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Improvement of Bearing Capacity of Clay Soil Using Fly Ash

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***Abstract*— The principal aim of the study is to improve the engineering properties of the soil sample using fly ash as a binding material. Bangladeshi fly ash was used in this study. Effects of fly ash on physical and mechanical properties of soil (Atterberg limits, moisture-density relationship, and unconfined compressive strength) are evaluated in the presence of 0%, 2%, 4%, 5%, 8%, 10%, 15%, 20% & 25% fly ash. For understanding the improvement of engineering properties of soil, a parametric analysis is conducted to determine the allowable bearing capacity, settlement and the time required for the consolidation. The allowable bearing capacity is evaluated using several equations for both saturated and unsaturated conditions. It is found that for 5% fly ash content, the maximum allowable bearing capacity is achieved. The maximum value of allowable bearing capacity is 660.12 kN/m2 in the unsaturated condition. The increment of maximum allowable bearing capacity is 77.74% for 5% fly ash content. The lowest value of the settlement was 336 mm (saturated) and 183 mm (unsaturated) for 25% fly ash content. Considering normally consolidated soil, it is found that the least time required for consolidation is 3.19 years for 25% fly ash content.**

***Index Terms*— Fly Ash, unconfined compressive strength, Bearing Capacity, Settlement, clay soil.**

I. INTRODUCTION

Bangladesh has a large lowland and coastal area, covered with soft clay. As subgrade material, most of the soils classify as AASHTO A-4 to A-7-6, which means they are mainly fine-grained silt and clay soils. The problem with these soils is that they have undesirable engineering properties (Şenol et al., 2006; Horpibulsuk et al., 2012), such as low bearing capacity, high shrinkage and swell characteristics (Şenol et al., 2003; Prabakar et al., 2004) Structures and roads built on these soils undergo large amount of settlement (Turner, 1997; Tastan et al., 2011). These problematic soils usually have low shear strength (Senol et al., 2002). Therefore, modifications of engineering properties of these soils should be done through a process called soil stabilization (Dermatas and Meng, 2003; Keshawarz and Dutta, 1993) which aggravates the engineering performance of these problematic soils (Savran et al., 1988; Inan and Sezer, 2003). The binders used for the present is fly ash. Haque (2013) stated that Bangladesh has six potential coal fields with fly ash production of 1 million tons per years, and the Barapukuria Coal-fired Thermal Power Plant alone produces 65% of the total production. So, using the fly ash for soil stabilization would be a great way to minimize the waste and maximize the profit (Chu and Kao, 1993; Kumar and Sharma, 2004; Zha et al., 2008).

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II. EXPERIMENTAL PROGRAM

The soil sample was collected from 3 m below (Horpibulsuk et al., 2010) of a paddy field for the present study. Tests that were carried out for the collected soil sample were field moisture content, field density, grain size analysis, specific gravity test, Atterberg limits test, compaction test and unconfined compression test.

Atterberg limits tests were also performed in the presence of 2%, 4%, 5%, 8%, 10%, 15%, 20% and 25% (mass/mass) fly ash. Compaction tests and unconfined compression tests were performed in the presence of 0%, 2%, 4%, 5%, 8%, 10%, 15%, 20% and 25% fly ash for determining the maximum dry density and unconfined compressive strength. The unconfined compressive test sample was tested at 3, 7, 14, 28 and 90 days.

A. *Moisture Content Test*

ASTM D2216-04 Standard Test Method for laboratory determination of moisture content of the soil, rock, and soil-aggregate mixtures was followed for the experiments. Average value of moisture content was found 43.1285%. The water content was relatively high as the soil was from a paddy field.

B. *Specific Gravity Test*

ASTM D854-00 Standard was followed throughout the experiments. The specific gravity was found to be 2.58, which falls between the range of clay (1.8~2.6). The specific gravity of soil was relatively high as a higher percentage of organic component was present in the paddy field.

C. *Grain Size Analysis*

ASTM D422-04 Standard test method was followed. The soil was found to be composed of 1.46% gravel, 46.89% sand, 51.65% silt and clay (Fig. 1). Therefore, the major constituents were silt and clay.

