FLY ASHUTILISATION IN ROAD CONSTRUCTION


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PREPARED BY

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CONTENT

1.0 Introduction:

Fly ash is a fine residue of coal combustion in the Thermal Power Plants. With the increasing demand of power and coal being the major source of energy, more no. of Thermal Power Plants have been setup. The thermal grade Indian coal contains 35 to 45% of ash resulting in generation of huge quantity of fly ash. Management and disposal of fly ash is an environmental issue. Storage of ash in ponds and mounds also require large amount of land. The State of Odisha is in the course of rapid industrialization, as a result power requirement has considerably increased. Coal being the main raw material for thermal power generation, ash is the essential by product.

Huge quantity of bottom ash & fly ash are generated from boilers of coal fired Thermal Power Plants (TPP). Fly ash being light in weight is collected in Electro Static Precipitator (ESP) & Bag Filters connected to the coal fired boilers of the TPPs. The ash collected from these air Pollution control equipment are either transported in the form of slurry to the Ash Pond or deposited in dry form, in ash Mounds otherwise.

Internationally fly ash is considered as a byproduct which can be used for many appliances.

Presently the quantity of ash generation from the Thermal Power Plant in Odisha is around 25 Million Tonne / Annum. An amount of 15.16 Million Tonnes (62 %) was utilized in various sectors during year 2013-14.

Coal is the major energy source in the power production scenario not only in India but in many other countries. More than 60 per cent of power generated in India is from coal. India has vast reserves of coal estimated at 200 billion tonne and it is expected that coal would remain as prime source of energy for many more years. Use of coal for power generation generates huge amount of ash. India currently produces about 130 million tonnes of fly ash. About two decades back, hardly 3 per cent of 40 million tonnes of ash produced was utilised. Presently about 60 million tonne/annum of fly ash is being utilised in various applications.

In order to address the problems associated with fly ash management, various opportunities of utilisation has been explored. Besides use of fly ash in manufacture of construction material, land development, mine void filling, the use of fly ash for road construction has also increased phenomenally in India with an annual utilisation of about 8.82 million tonnes in road construction, which constitutes about 16 per cent of total utilisation. Hence use of fly ash for road and embankment construction is thus justifiably called high-volume ash utilisation. The typical approach for redemption of soft sub-grade has consisted of removal of poor soil and its replacement with large quantity of crushed rock. The high cost of removal of poor top soil and transportation of aggregates, along with increasing interest in re-usable of industrial by product has prompted investigation to find out solution that compliments the need of highway construction. Use of fly ash for stabilization of soft sub-grade as a replacement to soil is one of these solution.

CSIR-Central Road Research Institute (CRRI) during last 15 years has undertaken many road and embankment demonstration projects using fly ash. As a result of experiences gained in these projects, specifications for construction of road embankments and guidelines for usage of fly ash for rural roads were compiled and these have been published by the Indian Roads Congress. The road construction industry no longer considers fly ash as an un-known material but is using fly ash for road works at many locations. This report is prepared on the basis of such reports / guidelines available in India.

When pulverised coal is burned in a furnace at the power stations, it produces very fine ash called "Fly ash" which comes out of the furnace along with flue gases. Fly ash accounts for about 75-85 per cent of the total ash formed. The remaining coarser fraction of the ash falls to the bottom of the furnace where it sinters to form "Bottom ash". Fly ash is removed from the flue gases using electrostatic precipitators (ESP) and is initially collected in hoppers. Bottom ash (after grinding) and fly ash from hopper are mixed with water and disposed off in a slurry form to ponds. This deposit is called "Pond ash". However, generally the term fly ash is used as a generic (common) name to denote any of these three types of ashes.

2.0 Fly Ash as a Road Construction Material:

For overall evaluation of industrial wastes for use as construction materials a 'NICE' criterion has been suggested which is explained below:

(i) 'N' on-hazardous: Fly Ash non-hazardous with regard to ignitability, corrosivity, reactivity and toxicity.

(ii) 'I'm provable: It should possess high potential for improvability of its properties, such as workability, performance in conjunction with additives.

(iii) 'C'ompatible with other construction materials and consistent in its properties.

(iv) 'E'conomically feasible, it should have the characteristics of low unit cost and high quality resulting in savings on construction cost, usable as produced without costly processing, enough and easily available, easy to handle and store and possessing long term stability in performance.

By all these counts, fly ash is a really 'NICE' material for use in road pavements and embankments.

2.1 Favourable Characteristics of Fly Ash for use in Roads and Embankments

The following characteristics of fly ash make it a preferred material for road construction.

- **Lightweight** as compared to commonly used fill material (local soils), therefore, causes lesser settlements.

It is especially attractive for embankment construction over weak sub-soils where excessive weight could cause failure. Fly ash also causes lesser pressure on retaining walls due to lower weight.

- **Higher value of California Bearing Ratio** as compared to soil provides for a more efficient design of road pavement.

- **Pozzolanic hardening** property imparts additional strength to the road pavements/embankments and decreases the post construction horizontal pressure on retaining walls.
- **Amenable** to stabilisation with lime and cement.
- Can be compacted over a wide range of moisture content, and therefore, results in lesser variations in density with changes in moisture content.
- **Easy to handle** and compact because the material is light and there are no large lumps to be broken down.
- Can be compacted using either vibratory or static rollers.
- **Offers greater stability of slopes** due to higher angle of friction. Value of angle of internal friction increases even more upon compaction.
- **High permeability** ensures free and efficient drainage. After rainfall, water gets drained out freely ensuring better workability than soil, especially during monsoons. Work on fly ash fills/ embankments can be restarted within a few hours after rainfall, while in case of soil it requires much longer period.
- **Faster rate of consolidation**; a major part of decrease in volume occurs during primary consolidation phase, which is generally rapid, thus making it an ideal material for road fills.
- Considerable **low compressibility** results in ease of compaction and shows negligible subsequent settlement within the fill.
- **Conserves good earth**, which is precious topsoil, thereby protecting the environment.
- High sulphur contents can cause formation of expansive minerals which severely reduces the long term strength and durability. But low sulphur content Indian fly ash (less than 0.6 %) can add long term strength and durability to sub grade.
- Fly Ash effectively dries wet soil and provides an initial rapid strength gain which is very useful during construction in wet, unstable ground conditions.
- Fly Ash decreases swelling potential of expansive soils.

