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Strength Characteristics of Fly Ash Mixed With Lime Stabilized Soil

Sahoo, Jagdish Prasad
Research Scholar
e-mail: jpscivil@gmail.com

Sahoo, Sasmita[1]
Assistant Professor
e-mail: rubygt01@yahoo.com

Yadav, Vinod Kumar[2]
Formerly M.Tech. Student
e-mail: vinodmau2002@yahoo.co.in

Department of Civil Engineering, Indian Institute of Science, Bangalore
[1]Department of Civil Engineering, CVRCE, Bhubaneswar
[2]Department of Civil Engineering, Motilal Nehru National Institute of Technolgy, Allahabad

ABSTRACT

This paper reports the outcome of an experimental investigation into the effect of fly ash mixed with small amount of lime on the strength characteristics of soil, to ascertain its suitability for use as a construction material. In the present investigation, a series of laboratory tests (Compaction tests, Triaxial tests, Unconfined compressive strength (UCS) tests and California bearing ratio (CBR)) were conducted on soil specimens added with various percentages of fly ash and fly ash mixed with lime by the weight of dry soil. The test result reveals that the optimum content of admixture for achieving maximum strength is approximately 15% fly ash mixed with 4% lime of the dry weight of the soil.

1. INTRODUCTION

Fly ash, which is a waste material of coal combustion in the thermal power plants, is produced in large quantities in many parts of the world. The annual production of fly ash in India is about 100 million tonnes posing serious problems of disposal as well as air, land and water pollution. Hence, research and development are being carried out to use fly ash because of its potential for manifold applications. The large-scale utilization of fly ash is possible only in geotechnical engineering applications either alone or with soil as stabilizer.

Constructive use options for ash in low technology applications include the use of coal ash in fills and embankments, pavement and sub-base courses, sub-grade stabilization, landfill cover, soil improvement, land reclamation, & water pollution control. In all the above applications, the strength behaviour of soil fly ash mixes forms an important consideration. Strength behaviour of fly ashes varies with density, free lime content and pozzolanic property. Viskochil et al. (1958) studied the strength of lime and fly ash stabilized sand, silt and clay and found that the lime and fly ash ratio is not very critical, but higher strength was obtained when lime-fly ash ratios were in the range of 1:9-2:8. Yudbhir & Honjo (1991) considered unconfined compressive strength of fly ashes as a measure of self-hardening property of fly ashes.

Singh (1996) studied the unconfined compressive strength of fly ashes as a function of free lime present in them. It was found that fly ash having higher free lime content shows higher strength. Gray and Lin (1972) have reported that fly ashes have the requisite properties for use in highway sub-bases. Joshi et. al. (1975) have carried out CBR tests on fly ash samples compacted at optimum moisture content and maximum dry density and reported the soaked CBR to range between 10% to 18%. Toth et. al. (1988) reported the CBR of fly ashes to vary between 6.8 – 13.5 % for soaked condition and 10.8 – 15.4 % for unsoaked condition. Pandian & Krishna (2001) have reported the beneficial aspects of fly ash soil mixes in road construction. In this paper, the strength characteristics of fly ash and fly ash-lime stabilized soils have been investigated.

2. MATERIALS AND METHODS

In this study, fly ash, which is class C category, was procured from Panki Thermal Power Station, Kanpur. The soil in the present study was taken from Meza road, Allahabad by open excavation from a depth of 1m below natural ground level. The properties of both fly ash and soil are given in Table 1. The soil was stabilized with either by fly ash or fly ash mixed with lime to compare its behavior with non-stabilized soil. Firstly, fly ash in different percentages (5 to 25) at an interval of 5% by the weight of dry soil was mixed with dry soil, which is designated as M_1, M_2, M_3, M_4 and M_5 as given in Table 2. The standard Proctor compaction test was carried out to know the optimum moisture content (OMC) and maximum dry unit of various mixes. The material quantities were determined based on their standard

Proctor optimum condition and the volume of the mould for triaxial test, UCS test and CBR test. In order to prepare the samples for triaxial test, unconfined compression test and CBR test in unsoaked condition, the different mixes were thoroughly mixed with water corresponding to OMC of the respective mix, and kept in desiccators for a period of about 24 hours in order to allow the moisture equilibrium to take place. To prepare samples for CBR testing in soaked condition, the various mixes were compacted at their standard optimum condition in to the CBR mould and kept inside a water tank for periods of 4 days.

