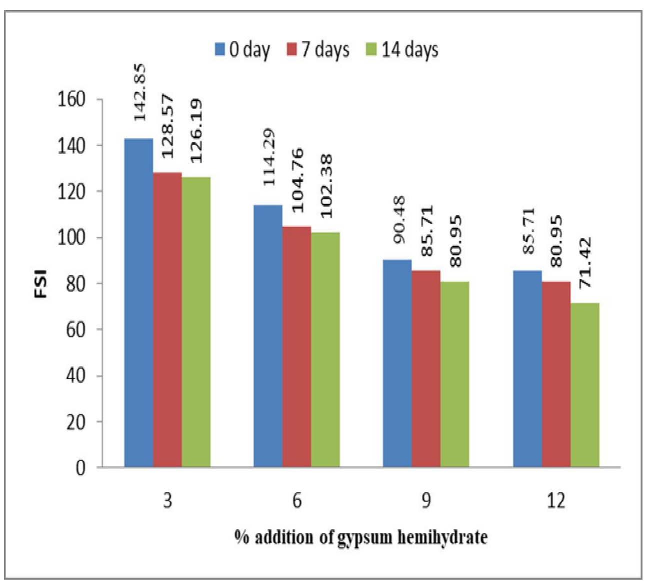

Fig 8. Test Result for Unconfined Compression Test.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

F. Consolidation test

The graph for time vs dial gauge reading for pressure range 0-100 kPa and 100-200 kPa for untreated and treated soil with various percentage of gypsum hemihydrate using Casagrande's logarithmic time fitting method are shown below.

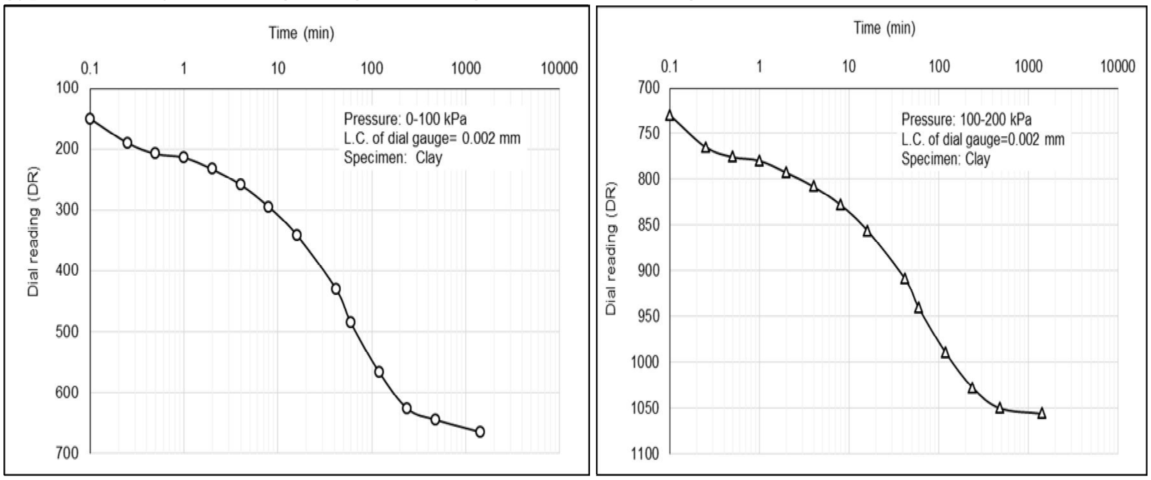

Fig 9. Time vs dial gauge reading graph for pressure range 0-100 kPa (untreated soil)

