Utilization of Brine Sludge to Improve the Strength and Compressibility Characteristics of Soft Clays

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Abstract: Stabilization of soil is a method to enhance the properties of soil by mixing and blending other materials. In past decades, efforts have been made to utilize the by-products of industrial waste such as blast furnace slag, fly ash etc., in large scale, to stabilize soils. An inefficient treatment and disposal practice of industrial waste causes serious damage to the environment. Therefore, the proper use of these wastes is highly advisable for ensuring a clean and safe environment. This paper aims to make use of the waste generated from a major industry located in Kochi for the purpose of stabilization of soft marine clay. The waste, known as 'Brine sludge' is generated during the manufacturing of caustic soda and chlorine through electrolysis of brine. This study explores the potential use of brine sludge in soil stabilization. In the present work, brine sludge was mixed with marine clay at various percentages of 10%, 20%, 30% and 40% by dry weight of the moist clay. In an attempt to determine the effect of a calcium based stabilizer on brine sludge stabilized clay, 3% of lime was added with brine sludge treated clay specimens. Atterberg limits, free swell index, unconfined compression tests, one dimensional consolidation tests etc. were carried out on different samples of brine sludge stabilized clay specimens. These experiments were conducted on soil specimens for curing periods of 7, 30, 60, 90 and 120 days. From the test results, it was found that brine sludge can be used as a stabilizer for refining the properties of soft clays. The incorporation of very small percentages of lime along with this industrial waste can further improve the geotechnical engineering properties of these soft clays.

Keywords: Brine sludge; Marine clay; Stabilization; Lime.

1 Introduction

Increase in population coupled with rapid industrialization has led to extensive generation of industrial wastes. Globalization has also triggered considerable development in infrastructure in urban areas recently. Due to the scarcity of land, the soils having low bearing capacity and high compressibility characteristics are also being considered for construction purposes. Hence, much priority has been placed to modify and stabilize these soils. Scientists, all over the world, are trying to convert the industrial waste to value-added materials. Over the past decade, several attempts have been made to utilize the industrial waste in the construction industry. Brine sludge is an industrial waste product, precipitated during chlorine and caustic soda production through the electrolysis of brine. India's Caustic Soda plant capacity is predicted to grow from 3.751 million tonnes per annum (mtpa) in 2017 to 5.032 mtpa in 2022, as perthe findings of GlobalData, a leading data and analytics company [1]. Substantial levels of dissolved metals and impurities may be present in brine sludge. These toxic substances that get precipitated from the brine affect the environment adversely and hence, timely and proper disposal of brine should be advocated by this industrial sector. Several researchers have investigated the reuse of brine sludge, in addition to cement and fly ash, in non structural building components such as paver block and bricks [2]. The percentage of brine sludge was optimized to be 35% for the construction of non-traffic (M30) paver blocks [3]. A sustainable way has been conceived to address environmental hazards of brine sludge by developing non-toxic, geo-polymeric (cement-free) materials. The fabrication of advanced composite wassuccessfully done by incorporating geo-polymerized brine sludge matrix [4].

No research has been reported regarding the utilization of brine sludge in soil stabilization. In light of this, the aim of the present study is to examine the potential of brine sludge as an additive to stabilize a soft clayey soil such as Cochin marine clay, known for its low shear strength and high compressibility [5]. The research also paves way to understand whether the inclusion of lime can further advance the properties of soil.

2 Experimental investigations

2.1 Materials

Marine Clay

The soil used in the present study was Marine clay, which was collected from a site near Kundanoor, located in Ernakulam district, Kerala. It was extracted from a depth of 13m below the ground level. The collected soil was stored in polythene bags, without losing the moisture content. The soil was grayish black in color and had a natural moisture content of 94%.

Table 1. Physical Properties of the soil in moist condition

Property	Test values
Natural Moisture Content (%)	94
Liquid Limit (%)	110
Plastic Limit (%)	39
Plasticity Index (%)	71
Shrinkage Limit (%)	27
Free Swell Index (cc/g)	4.8
Clay Size (<0.002mm) %	49
Silt Size (<0.002mm – 0.075mm) %	25

Sand Size (0.075mm – 4.75mm) %	26
Unconfined Compressive Strength at NMC (kPa)	4.1

Brine Sludge (BS)

The brine sludge was collected from Travancore Cochin Chemicals, Ernakulam. The brine sludge was analyzed for its chemical constituents by quantitative analysis (Table 2).

