International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 06, June-2019

Effect of Lime and Fly Ash on Load Bearing Capacity of Expansive Soil: A Review

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Abstract*— Expansive soil is a sticky soil which found in wide part of the world that has a high degree of sensitivity, nature of expansion and shrink behavior during water adding and removing through it. Expansive clay has the behavior of high compressibility, low shear strength, low permeability, high plasticity and potential shrinkage. This condition can cause demolish of building structures, road highway and gravity dam. Problems happen in clay expansive soils are inadequate bearing capacity and excessive settlement. Construction takes place in such type of soil result will be bearing capacity failure, excessive deferential settlement, heave and subsidence problem. The aim of this paper focuses that by adding lime and fly ash to the clay expansive soil can improve the physical properties, effectively increase the bearing capacity and decrease the swelling potential of the soil base. Application of lime and fly ash to improved Atterberg limits, compaction characteristics, bearing capacity and prevention of swelling problem of expansive clay. Adding various percentage of lime and fly ash with expansive soil and then study how much it modify the characteristics of soil like maximum dry density, moisture content, consistency limits, swelling index, unconfined compression strength, durability and CBR value which compare to untreated soil and other stabilizers. The main reason to select lime and fly ash in this paper, both are good material to increase the bearing capacity of soil, durability, reduce swelling potential and shrinkage problem. Soil is mixed with lime and fly ash and carried out various tests Such as Sieve analysis or hygrometry analysis test, Moisture content test, consistency limit, Specific gravity test, compaction test, Unconfined Compression test, swelling index test and California bearing ratio test. Classification of soil was determined by conducting index property and grain size analysis tests. Effect of lime and fly ash on plasticity index properties were assessed by conducting Atterberg limits test, strength properties were assessed by conducting compaction test, UCS tests and CBR test and swelling properties were checked by conducting free swelling index test. Expansive clay soil were mixed with different proportion of combination of lime with fly ash by replacement soil and cured for 7, 14 and 28 days.

***Keywords*— Atterberg limits, bearing capacity, unconfined compressive strength (UCS), CBR**

I. INTRODUCTION

The aim of determination of ultimate bearing capacity of the soil under foundation can handle the load without shear failure. The settlement caused by the structural load should not exceed the allowed deformation for stability of construction. Investigation on the load bearing capacity of expansive soil can be carried out using either analytical solutions or experimental investigations. A reasonable solution is established only when theoretical results fit with those obtained from experimental result. A literature analysis expression that the majority of the bearing capacity theories include homogeneous soils in the foundations. Soil behaviors were assumed to remain constant for the load bearing capacity exploration, and hence analytical solutions, such as Terzaghi's bearing capacity theory, coordinated with the experimental results. Expansive soils is not permit for road construction, foundation of buildings, alignment of lined canal ,gravity dam because of high volume fluctuations happen as a result of saturating and drying with seasonal variation of climate especially in Ethiopia has failed entirely. These main engineering structures subsequently suffer from serious distresses and damages due to problem of expansive soil. Expansive soil has low bearing capacity which needs to be improved so that the foundation swell to get a more rigid. Low soil bearing capacity is not suitable when used as a road pavement as well as subgrade to support a building. According to Chen (1972) the relationship between plasticity index and swelling potential described by the table below.

Table.1 shows swelling properties associated with plastic index

Degree of expansion	Plasticity index (%)
Low	0 - 15
Medium	10 – 35
High	20 – 55
Very high	>55

Indian standard (2000), 1498 – 1970, Classification and Identification of Soils for General Engineering Purposes. Fine grained soils depending upon the presence of clay mineral exhibit low to very high degree of expansion. Based upon Atterberg limits and free swell of the soils the degree of expansion should be justify by the following table.

Table. 2 shows relationship of degree of expansion, free swell index with atterberg limits

Degree of expansion	Free swell index (%)	Liquid limit	Plasticity index (%)	Shrinkage limit
Low	<50	20 -30	<12	<15
Medium	50 -100	35 - 50	12 – 23	15 -30
High	100 – 200	50 - 70	23 -32	30 -60
Very high	> 200	70 -90	>32	>60

S. Ria and N. Panjaitan (2014) determined bearing capacity of soil by California bearing ratio. Bearing capacity of soil depends on penetration resistance of soil, if the penetration resistance of pavement is high, the bearing capacity of the soil will be high. Generally the CBR value of the soil improved, we can say bearing capacity of soil improved.

