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# Geotechnical Properties of Parawada Fly Ash and Thagarapuvalasa soil Mixtures for Use in Highway Embankments

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**Abstract**

Fly ash continues to pose a severe threat to environment after several decades of problem recognition due to increasing power production from thermal plants and inadequate fly ash utilization. The solution calls for finding avenues for bulk utilization of fly ash as for embankment construction, for subgrade and as backfill material. This necessitates evaluation of geotechnical characteristics of fly ash mixed with locally available soils. The present study investigates the physical and engineering characteristics of locally available Thagarapuvalasa soil mixed with 0 to 60% of fly ash collected from NTPC, Parawada, Visakhapatnam, India. The results obtained are quite encouraging and confidence building to the engineers, showing significant improvement in cohesion (18.5 to 44 kN/m$^2$) and friction angle (31.4° to 44.7°), unconfined compression strength (75.7 to 163.2 kN/m$^2$) and soaked CBR (7.4 to 24.5%) for 40% fly ash content. Even at 60% fly ash, there is significant improvement in the properties of natural soil. The decrease in MDD is another advantage decreasing the loads on the foundation soils of the embankments and lateral earth pressure on retaining walls.

**Key Words**: Fly ash, Geotechnical characteristics, Highway embankment, NTPC Parawada, Thagarapuvalasa soil, Waste utilization.

## 1. Introduction

Thermal power plants produce huge quantities of fly ash as waste across the world, which has become a major source of environmental pollution. Ultimately, these materials require removal and disposal in solid state landfills or other management units, typically at substantial cost. Major portion of fly ash is disposed as waste even today.

Infrastructure projects such as highways, railways, reservoirs, land reclamation etc. require earth material in very large quantity. In urban areas, borrow earth is not easily available which has to be hauled from a long distance. As fly ash is freely available, for projects in the vicinity of a Thermal Power Plants, it can be utilized in bulk in geotechnical engineering applications such as construction of embankments, as a backfill material, as a sub-base material, etc. The properties of fly ash depend on the type of coal and method used for the power generation in the power plants. This calls for an in-depth understanding of the physical and chemical properties, and engineering behavior of fly ash (Pandian, 2004). If understood and managed properly, fly ash can prove to be a valuable resource material.

The present study is a part of the research work aimed in this direction. Narasinga Rao and Anantha Sairam (2017) and Narasinga Rao (2016) demonstrated that M25 and M20 grade concrete can be used using 41% and 50% NTPC Parawada fly ash replacing the cement, achieving the desired target mean compression strength.

The present paper presents the physical and engineering properties of Thagarapuvalasa soil mixed with fly ash from NTPC, Parawada in proportions from 0 to 60 percent.

## 2. Literature Review

Erdal Cokca (2001) carried out investigations using both high calcium and low calcium class C fly ashes from Soma Fly ash and Tuncbilek fly ash and added to expansive soil at 0-25%.

Pandian et.al. (2002) studied the effect of Raichur fly ash (Class F) and Neyveli fly ash (Class C) on the CBR characteristics of the black cotton soil from Karnataka, India and reported the beneficial aspects of the fly ash-soil mixes in road construction. The fly ash content was increased from 0 to 100%.

Bhuvaneshwari et al (2005) reported that the UCS of BC soil increased significantly by 30% for 10% addition of fly ash and only by about 5% for 20% addition of fly ash. Further addition of fly ash decreased the UCS by about -20% and -56% respectively for 40% and 50% addition of fly ash.

The road subbase for the industry access truck route in Meredosia, Illinois, used approximately 60,000 cubic meters of compacted high loss-on-ignition Class-F ponded fly ash (Samrat and Chugh, 2006) to construct the subbase for the 7.3 m wide and 3.4 km long road. The fly ash control section was 2.2 km long and was built on silty/clayey subgrade using fly ash as subbase. The fly ash control section in particular has exhibited very good structural performance.

Results from field quality control tests performed (Sungmin et al, 2009) during construction of the demonstration embankment and monitoring data from vertical and horizontal inclinometers and settlement plates indicate that the ash mixture investigated can be considered an acceptable embankment construction material.

