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Study of Compaction and Strength Properties of Expansive Soil under Influence of Fly Ash, Lime and Polyester Fibers

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Abstract: A test program was embraced to concentrate on the impacts of polyester fiber incorporations and lime adjustment on the geotechnical qualities of fly ash soil blends. An Indian fly ash was blended in with broad soil in various extents. The geotechnical qualities of fly ash soil examples, lime-soil examples and lime-fly ash soil examples blended in with various proportions of haphazardly arranged filaments were researched. Lime and fly ash were added to a far-reaching soil at scopes of 1–10% and 1–20%, individually. Test examples were exposed to compaction tests, unconfined pressure tests and split elasticity tests. Examples were restored for 7, 14, and 28 days after which they were tried for unconfined pressure tests and split malleable tests. In view of ideal qualities acquired for lime and fly ash, tests were directed on test examples arranged from fly ash extensive soil-lime-fiber combination following 28 days of restoring. Tests were tried with 0, 0.5, 1.0, 1.5, and 2% plain and creased polyester strands by dry weight. In light of the great outcomes got, it tends to be reasoned that the sweeping soil can be effectively settled by the joined activity of filaments, lime, and fly ash.

Keywords : Fiber reinforced materials; Expansive soils; Fly ash; Soil stabilization; Soil compaction.

Introduction

The term expansive soil applies to soils that have the tendency to swell when their moisture content is increased. Soils containing the clay mineral montmorillonite generally exhibit these properties (Chen 1975). Black cotton soils of India are well known for their expansive nature. These expansive soils are called black cotton soils because of their predominant black color and the cotton crop that is grown abundantly on such soils. These soils cover about 0.8×10^6 km^2 area which is more than one-fifth of the country and extend over the states of Maharashtra, Gujarat, Southern part of Utter Pradesh, eastern part of Rajasthan, southern and western part of Madhya Pradesh, and few parts of Andhra Pradesh and Chennai.

Separate from the issue of expansive soils is the need to identify reuse alternatives for industrial wastes. Finding a beneficial way to utilize these wastes is a practical way of encouraging sustainable development. Recent projects illustrated that successful waste utilization (e.g., combining industrial waste with lime for soil stabilization) could result in considerable savings in construction costs (Kamon and Nontananandh 1991).

Lime Stabilization

The use of lime for stabilizing plastic montmorillonitic clays has been increasing in favor during the last few decades because it lowers volume change characteristics (TRB 1976). Generally the amount of lime required to stabilize expansive soils ranges from 2 to 8% by weight (Chen 1975).

The addition of lime to clay soil provides an abundance of calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}). These ions tend to displace other common cations such as sodium (Na^{+}) and potassium (K^{+}), in a process known as cation exchange. Replacement of sodium and potassium ions with calcium significantly reduces the plasticity index of the clay. A reduction in plasticity is usually accompanied by reduced potential for swelling. The addition of lime increases the soil pH, which also increases the cation exchange capacity.

A change of soil texture takes place when lime is mixed with clays. With the increase in lime content, there is an apparent reduction in clay content and a corresponding increase in percentage of coarse particles (Chen 1975).

Fly Ash Stabilization

Fly ash is defined as the mineral matter extracted from the flue gases of a furnace fired with coal. Fly ash consists of often hollow spheres of silicon, aluminum and iron oxides, and unoxidized carbon. Fly ash can be regarded as nonplastic fine silt by the Unified Soil Classification System. The composition of fly ash varies considerably depending on the nature of the coal burned and the power plant operational characteristics (Cabrera and Woolley 1994). Fly ash is a pozzolanic material, which is defined as siliceous or siliceous and aluminous and, therefore, its engineering behavior can be improved by the addition of cement or lime.