Table. 3 shows the bearing capacity of soil connected with the CBR value

CBR (%)	Bearing capacity
2 – 5	Poor
6 -9	Medium
> 9	Good

Dr. K. R. Arora (2004) soil mechanics and foundation engineering book described consistency associated with unconfined compression strength of soil. Consistency of soil is described as a resistance of deformation. .conventionally defined as very soft, medium, stiff, very stiff, and hard. Consistency associated to shear strength or compressive strength. Unconfined compression strength (qu) of a soil is equivalent to failure load per unit area when standard cylindrical specimen is tested in unconfined compression testing machine.

Table 4. Consistency of soil related with unconfined compression strength

Consistency of soil	Unconfined compression strength (qu) (KN/m2)
Very soft	<25
Soft	25 – 50
Medium	50 – 100
Stiff	100 -200
Very stiff	200 – 400
Hard	>400

The study focuses that collecting research prepares related to the effect of lime and fly ash on atterberg limits, bearing capacity and swelling properties of the expansive clay soil and investigate the effectiveness of lime and fly ash to improve the shear strength of soil, successfully increase the bearing capacity and decrease the swelling properties of expansive clay soil compare to other stabilizers.

II. Literature Review

Kishore and Gayathri (2019) investigated efficacy of lime and fly ash on CBR value of dredged marine Soil. The investigation conducted compaction and CBR test by adding lime (2%, 4%, 6 % and 8%) and fly ash (5%, 10%, 15% and 20%) in various concentrations. Test outcomes show that the optimum water content increases and maximum dry density drops up to 2% of lime, beyond 2 % lime, it was increase. The optimum water content decline and peak dry density increases upon addition of the fly ash. Addition of lime up to (6%) and fly ash up to (15%) enhanced unsoaked CBR value from 1.86 % to 5.92 % and 1.86 to 4.29 % respectively, The CBR value of the soil lime treated soil is higher than that of fly ash treated soil, this indicated that the lime can be successfully used for improving the strength and bearing capacity of such type of soils.

Babu and Poulose (2018) presented a review paper on effect of lime on soil properties: Lime provides cost-effective technique of soil stabilization. The method of soil enhancement where lime is mixed with the soil to modify engineering properties is recognized as lime stabilization. The types of lime used to soil improvement are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, dolomite lime. The amount of lime used for stabilization of soil is recommended from 5% to 10%. Lime amendment of soil results in an increased in strength by cat ion exchange capacity other than cementing effect due to the pozzolanic reaction. Lime stabilization can also be referred to pozzolanic reaction in which pozzolanic materials reacts with lime in presence of water to form cementitious compounds. The effect can be brought either by quicklime, CaO or hydrated lime.

Sandyarani et al. (2018) reported that Effect of Lime on Engineering Properties of Expansive Soil. Lime is added to soil with varying percentages, from 2%, 5%, 9% and 12% to Alters the following parameters i.e. strength of the soil, bearing capacity and consistency limit of the soil. The Maximum dry density at optimum moisture content, unconfined compressive strength and The CBR (Unsoaked) value of soil is increased at 9% lime mixed with soil while specific gravity, plasticity index and swelling index decreased compared to untreated soil.

Table 5. Geotechnical characteristics of soil with various percentage of lime (San dyarani et al. (2018))

Description	**B.C soil**	**B.C soil +2% lime**	**B.C soil +5% lime**	**B.Csoil+9% lime**	**B.C soil + 12% lime**
Specific gravity	2.68	2.37	2	1.99	1.66
Liquid limit (%)	66	39	36	34	32
Plastic limit (%)	27.2	20	18	15	16
Plastic index (%)	38.8	19	18	19	16
MDD(g/cc)	1.47	1.34	1.43	1.5	1.45
OMC (%)	20	24	29	29	22.5
CBR (Unsoaked, %)	2.77	4.35	4.71	5.65	4.04
UCS (kg/cm2)	0.55	0.62	0.63	0.66	0.64
UCS of 1 day	0.57	0.655	0.675	0.71	0.695
UCS of 3 day	0.59	0.66	0.68	0.81	0.733
UCS of 7 day	0.60	0.69	0.74	0.85	0.75