Prasanna Kumar (2011) attempted to improve physical and strength properties of black cotton (BC) soil and a non-expansive red earth (RE). Raichur Fly Ash (RFA) and Neyveli Fly Ash (NFA) have been incorporated to black cotton soil and red earth to test improved properties. Cement is also used to improve further strength of soils. The combination of RE+NFA mixtures has reached strength of 2306 kPa for addition of 40% NFA after 28 days curing from as low as 590 kPa of red earth. The effect of pozzolanic reaction dominates strength gain at higher curing periods, whereas the effect of density dominates strength gain at lower curing periods. For all combinations, an addition of 30 to 40% of ash has shown high strength gain by both soils.

Vukićević et al (2013) observed that increasing percentage of Kolubara fly ash (KFA), Serbia, results in decrease in the liquid limit and plasticity index, for soil A of high plasticity,

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which is not the case for low plasticity soil (soil B). Maximum dry density decreases and optimum moisture content increases as the KFA content increases for both soil types. Soil UCS for soil A is increased by 15-25%, dependent of elapsed time. UCS for soil B without stabilizer was around 400 kPa and addition of fly ash didn't result in strength gain. Obtained results show that long term friction angle doesn't substantially change with addition of fly ash, for both soil types. On the other hand, cohesion significantly increases with time for all tested mixtures. CBR value was increased from 2.1 to 5.8.

Gyanen et al (2013) investigated the compaction and unconfined compression strength of stabilized black cotton soil using 5 to 30% of fine and coarse fly ash mixtures. The study concludes that with percentage addition of fine, coarse fly ash improves the strength of stabilized black cotton soil and exhibit relatively well-defined moisture-density relationship. It was found that the peak strength attained by fine fly ash mixture was 25% more when compared to coarse fly ash.

Studies by Saravanan et al (2013) on BC soil mixed with various percentage of fly ash (FA) collected from Mettur Thermal Power plant indicated that addition of fly ash reduces the plasticity index and specific gravity of the expansive clayey soil. MDD increases maximum by 16.9% for 10% addition of FA but further addition of FA causes less increase in MDD. OMC decreases steadily for addition of FA up to 40%. Similarly the UCS increases maximum by about 21% for 10% addition of FA but further addition of FA (20%) causes less increase in UCS (16%). At 30% addition of FA the change in UCS is negligible and further increase in FA to 40% causes a decrease in UCS by about 7%.

Arash Hosseini (2015) reported results with fly ash from Bellary Thermal Power Station (BTPS), Kudutini (Bellary Dist, Karnataka). The liquid limit decreases from 63% to 46%, plastic limit marginally increases from 25% to 28% and the plasticity index decreases from 38% to 18% for the corresponding increase in the addition of fly ash from 10% to 60% respectively. The maximum dry density is found to increase from 1.72 g/cc (17.2 $kN/m^3$) for FBC-10 mix to 2.07 g/cc (20.7 $kN/m^3$) for FBC-30 mix and further increase in the addition of DFA is observed to decrease it. The optimum moisture content decreases from 15% for FBC-10 mix to 5% for FBC-30 mix. The unconfined compression strength of these soils, increases from 0.00032 $N/mm^2$ for M-10 mix to 0.00037 $N/mm^2$ for M-50 mix for a curing period of 7 days. For both the cases of curing periods maximum unconfined compression strength is found to be at 30 % of fly ash (FBC- 30 mix).

The effect of adding Fly ash from West Coast Paper Mills, Dandeli (Karwar Dist, Karnataka) on three natural black cotton soil samples from different locations of Hubballi-Dharwad Municipal Corporation (HDMC) area, one Highly expansive, second Moderately expansive and third Least expansive soil in the range of 0-60% was investigated by Udayashankar and Puranik (2012). Increase in MDD and decrease in OMC with increasing percentages of DFA is observed up to 30 -40% and the MDD is observed to decrease with further increase in the DFA percentages. It is seen that the strength increases on addition of small percentage of 10% or 20% of fly ash. Further increase in fly ash percentage shows no considerable increase in the strength.