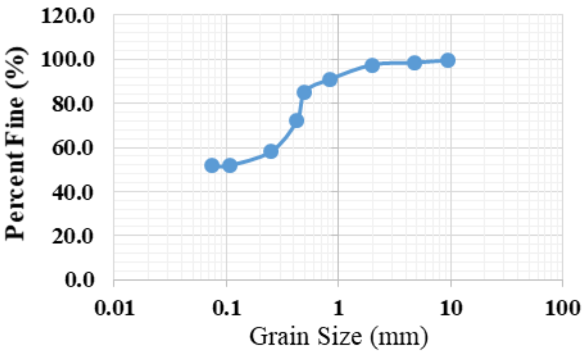

Fig. 1. Grain size distribution of sandy fat clay soil

Ngoma and Chirwa (2011) used clay soil composed of 6.9% gravel, 33.8% sand, 59.3% silt and clay in their research. Sharma et al. (2012) study soil was composed of 0.22% Gravel, 13.16% Sand, 74.49% Silt and 7.45% Clay.

D. *Atterberg Limits:*

ASTM D4318-04 Standard was followed for the tests. Liquid limits and plastic limits of the sample are shown in Table 1. With the increase of fly ash in the soil, the liquid limit decreased and the plastic limit increased, meaning the soil was losing its consistency for the lower amount of water with the increase of fly ash.

It was observed that liquid limit was decreasing with increasing of fly ash content. For fly ash contents of 0%, 10%, 20% and 30%, liquid limit were 54%, 51%, 49%, and 47%, respectively. On the other hand, plastic limit (20%, 22%, 23% and 26%) increased with increment of fly ash content (0%, 10%, 20% and 30%) (Ngoma and Chirwa, 2011). Sharma et al. (2012) showed that liquid limit (34.79%, 34.48%, 33.83%, 33.21% and 32.85%) decrease and plastic limit (20%, 24%, 20.79%, 21.28%, 21.54% and 22.09%) increase with increase of fly ash content (0%, 10%, 15%, 20% and 25%) in the soil.

E. *Compaction Test*

ASTM D1557-04 Standard Test Methods for laboratory compaction characteristics of soil using modified effort (56,000 ft-lbs/ft3 (2,700 KN-m/m3)) was followed. Results are shown in Table 2. We see that the optimum moisture content increases and corresponding maximum dry density decreases with the increase fly ash in the soil.

Ngoma and Chirwa (2011) found the MDD and OMC to be 1830, 1780, 1700, and 1500 kg/m3 and 15%, 16%, 18%, and 19%, for 0%, 10%, 20% and 30% fly ash content respectively. Sharma et al. (2012) showed that OMC (17.82%, 18.65%, 19.42%, 17.87% and 20.46%) and MDD (1.77, 1.87, 1.92, 2.02 and 2.04 g/cm3) increase with increase in fly ash content (0%, 10%, 15%, 20% and 25%).

F. *Unconfined Compression Test*

ASTM D2166-04 Standard test method was followed for the experiments. The mold used for the test was 38.2 mm (1.50394 in.) in diameter and 78.2 mm (3.07874 in.) in height. From Table 2, we see that the strength of soil is also increasing, with the curing period, for the increase in fly ash content.

Ngoma and Chirwa (2011) found the compressive strength to be 256.8, 337.82, 490 and 375kN/m2 for the soil of 0%, 10%, 20% and 30% fly ash content. Shah et al. (2003), for fuel oil contaminated soil, found that compressive strength is is 61.78, 68.65 and 76.49 KPa for 5%, 10%, and 20% fly ash, respectively for 7 days curing. Sharma et al. (2012) found the compressive strength of soil to be 24.73, 34.73, 38.83, 63.38 and 45.11 KPa for 0%, 10%, 15%, 20% and 25% fly ash content, respectively, for 90 day curing.

TABLE I
ATTERBERG LIMITS, COMPRESSIBILITY INDEX AND VOID RATIO OF SOIL-FLY ASH MIX

Sample No	% of Fly ash	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	Compressibility Index (C_c)	Void ratio (e_o)
A.S.0	N/A	54.48	29.68	24.79	0.332	0.672
A.O.2	2	54.43	29.98	24.45	0.332	0.710
A.O.4	4	54.29	30.61	23.57	0.331	0.711
A.O.5	5	54.25	30.67	23.58	0.330	0.732
A.O.8	8	53.86	31.85	22.01	0.328	0.765
A.O.10	10	53.82	32.07	21.75	0.327	0.787
A.O.15	15	53.36	34.22	19.14	0.324	0.805
A.O.20	20	53.06	35.65	17.41	0.322	0.810
A.O.25	25	52.71	37.21	15.50	0.319	0.865

G. *Attributes Calculated from Empirical Equations*

For disturbed clay sample or remolding, results are shown in Table 1.