Sabat (2017) investigated unconfined compressive strength of dolime fine stabilized diesel contaminated expansive soil, the effect of diesel contamination on UCS of expansive, as increase in diesel contamination the UCS value decreased. The UCS decreased to 36 kN/m2 from 86 kN/m2 with increase of diesel from 0 to 9%, a decrease of 58.14 % with addition 9% diesel. The effect of dolime fine on OMC of diesel contaminated expansive soil has been increased with increased in addition of dolime fine, The effect of dolime fine on MDD of diesel contaminated expansive soil, MDD decreased with increased in addition of dolime fine.

The variation of percentage increase in UCS of dolime fine (9%) stabilized diesel contaminated expansive soil as compared to UCS of diesel contaminated expansive soil with curing period.

The percentage increase in UCS increased to 747.22% from 38.88% when the curing period increased to 28 days from 0 day as compared diesel contaminated expansive soil.

Kalita1 et al (2017) studied effect of fly-ash on strength behavior of clay soil. A series of tests were conducted on clayey soil treated with fly-ash alone (i.e. 2%, the addition of different proportions of gypsum and fly ash (4%, 6%, 8% and 10%), I observed from this research, the increase in fly ash content, maximum dry density and unconfined compressive strength is increasing and attained a maximum value at 6% of fly ash and the increasing of dry density and UCS were 5.81 %, 10.9 % respectively. Further increase in quantity of fly ash the unconfined compressive strength decreases.

Nayak and Singh (2017) studied the effect of the chemicals like Sodium Carbonate (Na_2CO_3), Calcium Carbonate, on the geotechnical properties of an expansive soil. High improvement found in CBR value when 1% of the chemical used in case of Sodium and Calcium Carbonate, after all determination value, Calcium Carbonate ($CaCO_3$) is more effective in improving the CBR value and bearing capacity of soil when compared to Sodium carbonate.

Iyappan et al. (2017) reported on experimental investigation on clay soil stabilization using Lime and Rice Husk Ash. Clay soil provides poor carrying capacity due to its plasticity behavior, due to high plasticity and poor bearing capacity, the foundation exposes Excessive settlement, uplift of structures, Creation of cracks in the superstructure, failure of structural elements. In this research work mainly consider the reducing plasticity and improving the shear strength of clay in treated and untreated samples, Treated samples are made up of chemical admixtures in various proportion like 4%, 6%, 8% of lime and 5%, 10%, 15% rice husk ash and combination of 8%L+5%R, 8%L+10%R, 8%L+15%R.. Finally, they were concluded comparatively with treated and untreated samples due to reducing the plasticity characteristics and improving the shear strength of clay are found through the experimental analysis. the following table shows lime and rice husk ash improves the shear strength of clay soil From 106 KN/m2 to 439.47KN/m2 at 6% lime while shrinkage limit, plasticity index and swelling index decreased from 5.4% to 0%, 37.47% to 8.18% and 47.87% to 7% respectively at 10% RHA+8% lime.

Table 6. Th3e test results for clay soil treated with different percentages of lime and RHA (Iyappan et al. (2017))

Mixes	**LL (%)**	**PL (%)**	**SL (%)**	**PL (%)**	**Free swell index (%)**	**UCS (KN/m2)**
Clay	58	20.57	5.4	37.47	47.83	106
Clay+5%RHA	43.77	29.32	8.13	14.45	30	174
Clay +10%RHA	54	37.87	36.66	16.13	20	164.55
Clay +15%RHA	56	NP	NS	56	10.53	176.8
Clat+4%lime	40	26.26	9.55	13.7	25	369.91
Clay+6% lime	39.1	30.1	14.29	9.0	18	439.47
Clay+8%lime	36.21	29.05	22.87	7.16	7	144.78
Clay+5%RHA+8%lime	38.72	28.71	NS	10.01	7	198.23
Clay+10%RHA+8%lime	45.65	37.47	NS	8.18	7	_
Clay+15%RHA+8%lime	50.48	43.28	NS	7.2	16	_