3.0 Characteristics of Fly Ash:

The chemical properties of the fly ash are largely influenced by the chemical content of the coal burnt (i.e., anthracite, bituminous, and lignite).

Fly ash generated from the Thermal Power Plant of Odisha contains several minerals in the form of oxides in different proportions. However the proportion of minerals vary depending on the type and quality of coal.

Chemically, fly ash is amorphous ferro-alumina silicate mineral with major matrix elements like, Si, Al, Fe, together with significant amounts of major / secondary nutrients (K, P, Ca, Mg, S) and micro nutrients (Cu, Zn, Mn, Fe, Mo).

Table-1

Chemical Composition of Fly Ash, Pond Ash and Soil

Sl. No.	Compounds (per cent)	Fly Ash	Pond Ash	Soil
1.	SiO_2	38-63	37.7-75.1	43-61
2.	Al_2O_3	27-44	11.7-53.3	12-39
3.	TiO_2	0.4-1.8	0.2-1.4	0.2-2
4.	Fe_2O_3	3.3-6.4	3.5-34.6	1-14
5.	MnO	b.d-0.5	b.d-0.6	0.02-0.1
6.	MgO	0.01-0.5	0.1-0.8	0.2-3
7.	CaO	0.2-8	0.2-0.6	1-7
8.	K_2O	0.04-0.9	0.1-0.7	0.4-2
9.	Na_2O	0.07-0.43	0.05-0.31	0.2-3
10.	LOI	0.2-5.0	-	5-16
11.	pH	6-8	6.5-8.5	4.5-8.0
bd : below detection ; LOI : Loss on Ignition				

3.1 Properties of Fly Ash:

It is necessary to understand the characteristics of fly ash before we consider its applications, as the characteristics govern its suitability for various end uses. Indian coals generally have high percentages of ash content and low sulphur content (less than 0.6 per cent) except in Assam coal where sulphur content is relatively high (2 to 8 per cent). In India, low ash, and low volatile coals with high calorific value such as anthracite are reserved for steel industry. Bituminous and sub-bituminous coal with volatile content between 18 to 35 per cent and ash content from 30 to 50 per cent are generally used in our thermal power plants. The fly ash produced from different types of coal differs in their chemical composition. Fly ashes from anthracite and bituminous coal are rich in silica, alumina and iron oxide and are classified as class F as per ASTM C 618, whereas lignitic (sub-bituminous) coals produce fly ash having high calcium oxide content and are classified as Class C. Class C fly ash is generally more pozzolanic and possesses some hydraulic/ cementitious properties also as compared to Class F fly ash which is inert but will react with hydrated lime in the presence of water to form cementitious compounds. This property (reacting with lime in presence of water) is called pozzolanic activity. The pozzolanic activity is attributable to the presence of SiO_2 and Al_2O_3 in amorphous form. The pozzolanic activity of fly ash is sensitive to temperature of curing. Steam curing or autoclaving greatly accelerates pozzolanic activity. Pozzolanic reaction is an exothermic reaction generating heat similar in nature to the heat of hydration of cement but to a lesser scale. Addition of fly ash as pozzolana reduces volume change and therefore controls cracking. Therefore, fly ash is the ideal admixture with cement for mass concrete works as in dams, raft foundations and concrete pavements. The minimum requirement of pozzolanic activity for fly ash as determined by lime reactivity test is 4.5 MPa (IS 3812). Pond ash and bottom ash do not possess sufficient degree of pozzolanic reactivity as compared to fly ash collected in dry form.

3.2 Chemical reactions in soil-fly ash and lime-soil-fly ash mixes:

Suitability of fly ash for use in fills and embankments, and in soil stabilisation (in unprocessed form as well as blended with lime and cement) has been well established. Class C fly ashes possess self-hardening property and can be used as such or mixed with cement/ lime to stabilise soils. Low calcium fly ashes (Class F) blended with lime or cement can be used to stabilise soils. Pozzolanic reaction between fly ash, lime and water gives rise to cementitious products, which bind the soil particles. The reactive silica and alumina present in fly ash reacting with lime as given below:

$Ca(OH)_2 + SiO_2 + H_2O \rightarrow CaO.SiO_2.2H_2O$ (i.e. Calcium silicate hydrate)

$4Ca(OH)_2 + 4Al_2O_3 + 9H_2O \rightarrow 4CaO.Al_2O_3.13H_2O$ (i.e. Calcium aluminate hydrate)

$2Ca(OH)_2 + 2Al_2O_3 + 2SiO_2 + 6H_2O \rightarrow 2CaO.Al_2O_3.SiO_2.8H_2O$ (i.e Startlings compounds)

The kinetics of reactions of $Ca(OH)_2$ with SiO_2 and Al_2O_3 in the fly ash are slow at ambient temperature and increase with rise in temperature. Therefore, in the initial stages of hydration, there is no appreciable strength development. The rate of reaction can be increased by raising temperature or by addition of gypsum in the lime-fly ash matrix. When gypsum ($CaSO_4.2H_2O$) is added to the lime-fly ash matrix, ettringite ($3CaO.Al_2O_3.3CaSO_4.31H_2O$) is formed initially. Later this compound changes over to monosulphate ($3CaO.Al_2O_3.3CaSO_4.12H_2O$) as the water is removed from the system.

The optimum requirement of lime for lime-fly ash matrix is determined on the basis of maximum strength obtained under the field conditions of its compaction and curing. Normally 3 to 5 % of lime is generally found to be sufficient depending on the quality of lime. Increase in strength of the stabilised fly ash can be observed in terms of improved California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values. Lime-fly ash can be used for base/sub-base of road pavements, subject to medium to heavy traffic load.

3.3 Chemical reactions in cement-fly ash mixes:

As mentioned earlier, for the pozzolanic reaction to take place, lime is necessary. In the case of cement-fly ash matrix, lime is released during hydration of tri-calcium silicate ($3CaO.SiO_2$) and di-Calcium silicate ($2CaO.SiO_2$) as shown below:

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$$

The reaction of di-calcium silicate with water is very slow in comparison to tricalcium silicate. Hence, those cements, which have high content of tri-calcium silicate, are more suitable for stabilisation with fly ash. As the cement-water system is highly alkaline, only that portion of silica and alumina, which are soluble in alkaline environment can take part in the pozzolanic reaction. Hence, total silica and alumina in fly ash do not react with calcium content. The soluble silica and alumina content of fly ash is the characteristic criteria for potential reactivity of fly ash. There are certain studies, which show that ultimate strength of fly ash-lime blends increases with long periods of curing and high content of silica and alumina. Reactive silica is particularly present in amorphous and mostly vitreous part of the ash, whereas, crystalline siliceous compounds such as quartz and mullite, are virtually inert in an alkaline environment. The release of alkalies and sulphates from fly ash in water and acid solutions gives some interesting data on the chemical composition and specially the distribution of alkalies and sulphates through different fly ash phases. The Na_2O, K_2O and CaO in presence of water (added to fly ash during wet disposal) are converted to NaOH, KOH and $Ca(OH)_2$ respectively, and $Ca(OH)_2$ in turn reacts with amorphous silica to form calcium silicate hydrate. NaOH and KOH act as accelerator for this reaction. This process results in loss of much of the reactivity of the fly ash.