The moisture content of the soil is so high (43.13%) that, maximum soil particles are silt and clay (51.65%). With the increase of fly ash in the soil, the liquid limit decreases and the plastic limit increases.

The optimum moisture content increases and corresponding maximum dry density decreases with the increase of fly ash in the soil. The strength of soil is increasing, with the curing period, for the increase in fly ash content.

TABLE II
RESULTS OF COMPACTION TEST AND UNCONFINED COMPRESSION TEST

Sample type	% of Fly ash	Sample No	Max. Dry density (Kg/m3)	Unconfined Compressive Strength (KN/m2)	Optimum Moisture Content (%)	Curing time (Days)
Normal soil	N/	U.S.0.	1615	263.95	20.30	3
		U.S.0.	1615	270.99	20.30	7
		U.S.0.	1615	277.64	20.30	14
		U.S.0.	1615	289.07	20.30	28
		U.S.0.	1615	296.70	20.30	90
Fly ash mixed soil	2	U.O.2	1591	272.98	20.52	3
		U.O.2	1591	297.93	20.52	7
		U.O.2	1591	331.80	20.52	14
		U.O.2	1591	345.63	20.52	28
		U.O.2	1591	379.61	20.52	90
	4	U.O.4	1576	286.55	20.77	3
		U.O.4	1576	318.85	20.77	7
		U.O.4	1576	354.95	20.77	14
		U.O.4	1576	393.67	20.77	28
		U.O.4	1576	442.79	20.77	90
	5	U.O.5	1564	299.65	20.85	3
		U.O.5	1564	349.15	20.85	7
		U.O.5	1564	395.40	20.85	14
		U.O.5	1564	430.96	20.85	28
		U.O.5	1564	474.53	20.85	90
	8	U.O.8	1555	291.59	21.25	3
		U.O.8	1555	337.80	21.25	7
		U.O.8	1555	383.32	21.25	14
		U.O.8	1555	419.21	21.25	28
		U.O.8	1555	462.80	21.25	90
	10	U.O.1	1543	277.91	21.40	3
		U.O.1	1543	320.90	21.40	7
		U.O.1	1543	361.34	21.40	14
		U.O.1	1543	403.52	21.40	28
		U.O.1	1543	451.44	21.40	90
	15	U.O.1	1523	268.19	22.56	3
		U.O.1	1523	301.80	22.56	7
		U.O.1	1523	345.63	22.56	14
		U.O.1	1523	372.74	22.56	28
		U.O.1	1523	406.11	22.56	90
	20	U.O.2	1504	244.30	23.05	3
		U.O.2	1504	271.49	23.05	7
		U.O.2	1504	308.19	23.05	14
		U.O.2	1504	326.93	23.05	28
		U.O.2	1504	371.02	23.05	90
	25	U.O.2	1510	230.50	23.74	3
		U.O.2	1510	256.76	23.74	7
		U.O.2	1510	276.60	23.74	14
		U.O.2	1510	307.58	23.74	28
		U.O.2	1510	356.66	23.74	90

H. *Parametric Analysis*

For the improvement of soil, fly ash were used. The percentage of fly ash used for soil stabilization were 2%, 4%, 5%, 8%, 10%, 15%, 20% and 25% with a respect time of 3, 7, 14, 28 and 90 days. Evaluation of the allowable bearing capacity was a major concern for achieving the goal.

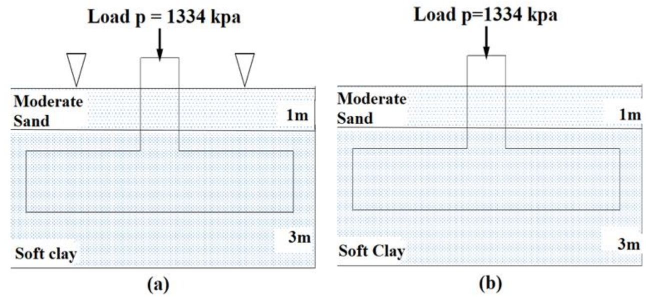

Fig. 2. Parametric analysis for (a) saturated condition and (b) unsaturated condition

TABLE III
PARAMETRIC ANALYSIS DATA TABLE

	Layer depth (m)	Breath of square footing (m)	Depth of footing (m)	Soil type
Layer 1	1			Moderate sand
		2.5	2	
Layer 2	**3**			**Soft clay**