Table 1: Properties of Fly Ash and Soil

Properties	*Fly ash*	*Soil*
Grain size analysis:		
Clay (< 0.002mm) in %	08	27
Silt (0.002mm to 0.075mm) in %	81	58
Sand (0.075mm to 4.75mm) in %	11	15
Consistency Limits:		
Liquid Limit (%)	56	45
Plastic Limit (%)	NP	20
Plasticity Index (%)	-	25
Shrinkage Limit (%)	-	14
Specific Gravity	2.01	2.69
Maximum dry unit weight (kN/m^3) (standard Proctor)	11.20	14.40
O.M.C (%) (standard Proctor)	32.0	19.05
Shear strength of samples compacted to standard Proctor optimum condition, UCS (kPa)	64	50.5

Table 2: Designation of Various Mix Proportions of Soil-Fly Ash–Lime

Designation	*Soil-fly Ash-lime Mixture*
M_0	Virgin Soil
M_1	Virgin Soil + 5 % fly ash
M_2	Virgin Soil + 10 % fly ash
M_3	Virgin Soil + 15 % fly ash
M_4	Virgin Soil + 20 % fly ash
M_5	Virgin Soil + 25 % fly ash
M_6	Virgin Soil + 15 % fly ash + 2 % lime
M_7	Virgin Soil + 15 % fly ash + 4 % lime
M_8	Virgin Soil + 15 % fly ash + 6 % lime
M_9	Virgin Soil + 15 % fly ash + 8 % lime

After this samples were kept in the loading machines of the respective test and the tests were carried out as per the relevant IS code provisions.

The various mixes of soil-fly ash-lime (M_6, M_7, M_8, and M_9) were prepared by adding lime of 2%, 4%, 6% and 8% by the weight of dry soil with the soil-fly ash mix corresponding to maximum strength and CBR value i.e. soil+15% fly ash, which was already obtained from the tests on soil-fly ash mixes. The preparation of samples and testing procedure for different tests on mixes of soil-fly ash-lime is same as described above in case of soil-fly ash samples.

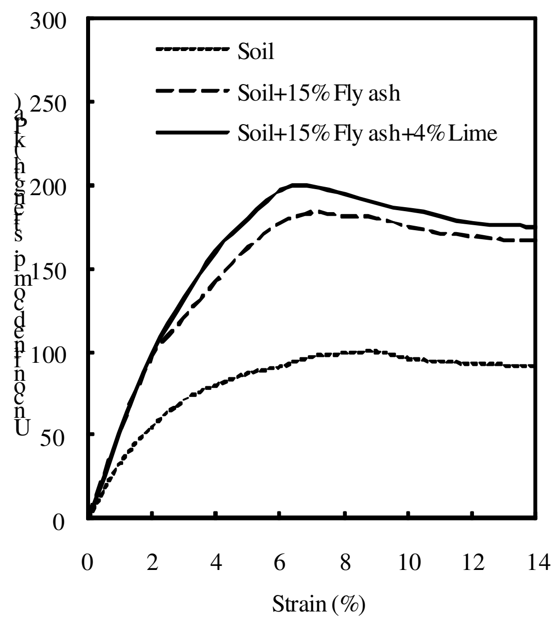

Fig. 1: Stress-Strain Behavior of Stabilized Soil at Optimum Content of Fly Ash and Fly ash + Lime

3. RESULTS AND DISCUSSIONS

The physical properties of fly ash as well as soil are given in Table1. Even though, the fly ash is non plastic, it exhibits liquid limit values due to the fabric effects. Its specific gravity is also low compared to the soil due to the presence of cenospheres (Pandian, et. al., 1998). Table 3 shows the results of compaction tests, triaxial tests (CU), unconfined compressive strength (UCS) tests and California bearing ratio (CBR)) for various mixes of stabilized soil. From Table 3, it is observed that the optimum moisture content (OMC) of the soil increases from 14.5% to 18.7%, and the maximum dry unit weight (γ_d) gradually decreases from 1.91 kN/m^3 to 1.65 kN/m^3, when the soil is stabilized with fly ash to fly ash-lime mixes. There is marginal improvement in the shear strength parameters i.e. cohesion (c) and angle of internal friction (Φ) of the soil either due to addition of fly ash or fly ash-lime mixes. From consolidated undrained triaxial shear test, the value of c and Φ increases from 60.7 kN/m² to 65.5 kN/m², and 13^0 to 15.2^0, respectively with increase in the amount of fly ash from 5% to 15% and then it decreases with further increase in fly ash. Also, at a constant percentage of fly ash (15%), the value of c and Φ increases to 68.5 kN/m², and 15.5^0, respectively by increasing the lime content up to 4%, beyond which it decreases with further increase in lime content.