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The CBR value of the soil increases with the addition of DFA up to a certain percentage of fly ash (30-40% here) and there after it starts decreasing for further addition of DFA.

Satyendra Singh and Yadav (2015), in their study, used fly-ash to stabilize the expansive soil, in proportions of 10%, 20%, 30%, 40%, 50%. The liquid limit of expansive soil decreased from 55.2% to 36.3% and plasticity index decreased from 27.1% to 18.1%, differential free swell (DFS) also reduced from 52% to 14% respectively. The compaction test results showed increase in optimum moisture content (OMC) from 19% to 23% and decrease in maximum dry density (MDD) from 1.63g/cc (16.3 kN/m$^3$) to 1.52g/cc (15.2 kN/m$^3$). Test result indicates that fly-ash has a potential to improve the properties of black cotton soil.

Somnath and Sujit Kumar (2015) reported the permeability and volume change behaviours of soil stabilized with up to 40% fly ash. With increase in fly ash content in NIT Agartala soil, maximum dry density (MDD) decreases and optimum moisture content (OMC) increases.

Gourav and Nikhlesh (2015) found that when fly ash from Koradi power plant, Nagpur, India, was added to black cotton soil, the liquid limit decreased and the plastic limit slightly changed. The plasticity index of virgin soil was found to be 36.78%, but with an increase in the amount of fly ash, the plasticity index decreased to 16.895% at 30% fly ash.

When fly ash is mixed with soil, it reduces the clay content, with a subsequent decrease in the plasticity index (Hardaha et al., 2013). At 0% fly ash, the MDD value was found to be 1.54 g/cm$^3$ (15.4 kN/m$^3$). When the amount of fly ash was increased, the MDD value decreased to a minimum MDD value of 1.44 gm/cm$^3$ (14.4 kN/m$^3$) at 20% fly ash. The decrease in the maximum dry unit weight with the increase in the percentage of fly ash is primarily a result of the lower specific gravity of the fly ash compared with expansive soil. In the case of shear strength characteristics, the UCS of natural soil was 7.6 N/cm$^2$, but when treated with fly ash, a maximum UCS value of 18.15 N/cm$^2$ was obtained at 20% fly ash.

## 3. Materials and Methods

**Table 1 Chemical composition of Parawada Fly ash**

| Chemical compound | Value (%) |
|---|---|
| $SiO_2$ | 60.01 |
| $SiO_2+Al_2O_3+Fe_2O_3$ | 94.48 |
| CaO | 8.7 |
| $Na_2O$ | 0.24 |
| MgO | 0.20 |
| $SO_3$ | 0.28 |
| Loss on ignition | 0.6 |