III. RESULTS AND DISCUSSION

The findings from the parametric analysis are discussed in this section. For different fly ash contents, the allowable bearing capacity, void ratio, settlement, degree of consolidation and time for consolidation are calculated. Moreover, the increment of allowable bearing capacity with time is also measured. These findings are discussed below-

A. *Effect of Fly Ash Content on Allowable Bearing Capacity*

The allowable bearing capacity and time graph is plotted for time duration of 90 days for fly ash mixed with normal soil. The analysis was performed by using Terzaghi (1943), Meyerhof (1963), Skempton (1951), Hansen (1970) and Vesic (1973) methods for both saturated and unsaturated conditions.

Fig. 3 shows the allowable bearing capacity and time graph for fly ash-soil mix in saturated condition. From the figure, it can be seen that the maximum allowable bearing capacity was achieved for 5% fly ash content.

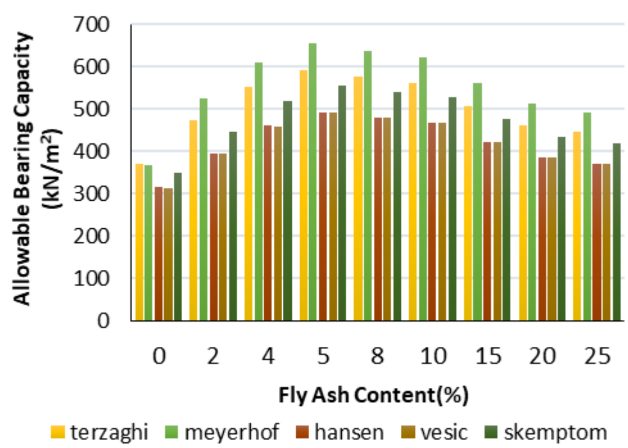

Fig. 3. Comparison of allowable bearing capacity with fly ash content for 90 day time interval (saturated)

For unsaturated soil, the allowable bearing capacity and time graph for fly ash-soil mix is demonstrated in Fig. 4. The allowable bearing capacity was found to be highest for 5% fly ash content.

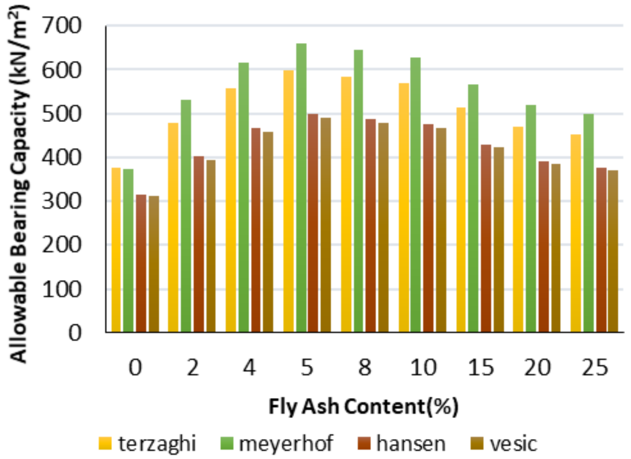

Fig. 4. Comparison of allowable bearing capacity with fly ash content for 90 day time interval (unsaturated)

B. Effect of Time on Allowable Bearing Capacity

After full analysis, it was found that using Meyerhof's method for fly ash content with the normal soil achieved the maximum allowable bearing capacity.

The relationship of time and allowable bearing capacity for saturated condition of soil and for fly ash mix is shown in Fig. 5.

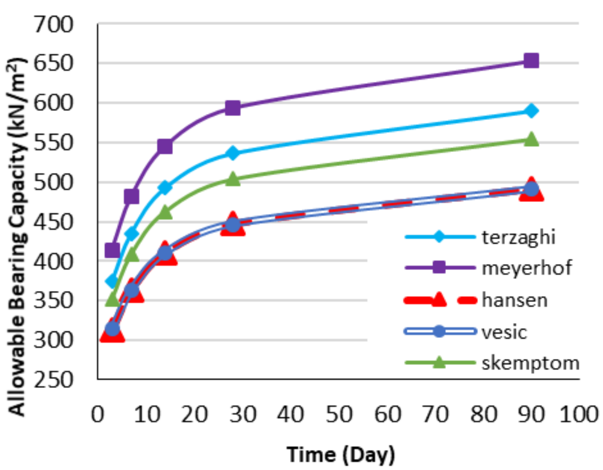

Fig. 5. Effect of allowable bearing capacity with Time for 5% fly ash (saturated)

This figure represents the allowable bearing capacity calculated by Terzaghi (1943), Meyerhof (1963), Skempton (1951), Hansen (1970) and Vesic (1973) methods for 5% fly ash content. It is revealed that the maximum value of bearing capacity was found in the 90-day time interval.