The engineering properties of fly ash (shear strength, permeability, CBR, etc) are similar to soil and in some cases better than soil. A comparison of engineering properties of fly ash with different types of soil is presented in **Table-2**. As the engineering properties of these materials generally vary, range of variation has been indicated in **Table-2**.

Table – 2

Comparison of Properties of Fly ash with Different types of Soil

Parameter	Fly ash	Sand	Silt	Clay
Specific gravity	1.90 – 2.55	2.65 – 2.7		
Plasticity index	Non Plastic NP)	NP	Zero (NP) to 7	More than 17
Compaction test Maximum Dry Density (gm/cc)	0.90 – 1.60	1.75–1.84	1.52– 2.00	1.45 – 1.80

Parameter	Fly ash	Sand	Silt	Clay
Optimum moisture content (%)	38.0 – 18.0	15 – 9	18 – 10	30 – 15
Angle of internal friction (ϕ)	$30^0 – 40^0$	$28^0 – 45^0$	$25^0 – 35^0$	$0^0 – 10^0$
Cohesion (kN/m^2)	Negligible	0	10 – 25	30 – 60
Compression index	0.05 – 0.4	–	0.05–0.15	0.30 – 1.50
Permeability (cm/sec)	$10^{-3} – 10^{-5}$	$10^{-2} – 10^{-4}$	$10^{-5} – 10^{-7}$	10^{-7} or Less
Particle size distribution Clay size fraction (%) Silt size fraction (%) Sand size fraction (%) Gravel size fraction (%)	 1 – 10 8 – 85 7 – 90 0 – 10	4.75 – 0.075 mm	0.075 – 0.002 mm	Less than 0.002 mm
Coefficient of uniformity	3.1 – 10.7	Depends on the gradation		

Some other Physical and Geotechnical Projects of fly ash and soil in general are compared in **Table-3**.

Table-3

Physical & Geotechnical Properties of Fly Ash Vs. Soil

Sl. No.	Parameters	Fly Ash	Natural Soil
1.	Bulk Density (gm / cc)	0.9-1.5	1.3-1.8
2.	Shrinkage Limit	Higher	Could be much lower
3.	Grain Size	Major fine sand / silt & small per cent of clay size particles	Sand / silt / clay size particles depending upon type of soil
4.	Clay (per cent)	Negligible	Depends on type of soil
5.	Free Swell Index	Very low	Variable
6.	Classification (Texture)	Sandy silt to silty loam	Sandy to clayey silty loam
7.	Water Holding Capacity (WHC) (per cent)	40-60	05-50
8.	Porosity (per cent)	30-65	25-60
9.	Surface Area (m^2 / kg)	500-5000	-
10.	Lime reactivity (MPa)	1-8	Variable

It may be seen from **Table-3** that physical and geotechnical properties of fly ash is comparable with natural soil and confirm to the specification. These properties of fly ash also satisfy the specification prescribed in the IRC:58:2001 for using fly ash in roads and embankment construction. The chemical characteristics of fly ash, which need to be evaluated, are pozzolanic property, leachability and self-hardening characteristics. Fly ash to be used as filling material should not have soluble sulphate content exceeding 1.9 gm (expressed as SO_3) per liter.

4.0 Use of Fly Ash in Road Making:

Bulk utilization of fly ash in construction has a lot of potential. National Highway Authority of India (NHAI) is currently using 100 lakh Tonne fly ash in construction in different NH projects in India and proposed to increase it two folds in the future.

The scope of utilization of fly ash in Road construction are:

- Embankments and backfills – Reinforced or unreinforced
- Stabilisation of subgrade, sub-base and base course
- For replacing a part of OPC in Concerete pavements, paving blocks, kerb stones

4.1 Construction of Fly Ash Embankment:

In developed urban areas natural borrow sources are scarce, expensive or inaccessible. The environmental degradation caused due to using topsoil for embankment construction is also very high. Fly ash can provide an economical and environmentally preferable alternative to natural borrow soil.

Successful field trials have shown the suitability of fly ash as a fill material for construction of road embankments. Many favourable properties for embankment construction are Light weight (ideal over weak subsoil), higher shear strength (greater stability), no lumps, usually moist, compacted under inclement weather, cost savings, etc. The properties required for design and construction are shear strength and compaction characteristics. Even though fly ash can be compacted using either vibratory or static rollers, vibratory rollers are recommended for achieving better compaction. Compaction is usually carried out at optimum moisture content or slightly higher. High rate of consolidation of fly ash suggests that in most cases primary consolidation of fly ash will be practically over by the time construction work of the embankment is completed. The slopes of the embankments should be protected by providing good earth cover using loamy soil. The thickness of side cover would be typically in the range of 1 to 3 m and in case of embankments upto 1 m height it can be kept equal to 0.3 to 0.5 m. The thickness of cover depends on the height of the embankment, site conditions, flooding if expected, etc. The cover soil and fly ash should be laid and compacted simultaneously to ensure confinement to pond ash. Construction of fly ash core and earth cover should proceed simultaneously. Stone pitching or turfing on this cover is necessary to prevent erosion due to running water. The design of fly ash embankments is basically similar to design of soil embankments. The design techniques use limit equilibrium method for stability analysis of embankment. Many computer softwares are available for quickly analysing stability of different types of embankment sections. Intermediate soil layers are often provided in the fly ash embankment for ease of construction, to facilitate compaction of ash and to provide adequate confinement. The compacted thickness of intermediate soil layers may vary from 0.2 to 0.4 m. While constructing high embankments using fly ash, to avoid the possibility of any liquefaction to occur, fly ash should be properly compacted to at least 95 per cent of modified proctor density and in case water table is high, it should be lowered by providing suitable drains or capillary cut-off.