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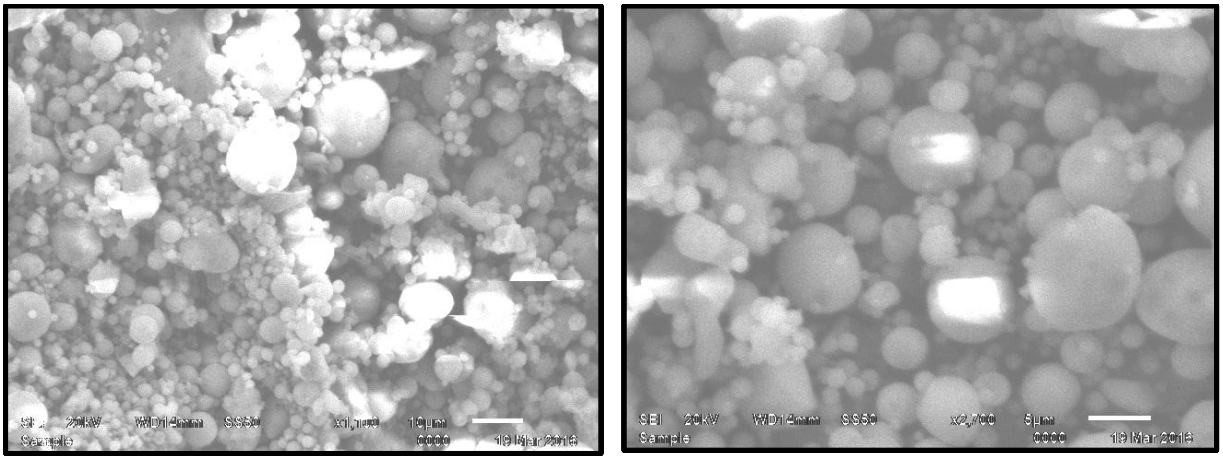
Fig.1 shows the samples of fly ash and soil used in the study. The fly ash is collected from NTPC, Parawada, Visakhapatnam, India. Table 1 presents the chemical composition of fly ash. Fig.2 shows the Scanning electron micrograph of the fly ash sample with two magnification levels. Wet sieve analysis indicated that fly ash has 75% fines and 25% sand. The fine fraction is subjected to hydrometer analysis. The % of clay is found to be about 2% and the rest 73% is silt. Fig.3 shows the combined grain size distribution curve of coarse and fine fractions of fly ash. As fly ash is found to be non-plastic, it may be classified as Sandy Silt. Specific gravity of collected fly ash was determined by density bottle method and was found to be 2.07.

(a) Parawada Fly ash (b) Thagarapuvalasa Soil

**Fig.1 Samples of fly ash and soil**



(a) Picture width 114.6 μm (b) Picture width 47.4 μm

**Fig.2 scanning electron micrographs of the fly ash sample**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Locally available soil is collected from Thagarapuvalasa, Visakhapatnam district is used in the study. The grain size analysis of soil indicated that the soil has 2.2% gravel, 95.2% sand and 2.6% fines. Fig.2 shows the GSD curve for soil. The soil is classified as Poorly graded Sand (SP) as per IS:1498-1970.

### 3.1 Soil -fly ash mixtures

Fly ash is added to the soil in dry form in the proportions shown in Table 2. The OMC and MDD of the soil-fly ash mixtures was determined using IS heavy (Modified Proctor) compaction. For determination of engineering properties of fly-ash amended soils, soil and fly ash are added in dry state in required proportion as in Table 2 and then compacted at OMC under IS heavy compaction. The samples are then cured for 2 days and specimens required for each test are extracted from the cured samples. The specimens are then subjected to tests including liquid limit, direct shear, unconfined compression, CBR and permeability. The CBR of the soil-fly ash mixtures is determined at OMC after soaking the compacted samples for 4 days in water.

**Table 2 Soil- Fly ash mixtures**

| Soil-fly ash mixture | % Soil | % Fly ash |
|---|---|---|
| SF0 | 100 | 0 |
| SF10 | 90 | 10 |
| SF20 | 80 | 20 |
| SF40 | 60 | 40 |
| SF60 | 40 | 60 |

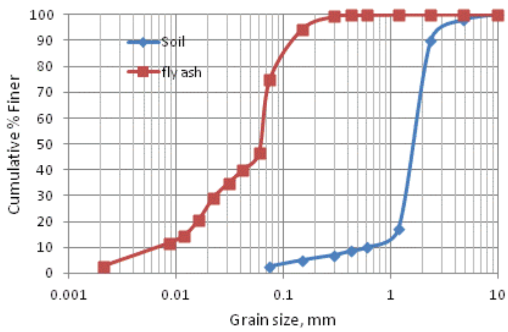


**Fig.3 Grain size distribution curves of fly ash and soil**

## 4. Results and Discussion

### 4.1 Index Properties

The soil sample is found to be non-plastic. The liquid limit of the soil when mixed with fly ash from 0 to 60% is determined using Uppal's cone penetration method and the results are


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presented in Table 3. As both soil and fly ash are non-plastic, there is no significant effect of fly ash on liquid limit of the soil.