In unsaturated condition, the value of bearing capacity increased with the time increment for fly ash and soil mix. Fig. 6 shows that the maximum value of the bearing capacity was found after 90 days for 5% fly ash content in unsaturated condition.

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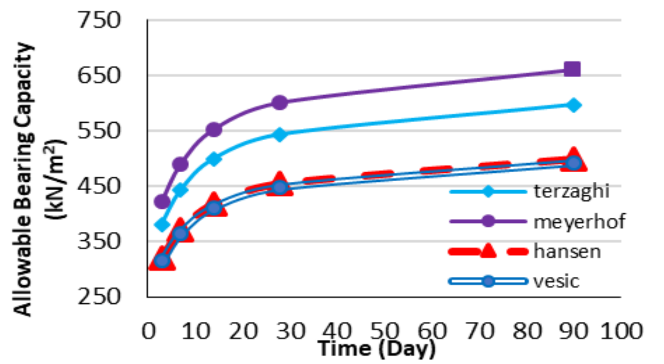

Fig. 6. Effect of allowable bearing capacity with Time for 5% fly ash (unsaturated)

C. Combined Effect of Fly Ash Content and Time on Allowable Bearing Capacity

Soil in a state of fully saturated condition, the maximum allowable bearing capacity was found 653.45 kN/m2 for 90-day interval. The nearest value at same time interval was 637.30 kN/m2 for 8% fly ash content mix (Fig. 7).

For unsaturated condition, from Fig.8, the maximum allowable bearing capacity was found 660.12 kN/m2 at 90 days interval for 5% fly ash mix, while the nearest value was 643.97 kN/m2 for 8% fly ash content. Similar to the saturated condition, Meyerhof's method was also used here to determine the allowable bearing capacity for the fly ash-soil mixture.

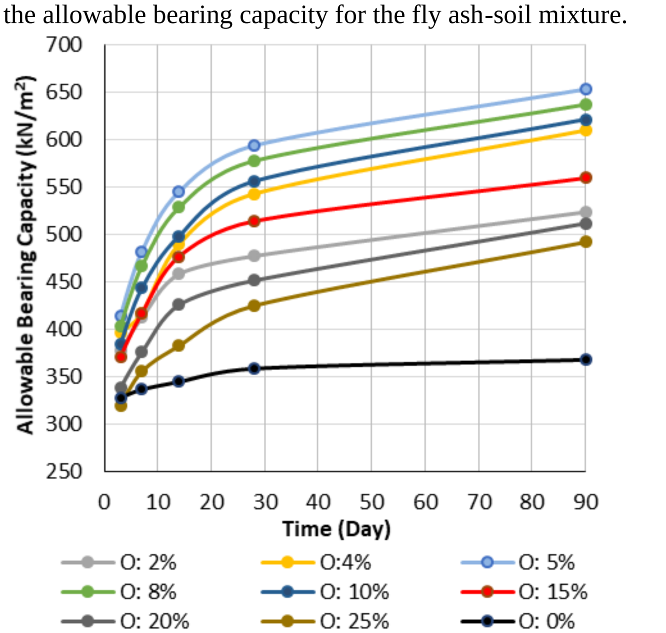

Fig. 7. Effect of allowable bearing capacity with Time for fly ash using Meyerhof method saturated state
("O" represents fly ash)

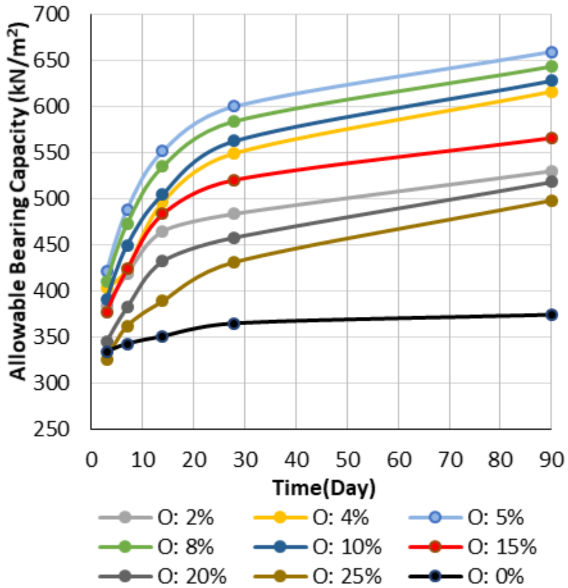

Fig. 8. Effect of allowable bearing capacity with Time for fly ash using Meyerhof method unsaturated state ("O" represents fly ash)