Ozdemir (2016) investigated the effect of fly ash on the bearing capacity of soft soil. He reported that high maximum dry density obtained from modified proctor test compare to standard proctor test with increased fly ash content as well as improvement of CBR (bearing capacity) and UCS was obtained adding 7% fly ash to the soft soil and decreased swelling properties of soil. the general tendency of bearing capacity improvement is related to CBR improvement behavior beside this 7% fly ash addition with curing is very effective in terms of CBR, swell, and UCS.

Tamang et al. (2016) explored improved of bearing capacity of soil using cement, lime and chemical. They were deals with stabilizing the soil using different stabilizers (lime, chemical, and cement) in by taken varying percentage of about 2%,4%,6%,8% and 10% of every stabilizer(lime, cement and calcium chloride). In this research work Lime is used as an excellent soil stabilizing materials for highly active soils and acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage, reduction in plasticity index, and increase in CBR and compression strength of soil i.e. it is the best economical method gave a result reliable up to 97%.

Oviya and Manikandan (2016) reported experimental investigation on stabilizing the soil using rice husk ash with Lime as Admixture. The bearing capacity and strength of the soil was increased by 1.5% using lime. The CBR value is widely used in the design of base course and sub base course in pavement construction. Unsoaked soil samples, the value of CBR has insignificant increase with addition of 2.5% of RHA and rises more at 5% RHA. The value of CBR drops down at 7.5% and 10% of RHA. The decrease in CBR value is due to clay content reduction in soil. This results in reduction of cohesive force in the soil sample. Initially RHA with high silica content forms the cementitious compound giving the good cohesion. When the RHA content increases in the soil, it slows down the pozzolanic reaction by occupying the void spaces in the soil and reducing the bond between soil and RHA mixtures.

Pallavi and Naagesh (2015) investigated effect of addition of lime on the Properties of RBI-81 treated expansive soil subgrade. Untreated soil exhibits CBR of 1.09%. Upon treatment with RBI-81, there is an increase in CBR value. As the dosage of RBI increased from 2% to 6%, for specimens cured for 7days, CBR increased from 2.19% to 3.35%. Upon further curing up to 28days, an overall increase ranging from11% to 14% in CBR was observed. Expansive soil described as highly plastic, with LL=90% exhibited a low CBR value of 1% and UCS of 34 kN/m2. Upon addition of RBI (0% to 6%), the CBR increased from 1% to 3.8%, unconfined compressive strength increased from 34kN/m2 to 193kN/m2 for specimens cured for 7days and to 269kN/m2 for specimens cured for 28 days. Combination of 4% RBI-81 with 6% lime mixed to the soil resulted in unconfined compressive strength of 703 kN/m2 and the CBR is increased to 15.1%. Thus, the study shows that the addition of RBI-81 alone is not sufficient for highly plastic soils irrespective of the curing period. Lime can be added with RBI-81 to achieve wanted strength.

S.M. Mahajan and D. K. Parbat (2015) Studied on Strength Characteristics of BC Soil-Fly ash mixes. Various percentage of fly ash i.e. 10 %, 20 %, 30 %, 40 %, 50 mixed with black cotton soil suggest that an improvement of strength characteristics and California bearing ratio of the black cotton soil takes place. Unconfined compressive strength attains peak value at fly ash % between 20 and 30, beyond which the increase in the strength is marginal and soaked California bearing ratio reaches peak value when the fly ash % is at 30, beyond which it starts decreasing with further addition of fly ash. Unsoaked California bearing ratio reaches peak value when the fly ash % is between 20 and 30, beyond which it starts decreasing with further addition of fly ash.

Panjaitan (2014) investigated that the effect of lime content on the bearing capacity and swelling potential of expansive soil. This report indicated increasing addition of lime (4%, 6%, 8% and 10%), plastic limit value is increasing and liquid limit, shrinkage limit, plastic index decreases. Addition of 4% lime, value of the IP is below 17%, i.e. 16.64%, but the addition of 10% of lime, value of IP is 10.67%.