**Table 3 Effect of fly ash on Liquid limit Proportion**

| Soil-fly ash mix | Liquid limit % |
|---|---|
| SF0 | 21.4 |
| SF10 | 21.2 |
| SF20 | 20.6 |
| SF40 | 20.0 |
| SF60 | 19.2 |

**4.2 Compaction characteristics**

Fig.4 presents the compaction curves of soil-fly ash mixtures. Addition of fly ash shifts the compactions curves to the right and bottom relative to that of natural soil. Table 4 presents OMC and MDD for different soil-fly ash mixtures. It may be observed from Table 4 that OMC increases significantly with the increase in percent fly ash from 10.1% at 0% fly ash to 15.5% at 60% fly ash. MDD decreases significantly from 20.0 kN/m$^3$ at 0% fly ash to 16.5 kN/m$^3$ at 60% fly ash.

Addition of fly ash increases the fine fraction in soil-fly ash mixtures, which attracts more water than the natural soil due to more affinity with water. This additional water attracted increases the OMC and decreases the dry density of soil-fly-ash mixture.

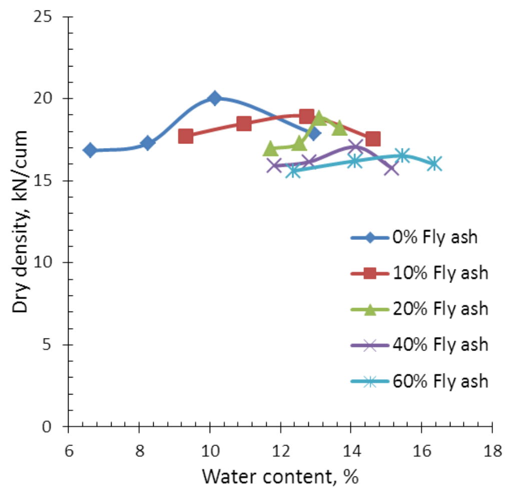


**Fig.4 Compaction curves of soil-fly ash mixtures**


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The decrease of maximum dry density with increasing percentage of fly ash is also mainly due to lower specific gravity of fly ash (2.07) than that of natural soil (2.69). The decrease in MDD of soil due to addition of fly ash has the following beneficial effects (Sridharan, 2012)

1. The fly ash-soil mixtures when used for embankments cause less overburden pressure on foundation soils
2. When fly ash-soil mixtures are used as backfill materials they cause lesser lateral earth pressure on retaining walls.

**Table 4 Effect of fly ash on OMC and MDD**

| Soil-fly ash mix | OMC (%) | % Variation with SF0 | MDD kN/m$^3$ | % Variation with SF0 |
|---|---|---|---|---|
| SF0 | 10.1 | 0.0 | 20.0 | 0.0 |
| SF10 | 12.7 | 25.7 | 18.9 | -5.5 |
| SF20 | 13.1 | 29.7 | 18.8 | -6.0 |
| SF40 | 14.2 | 40.6 | 17.1 | -14.5 |
| SF60 | 15.5 | 53.5 | 16.5 | -17.5 |

### 4.3 Shear Strength

Table 5 presents the shear parameters of the soil added with different percentages of fly ash. It may be observed from Table 5 that the cohesion of soil increases significantly from 18.5 kN/m$^2$ (0% fly ash) to 44 kN/m$^2$ (40% fly ash). Thus the cohesion of soil increases more than twice (137.8%) for 40% addition of fly ash. With further addition of fly ash beyond 40% the cohesion decreases to 36.6 kN/m$^2$ but this is still more than that of soil with 0% fly ash by 97.9%.

