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# Modification of Geotechnical Properties of Local Soil Mixed With Fly Ash

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**Abstract.** Coal will be the predominant source of global energy for coming several decades. The huge generation of fly ash from the combustion of coal in thermal power plants is apprehended to pose the concerns of its disposal and utilisation. It leads to groundwater contamination and if spills of bulk storage occur then exposure through skin contact, inhalation of fine particulate dust and ingestion through drinking water may happen. Fly ash contains crystalline silica which is known to cause lung disease. One way of handling waste fly ash is to use it as a construction material in highway embankments. This decreases the cost of landfilling and therefore, is an environmentally friendly option. Significant efforts have been made in recent years to use fly ash in soil stabilisation and highway construction. Some of the projects in Delhi that have utilised fly ash in the construction of embankments are Okhla flyover, Hanuman Setu flyover and Nizamuddin bridge. In the present study, an attempt was made to strengthen the hypothesis that fly ash can be effectively used in the construction of highway embankments. This study was aimed at finding an optimum mix of local soil and fly ash based on which appropriate combination of soil and fly ash may be determined for embankment construction. The overall testing was conducted in two phases. In the first phase, the geotechnical characteristics of local soil and fly ash were studied separately by conducting laboratory tests. In the second phase, local soil mixed with 0, 20, 40, 60, 80 and 100% of fly ash were subjected to various tests like standard proctor test, pycnometer test, unconfined compressive strength test, direct shear test and California bearing ratio test. Sample comprising of local soil and 40% fly ash content was found to have maximum California bearing ratio value in soaked as well as in unsoaked conditions. Therefore, this mix was concluded appropriate for the construction of highway embankments.

**Keywords:** Embankment, Fly Ash, Highway, Local Soil

## 1 Introduction

Power, being considered as an engine of growth, has always been a focus area for most of the developing countries. In India, a major source of power is generated through coal-based thermal power plants. Fly ash is a by-product of thermal power plants can be used as an excellent construction material. It is expected that India will produce 300-400 million tonnes per year of fly ash in the coming years, which is approximately double the quantity it has produced until now [1]. The huge amount of fly ash generation would pose serious environmental problems. Therefore, many projects have been undertaken for technology development, dissemination of information, awareness creation, facilitation of multiplier effects, providing inputs for policy interventions, etc. in the safe management and gainful utilisation of fly ash [2]. During the combustion process in power plants, coal is pulverised and organic matter in the coal is burned off immediately. The incombustible material undergoes particle melting and tends to fuse together to form ash. The coarser portion of the ash referred to as bottom ash and boiler slag settles at the bottom of the boiler furnace. Finer particles, referred as fly ash, remain suspended in the flue gas stream due to their small size and lightweight. Prior to being released in the atmosphere with the flue gas, fly ash is usually removed and collected by means of electrostatic precipitators, baghouses, etc. The efficiency of modern electrostatic precipitators is of the order 99.9% [3].

Fly ash showed relatively well-defined moisture-density relations. The values of the maximum compacted dry density tended to vary with the ash source, mainly due to a difference in specific gravity values of fly ash between ash sources [4]. The tendency for fly ash to be less sensitive to variation in moisture content could be explained by the higher air void content of it. The higher void content could tend to limit the build-up of pore pressures during compaction, thus allowing the sample to be compacted over a larger range of water content [5]. Fly ash in a moist but unsaturated condition displays an apparent cohesion due to the tension of retained capillary water but this cannot be relied upon for long term stability analysis. So, the strength property of major interest is the angle of shearing resistance [6].