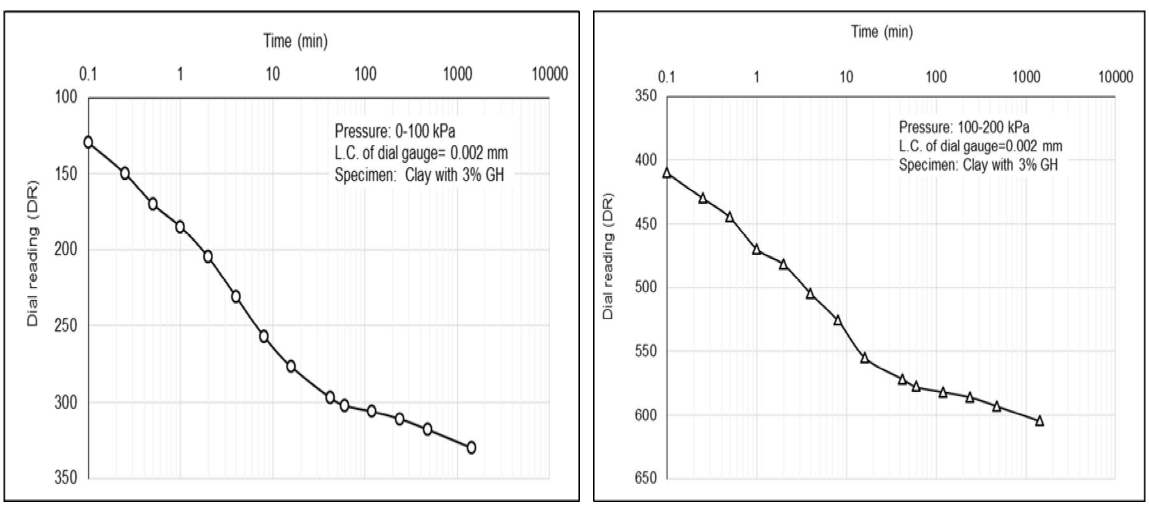

Fig 10. Time vs dial gauge reading graph for pressure range 0-100 kPa (3%GH) and 100-200kPa (3%GH)

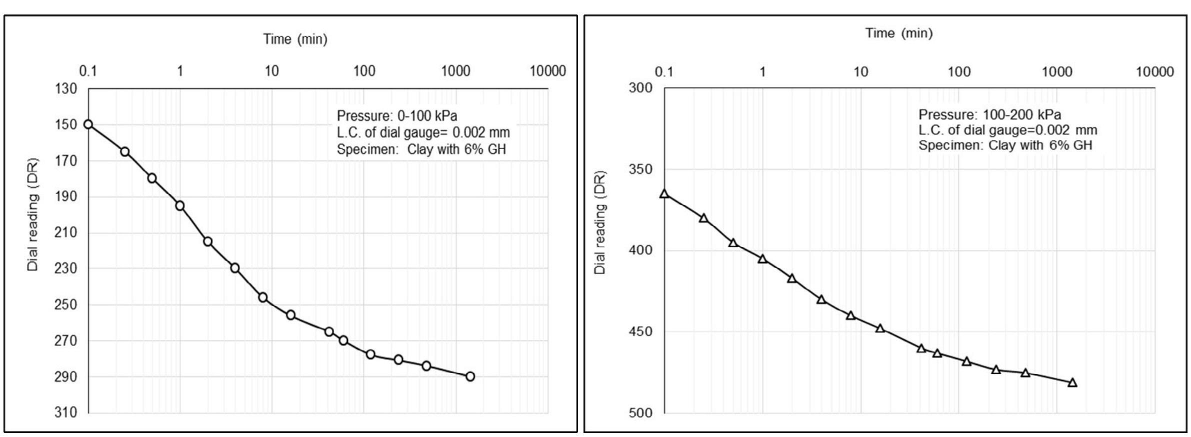

Fig 11. Time vs dial gauge reading graph for pressure range 0-100 kPa (6%GH) and 100- 200kPa (6%GH)