**Table 5 Effect of fly ash on Shear parameters of soil**

| Soil-fly ash mix | Cohesion kN/m$^2$ | % variation | $\phi$, Deg. | % variation |
|---|---|---|---|---|
| SF0 | 18.5 | 0 | 31.4 | 0 |
| SF10 | 28.0 | +51.4 | 35.9 | +14.40 |
| SF20 | 33.5 | +81.1 | 40.7 | +29.6 |
| SF40 | 44.0 | +137.8 | 46.5 | +48.3 |
| SF60 | 36.61 | +97.9 | 44.7 | +42.5 |

The friction angle increases significantly from 31.4° (0% fly ash) to 46.5° (40% fly ash). With further addition of fly ash, the friction angle of soil decreases marginally to 44.70° (60% fly ash). Fig.5 illustrates the effect of fly ash on shear parameters of soil. To understand the cumulative effect of fly ash on the shear parameters of soil, the shear strength of soil is determined


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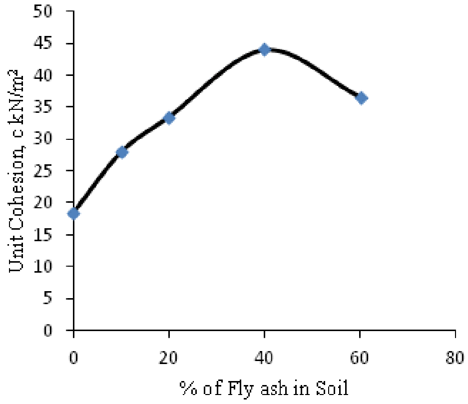
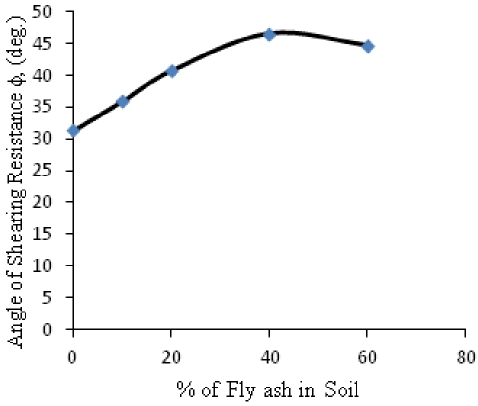
at different proportions of fly ash, considering a normal stress of 100 kN/m$^2$. Table 6 presents this data. It may be noted that the shear strength of soil increases by 88.1% for 40% addition of fly ash and by 70.6% for 60% fly ash.




(a) Cohesion




(b) Angle of Shearing Resistance (ϕ)

**Fig. 5 Effect of fly ash on Shear parameters of soil**

The grain size distribution curve of Thagarapuvalasa soil (see Fig.2) indicates that >85% particles in the soil are coarser than 1.0 mm. The GSD curve of fly ash (see Fig.2) indicates that >85% particles in fly ash are finer than 0.1 mm. The blending of soil and fly ash causes the finer particles of fly ash to fill the voids of the coarser particles of Thagarapuvalasa soil creating a denser mass of soil fly ash mixture, which increases the shear strength.

Also the increase of fine fraction of fly ash attracts more water than the natural soil. This additional water leads to chemical reaction and formation of cementation products by hydration improving the shear strength of the soil.

Although a dense mass is created in soil-fly ash blending, the dry density is less than that of untreated soil due to low specific gravity of fly ash (2.07) than that of natural soil (2.69).

With increase in the percentage of fly ash up to 40%, the free lime (CaO) promotes better cementitious bonding through chemical reaction, increasing the strength. When the fly ash content is more than 40%, the grain size distribution of the mixture is possibly affected due to excess of fines leading the decrease in the shear strength.

**Table 6 Effect of fly ash on Shear strength of soil**

| Soil-fly ash mix | Shear strength* kN/m$^2$ | % variation with SF0 |
|---|---|---|
| SF0 | 79.49 | 0 |
| SF10 | 100.39 | +26.3 |
| SF20 | 119.45 | +50.3 |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| | | |
|---|---|---|
| SF40 | 149.49 | +88.1 |
| SF60 | 135.60 | +70.6 |

** For normal stress of 100 kN/m²*

### 4.4 Unconfined compression strength

Table 7 presents the unconfined compression strength (UCS) of soil at different proportions of fly ash. When 10% of fly ash is added, the UCS increases marginally by 16.6%. With further addition of fly ash the UCC of soil increases significantly by 44.4% (20% fly ash) and by 115.6% (for 40% fly ash). With further addition of fly ash up to 60%, the UCS decreases from 163.2 kN/m$^2$ to 88.8 kN/m$^2$. However, the UCS of the soil with 60% fly ash is more than that of soil with 0% fly ash by +17.3%. Fig.6 illustrates the effect of fly ash on unconfined compression strength. The variation of UCS at varying fly ash content is similar to that of shear strength and hence can be understood on the same lines.