Table 2. Physical and Chemical Properties of Brine Sludge

Property	Test values
Color	Light grey
Physical state at room temperature	Semi-solid
pH	10
Water content	65%
$CaCO_3$	32.5%
$BaSO_3$	67.5%

Lime

For the preparation of lime, precisely chosen uniform shells were used. It was preserved in air tight multilayer polythene bag. On the day of preparation of lime treated samples, sufficient water wassprinkled over the shells which were stored in these polythene bags. It was sieved through IS 425 micron sieve when all the shells crumble to fine powder.

2.2 Specimen preparation and Testing

In an attempt to study the effectiveness of brine sludge and its performance in the presence of additive, soil specimens were prepared by mixing various ingredients in concentrations as given in Table 3. Some amount of moist clay was taken and its moisture content was determined. The moist soil was mixed with predetermined quantity of brine sludge as percentage by dry weight of soil. Varying percentage of brine sludge, 10%, 20%, 30% and 40% of the dry weight of soil was added to marine clay. Lime was also used as an additive to study its effect on brine sludge treated clayey sample. Samples were prepared with 30% of brine sludge + 3% of lime by dry weight of soil. Five different combinations were used for the preparation of various soil specimens and they are listed as follows:

1. Clay + 10% Brine Sludge
2. Clay + 20% Brine sludge
3. Clay + 30% Brine sludge
4. Clay + 40% Brine sludge

5. Clay + 30% Brine sludge + 3% lime

Soil samples required for Unconfined compressive tests and Consolidation tests were prepared in respective moulds and stored in sealed polythene bags under controlled temperature and humidity. These samples were tested at predetermined curing periods of 7, 30, 60, 90 and 120 days. The samples were covered with moist cotton cloth throughout its curing period. Unconfined compressive tests & Consolidation tests were conducted on the soil specimens in accordance with the Indian Standards [6].The prepared soil specimens were also tested for obtaining Atterberg limits and free swell index values at the same curing periods. The free swell index was determined by using the method suggested by Sridharan and Rao [7]. The experimental program for the study is given in Table 3.

Table 3. Experimental program for the study

Soil	Brine Sludge (%)	Additive Lime (%)	Curing period (days)	Tests Conducted
Marine Clay	0	0	0	UCC test, Liquid limit, Plastic limit, Free swell index & consolidation tests
	10	0	0, 7	UCC test
	20	0		
	30	0		
	40	0		
	30	0	0, 7, 30, 60, 90 & 120	UCC test, Liquid limit, Plastic limit, Free swell index & consolidation
	30	3		

3 Results and Discussions

3.1 Effect of brine sludge on unconfined compressive strength

The effect of different percentages of brine sludge on unconfined compressive strength of soil at curing periods, 0^{th} day and 7 days, is presented in Table 4. The results from the experiments performeddemonstrate that the soil sample treated with 30% of brine sludge has yielded highest strength at the endof 7 days of curing as compared to other soil specimens. Therefore, 30% of brine sludge was taken as the optimum dosage for further investigations.

Table 4. Variation of unconfined compressive strength with curing period

Type of sample	**Unconfined compressive strength (kPa) for a curing period of**	
	0 day	**7 days**
10% Brine Sludge	9	9.5
20% Brine Sludge	9.5	10.4
30% Brine Sludge	8.5	11.3
40% Brine Sludge	8.4	10.2

3.2 Effect of additive on unconfined compressive strength of brine sludge treated samples

Although the UCC strength is slightly increasing, it doesn't show considerable strength gain. Hence, attempts were made to see that whether small percentages of lime, if mixed with the brine sludge treated soil could bring in substantial improvement in strength. The effect of lime was determined by blendingthe marine clay with 30% of brine sludge and 3% of lime (by dry weight of soil). 30% brine sludge was chosen as the optimum dosage from the preliminary study by considering the increase in the percentage ofstrength gain at 7 days of curing. The effect of the addition of brine sludge and lime on unconfined compressive strength is presented in figure 1. Hydration reactions and development of strength in lime treated soil takes place immediately after mixing. With the use of lime, it was observed that the strengthof soil samples increased significantly. The unconfined compressive strength of lime treated samples increased to 20.33 kPa at 0^{th} day and continuously increased up to 25.8 kPa at the end of 120 days of curing. The increase in strength with the addition of lime can be due to the development of gelatinous compounds that improves the binding strength. These gelatinous compounds are formed when the pozzolanic reaction takes place between the soil and the stabilizer [8]. The strength gain of soil also depends on the curing period in all the cases. The test result implies that with the increase in curing period, the strength of soil also increases. Therefore, it can be inferred that brine sludge along with small percentage of lime can be effectively used to stabilize soft clayey soils.