D. *Increment of Allowable Bearing Capacity with Time*

The increment of allowable bearing capacity was reported for time intervals of 3, 7, 14, 28 and 90 days using fly ash. The values of allowable bearing capacity were found using Terzaghi (1943), Meyerhof (1963), Skempton (1951), Hansen (1970) and Vesic (1973) methods. Values obtained from Meyerhof (1963) method were maximum in all the cases.

In the case of saturated fly ash-soil mix, the maximum increment of allowable bearing capacity was found at 90 days interval. Fig. 9 shows the increment of allowable bearing capacity for different time intervals for 5% fly ash content. In the saturated condition, the maximum increment was found 77.74% for Meyerhof (1963) method.

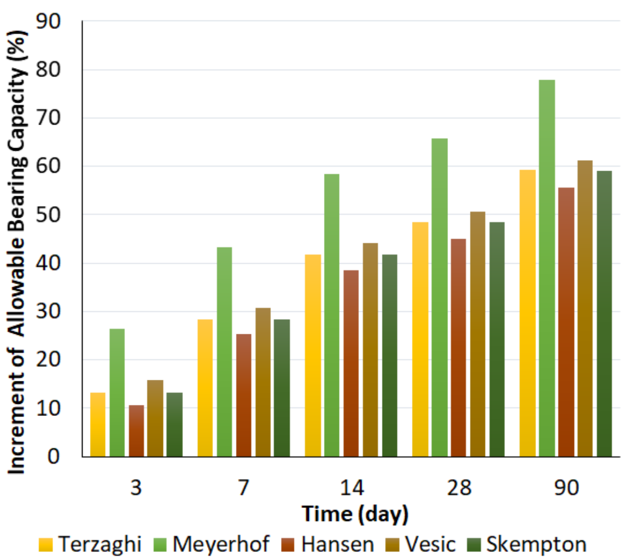

Fig. 9. Increment of allowable bearing capacity with time for 5% fly ash (saturated)

The maximum increment of allowable bearing capacity for unsaturated condition was also found at 90 days interval. Fig. 10 shows the increment of allowable bearing capacity for different time intervals for 5% fly ash content. In the unsaturated condition, the maximum increment was found 60.69% by using Meyerhof (1963) method.

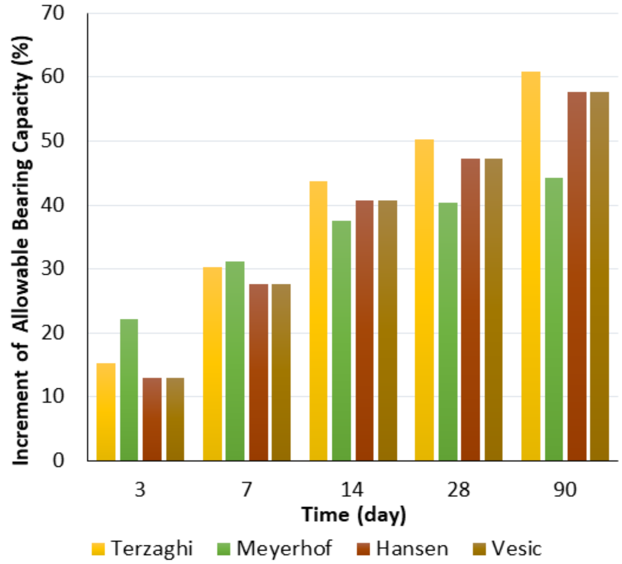

Fig. 10. Increment of allowable bearing capacity with time for 5% fly ash (unsaturated)

E. *Effect of Fly Ash Content on Void Ratio*

In this study, void ratio of the soil was measured before and after mixing fly ash with the soil.

The value of void ratio was found to increase with the increment of fly ash content.