The top 0.3 to 0.5 m of embankment should be constructed using selected earth to form the sub grade for the road pavement. Geo synthetic materials like geo grids or geo textiles can be used as reinforcement for construction of reinforced fly ash embankments. Such reinforcement improves the shear strength, minimise deformation and avoid necessity of retaining walls. Steeper slopes would be possible with the provision of geo grid/ geo textile reinforcements. The methodology of construction of embankment with fly ash differs from the construction with ordinary soil in the following ways :

- The Fly ash embankment should be covered on the sides and top up by suitable earth to prevent erosion of ash.
- Since ash is very fine, it may get air borne causing dust nuisance. So during its transportation and storing, it should be kept moist and preferably covered.
- Site investigation is required for determining characteristics of materials and detailed design before its application.
- Embankment constructed in flood–prone areas should be protected by stone pitching.
- The sulphate content in fly ash should be within the specified limits otherwise it may create corrosion, if metallic pipes, metallic reinforcement, etc come in contact with fly ash.

The following engineering properties are to be determined before undertaking fly ash embankment construction.

- Particle size distribution
- Maximum dry-density
- Shear strength and permeability
- Drainage properties

4.2 Highlights of IRC SP:58

- Design considerations are similar to earthen embankments
- FOS should be 1.25 (Minimum) under normal conditions, 1.0 (Minimum) under seismic / saturated conditions
- Density of compacted fly ash would be considerably lower than soil, fly ash with low MDD values not to be rejected
- Ash has no cohesion (c), ϕ should be basis for design
- Very little possibility of liquefaction of fly ash embankment
- Indian fly ash has lower SO_3 and lesser heavy metal content
- Earth cover to prevent erosion and water ingress

- Cover thickness – 1 m (up to 3 m high embankments), cover can be upto 3 m for high embankments
- Intermediate soil layer if embankment height more than 3 m
- Minimum thickness of intermediate soil layer – 200 mm
- Embankment construction similar to earthen embankments
- Loose layer thickness can be upto 400 mm if vibratory roller is used, loose layer can be upto 200 mm if 8-10 ton static roller is used
- Soil cover and ash to be compacted simultaneously

The various tests carried out on the fly ash produced from the thermal power plants of the state found to be favourable and meet the prescribed criteria laid for construction of roads and embankments. The procedure for road making and embankments are specified in the guidelines and specification issued by IRC. NHAI has been using fly ash in its road &embankment projects subject to satisfaction of the specification prescribed in IRC:SP:58:2001.

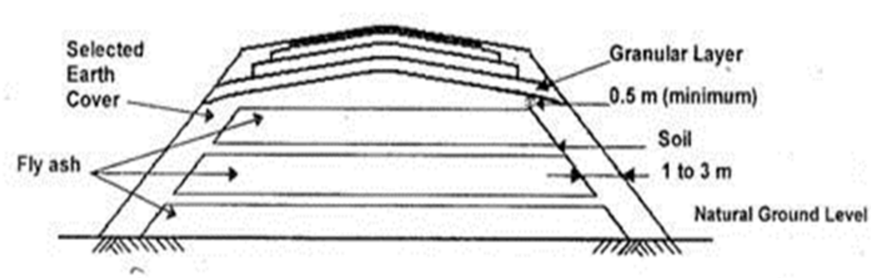


Fig. 1. Typical Cross-Section of Embankment with Alternate Layer of Fly Ash and Soil

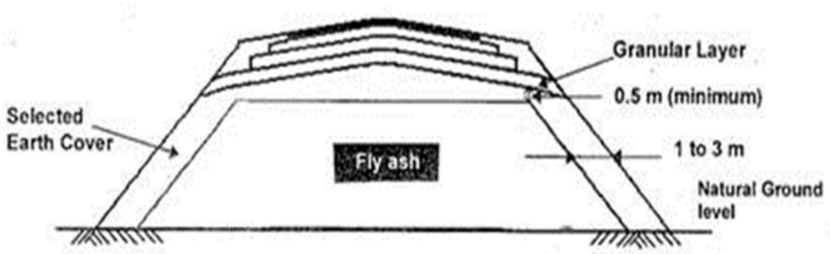


Fig. 2. Typical Cross-Section of Embankment with Core of Fly Ash

4.3 Utilisation of Fly Ash in Road Pavements:

Fly ash has been used for constructing different layers of road pavements. Utilisation of fly ash for stabilisation of sub-grades depends on the interaction between fly ash and subgrade soil. If the type of soil available in the area is found to be amenable to pozzolanic action with fly ash, strength parameters of the soil would improve when fly ash is added. This characteristics of fly ash is important in formulation of pavement specifications. Generally, clayey soils react with pozzolanic compounds present in fly ash. No such reaction is observed in case of sandy soils or gravels. Silty soils also react with fly ash but to a limited extent. This reaction can be improved by using additive such as lime. R&D studies conducted at the CSIR-Central Road Research Institute (CRRI), New Delhi on the effect of lime-fly ash stabilisation on the strength and engineering properties of different types of soils have indicated the following:

i. Addition of fly ash or lime-fly ash to soil decreases the maximum dry density of the soil and increases its optimum moisture content.

ii. The strength of soil stabilised with fly ash alone or with lime-fly ash, shows a significant improvement in California Bearing Ratio (CBR) values. The improvement in the strength characteristics depends on the proportions of the mix and the density to which mix is compacted.

iii. The unconfined compressive strength (UCS) test results of clayey soils show a decreasing trend in compressive strength with increase in addition of fly ash. This can be attributed to changes in gradation obtained with the addition of fly ash. But the UCS values of soils treated with lime and fly ash show a significant increase in the strength.

iv. Mixing of fly ash/lime-fly ash with soil in the field should preferably be carried out by mechanical means using rotavator and adequate quality control measures should be exercised during construction.

Some of the important points regarding 'Fly ash Stabilisation' are given in Annexure II.