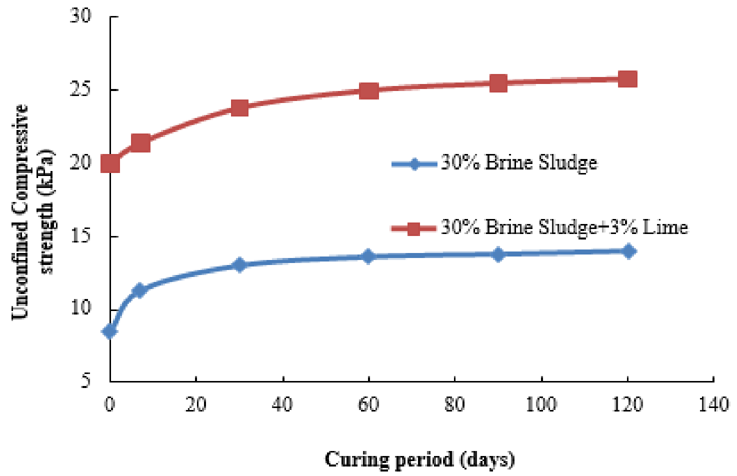

Fig. 1. Effect of brine sludge and lime on unconfined compressive strength with curing period

3.3 Effect of brine sludge and lime on liquid limit of soil

Liquid limit of the soil at its natural state was 110%. The liquid limit of treated clay sample seems to increase initially, when compared to that of untreated sample and thereafter, it decreases with curing period.

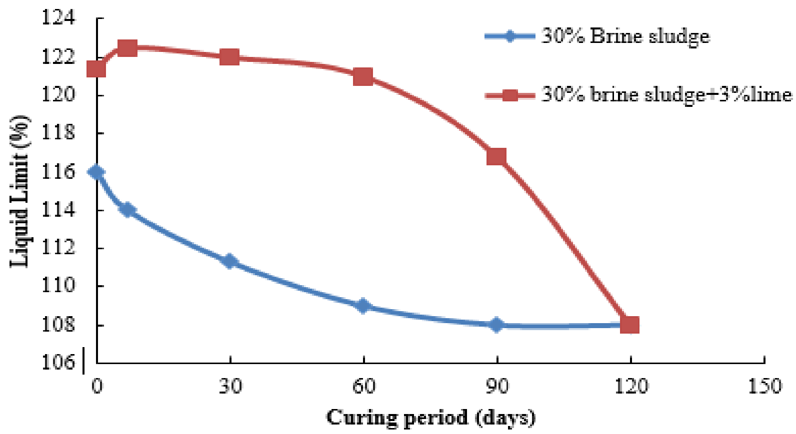

Fig. 2. Effect of brine sludge and lime on liquid limit of soil

The liquid limit of soil when lime was added to the clay treated with 30% of brine sludgeincreased to more than 120% immediately on mixing and then it decreased with respect to the increase in curing period. At the end of 120 days of curing, the liquid limit continuously decreases to a value of 108%, as shown in figure 2. It was observed that as the curing period increases, the liquid limit shows a decreasing trend. The decrease in double layer thickness and the formation of aggregates in treated soil may be concluded as the reason to the decrease in liquid limit [9,10].

3.4 Effect of brine sludge and lime on plasticity index of soil

The plasticity index of soil in its natural state was 71%. The effect of brine sludge and lime on plasticity index of the soil is depicted in figure 3.

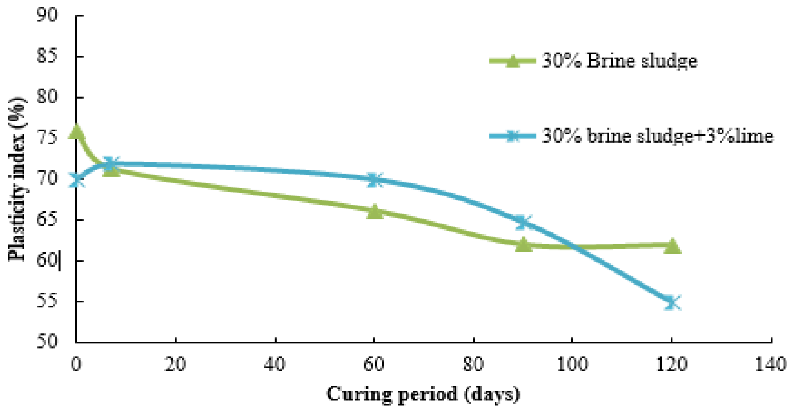

Fig. 3. Effect of brine sludge and lime on plasticity index of brine sludge treated soil

It was observed that the incorporation of brine sludge into clay sample decreases the plasticity index with respect to the curing time. The plasticity index of soil, with the addition of lime, increases slightly in the initial stage and then decreases, with respect to the increase in curing period.