Fly ash can provide an adequate array of divalent and trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+}, etc.) under ionized conditions that can promote flocculation of dispersed clay particles. Thus, expansive soils can be potentially stabilized by cation exchange using fly ash. Cokca (2001) studied the effect of fly ash for the stabilization of an expansive soil and concluded that the expansive soil can be stabilized successfully by fly ashes. The unsoaked unconfined compressive strength of fly ash-soil mixtures decreases as the amount of fly ash increases. The decrease in strength may be attributed to decrease in maximum dry density and increase in optimum moisture content on addition of fly ash to soils, keeping in mind that fly ash does not react with soil in the absence of lime.

Fiber-Reinforced Soil/Fly Ash

Fiber inclusions cause significant modification and improvement in the engineering behavior of soils. A number of research studies on fiber-reinforced soils have recently been carried out through triaxial tests, unconfined compression tests, CBR tests, direct shear tests, and tensile and flexural strength tests (Andersland and Khattak 1979; Freitag 1986; Setty and Rao 1987; Maher and Gray 1990; Al-Refeai 1991; Fatani et al. 1991; Maher and Ho 1994; Lawton et al. 1993; Michalowski and Zaho 1996; Ranjan et al. 1996, 1999; Consoli et al. 1998, 2002; Santoni et al. 2001; Kumar et al. 2005). One of the primary advantages of randomly distributed fibers is the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher and Gray 1990).

The literature cites various studies conducted to understand the behavior of soils modified by the addition of fibers and other components. Lima et al. (1996) observed a large increase in compressive strength with the addition of lime and cement to fiber reinforced soils. Consoli et al. (1998) carried out drained triaxial compression tests to study the individual and combined effects of cement stabilization and randomly oriented fiber inclusions on the behavior of silty sand. Consoli et al. (2002) conducted unconfined compression tests, splitting tensile tests, and saturated drained triaxial compression tests to evaluate the benefit of utilizing randomly distributed polyethylene fibers obtained from plastic wastes, alone and combined with rapid hardening Portland cement to improve the engineering behavior of uniform sand. Kumar et al. (2005) found that unconfined compressive strength of highly compressible clay increases with the addition of fibers and it further increases when fibers are mixed in clay sand mixtures.

Chakraborty and Dasgupta (1996) studied the strength characteristics of fiber reinforced fly ash by carrying out laboratory triaxial shear tests. The fly ash was collected from the Kolaghat thermal power station in India. Kaniraj and Havangi (2001) studied the behavior of cement-stabilized fiber-reinforced fly ash-soil mixtures. They mixed Indian fly ash with silt and sand in different proportions. The study showed that cement stabilization increases the strength of raw fly ash-soil specimens. The fiber inclusions increased the strength of raw fly ash-soil specimens and as well as that of cement stabilized specimens and changed their brittle behavior to ductile behavior. They further concluded that the combined action of cement and fibers is either more than or nearly equal to the sum of the increase caused by them individually.

The objectives of this paper are to study the effects of fiber inclusions and lime stabilization on the geotechnical characteristics of fly ash-soil mixtures.

Scope of Present Study

The geotechnical characteristics of fly ash-soil specimens, lime-soil specimens, and lime-fly ash-soil specimens mixed with dif-

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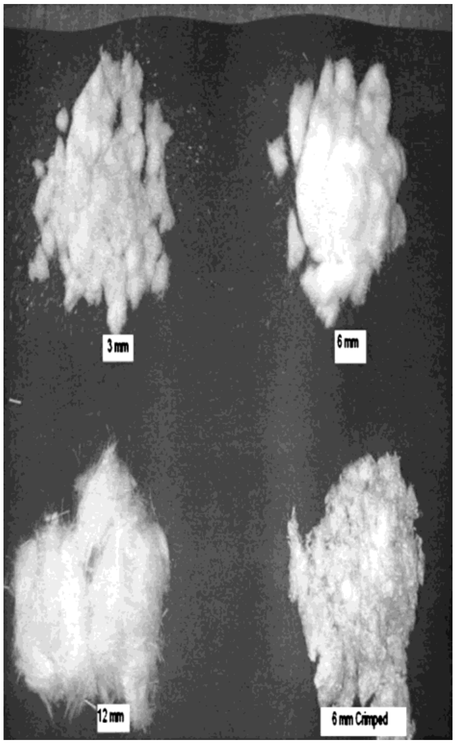