**Table 7 Effect of fly ash on unconfined compression strength of soil**

| Soil-fly ash mix | Unconfined compression strength kN/m$^2$ | % variation with SF0 |
|---|---|---|
| SF0 | 75.7 | 0 |
| SF10 | 88.3 | +16.6 |
| SF20 | 109.3 | +44.4 |
| SF40 | 163.2 | +115.6 |
| SF60 | 88.8 | +17.3 |

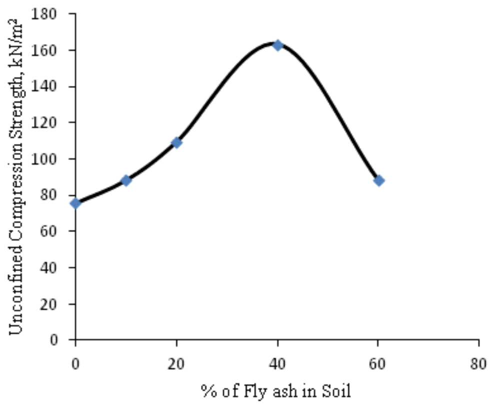


**Fig. 6 Effect of fly ash on unconfined compression strength of soil**

### 4.5 CBR

Table 8 presents the soaked CBR of soil before and after addition of fly ash in different proportions. It may be observed from Table 8 that the soaked CBR of soil increases significantly


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from 7.4% to 24.5% when the fly ash is added from 0% to 40% respectively. Thus, the CBR of soil added with 40% fly ash increased by as much as three times that of natural soil. Further addition of fly ash decreases the CBR of soil. However, the CBR of soil with 60% fly ash is more than that with 0% fly ash by 126.1%. It may be concluded that soil treated with fly ash requires lesser thickness of pavement for the same traffic load. Fig.7 illustrates the effect of fly ash on CBR of soil.

**Table 8 Effect of fly ash on Soaked CBR of soil**

| Soil-fly ash mix | Soaked CBR % | % Variation with SF0 |
|---|---|---|
| SF0 | 7.40 | 0 |
| SF10 | 12.8 | 73.5 |
| SF20 | 21.4 | 189.2 |
| SF40 | 24.5 | 231.2 |
| SF60 | 16.7 | 126.1 |

The penetration resistance of the soil, which is reflected in CBR, improves by the addition of fly ash due to improvement in the denseness of the soil fly-ash mixture and formation of cementation bonds between the particles until the fly ash content increases up to 40%. When the fly ash content increases beyond 40%, the penetration resistance decreases (compared to 40% fly ash) presumably due to decrease in the shear strength because of increased fines and adverse gradation. The CBR at 60% fly ash content is however more than twice that of natural soil.

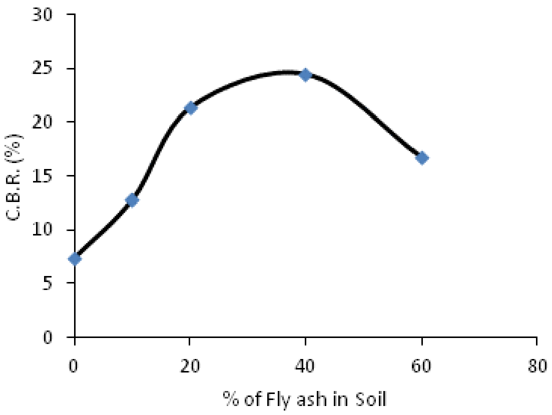


**Fig. 7 Effect of fly ash on CBR of soil**

**4.6 Permeability**

Table 9 presents the permeability of soil added with fly ash in different proportions. It may be observed from Table-9 that addition of fly ash decreases the permeability of soil significantly. Fig.8 illustrates the effect of fly ash on permeability of soil. The steady decrease in the permeability of the soil with increase in % of fly ash supports the idea that the soil fly ash mixture


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becomes denser due to better gradation and formation of cementation products up to fly ash content of 40%. Permeability of soil decreases marginally when fly ash is increased from 40% to 60%, possibly due to increased fines content from fly ash.