3.5 Effect of brine sludge and lime on free swell index

Free swell index of soil in its natural state was 4.28cm^3/g. Table 5 displays the results of free swell index on treatment with different percentage of brine sludge with curing period. The free swell index values of all treated soil samples decrease marginally as the curing period increases. The reduction in swelling potential of all the treated clayey samples can be attributed to the formation of pozzolanic compounds, which helps in cementing the soil particles together [11].

Table 5. Effect of brine sludge and lime on free swell index with curing period

Samples	Free swell index (cm^3/g) for a curing period of				
	0 day	7 days	1 month	3 months	4 months
Clay + 30% brine sludge	4.19	4.18	4.16	4.14	3.26
Clay + 30% brine sludge + 3%lime	4.59	5.52	4.28	4.07	3.88

3.6 Effect of brine sludge and lime on compressibility characteristics of soil

In order to determine the effectiveness of calcium based stabilizers on brine sludge treated samples, the compressibility characteristics of brine sludge treated samples with lime is studied by performing one dimensional consolidation tests. The specimens were cured for 0 day, 1 month and 3 months and were subjected to consolidation test by giving different pressure increments.

Figure 4 compares the e- log p curves for samples treated with 30% of brine sludge at 0, 30 and 90 daysof curing with e-log p curve of untreated marine clay. It can be seen that the clay treated with 30% of brine sludge shows lesser compressibility compared to that untreated clay, indicating the effectiveness of brine sludge in reducing the compressibility characteristics of clay. The result also throws light on the significance of curing as brine sludge treated clay at 1 month of curing period yields higher compressibility with respect to samples at the end of 3 months of curing. Further the effectiveness of limeis investigated by conducting compressibility studies on lime with brine sludge treated soil.

Figure 5 displays the e- log p curves for samples treated with 30% of brine sludge + 3% lime at 0, 30 and 90 days of curing with e-log p curve of the untreated marine clay. It depicts the effect of curing on void ratio-pressure relationships for clay stabilized with lime and brine sludge. It is observed that addition of lime can decrease the compressibility quite effectively. The interactions in lime – soil matrix have been divided as long term and short term reactions [12]. The index properties of the soil are mainly affecteddue to short term reactions such as cation exchange, flocculation, pH, carbonation and lime migration, whereas the changes in the strength and compressibility characteristics are primarily accomplished from the long term reactions, which involves the development of various reaction products.

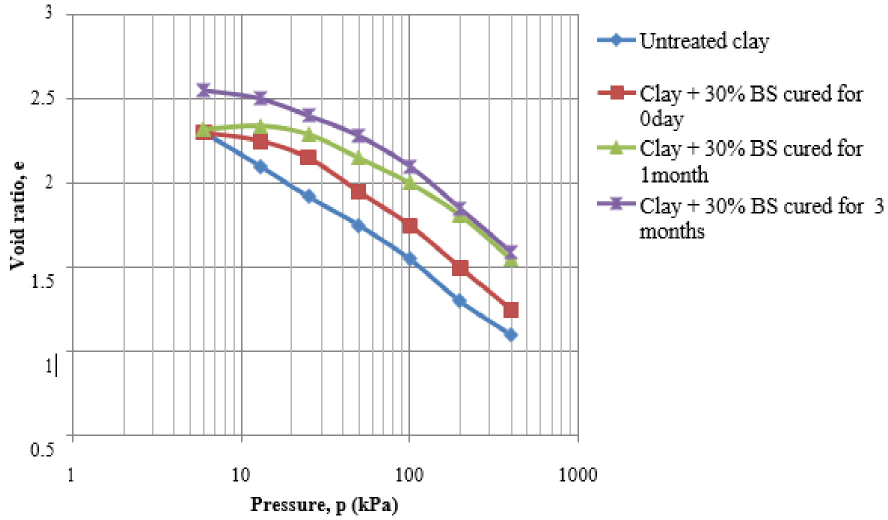

Fig. 4. Comparison of e-log *p* curves of untreated clay and clay treated with 30% brine sludge at different curing periods