Fig. 1. Loose polyester fibers

ferent proportions of randomly oriented fibers were investigated. Lime was added to expansive soil at 0–10% and fly ash was added to the expansive soil at 0–20% by dry weight. Test specimens were subjected to compaction tests, unconfined compression tests, and split tensile strength tests. Specimens were cured for 7, 14, and 28 days after which they were tested for unconfined compression tests and split tensile tests. Based on optimum com- paction values obtained for lime and fly ash, tests were conducted on test specimens prepared from fly ash-expansive soil-lime-fiber mixture after 28 days of curing. Samples were tested with 0, 0.5, 1.0, 1.5, and 2% plain polyester fibers (3, 6, 12 mm lengths) and crimped polyester fibers (6 mm lengths). Fig. 1 shows a photo- graph of loose polyester fibers. This paper presents the details and results of the experimental study and the conclusions from the study.

Unconfined Compression Tests

Unconfined compression tests were carried out on cylindrical specimens 38.1 mm diameter and 76.2 mm long. The fly ash-soil-lime-fiber mixtures were compacted at optimum moisture content and maximum dry density in standard molds. The mixture was compacted in three layers and each layer was compacted using 2.6 kg rammer under a free fall of 310 mm. The detail of various mixture combinations for which tests were conducted are given in Table 5. From molds, specimens of 38.1 mm diameter and 76.2 mm long were extracted and stored in desiccators partially filled with water at room temperature for curing. Samples were tested after 7, 14, and 28 days of curing. At the end of each curing period the specimens were soaked in water for a period of 24 h. The unconfined compressive strength was determined at a loading rate of 1.00 mm/ min. The unsoaked unconfined compressive strength was determined for virgin black cotton soil and fly ash-soil mixtures, as the specimens without lime admixture crumbled in water during soaking. The unsoaked unconfined compressive strength of fly ash-soil mixtures decreased from 159 to 98 kN/ m^2 as the amount of fly ash was increased from 0 to 20% (Fig. 4).

Figs. 5–7 show the effect of lime and fly ash content on soaked unconfined compressive strength of soil-lime specimens after 7, 14, and 28 days of curing. It is observed that time of curing does not produce much increase in strength up to 4% of lime. This may

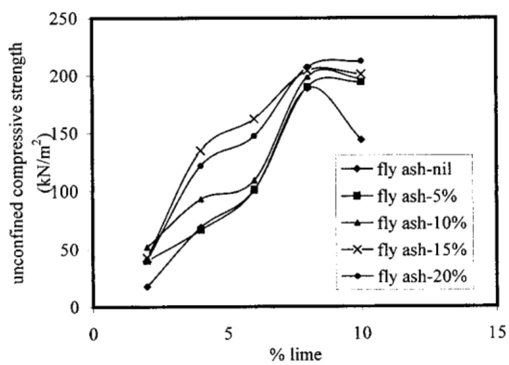

Fig. 6. Variation of unconfined compressive strength with % of lime for different % of fly ash (after 14 days curing)

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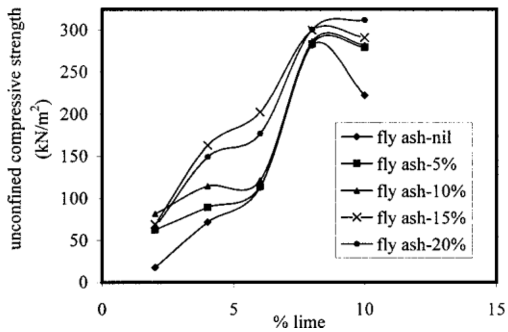

Fig. 7. Variation of unconfined compressive strength with % of lime for different % of fly ash (after 28 days curing)

be due to the reason that nearly all the lime is taken up by the clay fraction in soil at the early stages leaving very little to react with silica and alumina to produce pozzolanic reactions. Normally, a pozzolanic reaction between lime, silica, and alumina is found to be a slow process. The increase in strength with curing period after 6% of lime indicates that some amount of lime is available for pozzolanic reactions. Expansive soil-lime mixtures containing more than 8% lime show a decrease in strength. The decrease may be attributed to the platy shapes of the unreacted lime particles in the soil mass.

With respect to the fly ash content, the curves presented in Figs. 5–7 indicate that the strength of fly ash-soil-lime mixtures increases with increasing curing time. In addition, it can be observed that the unconfined compressive strengths of fly ash-soil-lime mixtures after 7, 14, and 28 days of curing period are always higher than those of respective soil-lime samples. The optimum value of fly ash and lime may be adopted as 15 and 8%, respectively, as is clear from Figs. 5–7.

Based on the previous discussion, the fiber-reinforced specimens were tested for 15% fly ash and 8% lime in the fly ash-soil-lime-fiber mixtures. Polyester fibers of length 3, 6, 12 plain and 6 mm crimped were mixed in different proportions of 0.5, 1.0, 1.5, and 2.0%. Specimens prepared for fly ash-soil-lime-fiber mixtures (as per Combination 8 shown in Table 5) were tested for each fiber length after 28 days of curing. At the end of curing period the specimens were soaked in water for a period of 24 h before testing. The results of unconfined compressive strength are presented in Fig. 8. The curves show that the addition of 1.5% of 6 mm plain fibers or 1.0% of 6 mm crimped fibers increases unconfined compressive strength by approximately 74% as compared to that of same mixture without fibers. Also, with the addition of 1.5% of 6 mm crimped fibers or 1% of 12 mm plain fibers, the gain in unconfined compressive strength is about 100% in comparison to that of the same mixture without fibers.

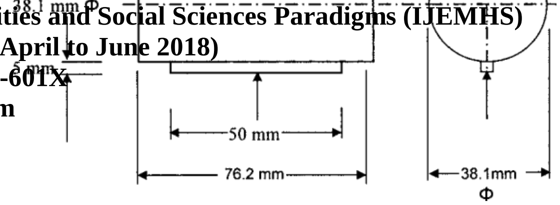

Fig. 9. Schematic sketch of specimen for split tensile test

Conclusions

On the basis of the present study, the following conclusions are made:

1. With the increase in lime content, the maximum dry density of soil-lime mixes decreases and optimum moisture content increases. The fall in density is more significant at lower percentages of lime. When fly ash is added to soil-lime mixture, maximum dry density decreases further and optimum moisture content increases. The results of compaction tests showed that limited quantity of polyester fibers (0.5–2.0%) had no significant effect on maximum dry density and optimum moisture content of fly ash-soil-lime-fiber mixtures
2. Time of curing does not produce much increase in strength up to 4% of lime content.
3. Fly ash is beneficial in combination with lime in improving properties of soil. With the increase in the percentage of fly ash keeping amount of lime as constant, strength tends to increase and reaches a certain maximum value and thereafter it starts decreasing, but is always higher than that of the respective soil-lime mixture.
4. The optimum value of lime content and fly ash content in fly ash-soil-lime mixtures may be taken as 8 and 15%, respectively.
5. The addition of 1.5% of 6 mm plain fibers or 1.0% of 6 mm crimped fibers to fly ash-soil-lime-fiber mixtures (at 8% lime content and 15% fly ash content) increases unconfined compressive strength and split tensile strength by about 74 and 100% respectively, as compared to that of same mixture without fibers. Also, with the addition of 1.5% of 6 mm crimped fibers or 1% of 12 mm plain fibers, the gain in unconfined compressive strength and split tensile strength is about 100 and 135%, respectively, in comparison to that of the same mixture without fibers.
6. The ratio of split tensile strength and unconfined compressive strength increases with increase in fiber content, which shows that polyester fibers are more efficient when soil was subjected to tension rather than to compression.

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