**Table 9 effect of fly ash on permeability of soil**

| Soil-fly ash mix | Permeability, ($\times 10^{-4}$ cm/sec) | % variation with SF0 |
|---|---|---|
| SF0 | 8.87 | 0 |
| SF10 | 4.62 | -47.91 |
| SF20 | 3.11 | -64.94 |
| SF40 | 0.163 | -98.16 |
| SF60 | 0.0665 | -99.25 |

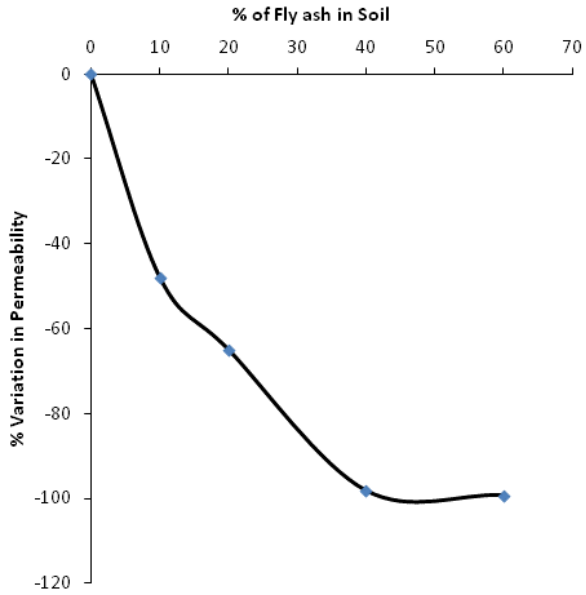


**Fig. 8 Effect of fly ash on permeability of soil**

## 5. Conclusions

Following conclusions may be drawn based on the results obtained from the present study, where Thagarapuvalasa soil is added with 0 to 60% of fly ash from NTPC Parawada.

1) Thagarapuvalasa soil and fly ash are both non-plastic, and there is no significant effect of fly ash on liquid limit of the soil.

2) OMC increases significantly with the increase in percent fly ash from 10.1% at 0% fly ash to 15.5% at 60% fly ash. MDD decreases significantly with increase in percent fly ash.
3) Both cohesion and friction angle of Thagarapuvalasa soil increase significantly due to addition of fly ash up to 40%. The shear strength of soil increases by 70.6% for 60% fly ash for a normal stress of 100 kPa. The effect of fly ash on the UCS of soil is similar to that on shear strength.
4) The soaked CBR of Thagarapuvalasa soil increases significantly to more than 3 times that of natural soil for 40% fly ash addition and to more than 2 times that of natural soil for 60% fly ash.
5) The permeability decreases by 98% of that of natural soil for 40% fly ash and decreases marginally for further addition of fly ash.
6) Addition of fly ash increases the fine fraction in soil-fly ash mixtures, which attracts more water than the natural soil due to better affinity with water, which increases the OMC and decreases the dry density of soil-fly-ash mixture. The decrease of maximum dry density with increasing percentage of fly ash is also mainly due to lower specific gravity of fly ash (2.07) than that of natural soil (2.69).
7) Typical nature of soil-fly ash mixtures used in this study is that they show less MDD due to lower specific gravity of fly ash, although the denseness of the soil is improved due to improved gradation.
8) Apart from this physical interaction between soil and fly ash, the formation of cementation products by hydration leads to significant improvement in the shear strength, UCS and CBR.
9) The study confirms that fly-soil embankments are subjected to significantly less stresses and improved slope stability with reduced driving moments, due to lower MDD. When used as backfill material, fly ash-soil mixtures exert less lateral earth pressure.

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