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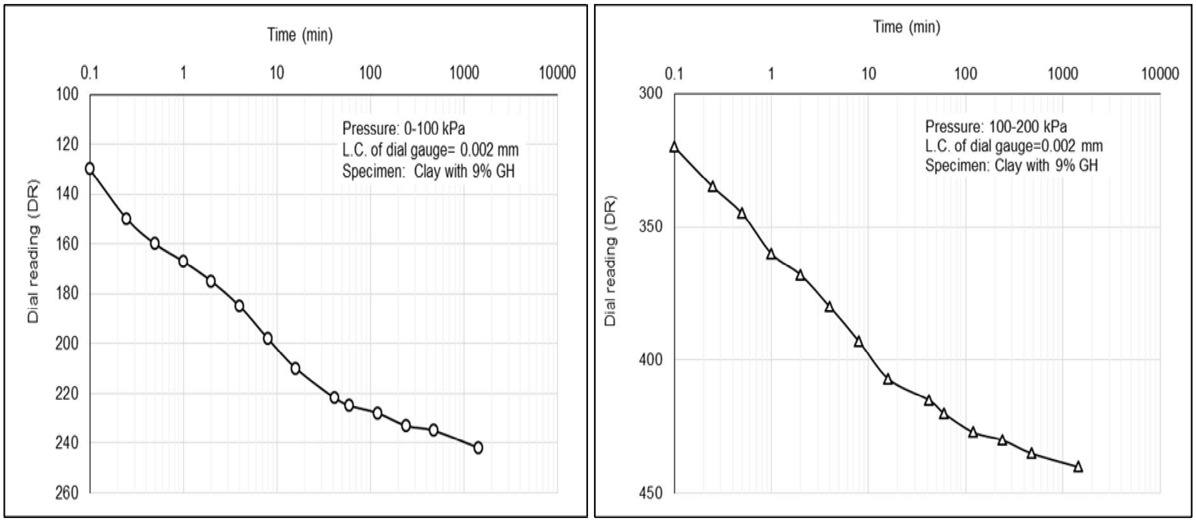

Fig 12. Time vs dial gauge reading graph for pressure range 0- 100kPa (9%GH) and 100- 200kPa (9%GH)

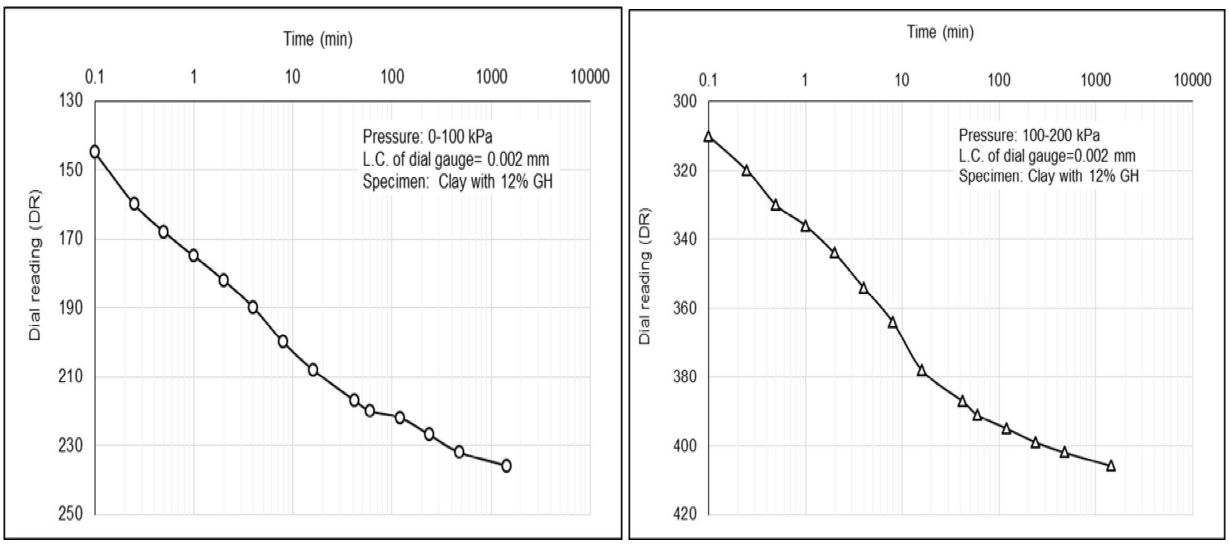

Fig 13. Time vs dial gauge reading graph for pressure range 0- 100kPa (12%GH) and 100-200kPa (12%GH)

The coefficient of consolidation (C_v) obtained from the consolidation test for untreated and treated soil with the addition of 0%, 3%, 6%, 9% and 12% increases from 0.91 mm^2/min to 21.03 mm^2/min for pressure range 0-100 kPa and 0.74 mm^2/min to 20.34 mm^2/min for pressure range 100-200 kPa. This is due to the fact that the increase content of gypsum hemihydrate decreases the plastic characteristics of the blended sample. As a result the compressibility of blended same are decreases and hence time required for consolidation is also decreased. The increase in the coefficient of consolidation value is enormous from 6% to 9% but the increase is less from 9% to 12%. So, the optimum percentage is 9 %.