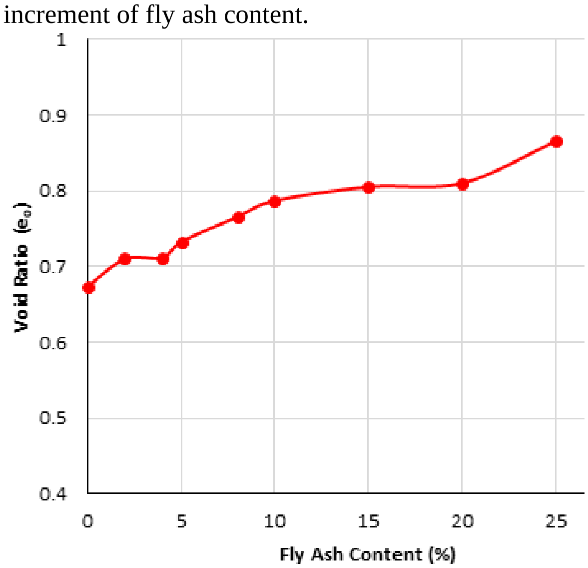

Fig. 11. Effect of fly ash content on void ratio

The test was conducted using 0%, 2%, 4%, 5%, 8%, 10%, 15%, 20% and 25% fly ash contents. From Fig. 11, it can be seen that the maximum void ratio was found for 25% fly ash content (0.865). The lowest void ratio was found 0.672 for normal soil.

F. Effect of Fly Ash Content on Settlement

In this study, the secondary settlement was assumed as very small and it was neglected. The immediate settlement was also calculated and aggregated with the consolidation settlement, which is referred to as the total settlement. In the study, it was found that the value of the total settlement decreases as the fly ash content increases. The immediate settlement was 16 mm for both saturated and unsaturated conditions.

For soil with fly ash content, the lowest values of settlement were found 0.3166m (316mm) and 0.183m (183mm) for saturated and unsaturated conditions, respectively. Both of these values were obtained for 25% fly ash content (Fig. 12).

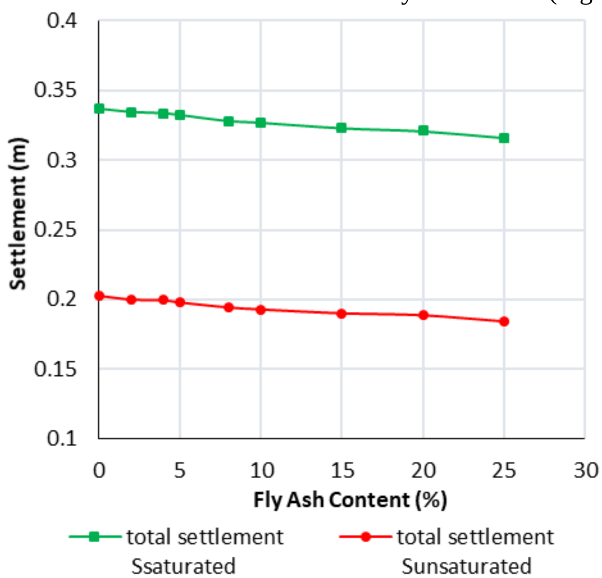

Fig. 12. Effect of fly ash content on settlement

Soil without the presence of fly ash experienced the highest total settlement, which were 0.336m (336mm) and 0.203m (203mm) for saturated and unsaturated soil, respectively.

G. Effect of Fly Ash Content on Degree of Consolidation

After performing the degree of consolidation test, it was found that the degree of consolidation decreased with the increase in fly ash content. For 25% fly ash content, the least degree of consolidation values were achieved in both saturated and unsaturated condition, which were respectively 92.09% and 86.39% (Fig. 13).

In each of the two conditions (e.g., fly ash & saturated, fly ash & unsaturated), the highest degree of consolidation values were achieved for 0% fly ash content (Fig. 13).

H. Effect of Fly Ash Content on Time for Consolidation

Fig. 14 shows that the time required for consolidation is decreasing as the fly ash content is increasing.

For fly ash- soil mix, the least time required for consolidation were found 4.16 years and 3.19 years respectively for saturated and unsaturated condition (Fig. 14). These least durations were achieved for 25% fly ash content in both the cases.

In each of the two conditions (e.g., fly ash & saturated, fly ash & unsaturated), soil with 0% fly ash content required the highest time for consolidation (Fig. 14).