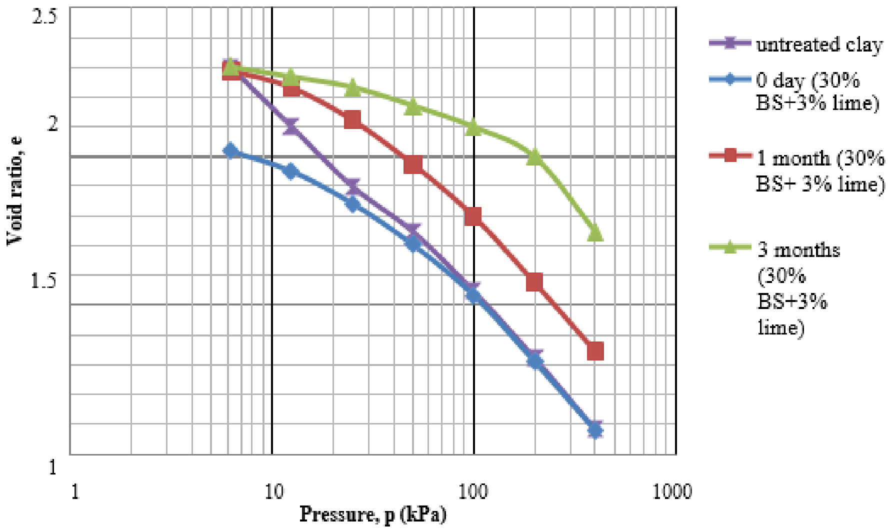

Fig. 5. Comparison of e-log *p* curves for 30% brine sludge+3% lime at different curing period

With the inclusion of lime and brine sludge in the soil matrix, the compression loading can be suppressed in a much better way and as a result, it shows lesser compressibility. The results also clearly indicate the presence of lime in cured samples helps to resist the axial load very effectively resulting in flatter load – compression curves.

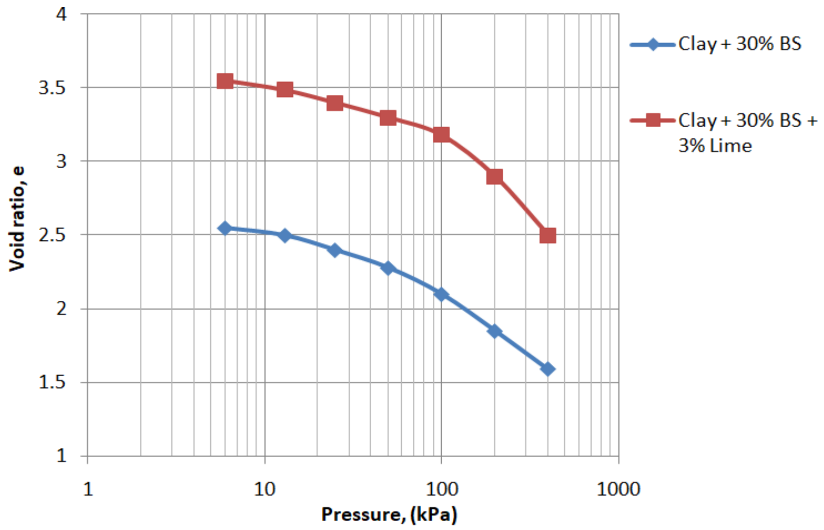

Fig. 6. Comparison of e- log p curves of 30% brine sludge and 30% brine sludge+3% lime (Curing period: 3 months)

Figure 6 compares the compressibility curves of brine sludge treated samples with and without lime. It clearly shows the effectiveness of lime in reducing the compress-ibility behavior of brine sludge treated clay.

The variation of de/d(log p) with curing period for treated clay is presented in Figure 7. By addition of lime with brine sludge, de/d(log p) seems to decrease drastically, clearly showing the effectiveness of lime in reducing the settlement of the brine sludge treated marine clay.

Figure 8 shows the variation of coefficient of consolidation with curing period for 30% brine sludge and 30% brine sludge + 3% lime at a pressure range of 50-100kPa. From the figure, it can be inferred that the incorporation of lime into brine sludge treated sample resulted in higher coefficient of consolidation at 3 month of curing period, which indicates that the treated soil undergoes consolidation at a faster rate than untreated clay. Therefore, this will help in reducing the settlement of the soil during its design life.