The stress-strain curves obtained from unconfined compression tests are given in Fig.1 for virgin soil, and virgin soil with fly ash and fly ash + lime at optimum content. From Fig. 1, it is observed that the failure occurs at stress of 101 kPa, 183 kPa and 198 kPa corresponding to strain of 9%, 7% and 6.5% in virgin soil, virgin soil +15% fly ash and virgin soil +15% fly ash+ 4% lime, respectively. Increasing the fly ash content up to 15% for the soil samples shows a significant change in the unconfined compressive strength. The UCS increases from 101 kN/m² to 183 kN/m² and then decreases as the fly content exceeds beyond 15 %. The compressive strength of soil further increases to 198 kN/m² with addition of a small amount of lime (4%) to the soil-fly ash mixes. But, while the lime content is more than 4%, the strength decreases.

Adding a small amount of lime (4% by dry weight of soils) in addition to the fly ash increases unconfined compressive strength of soils considerably. This may be attributed to the presence of quick lime, which ensures a quick pozzolanic reaction leading to the formation of a cemented matrix, which provides extra strength to the soil mixture. This indicates that the quantity of fly ash up to optimum content can induce pozzolanic reaction and cemented materials effectively contributing to shear strength increase, while the additional quantity of fly ash acts as unbounded silt particles, which has neither appreciable friction nor cohesion, causing decrease in strength (Bell 1996; Kate 2005).

Table 3 presents the results of CBR test, which clearly shows that the addition of fly ash and fly ash-lime to the soil has influenced both unsoaked and soaked CBR value. The CBR value increases approximately 4.5 and 3.9 times than that of virgin soil alone in unsoaked and soaked conditions respectively at 15% of fly ash and with further increase in fly ash beyond 15%, the CBR value decreases. From Table 3, It is also observed that the value of CBR becomes approximately 4.9 and 4.3 times than that of virgin soil in unsoaked and soaked conditions respectively when soil is stabilized with 4 % of lime and 15% of fly ash mixes. The addition of lime beyond 4% with optimum quantity of fly ash (15%) content shows decrease in the CBR values. The CBR of a material is contributed by its cohesion and friction components. The CBR value decreases when the fly ash and lime content exceeds beyond 15% and 4%, respectively as the cohesion reduces and angle of friction remains constant due to addition of fly ash and lime beyond the optimum content, which is presented in Table 3.

Table 3: Test Results for Virgin Soil and Various Mixes

Designation	*Standard Proctor Test*		*Triaxial Test (CU)*		*Unconfined Compression Test (UCS)*	*CBR (%)*	
	OMC (%)	γ_d *(kN/m³)*	*c (kN/m²)*	*Φ in Degree*	*(kN/m²)*	*Unsoaked*	*Soaked*
M_0	14.5	1.91	60.7	13	101	2.63	0.95
M_1	16.3	1.80	61.2	13.3	133	5.28	1.84
M_2	16.5	1.78	64	14.6	175	8.18	3.04
M_3	16.8	1.75	65.5	15.2	183	11.82	3.72
M_4	17.0	1.72	63.3	14.9	174	10.55	3.15
M_5	17.1	1.72	62.5	14.4	161	9.97	2.76
M_6	17.5	1.71	64	15.1	179	11.78	3.70
M_7	17.8	1.69	68.5	15.5	198	12.86	4.10
M_8	18.3	1.67	66.3	15.5	187	12.71	4.08
M_9	18.7	1.65	65.5	15.5	177	11.95	3.91

4. CONCLUSIONS

Based on the experimental study of the soil stabilized using fly ash and fly ash-lime, the following conclusions can be drawn:

1. With an increase in fly ash and lime-fly ash content, the optimum water content increases and the maximum dry unit weight decreases.
2. There is marginal increase in the cohesion and angle of internal friction of soil with the increase in the fly ash content and lime up to 15% and 4%, respectively, beyond which the strength parameters decreases.
3. The maximum increase in unconfined compressive strength of soil is achieved by using fly ash-lime stabilized soil at fly ash and lime content of 15% and 4%, respectively, which may be taken as the optimum content of fly ash-lime mix for the stabilization of this soil. Further increase in fly ash or lime content results decrease in the strength of soil.
4. At optimum content of fly ash-lime, the CBR value of stabilized soil increases to 4.3 and 4.9 times than that of virgin soil alone in soaked and unsoaked conditions respectively.

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