## 2 Fly Ash Utilisation - Indian Context

Fly Ash Mission, a Technology Project in Mission Mode of Government of India was commissioned during 1994, as a joint activity of Department of Science and Technology (DST), Ministry of Power (MOP) and Ministry of Environment and Forests (MOEF), has provided new focus and thrust and the image of fly ash has been turned around from a 'Waste Material' to a 'Resource Material'. The fly ash and its products generated at various locations in the country have been analysed extensively for various technical parameters and possible harmful effects. Central Road Research Institute (CRRI), New Delhi, has undertaken many demonstration projects and some of these are jointly done with 'Fly Ash Mission' (presently 'Fly Ash Utilisation Programme') for embankment construction. Because of experience gained through these projects, specifications for construction of road embankments and guidelines for use of fly ash for rural roads were compiled and have since been published by the Indian Roads Congress. Some of the projects advised by CRRI are fly ash embankment construction for Okhla flyover and Hanuman Setu flyover at Delhi [3]. The use of fly ash in the Nizamuddin bridge road embankment at Delhi, for about 2 kilometres and a height of 8 meters in a flood zone have demonstrated the use of fly ash in adverse conditions. This has not only saved the topsoil and used fly ash which was otherwise a waste but also saved Rs. 1.4 crores in a total project of Rs. 10 crores [7].

## 3 Literature Review

Numerous studies have been conducted in which the characteristics of soil with fly ash mixes were determined in the laboratory. Sahu (2001) carried out tests on different proportions of soil and fly ash mixes. He concluded that maximum dry density decreased with the increase in fly ash proportion, and there was hardly any effect on optimum moisture content. This variation was expected, as the specific gravity of fly ash was relatively lower than that of soils. The amount of fly ash required for stabilisation was varied with the soil type [8]. Phani Kumar and Sharma (2004) concluded that the addition of fly ash reduced the plastic characteristics of expansive soils. With the increase in fly ash content, the liquid limit and free swell index decreased, whereas the plastic limit increased [9]. Bhuvaneshwari *et al.* (2005) revealed that the workability was maximum with 'soil and 25% fly ash' [10]. Edil *et al.* (2006) reported that the CBR value of soil with fly ash mixtures generally increased with fly ash content and decreased with increasing compaction water content. Adding 10% and 18% fly ash to fine-grained soils resulted in an increased CBR value by 4 and 8 times, respectively [11]. Kumar *et al.* (2007) concluded that with the increasing lime content, the maximum dry density of soil-lime mixes decreased and optimum moisture content increased. The fall in density was more significant at lower percentages of lime. When 'Class F' fly ash was added to the soil-lime mixture, maximum dry density decreased further, and optimum moisture content increased. As the amount of fly ash was increased from 0% to 20%, the unsoaked unconfined compressive strength of fly ash-soil mixtures decreased from 159 kN/m$^2$ to 98 kN/m$^2$ [12]. Sahoo *et al.* (2010) concluded that 15% fly ash and 4% lime was optimum content of fly ash and lime for soil stabilisation. At optimum content of fly ash-lime, the CBR value of stabilised soil increased by 4.3 and 4.9 times than that of only soil in soaked and unsoaked conditions, respectively [13]. Santos *et al.* (2011) reported that fly ash-soil mixtures exhibit relatively well-defined moisture density relationships, varying with mixture ratios. The dry unit weight of fly ash-soil mixtures was lower than those of typically compacted soils [14]. Sharma *et al.* (2012) studied the stabilisation of clayey soil with fly ash and lime. By the addition of 20% fly ash and 8.5% lime, the unconfined compressive strength value was observed to be 105.2 kPa [15].

It can be summarised from above that there is a wide variation of the geotechnical properties of soil when it is stabilised with fly ash and any other binding material (like lime).

## 4 Need For Investigation

The staggering increase in the production of fly ash and its disposal in an environmentally friendly manner has become a matter of global concern. Fly ash was considered a 'Polluting Industrial Waste' and most of it was being dumped in the ash ponds.

Very few utilisation areas of fly ash were known and the general perception of people about it was negative. The problem with fly ash lies in the fact that its disposal requires large quantities of land, water and energy. Its fine particles can become airborne, and if not properly disposed of, it pollutes air and water, causing respiratory problems when inhaled. There is an acute need for an investigation utilising fly ash in a manner in which its negative effects are minimised. The present study evaluates the suitability of local soil and fly ash mixtures with varying fly ash content, as substitutes for conventional fill materials in highway embankments. The prime concern of the research is to develop an optimum mix of local soil with fly ash for highway embankment construction. This practice will help in reducing the disposal problem of fly ash and maximise the beneficial uses of fly ash.