Table 7.shows the effect of lime on consistency limit, specific gravity and grain size distribution value with various percentage.

Properties of soil	**Unit**	**Clay soil +lime (%)**					
		0 %	2 %	4 %	6 %	8 %	10 %
Plastic limit	%	20.78	22.69	28.69	29.11	30.98	31.56
Liquid limit	%	50.18	48.72	45.33	42.58	42.31	42.23
Plastic index	%	29.40	26.03	16.64	13.47	11.33	10.67
Shrinkage limit	%	54.47	48.98	47.59	46.33	45.86	44.97
Specific gravity	-	2.66	2.65	2.6	2.58	2.53	2.56

Gunturi et al. (2014) explored effect of RBI-81 on Californian bearing ratio (CBR) and swelling behavior of expansive Soil. CBR value increased with the increased in percentage of RBI and curing period. A satisfactory result with a wonderful increase in the bearing capacity.

Hossain et al. (2014) described about improvement of plasticity index value of swelling clay soil by lime stabilization. In this paper addition of lime from 0% to 4%, liquid limit decreased from 49.8% to 10.86% but it shows increasing tendency for higher percentage of lime. Liquid limit (L.L) decreased 78.2% and plastic limit (P.L) decreased 70.4% due to addition of 4% lime. Plastic limit varies from 18.7% to 5.54% for 0% to 4% lime content. Now in case of plasticity index value, it shows 31.1% for 0% lime but it reduced to 5.32% for 4% lime content. So for finding minimum plasticity index value 4% lime addition is best.

Table8. The test results for swelling soil treated with different percentages of lime

% of lime	**LL**	**PL**	**PI**
0%	49.8%	18.7%	31.1%
2%	11.9%	4.57	7.33
4%	10.86	5.54	5.32
6%	11.72	5.85	5.87
8%	16.82	6.46	10.36

According to the above table as the lime content increase plastic limit increase and the minimum liquid limit and plasticity index is obtain at 4 % lime.

Zumrawi (2014) studied improving the characteristics of expansive subgrade soils using lime and fly ash. Applying combination of lime with fly ash on high expansive soil play important role to reduce Plasticity index i.e. the soil classification changed from high plasticity clay (CH) to ML with the addition of 8% lime and 10% fly ash, free swelling index at 8% lime with 20% fly ash reduced the FSI from 195% to 20% i.e. a reduction of about 175% of untreated swell value. The influence of lime-fly ash stabilized clay on CBR is the unsoaked values increase from 25% (untreated) to 70% and soaked CBR from 2.6% (untreated) to 15% with 8% lime only. Addition of fly ash led to decreased CBR.

Abebe et al. (2014) investigated the effects of combining lime and sodium silicate on expansive soil. Sodium silicate resulted in at least 12% reduction in PI of expansive soil However, sodium silicate decreased shear strength and increased swelling properties of expansive clay.

Combination of lime and sodium silicate resulted in decreased shear strength and aggravated swelling properties of expansive clay compared to the respective lime treatments.

Ramlakhan et al. (2013) investigated effect of lime and fly ash on Engineering Properties of Black Cotton soil. This experimental analysis assessed the influence of the lime and fly ash on the certain elementary engineering properties of BC soil such as Liquid limit, plastic limit, compaction and California bearing ratio (CBR) of BC Soil. Different percentage of fly ash (i.e.10%, 20%, 30%, 40%) mixed with soil and varying percentage of lime (i.e.3%, 6%, 9% and 12%) mixed with soil. Liquid limit and plastic limit of BC soil decreased from 38.9% to 29.9 %, 14.4 % to 10.9 % respectively with increased quantity of fly ash. But Liquid limit and plastic limit of BC soil increase from 39.25 % to 42.98 %, 17.77 % to 25.89 % respectively with increasing % lime. Compaction characters of BC soil also affected by various % of fly ash, i.e. OMC of BC Soil increased with increasing % fly ash and MDD decrease with increased of fly ash Likewise Compaction characters of BC soil also affected by lime, i.e. OMC of BC Soil increased with increasing % lime and MDD decrease with increase of lime .CBR value of black cotton soil also increased with increasing amount of % fly ash and lime. At 40% of fly ash and 12 % of lime mixed with soil, improved from 2.166% to 7.95 and 2.88 to 5.6. CBR value of BC soil also increases with increasing percentage of combination of lime with fly ash.12%lime +20% fly ash which provides the CBR value 7.99, this is best result for sub grade soil.