4.4 Construction of Cement Concrete Pavements:

Fly ash can be used for constructing upper layers of pavements using specifications of lime-fly ash concrete, dry lean cement-fly ash concrete, roller compacted concrete, etc. They can be adopted in a variety of ways like base courses or wearing courses for heavy traffic corridors or for low traffic volume roads. Usage of fly ash to replace a part of cement has following advantages:

- Replacement of cement – Mix to be redesigned based on improvement in workability.
- Increase in durability, sulphate resistance and reduction in alkali – aggregate reaction even in chemically aggressive environment.
- Grade 53 has higher amount of C_3S and lower amount of C_2S than Grade 43, ensuring high initial strength but quantity of free lime leached is more, hence fly ash usage is a must. Fly ash delays the heat of hydration and hence reduces the thermal cracks in concrete.
- It improves the workability of concrete.
- It makes the mix homogeneous and hence reduces segregation and bleeding.
- The concrete finish is improved due to perfectly spherical fly ash particles.
- The concrete permeability is substantially reduced which enhances the life of the structure. Concrete becomes more impervious.
- Usage is economical and environment friendly. Fly ash contributes to the long term strength in concrete.

5.0 Limitations for Bulk Utilisation of Fly Ash in Road Works:

The system adopted for generation, collection and disposal of fly ash coupled with administrative and techno-economic constraints have restricted the bulk utilisation of fly ash. The following points need to be considered by policy makers/ engineers/ fly ash producers:

- Thermal power plants mostly adopt wet disposal system, where in bottom ash and fly ash are mixed and disposed as slurry to ash ponds. On one hand it makes dry fly ash unavailable for replacement of cement. The coarser bottom ash is better suited as a fill material. There is urgent need to adopt dry disposal system and to make available bottom ash and fly ash separately for specific uses.
- The transportation cost component of ash sometimes limits the lead distance up to which fly ash can be economically utilised in place of borrow soil.
- The other issue of concern is the variations in properties of fly ash. The properties of fly ash vary depending upon type of coal, its pulverisation and combustion techniques, their collection and disposal systems, etc. Obviously ash from two different thermal power plants would be having entirely different properties. These factors can be taken care during characterisation and quality control operations.
- Absence of adequate fiscal incentives/subsidies to prospective users by the Government needs to be addressed. Conventional construction materials should be taxed at a higher rate to discourage their use and subsidies/incentives can be provided to contractors who utilise fly ash.
- The schedule of rates, specifications/standards and contract systems of Government Departments should make a conscious effort to facilitate greater use of fly ash in road works.
- Absence of technology transfer services has resulted in lack of awareness among engineers.

6.0 Environmental Concerns:

The major environmental concerns with respect to the potential impact of fly ash usage in road and embankment construction are erosion of fly ash due to run-off, dust nuisance and possibility of leaching of heavy metals into sub-soil. During the construction of fly ash embankments, dust nuisance (fly ash particles being dispersed into air on account of wind) can be minimised by keeping the ash moist. Side soil cover protects fly ash core from running water (surface run-off) also. Erosion protection can be enhanced by grass turfing on the side slopes. Access of rain water from the top of embankment can be minimised by providing top soil cover for embankment, i.e. the subgrade and other pavement layers which restrict ingress of water. Comparison of the Indian and US fly ashes from environmental perspective is shown in **Table 4.**

Table – 4

Comparison of Fly ash Produced from Indian and Imported Coals

Property compared	Indian fly ash	Fly ash produced from imported coal
Loss on ignition (Un burnt carbon)	Less than 2 per cent	5 to 8 per cent
SO_3 content	0.1 to 0.2 per cent	3 to 4 per cent
CaO content	1 to 3 per cent	5 to 8 per cent
Increase in concentration of heavy metals	3 to 4 times in comparison to source coal	10 times or more in comparison to source coal
Rate of leaching	Lower	Higher

The sub-base/base layers of road pavements constructed using fly ash, need to be covered with impervious wearing course at top and on the slopes to prevent percolation of rain water. In spite of all these precautions, fly ash may sometimes, accidentally come in contact with running water or ground water. Studies done in this aspect show that fly ash-water mixture is basic in nature, which tends to restrict the heavy metal leaching. Additionally tests conducted on fly ash and borrow soil have shown that there is practically not much difference in heavy metal concentration that is encountered in soil vis-à-vis fly ash. It may be noted that most of the fly ashes are generally inert. Moreover, as the Indian coal has high ash content, enrichment of heavy metal is lower compared to fly ash using imported coal. Further the alkaline nature of fly ash water solution restricts heavy metal leaching. Certain heavy metal content tested in case of pond ash samples and local soil is given in **Table-5**. It can be seen that, except Chromium, other heavy metal contents are within specified limits and in case of Chromium, its content even in the local soil was also more.

Table – 5

Comparison of Heavy metal Content in Pond ash and Local Soil

Contaminant (mg/kg) ppm	Pond ash (Sample 1)	Pond ash (Sample 2)	Pond ash (Sample 3)	Local Soil (Sample 1)	Local Soil (Sample 2)	Limits as specified for Hazardous Materials by MOEF, GOI
Copper	23	43	83	40	23	5000
Cadmium	01	BDL	01	01	01	50
Hexa and Trivalent	55	113	76	115	55	50
Zinc	104	105	98	102	80	20,000
Lead	14	24	80	20	16	5000

BDL – 1 mg/kg (Below detection level)

7.0 Quantitative Utilisation of Fly Ash in Road Works:

The quantitative utilisation of fly ash in different types of road construction activities is given below in **Table -6**.

Table – 6

Quantitative Utilisation of Fly Ash in Road Works

For Road Pavement Construction (Length = 1 km, Width = 3.5m, Layer thickness = 0.15 m)	**Quantity of use Tonnes**
Compacted bottom ash sub-base	675
Bottom ash and local soil stabilised layer Lime-fly ash stabilised soil layer	600 118
Dry lean cement fly ash concrete	145
Lime-fly ash concrete Roller compacted concrete	176 48
Lime-fly ash bound macadam	20
For Embankment Construction (per km length) (1 m height, 7 m wide at top, 1V:2H Slope)	9,700

8.0 MoEF Notification:

Fly ash utilisation is mandated by notifications under Environment Protection Act, 1986. Ministry of Environment & Forest, Govt. of India have brought out Fly Ash Notifications S.O. 763(E) dated 14 Sept 1999, its amendment notification on S.O 979(E) dated 27 Aug 2003 and notification

S.O 2804(E) dated 3 Nov 2009.Clause 5 of the said Notification stipulates use of fly ash in road making which reads as under:

"No agency, person or organization shall within a radius of hundred kilometers of a thermal power plant undertake construction or approve design for construction of roads of flyover embankments with top soil, the guidelines or specifications issued by the Indian Road Congress (IRC) as contained in IRC specification No.SP:58 of 2001 as amended from time to time regarding use of fly ash shall be followed and any deviation from this direction can only be agreed to on technical reasons if the same is approved by Chief Engineer (Design) or Engineer in Chief of the concerned agency or organization or on production of a certificate of "fly ash not available" from the thermal power plant(s) (TPPs) located within hundred kilometers of the site of construction and this certificate shall be provided by the TPP within two working days from the date of receipt of a request for fly ash, if fly ash is not available ".