From all the above tests, the findings are summarized here. Using Meyerhof's method, the maximum allowable bearing capacity was achieved for 5% fly ash content. As the time duration increased, the allowable bearing capacity also increased. From settlement analysis, it was observed that the settlement decreases with the increase in fly ash content in soil-fly ash mix. The void ratio also increased with the increase in fly ash content in soil-fly ash mix. Both the degree of consolidation and time required for consolidation decreased with the increase in fly ash content in the soil-fly ash mix.

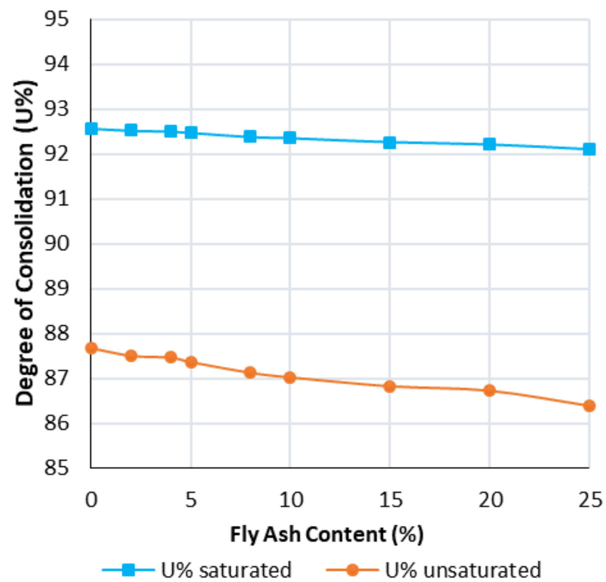

Fig. 13. Effect of fly ash content on degree of consolidation

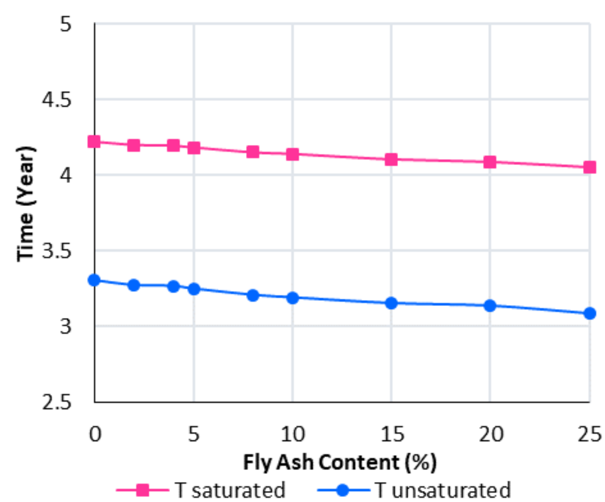

Fig. 14. Effect of fly ash content on time for consolidation

IV. CONCLUSION

In this study, several laboratory UCS tests have been conducted for evaluating the improvement of the allowable bearing capacity of the collected soil sample from the paddy field. Besides these, the Atterberg limits are also evaluated for the settlement calculation of the same soil. After evaluation of the settlement, the degree of consolidation is also calculated, along with the time required for the desired degree of consolidation. All the engineering properties are evaluated here by performing a parametric analysis for a shallow foundation. From the analysis, it has been found that for 5% fly ash content, the maximum allowable bearing capacity is achieved. Here, for determination of allowable bearing capacity, Terzaghi, Meyerhof, Skempton, Hansen, Vesic methods have been used and it is noted that from the Meyerhof method, the allowable bearing capacity demonstrates the highest value. The change of bearing capacity is observed for duration of 90 days and it is found that the bearing capacity increases with time. Besides these, the settlement and void ratio analysis have also been conducted and it has been found that for an increase in fly ash content, the total settlement decreases, while void ratio increases with the increment of fly ash content. From the analysis, it is also established that both the time requirement for the consolidation and the degree of consolidation decreases as the fly ash content increases.

Finally, it can be concluded that fly ash can be useful for the development of the bearing capacity of the soil and reducing settlement. Considering fly ash is a byproduct of power plants along with the fact that unplanned disposal of it can lead to serious environmental pollution, the use of fly ash in the development of the engineering properties of soil can certainly reduce the environment pollution. Therefore, it is recommended for convenient construction materials in the foundation, road construction, etc. As the compaction test cannot be done for soil having moisture content less than 20%, study on a fully remolded soil sample for a high range of moisture content can also be considered. The interval between the percentages of fly ash content should be reduced in future studies. For example, the obtained results will be more precise if the difference of fly ash contents can be reduced to 1% or 0.5%. Moreover, the effectiveness of other types of stabilizers such as polymers may also be investigated.

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