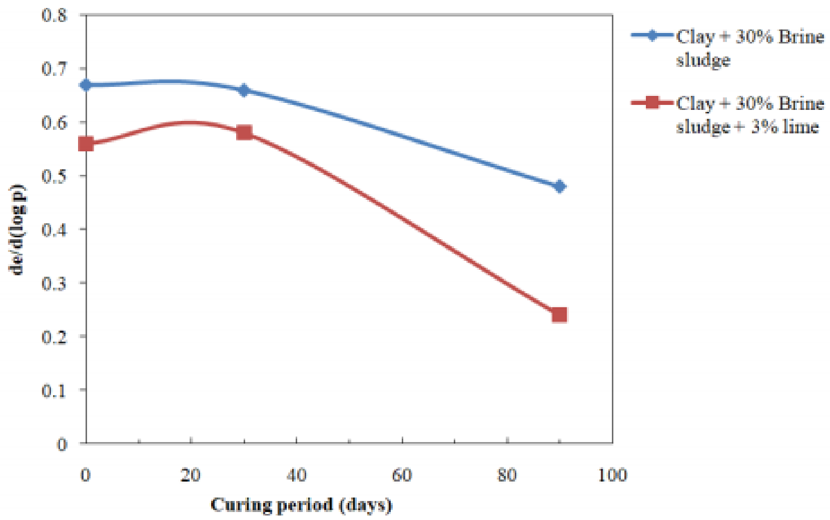

Fig. 7. Variation of de/d(log p) with curing period for treated clay (Pressure range = 50 – 100 kPa)

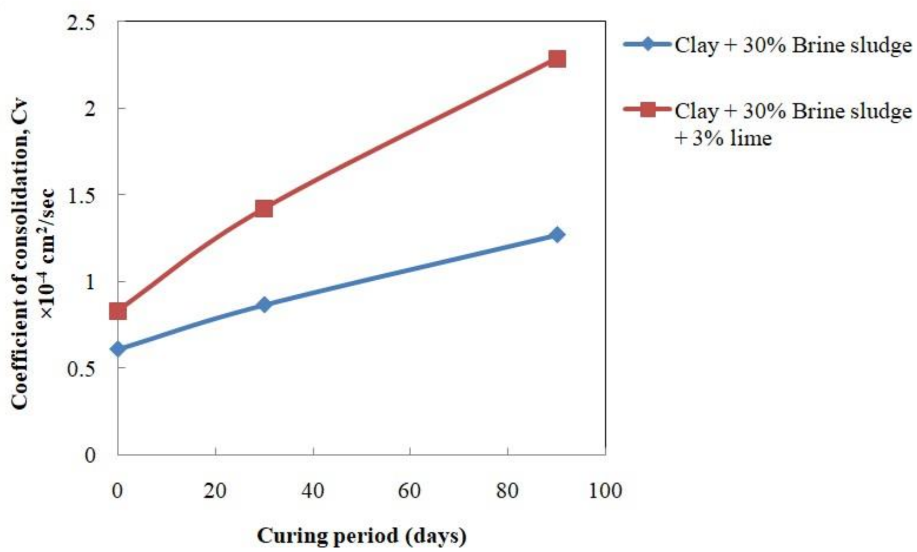

Fig. 8. Variation of coefficient of consolidation with curing period for treated clay (Pressure range = 50 – 100 kPa)

Conclusions

In the framework of experiments conducted on the marine clay sample, the following conclusions are drawn.

1. The studies carried out have addressed the environmental concern of brine sludge from chloral alkali industry by utilizing it for soil stabilization.
2. The incorporation of brine sludge has improved the index properties of clayey soil. The liquid limit has showed a decreasing trend with the increase in curing period. When lime is used as an additive, the liquid limit decreases with curing period. Plasticity index displays a decreasing trendin the case of both brine sludge treated marine clay with or without additive.
3. The free swell index tends to decrease with curing period for all the treated clayey soils.
4. Even though the inclusion of brine sludge provides increase in unconfined compressive strength,a considerable increase can be brought about only with the addition of small percentages of lime. With the increase in curing period, the strength seems to increase significantly.
5. The compressibility characteristics get improved on addition of lime to the brine sludge treated marine clay. With the addition of lime with brine sludge, de/d(log p) seems to decrease drastically, clearly showing the effectiveness of lime in reducing the settlement of the brine sludge treated marine clay. The increase in the coefficient of consolidation values indicates that the treated soil undergoes consolidation at a faster rate than untreated clay.

Hence, it can be concluded that, Brine sludge, an industrial waste material can be effectively utilized for improving the strength characteristics of soft marine clays.

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