9.0 Thermal Power Plants meeting the criteria of IRC:SP:58:2001

The following major Thermal Power Plants have carried out the test as per the specification IRC: SP: 58:2001 and the results reveal that it satisfies and can be used for road making. The results are **Annexed at 'A'.**

Sl. No.	Name of the Thermal Power Plants
1.	M/s Aarti Steel Ltd., Ghantikhala, Cuttack
2.	M/s ACC Ltd., Bargarh Cement Works, Bargarh
3.	M/s Bhusan Power & Steel Ltd., Lapanga, Sambalpur
4.	M/s Bhusan Steel Ltd., Meramundali, Dhenkanal
5.	M/s Bhushan Energy Ltd., Narendrapur, Dhenkanal
6.	M/s FACOR Power Ltd., Randia, Bhadrak
7.	M/s Jindal Steel and Power Ltd., Nisha, Angul

Sl. No.	Name of the Thermal Power Plants
8.	M/s Jindal Stainless Ltd. (CPP), Kalinga Nagar Industrial Complex, Duburi, Jajpur
9.	M/s Nava Bharat Ventures Ltd., Kharagprasad, Dhenkanal
10.	M/s SMC Power Generation Ltd., Hirma, Jharsuguda
11.	M/s SesaSterlite Ltd., Bhurkahamunda, Jharsuguda
12.	M/s TATA Sponge Iron Ltd., Bileipada, Keonjhar

10.0 IRC:37-2001

The Guidelines in IRC: 37-2001 (Amended in 2012) considers the design of flexible pavements.

Five different combinations of traffic and material properties have been considered for which pavement composition has been suggested in the form of design charts.

The five combinations are as under:

(1) Granular Base and Granular Subbase.

(2) Cementitious Base and Cementitious Subbase with aggregate interlayer for crack relief. Upper 100 mm of the cementitious subbase is the drainage layer.

(3) Cementitious base and subbase with SAMI at the interface of base and bituminous layer.

(4) Foamed bitumen / bitumen emulsion treated RAP or fresh aggregates 250mm Cementitious subbase.

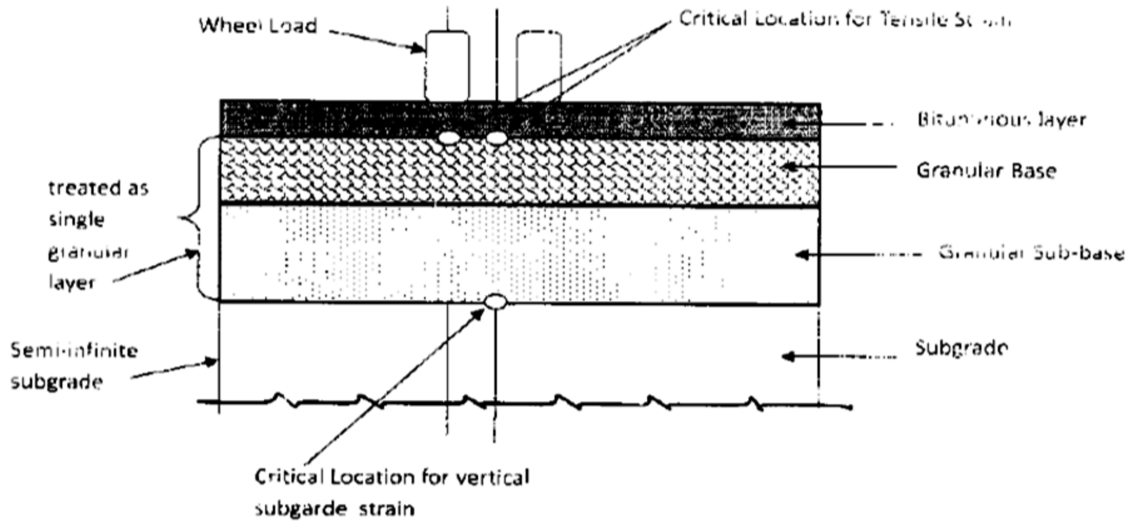
(5) Cementitious base and granular subbase with crack relief layer of aggregate layer above the cementitious base.

(6) These charts are to be used for traffic of 2 msa and above.

(7) Thickness design for traffic between 2 and 30 msa is exactly as per IRC 37-2001.

(8) In all cases of cementitious sub-bases (i.e. cases 2,3 and 4 above) the top 100 mm thickness of sub-base is to be porous and act as drainage layer.

Granular Base and Granular Sub-base



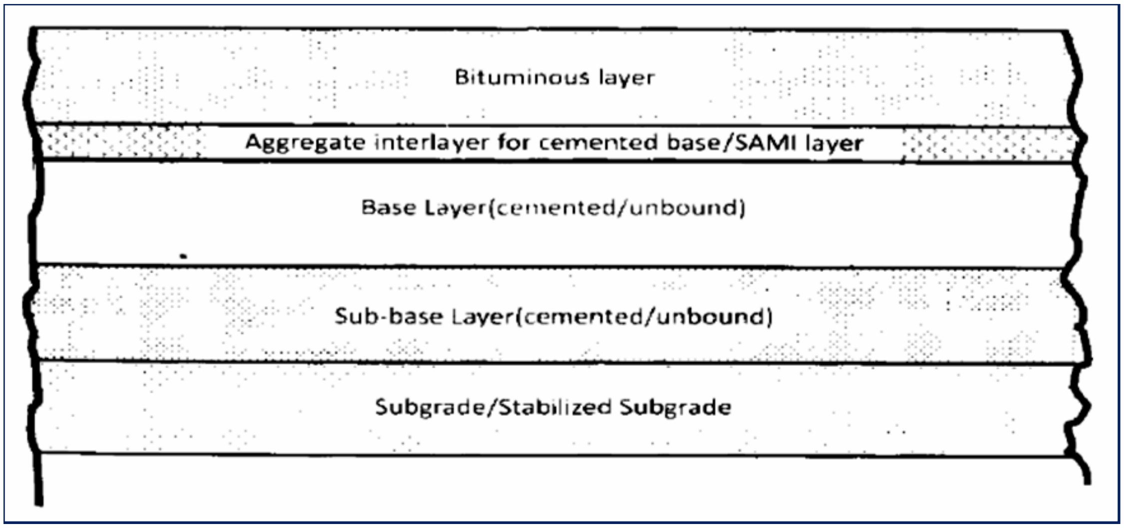
The above Fig. shows the cross section of a bituminous pavement with granular base and sub-base. It is considered as a three layer elastic structure consisting of bituminous surfacing, granular base and sub-base and the subgrade.