Verma (2013) studied behavior of expansive soils with lime and its effect on Structures.

Tests on expansive soils were conducted at different curing i.e., 7, 14, 28 and 56 days. The test results shown that maximum increase in strength achieved after 14 days of curing period with 8% of lime content. He described that lime is the basic binding material to increase the strength of expansive soil. The maximum increase in strength of expansive soil was achieved by using lime content of 8% at a given curing period. Further increased in lime content results in a marginal decrease in the strength of expansive soil. With increased in curing period beyond 14 days, no considerable change in the strength was observed. At optimum content of lime and curing period of 14 days, the unconfined compressive Strength of black cotton soil increases.

Mahesh. (2013) investigated the effect of fly ash on the properties of expansive soil. This research shows addition of fly ash used to reduce the plasticity characteristics of expansive soil. At higher percentage of fly ash, The liquid limit, plastic index , optimum moisture content (OMC),free swell and swelling pressure decreased while plastic limit ,shrinkage limit, maximum dry density (MDD) and CBR value increases with an increase in fly ash content. Plasticity index reduces by 30-40% with the addition of 10-15% fly ash.

Umesha et al. (2013) had studied the effect of lime to improve the unconfined compressive strength of acid contaminated soil. Addition of 3% of lime generally increases the unconfined compression strength of the soil but found to be ineffective to enhance the strength of contaminated soil. Addition of 3% lime has developed considerable strength after curing. The improvement in Young's modulus of lime stabilized soils is better than contaminated soil and lime the best stabilizers to reduce acidity of soil.

Bose (2012) conducted geo-engineering properties of expansive soil stabilized with fly ash. Plasticity index, the free swell Index and swelling pressure is found to decrease with increase 20% fly ash content while the maximum dry density and unconfined compressive strength was obtained at 20% fly ash mix with clay and further addition of fly ash reduces the strength and gradually decreases maximum dry density.

Al-Rawas (2005) studied effect of lime, cement and Sarooj on the swelling potential of an expansive soil. Swell percent and swell pressure tests were carried out on untreated samples to measure these two parameters in order to examine the effect of the various additives on the reduction of the swelling potential of the soil. The swell percent and the swell pressure values obtained were 9.39% and 249 kPa without treatment respectively. Lime reduced the swell pressure from 249 KPa to 158 KPa. The addition of 3% Sarooj+ 5% lime+3% cement stabilizer caused significant reduction in swell pressure when compared with 3% sarooj+3% lime+3% cement stabilizer. From this research lime is the most important stabilizers compared to cement and sarooj.

III. CONCLUSIONS

From the reviewed literature I was observed that most of the studies have been done on effect, stabilization and engineering properties of expansive soil. Stabilization has mostly done with lime and fly ash. Some researchers have used some other chemicals like RBI-81, Rice husk ash, cement and fluid chemicals. I understand from using different stabilizers, lime and fly ash is the best due to their pozzolanic properties, both admixtures are binding materials, effective for stabilization, have low cost benefit analysis and increase bearing capacity of problematic soil. Various characteristics of expansive soil have been determined by the researchers and their work were concentrated on reduction in swelling properties, plasticity index ,and increase bearing capacity or CBR of soil and unconfined compression strength of soil . More problems associated with expansive soil are related to very low bearing capacity, cracking and breaking up of pavements. Expansive soil cause serious problems in the engineering practice due to swell and shrinkage. Although there have been instances in the area where foundations and other concrete work have fractured and been displaced, the cause of problem listed above happen due lack of remedial measure or lack of stabilization of soil properly. Further research is required in this direction to know the exact cause and remedial measures against the failure of structures that construct on weak soil.

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