## 5 Materials and Methods

Fly ash and local soil were used as main materials for conducting the study. The soil was taken from fields of Pantnagar, district Udham Singh Nagar, Uttarakhand. The soil was pulverised before conducting the tests. The sample of fly ash was procured from the Century Pulp and Paper Mill, Lal Kuan, district Nainital, Uttarakhand. It was 'Class F' type, dark grey in colour and has been dried in the sun before conducting further investigations. The chemical properties as provided by the Century Pulp and Paper Mill, Lal Kuan are represented in Table I.

**Table 1.** Chemical properties of 'Class F' fly ash

| Name | Formula | Percentage by Weight |
|---|---|---|
| Silica Oxide | $SiO_2$ | 63.20 |
| Iron Oxide | $Fe_2O_3$ | 3.10 |
| Alumina Oxide | $Al_2O_3$ | 26.40 |
| Titanium Oxide | $TiO_2$ | 0.8 |
| Calcium Oxide | $CaO$ | 4.70 |
| Magnesium Oxide | $MgO$ | 0.1 |
| Sodium Oxide | $Na_2O$ | 0.1 |
| Potassium Oxide | $K_2O$ | Traces |
| Sulphur Trioxide | $SO_3$ | 0.2 |

The overall testing program was conducted in two phases. In the first phase, the geotechnical characteristics of local soil and fly ash were studied separately by conducting laboratory tests. In the second phase, local soil mixed with 0, 20, 40, 60, 80 and

100% of fly ash were subjected to various tests like standard proctor test, pycnometer test, unconfined compressive strength test, direct shear test and California bearing ratio test.

## 6 Results and Discussion

The results of various laboratory tests conducted on different proportions of fly ash and local soil mixes were analysed. Further, results have been discussed for drawing conclusions.

### 6.1 Geotechnical parameters of local soil and fly ash

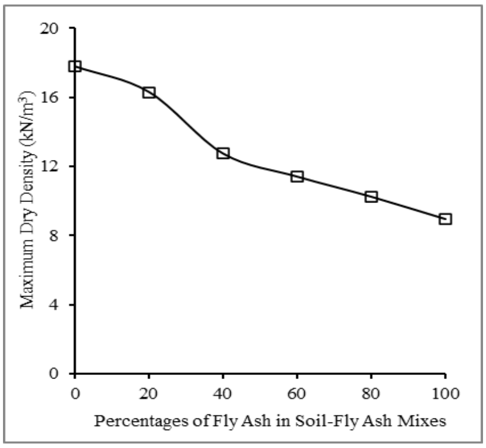
After drying the local soil and fly ash, basic tests were performed on it such as Grain size analysis, Atterberg's limit analysis and Permeability test. The results have been shown in Table II.

**Table 2.** Geotechnical properties of local soil and fly ash

| S.No. | Parameters | Results | |
|---|---|---|---|
| | | Local soil | Fly ash |
| 1 | Classification | CL | ML |
| 2 | Atterberg's limit (%) | Liquid limit: 22.10<br>Plastic limit: 13.04<br>Plasticity index: 9.06 | Nil (Non-plastic) |
| 3 | Permeability (cm/sec) | $2.70 \times 10^{-4}$ | $1.92 \times 10^{-4}$ |

### 6.2 Standard proctor test

Standard proctor test was conducted to determine the relationship between moisture content and dry density of the sample for a specified compactive effort. This test was performed using various combinations of local soil and fly ash samples, ranging from 0% to 100%. The results obtained have been used to draw inferences under each category of mixes as follows.