The granular layers are treated as a single layer. Strain and stresses are required only for three layer elastic system. The critical strains locations are shown in the figure. For traffic > 30 msa., VG 40 bitumen is recommended for BC as well as DBM or plains in India. Thickness of DBM for 50 msa is lower than that for 30 msa for a few cases due stiffer bitumen. Lower DBM is compacted to an air void of 3 percent after rolling with volume bitumen close to 13 percent (Bitumen content may be 0.5 per cent to 0.6 percent higher than the optimum). Thickness combinations up to 30 msa are the same as those adopted in IRC:37-2001, GSB consists of a separation/filter in the bottom and a drainage layer.

10.1 Pavement Composition

General

A flexible pavement covered in these guidelines consists of different layers as shown in the figure below:



Different Layers of Bituminous Pavement

The sub-base and base layer can be unbound with stabilizers such as cement, lime, fly ash.

Stabilisation Technique:

- **Effective use** of local materials**(Fly ash)**/ soils by using suitable stabilising technique
- Stabilisation – Improving stability or bearing capacity of soil or fly ash layer by **controlled compaction, proportioning and/or addition** of suitable stabilisers
- Stabilisation – Process of **blending materials with soil** to improve its properties
- Soil or Fly ash (Locally available material) + Additive
- Modification **(plasticity, workability, gradation)** Cementation **(Strength Gain)**

Advantages of Stabilisation :*IRC : SP: 89*

- Pavement **thickness** is considerably **reduced**
- **Strength retained** even after soaking stabilised layer
- Resistance to **erosion,** reduced **deflections**
- **No contamination** due to subgrade fines
- Increase in**elastic modulus** for granular above stabilised layer
- Acts as **working platform** over weak / wet soils

Methods of Stabilisation:

- Mechanical stabilisation
- Lime stabilisation
- Cement stabilisation
- Lime pozzolana stabilisation
- Bitumen stabilisation
- Stabilisation using other chemicals

Stabilisation Using Fly Ash:

- Stabilised soil subgrade & sub-base/base courses
- Mixing with soil **reduces plasticity** of subgrade
- Addition of small percentage of cement greatly **improves unconfined compressive strength**
- **Leaching** of lime is **inhibited** and **durability improves** due to addition of fly ash
- Pond ash and bottom ash can also be stabilized

Gradation – Cement Stabilisation (Revised MORD Specifications):

IS Sieve	Per cent by weight passing	
	Sub-base	Base
53 mm		100
37.5 mm	95 – 100	
19 mm	45 – 100	

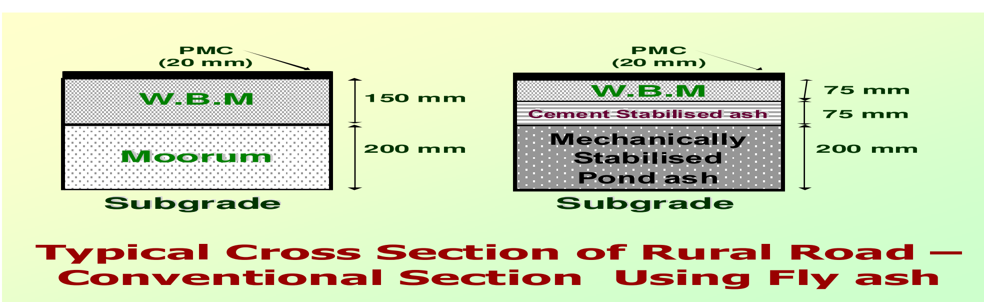
IS Sieve	Per cent by weight passing	
	Sub-base	Base
9.5 mm		35 – 100
4.75 mm 600 micron	 8 – 65	25 – 100
300 micron	5 – 40	
75 micron	0 – 10	