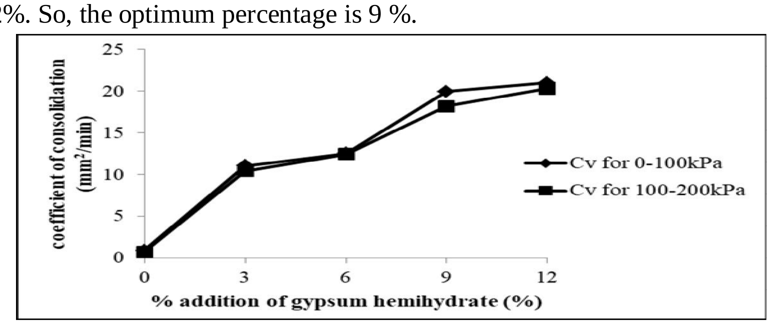

Fig 14. Comparison graph showing the coefficient of consolidation for various % of GH

VI. CONCLUSIONS

The coefficient of consolidation (C_v) obtained from the consolidation test for untreated and treated soil with the addition of 0%, 3%, 6%, 9% and 12% increases from 0.91 mm^2/min to 21.03 mm^2/min for pressure range 0-100 kPa and 0.74 mm^2/min to 20.34 mm^2/min for pressure range 100-200 kPa. This is due to the fact that the increase content of gypsum hemihydrate decreases the plastic characteristics of the blended sample. As the result the compressibility of blended sample are decreases and hence time required for consolidation is also decreased. The increase in the coefficient of consolidation value is enormous from 6% to 9% but the increase is less from 9% to 12%. So, the optimum percentage is 9 %.

The entire conclusion is drawn from the experimental study performed on expansive clay soil and scope for future work. Different percentages of gypsum hemihydrate is added to the soil to evaluate plasticity characteristics, swell characteristics, chemical characteristics and curing effect on strength of gypsum hemihydrate treated soil. The experiments conducted led to the following conclusions:

1) With the addition of 0%, 3%, 9%, and 12% gypsum hemihydrate on treated and non- treated soil, the liquid limit, plastic limit, plasticity index the values reduces with rise in the percentage addition of gypsum hemihydrate. The shrinkage limit rises with rise in addition of gypsum hemihydrate.
2) The result obtained from the pH test for soil with the addition of 0%, 3%, 6%, 9% and 12% increases from 5.92 to 12.3 due to release of Ca^{2+} ions which is basic in nature.
3) The result obtained from the conductivity test for soil with the addition of 0 %, 3%, 6%, 9% and 12% increases from 2.56 to 5.43.
4) The compressive strength obtained from the UCS test for soil increases with the addition of 0%, 3%, 6%, 9% and 12% due to the fact that the soil when mixed with gypsum hemihydrate, the alkaline cation exchange process occurs. The highest compressive strength is 910.31 KN/ m^2 at 12 % addition of gypsum hemihydrate for 14 days curing.
5) With the addition of 0%, 3%, 6%, 9%, and 12% gypsum hemihydrate on soil, the swelling characteristics decreases with rises in the percentage addition of gypsum hemihydrate. The decrease in the swelling potential is enormous (23.81) from 6% to 9% but the reduction potential is less (4.76) from 9% to 12%. So, the optimum percentage is 9 %.
6) With the addition of 0%, 3%, 6%, 9%, and 12% gypsum hemihydrate on soil, the coefficient of consolidation increases with rise in the percentage addition of gypsum hemihydrate. The increase in the coefficient of consolidation value is drastic (7.42mm ^{2}/min for 0-100kPa and 5.77 mm^2/min for 100 to 200kPa) from 6% to 9% but the increase is less (1.07 mm^2/min for 0-100kPa and 2.13 mm^2/min for 100-200kPa) from 9% to 12%. So, the optimum percentage is 9 %. From the above conclusion, the expansive clayey soil can be stabilized with the stabilizing agent gypsum hemihydrate (Plaster of Paris). The use of gypsum hemihydrate successfully strengthens the soil while minimizing the swelling.

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