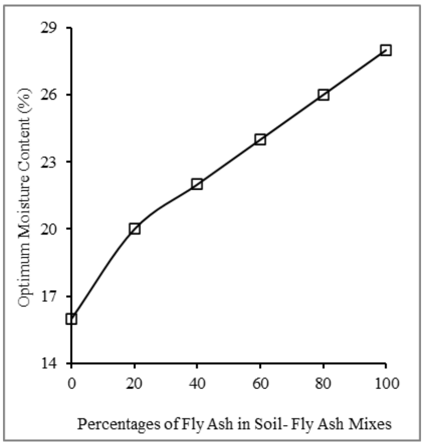




**Fig. 1.** Variation of maximum dry density **Fig. 2.** Variation of optimum moisture content

It is evident from Fig. 1-2, when fly ash content increased from 0% to 100%, the optimum moisture content (OMC) of the sample increased from 16% to 28% and maximum dry density (MDD) decreased from 17.76 kN/m$^3$ to 8.95 kN/m$^3$. Therefore, based on the above results it can be concluded that optimum moisture content showed an increasing trend and the maximum dry density showed a decreasing trend with an increasing percentage of fly ash. The results are summarised in Table III.

**Table 3.** Standard proctor test results

| S.No. | Sample | OMC (%) | MDD (kN/m$^3$) |
|---|---|---|---|
| 1 | Soil and 0% fly ash | 16 | 17.76 |
| 2 | Soil and 20% fly ash | 20 | 16.28 |
| 3 | Soil and 40% fly ash | 22 | 12.73 |
| 4 | Soil and 60% fly ash | 24 | 11.40 |
| 5 | Soil and 80% fly ash | 26 | 10.24 |
| 6 | Soil and 100% fly ash | 28 | 8.95 |

### 6.3 Pycnometer test

This test was conducted to determine the specific gravity of samples. Specific gravity is the ratio of the mass of the given volume of sample to the mass of an equal volume of water at 27°C. The test was performed using various combinations of local soil and fly ash mixes, ranging from 0% to 100%. The results recorded during the test have been presented in Table IV.

**Table 4.** Pycnometer test results

| S.No. | Sample | Specific gravity |
|---|---|---|
| 1 | Soil and 0% fly ash | 2.63 |
| 2 | Soil and 20% fly ash | 2.40 |
| 3 | Soil and 40% fly ash | 2.33 |
| 4 | Soil and 60% fly ash | 2.21 |
| 5 | Soil and 80% fly ash | 2.09 |
| 6 | Soil and 100% fly ash | 2.04 |

A perusal of Table IV clearly shows that the specific gravity of the sample decreased from 2.63 to 2.04 with an increase in fly ash content ranging from 0% to 100%. Therefore, the pycnometer test revealed a decreasing trend in specific gravity of the soil mixed with fly ash samples with increasing percentage of fly ash.

### 6.4 Unconfined compressive strength (UCS) test

Unconfined compressive strength test was conducted strain-controlled to obtain the compressive strength of mixes in an undrained state. It can be contidered as a special case of triaxial test having no confining pressure. The graphical representations of the results have been shown in Fig. 3-6.

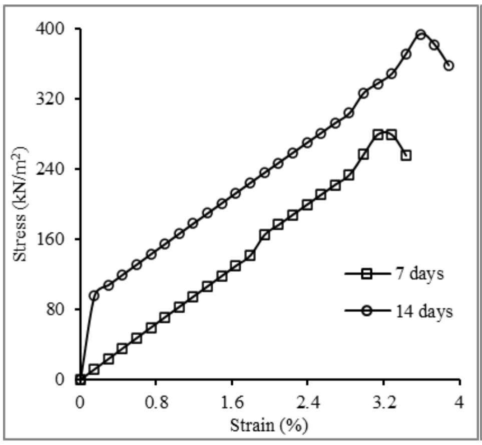



**Fig. 3.** Stress-strain relation of soil with 0% fly ash

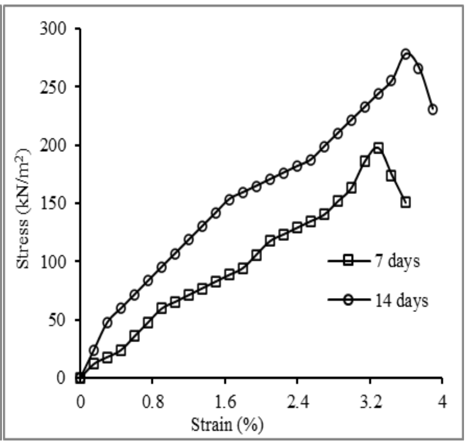



**Fig. 4.** Stress-strain relation of soil with 20% fly ash

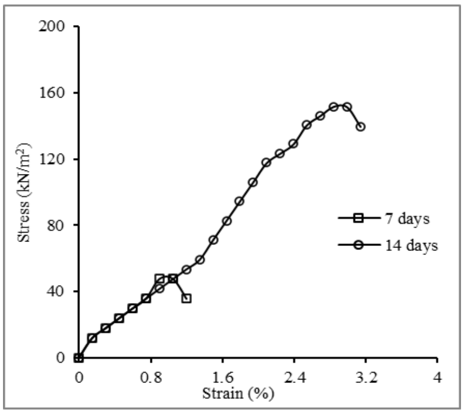



**Fig. 5.** Stress-strain relation of soil with 40% fly ash

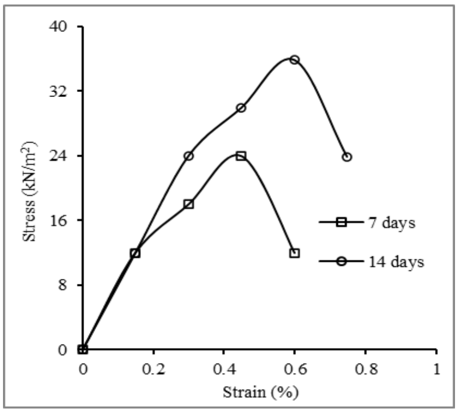



**Fig. 6.** Stress-strain relation of soil with 60% fly ash

It is clear from Fig. 3-6, when fly ash content increased from 0% to 60%, the unconfined compressive strength of 7 days sample decreased from 279.29 kN/m$^2$ to 23.92 kN/m$^2$ and of 14 days decreased from 393.78 kN/m$^2$ to 35.83 kN/m$^2$. Therefore, based on the above results it can be concluded that all the mixes had unconfined compressive strength values of 14 days greater than 7 days. Strength values showed a decreasing trend with an increasing percentage of fly ash. It was not possible to perform the test on mixes having 80% and 100% fly ash content, as the samples were too fragile. The results are summarised in Table V.

**Table 5.** Unconfined compressive strength test results

| S.No. | Sample | Unconfined compressive strength (kN/m$^2$) | |
|---|---|---|---|
| | | 7 days | 14 days |
| 1 | Soil and 0% fly ash | 279.29 | 393.78 |
| 2 | Soil and 20% fly ash | 197.51 | 277.99 |
| 3 | Soil and 40% fly ash | 47.62 | 151.75 |
| 4 | Soil and 60% fly ash | 23.92 | 35.83 |
| 5 | Soil and 80% fly ash | * | * |
| 6 | Soil and 100% fly ash | * | * |

* Sample could not be prepared due to their fragile nature.

### 6.5 Direct shear test

The direct shear test was conducted to determine the shear parameters of the mixes. The undrained test was performed, so there was no dissipation of pore pressure. This test was carried out using various combinations of local soil and fly ash mixes, ranging from 0% to 100%. The results obtained have been used to draw inferences under each category of mixes as follows.

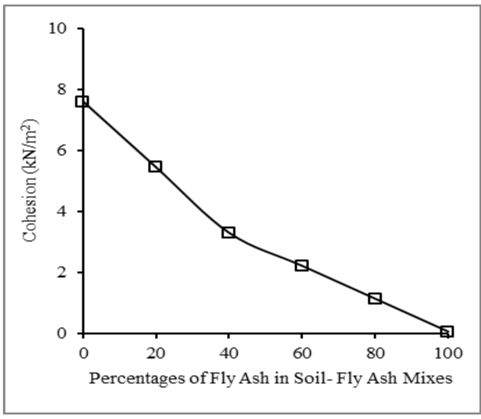



**Fig. 7.** Variation of cohesion

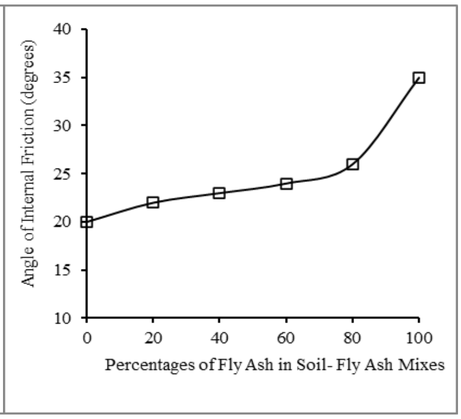



**Fig. 8.** Variation of angle of internal friction

A perusal of Fig. 7-8 clearly shows that when fly ash content increased from 0% to 100%, the cohesion decreased from 7.60 kN/m$^2$ to 0.05 kN/m$^2$ and angle of internal friction increased from 20° to 35°. Therefore, based on the above results it can be concluded that cohesion showed a decreasing trend and angle of internal friction showed an increasing trend with an increasing percentage of fly ash. The results are summarised in Table 6

**Table 6.** Direct shear test results

| S.No. | Sample | Cohesion (kN/m$^2$) | Angle of internal friction (degrees) |
|---|---|---|---|
| 1 | Soil and 0% fly ash | 7.60 | 20 |
| 2 | Soil and 20% fly ash | 5.44 | 22 |
| 3 | Soil and 40% fly ash | 3.29 | 23 |
| 4 | Soil and 60% fly ash | 2.21 | 24 |
| 5 | Soil and 80% fly ash | 1.13 | 26 |
| 6 | Soil and 100% fly ash | 0.05 | 35 |

### 6.6 California bearing ratio test

California bearing ratio test was conducted to evaluate the strength of materials that were proposed to be utilised in the construction of embankment. Three simultaneous tests have been performed on each mix. The average CBR value at 2.5 mm penetration was compared with the average value of CBR at 5 mm penetration. The results obtained have been used to draw inferences under each category of mixes as follows.

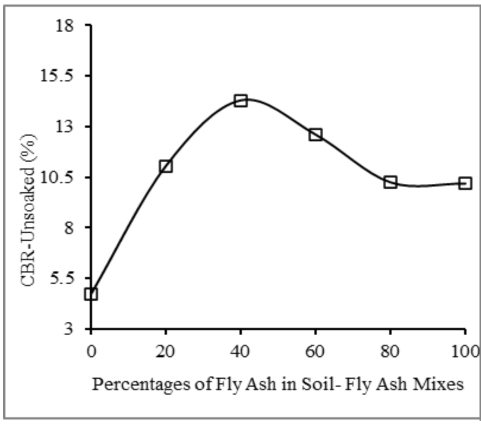



**Fig. 9.** Variation of unsoaked California bearing ratio value

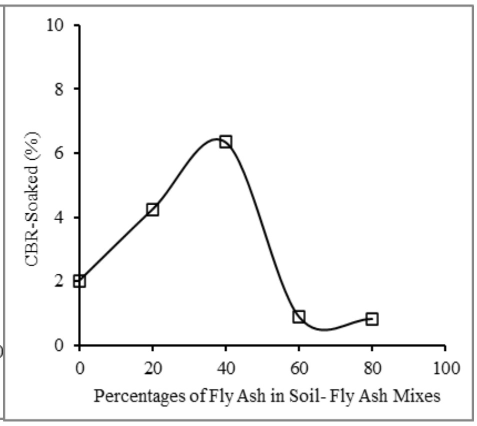



**Fig. 10.** Variation of soaked California bearing ratio value

It is clear from Fig. 9-10, when fly ash content increased from 0% to 100%, the unsoaked CBR value varied from 4.72% to 10.18%. As fly ash content increased from 0% to 80%, the soaked CBR value varied from 2.02% to 0.81%. The soaked CBR value of the sample having 100% fly ash content was not determined due to high bulging effect. As a result, the California bearing ratio test revealed an increasing trend in unsoaked and soaked values of the samples with an increase in the percentage of fly ash till sample having 40% fly ash content. After this, the values showed a decreasing trend. A summary of the result has been represented in Table 7.

**Table 7.** California bearing ratio test results

| S.No. | Sample | Unsoaked CBR (%) | Soaked CBR (%) |
|---|---|---|---|
| 1 | Soil and 0% fly ash | 4.72 | 2.02 |
| 2 | Soil and 20% fly ash | 11.05 | 4.25 |
| 3 | Soil and 40% fly ash | 14.29 | 6.34 |
| 4 | Soil and 60% fly ash | 12.60 | 0.88 |
| 5 | Soil and 80% fly ash | 10.24 | 0.81 |
| 6 | Soil and 100% fly ash | 10.18 | * |

* Sample could not be prepared due to bulging.

## 7 Summary and Conclusions

Coal-based thermal power plants face serious problems in handling produced fly ash. Safe disposal of the ash without adversely affecting the environment are major concerns. Hence, attempts are being made to utilise the fly ash rather than to dump it. Fly ash can be utilised in bulk only in geotechnical engineering applications such as the construction of embankments, as a backfill material, as a sub-base material, etc. The present study evaluates the suitability of local soil and fly ash mixtures with varying fly ash content, as a substitute for conventional fill materials in highway embankments. Based on the results, the following conclusions have been drawn.

1. Fly ash was 'ML' type with non-plastic nature, and permeability was observed to be $1.92 \times 10^{-4}$ cm/sec.
2. Local soil was 'CL' type with plastic nature and permeability was observed to be $2.70 \times 10^{-4}$ cm/sec.
3. OMC followed an increasing trend, and MDD followed a decreasing trend with an increasing percentage of fly ash.
4. The specific gravity of the soil and fly ash samples showed a decreasing trend with an increasing percentage of fly ash.
5. For unconfined compressive strength test, the mixes had strength values of 14 days greater than 7 days, i.e. increase in curing period increased the strength of the mixes.
6. Unconfined compressive strength values displayed a decreasing trend with an increasing percentage of fly ash.
7. It was not possible to perform an unconfined compressive strength test on mixes having 80% and 100% fly ash content, as the samples were too fragile.
8. Cohesion followed a decreasing trend and angle of internal friction followed an increasing trend with an increasing percentage of fly ash.
9. Unsoaked and soaked values of CBR showed an increasing trend with an increasing percentage of fly ash till 40% fly ash content and after this, the values showed a decreasing trend.
10. The soaked CBR value of the sample having 100% fly ash content was not determined due to high bulging effect.

The study is focused on finding an optimum mix of local soil and fly ash based on which the appropriate combination of soil and fly ash may be determined to be used for embankment construction. Based on the study, it can be concluded that local soil with 40% fly ash content is optimum for the construction of highway embankments. The specified sample has maximum CBR value in unsoaked as well as in soaked conditions. The geotechnical parameters of the sample having local soil with 40% fly ash content are summarised below:

1. MDD as 12.73 kN/m$^3$ and OMC as 22%.
2. Specific gravity as 2.33.
3. UCS of 7 days as 47.62 kN/m$^2$ and of 14 days as 151.75 kN/m$^2$.
4. Cohesion as 3.29 kN/m$^2$ and angle of internal friction as 23 degrees.
5. CBR value as 14.29% in unsoaked condition and 6.34% in soaked condition.

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