Durability Test (Moderate Climate) IRC:SP: 89

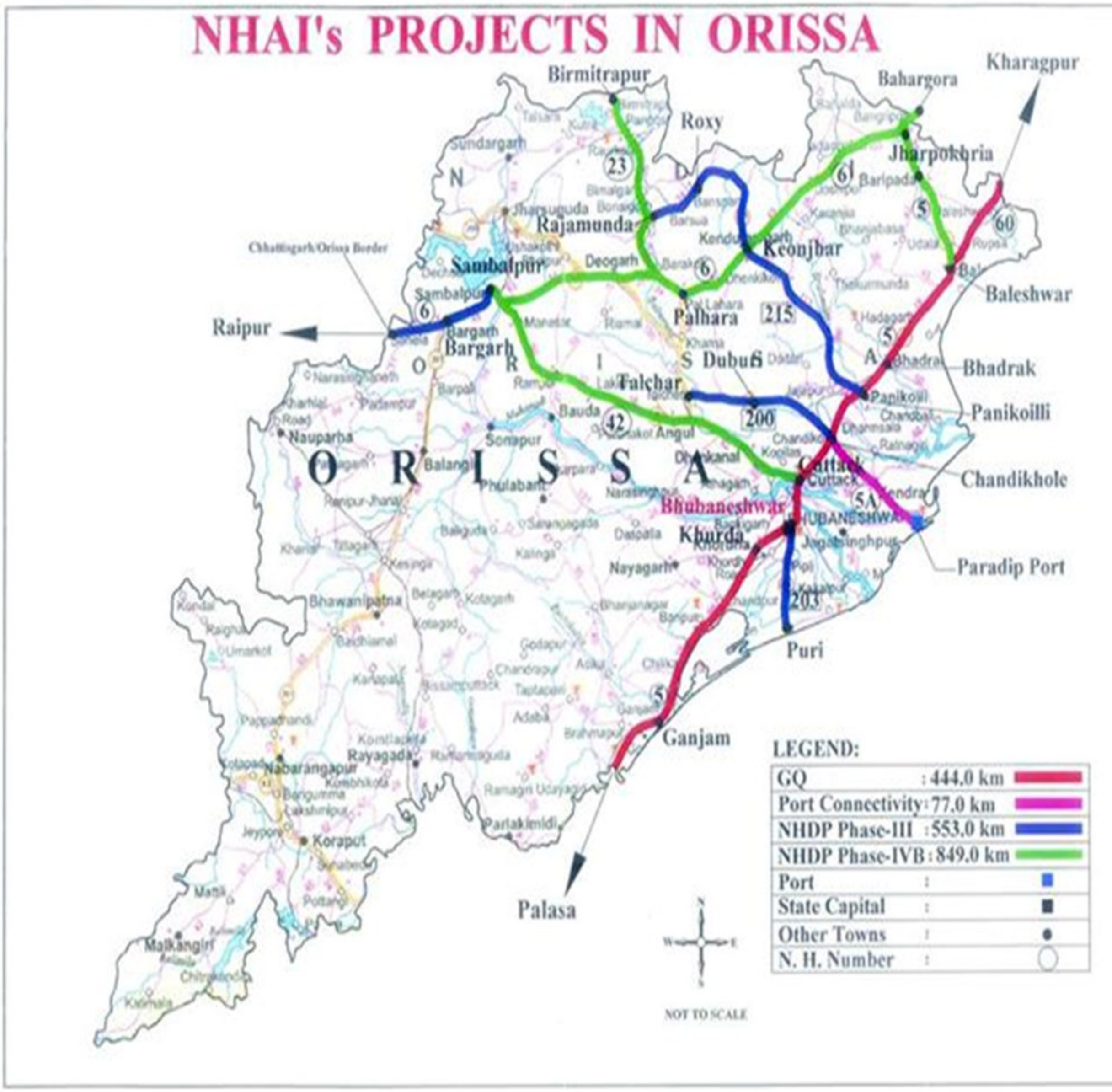
- 6 UCS specimens to be prepared and cured in moist chamber for 7 days
- 3 specimens to be placed in water for next 7 days
- 3 other specimens to be moist cured for next 7 days
- UCS of specimens kept in water should be at least 80% of moist cured samples

Soil Stabilisation – Possible Problems:

- Cracking and long term durability.
- Traffic, thermal and shrinkage cracks.
- Cracks can reflect even to surface layers, resulting in water ingress, de-bonding, deterioration and failure.
- Cracks may not be due to structural deficiency, but a natural characteristic of cement stabilised material.
- Construction requires more skill and control.
- Preventive Measure – Crack Relief Layer



11.0 National Highway Projects in Odisha:



For the National Highway projects in Odisha, during **2013-14,** the overall utilisation of fly ash in road construction was around 284565 T which is 1.2% of the total fly ash utilized. The fly ash was lifted from the TPPs like M/s Hindalco Industries Ltd., Sambalpur, M/s FACOR, Bhadrak, M/s ACC Ltd., Bargarh, M/s Bhushan Steel & Power Ltd., Sambalpur. Around 1 lakh tonne of fly ash has been utilized in the NH-6 (Sohela- Sambalpur) project.

Proposed and Ongoing NH Projects in Odisha

NHDP Phase III projects under implementation in Odisha

Stretch	NH No.	Length In Km	Start Mm/Yy	Completion Estimated Mm/Yy	Concessioner	Projected Fly Ash Utilisation	TPPs in 100 km vicinity
Four Laning Cuttack-Angul	42	112	-	-	AshokaBuild con (Sambalpur-Bargarh Expressway Ltd)	3 Lakh Tonne	IMFA, NALCO, Bhushan, GMR,
Sambalpur-Bargarh (Sohela)	6	88	Nov 2011	Complet ed May 2014	-Do-	90,528 tonnes	ACC, Bargarh, BSPL,
Bhubanesw ar-Puri	203	67	May 2011	Complet ed	KSS Valecha(Bh ubaneswar Expressway Pvt. Ltd)	--	Nil
Panikoili-Remoli	215	163	Jun 2013	Oct 2015	Gayatri Projects Ltd	5 Lakh Tonne	FACOR, Birla Tyres, Emami,
Rimoli-Rajamunda	215	96	Jun 2012	Dec 2014	MBL-SLEI	--	
NH DP Phase-IVB-849 Km							
Sambalpur-Bahargoda	6	366	Bidding in progress			8.7 Lakh Tonne	BSPL, Sesa Sterlite
Angul-Sambalpur,	42	263	Bidding process completed			6.3 Lakh Tonne	NALCO, GMR, JSPL, BSPL, BSL, Sesa Sterlite
Barkot-Biramitrapur	23	125				3 Lakh Tonne	
Balasore - Jharpokhori a	5		Bidding in Process				Emami, FACOR, Birla

- **Recent Declared NH Projects:**

1. Palasa-Paralakhemundi-Bisam-Kotak-Muniguda-Bhawanipatna-Kharia-Padmapur (NH-6)-400 km.
2. Bhubaneswar-Athagarh-Badkera (NH-42) 150 km.

3. Naranpur (Keonjhar)-Kamakshyanagar-Parjang (NH-42) 140 km.
4. Cuttack-Chandbali-Dhamra-Bhadrak-Anandapur (190 km.)
5. Angul-Hindol-Bhanjanagar (120 km)
6. Nayagarh-Jankia-Chandpur (130 km)
7. Bolangir-Patnagarh-Nuapada (130 km)

- FARC is coordinating with Project Directors of NHAI for update information on award of contract and proposed date of start of work for the above projects to facilitate the supply of fly ash from the TPPs for the said projects.

12.0 State Highway Projects:

SH-53, Anandpur-Bhadrakh (50 km), SH-9, Bhadrakh–Chandabali (45 km) project are completed. The fly ash utilised is obtained from FACOR, Balasore.

The work is executed by ISOLUX CORSAN (a Spanish company). FARC had discussions with the chief engineer, State Highway (World Bank Projects) and the outcome was encouraging. As FACOR Power is near to the ongoing project it had supplied the ash free of cost from their power plant.

Other State Highway Projects:

i) Four laning of State Highway Project SH-10 from Sambalpur to Rourkela has commenced from 14th July 2014 in PPP mode and the target date of completion is 36 months from the date of commencement. The fly ash requirement for the said project is sourced from M/s Sesa Sterlite Ltd., Jharsuguda, Bhushan Steel & Power Ltd., