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RESEARCH ARTICLE

Stabilization of Soil by Different Proportions of Fly Ash as Partial Replacement

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Abstract

Since every structure is ultimately built on the soil, its consideration plays a key role in the design of every structure that is built on it. Roads, buildings, towers, bridges and many other structures are dependent on soil and without these in this age of developing technology it would be unimaginable. Checking the stability of soil becomes a necessity in order to build reliable structures and therefore, it is important to study the response of soil in different conditions. Studies have shown that replacing portions of soil with different pozzolanic and waste materials increases the stability of soil. In this study, efforts have been done in order to compare the stability between the virgin soil and soil partially replaced with different ratios of fly ash using laboratory experiments. Results from experiment of standard proctor tests for optimum moisture content and maximum dry densities have been studied. The results show that fly ash replaced soil at a value of 20% fly ash exhibits the most stability.

Keywords: Virgin soil, fly ash, partial replacement, pozzolanic, waste materials, proctor test.

Introduction

Determination of additives and admixtures are necessary in order to get the appropriate engineering properties of soil. Advantages of stabilizing the soils can result in increased resistance values, decrease in plasticity and also controls the swelling behaviour of soil and hence, changes in the volume of soils are negotiated (Gyanen *et al*., 2013). Soil strength too is increased as a result of stabilization. Since, some soils are expansive in nature; intake of moisture can result in the changes in volume of soil which directly affects the durability of the structure which is built on it. As a result, the problems of excessive settlement and also differential movements are faced which causes damage to foundation systems, structural elements and architectural features and most of the time the structure becomes uninhabitable (Malhotra and Naval, 2013). Sudden failures can result due to excessive changes in soil volumes and alternate increase and decrease in the volume of soil due to different soil moisture content can result in cracks and a gradual failure in the structure. Numerous methods are available to stabilize soil to gain the desired engineering specifications. They consist of mechanical and chemical stabilization. For nations that are developing at a very slow rate, most of these methods are very expensive and the best alternative is to use locally available materials that are not very costly and are easily affordable (Magafu and Li, 2010). In India, the increase in the need for energy due to industrial development has been a great cause for the production of a by-product like fly ash, which is generated in the coal burning power plants. Fly ash has a lot of utilizations including stabilization of soils which result in the better engineering properties. Stabilization of soils can be expensive but using an alternative such as fly ash is very cheap since fly ash is easily available. At present the fly ash produced is far greater than the amount of its utilization. It can be used instead of all the conventional materials for the construction of geotechnical and geo-environment infrastructures (Bidula Bose, 2012). Fly ash, which is a pozzolana, increases the strength of composites and also a potential material for waste liner (Joshi and Lohtia, 1997). It is also used as a substance for the stabilization of road base courses. The appropriate fly ash ratio for improving the engineering properties of the soil ranges from 15-30% being dependant on the soil type (Sharma *et al*., 2012). Fly ash can form cations like Ca^{2+}, Al^{3+}, Fe^{3+} etc. under ionized conditions that can cause flocculation of dispersed clay particles and therefore, the surface area and water affinities of these decrease, so the swell potential decreases. So, expensive soils can be effectively stabilized by using fly ash by cation exchange (Mollamahmutoglu *et al*., 2009). In this study, soil was replaced with different ratios of fly ash at 10, 20, 30 and 40%. Plastic limits, optimum moisture content and maximum dry density were determined for virgin soil and soil fly ash mixtures.

Materials and methods

Soil: The natural black cotton soil was taken from the Allahabad district of Uttar Pradesh, India. The properties of the soil used in the study are given in Table 1.

Fly ash: The fly ash used was taken from National Thermal Power Corporation (NTPC) in Unchahar between Allahabad and Lucknow (Table 2).

Table 1. Soil properties and grain size distribution.

Gravel	Sand	Silt	Clay	Plastic Limit
0%	10.05 %	50%	39.05%	17%

Table 2. Physical and chemical properties of fly ash.

Physical properties	
Specific gravity	2.30
Mean grain size (μm)	20
Specific area (cm^2/g)	2680
Colour	Grey to black
Chemical composition (%)	
Silicon dioxide (SiO_2)	60.5
Aluminium oxide (Al_2O_3)	22.80
Iron oxide (Fe_2O_3)	8.80
Calcium oxide (CaO)	2.38
Magnesium oxide (MgO)	1.39
Loss on Ignition	1.1
Sodium oxide (Na_2O)	0.1
Potassium oxide (K_2O)	2.81

Experimental design: The samples of virgin soil and soil replaced by fly ash at 10%. The samples of virgin soil, and soil replaced by fly ash at 10, 20, 30 and 40% were prepared. The following tests were carried out to check the properties of stabilized soils.

Plastic limit: This test was done according to IS 2720 (part 5, 1985). The plastic limit was found by conducting the hand rolling method by pulling approx. 2 g of the soil mass, squeezing and forming it into an ellipsoidal shape and rolling it between fingers and palms against a rolling surface like glass and applying enough pressure to roll it into a thread of equal diameter. The sample was gathered again after it broke into pieces and this process was repeated till it could no longer be rolled into a thread.

$$\text{Plastic limit} = \frac{\text{Weight of water}}{\text{Weight of oven dry soil}} \times 100$$

Standard proctor test: This test was done in order to calculate the optimum moisture content and maximum dry density (IS 2720, Part 7, 1985). The soil sample was weighed and passed through 4.75 mm sieve. Measured amount of water was added to it and mixed thoroughly and was divided into three parts. Compaction was done by taking one sample and giving 25 blows by the metal rammer and then successively, the other parts of the sample were compacted with 25 blows each with a total of 75 blows. The metal collar was removed and the compacted soil inside the mould was weighed. Moisture content was determined from that sample. The amount of the compaction is represented by the dry density and the corresponding value of moisture content of the maximum value of that dry density is the optimum moisture content.

$$\text{Moisture content} = \frac{\text{Weight of moisture}}{\text{Weight of dry soil}} \times 100$$

$$\text{Dry density} = \frac{\text{Wet density}}{100+\%\ \text{Moisture}} \times 100$$

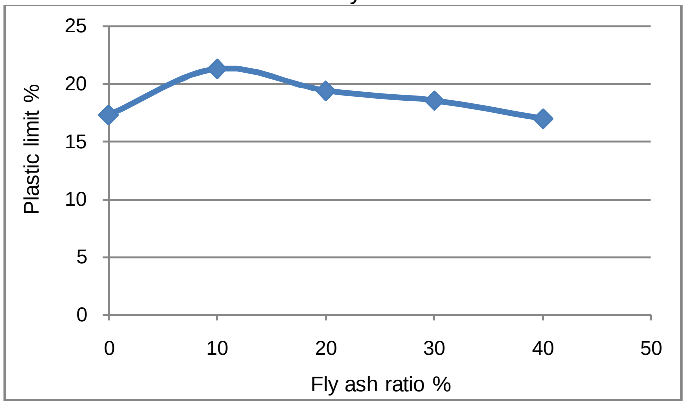
$$\text{Wet density} = \frac{\text{Weight of soil}}{\text{Volume of mould}} \times 100$$

The graph of dry density Vs moisture content is plotted in order to attain the values of maximum dry density and the optimum moisture content.

Results and discussion

Plastic limit: This is the moisture content at which the thread of the soil breaks apart at a diameter of around 3.2 mm. It was noticed that as the fly ash ratio increased, the plastic limit of the soil increased (Fig. 1). The plastic limit of the virgin soil without any fly ash was found to be 17.32%. As the fly ash was added, it started to increase, and with the further increase of the fly ash, it started to decrease again (Fig. 1). The maximum plastic limit of 21.294% was found at 10% fly ash content. The value for the plastic limit at 20% fly ash is 19.40% which is fairly good for the soil.

Fig. 1. Graph plastic limit Vs Soil replaced by different ratios of fly ash.



Standard proctor test: The amount of compaction is shown by the value of dry density. So, the particular moisture content at the maximum dry density gives the optimum moisture content. Figure 2 shows that in virgin soil, the dry density sharply increases and gradually decreases as moisture content is increased. When 10% fly ash was added to the soil, there was a sharp increase in dry density and then it started to decrease sharply (Fig. 3). On addition of 20% fly ash content, there was a continuous increase in dry density and further increase in fly ash resulted in sharp decrease in dry density (Fig. 4). In 30% fly ash content, there was a sharp increase in dry density and then after reaching a peak value of 1.53 g/cc, there was a sharp decrease in dry density (Fig. 5). Figure 6 shows that at 40% fly ash content, there is a sharp increase in dry density and then a gradual decrease in dry density. Comparing all the maximum dry densities of the samples at different ratios, the highest dry density is found to be at 20% fly ash ratio at a value of 1.745 g/cc. The comparative results of the different ratios of fly ash replaced in the soil are given in Table 3.

Fig. 2. Virgin soil with no fly ash mixed Vs Moisture content.

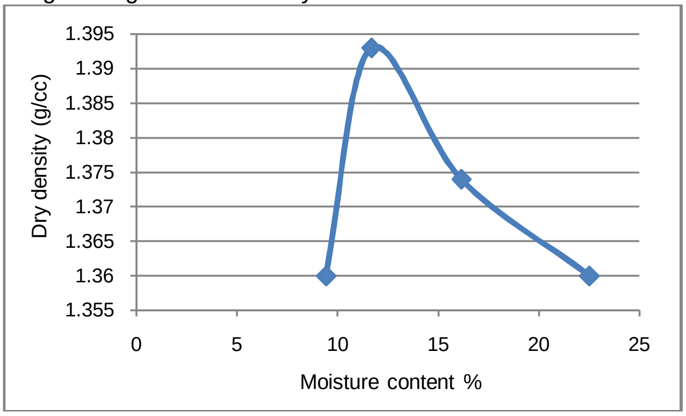


Fig. 3. Soil replaced by 10% fly ash Vs Moisture content.

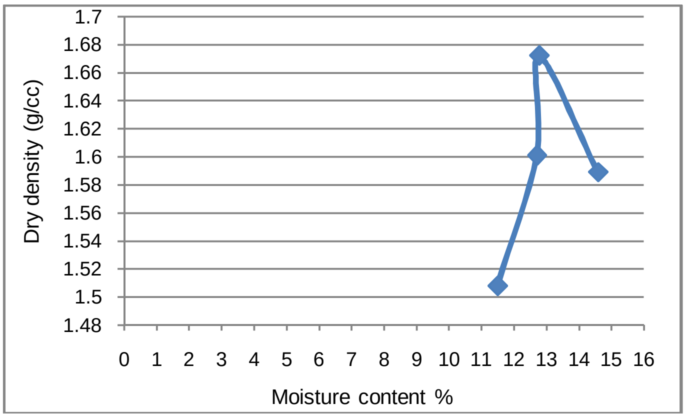


Fig. 4. Soil replaced by 20% fly ash Vs Moisture content.

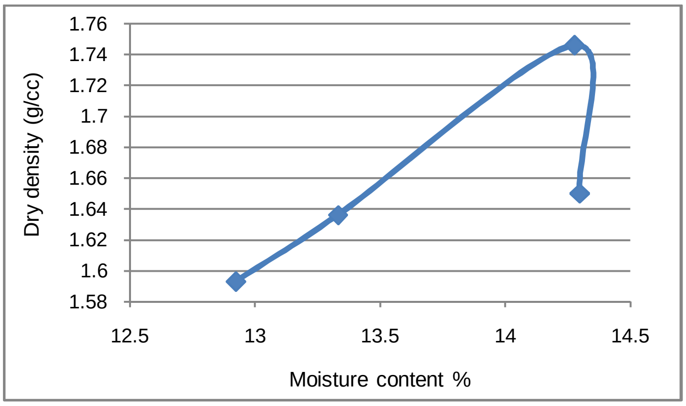


Fig. 5. Soil replaced by 30% fly ash Vs Moisture content.

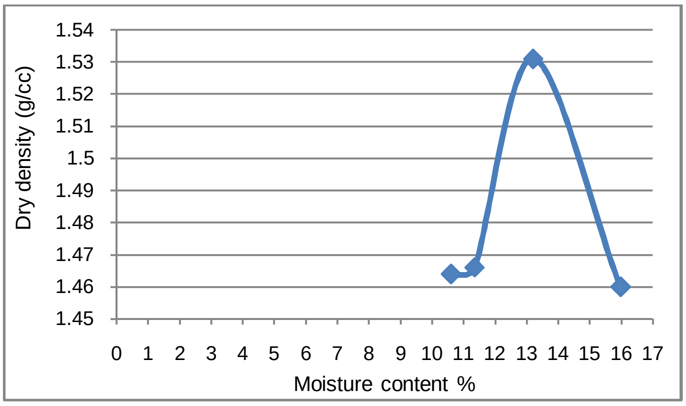


Fig. 6. Soil replaced by 40% fly ash Vs Moisture content.

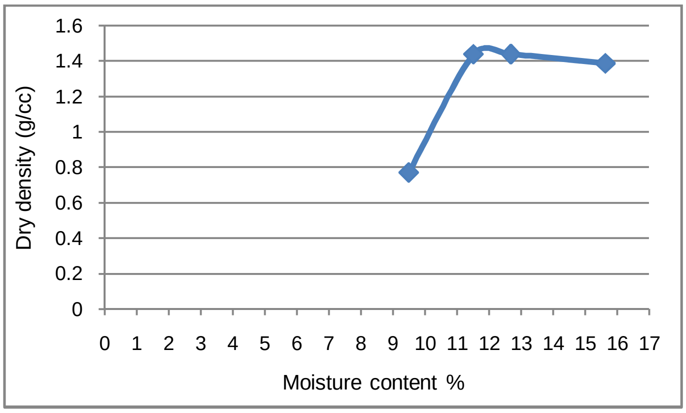


Fig. 7. Maximum dry density Vs Fly ash ratio.

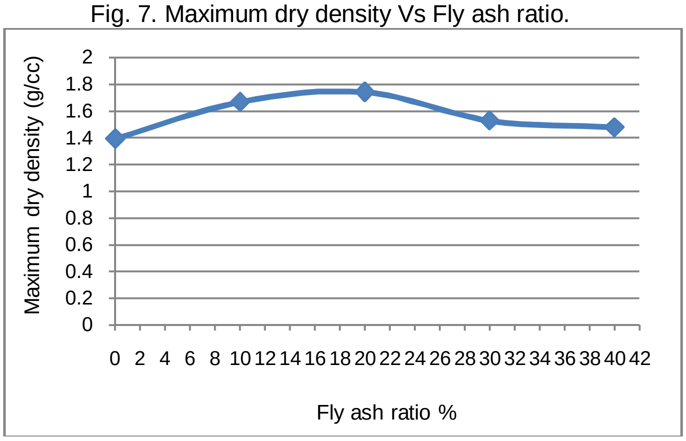


Table 3. Comparative results of the different ratios of fly ash replaced in the soil.

Ratio of fly ash added	Maximum dry density (g/cc)	Optimum moisture content
Virgin soil (0% Fly ash)	1.394	12%
Soil + 10% Fly ash	1.67	13%
Soil + 20% Fly ash	1.745	14.3%
Soil + 30% Fly ash	1.53	13.5%
Soil + 40% Fly ash	1.48	12%

It has been noticed that as the fly ash composition increased in the soil sample, the stability increased. The dry density increased as fly ash was added. This may be because while compaction, we try to remove the air voids so that the soil would not expand on absorbing water and hence, would be more stable and will not face sudden failure. When adding fly ash, the amount of water that is required for the orientation of the particles is less. The resistance offered to the particles for the movement decreases with the increase in the fly ash content. Hence, on addition of fly ash, the dry density increases, but as the fly ash content is further added, the dry density gradually starts to drop down due to the water absorbing quality of the fly ash itself. The maximum dry density was found to be at 20% fly ash replacement.

Conclusion

1. The maximum dry density was obtained for 20% of soil replacement with flyash.
2. It was noticed that as the fly ash was added in the soil as a partial replacement, the maximum dry density increased, but it started decreasing as the fly ash was added continuously.
3. The optimum moisture content was found to be 14.3% at 20% fly ash.
4. The plastic limit was found to be 19.405% for 20% fly ash replacement, which is fairly in range for a good soil.
5. Hence, 20% fly ash replacement proves to give the best results and this ratio of fly ash when added increases the stability of the soil.

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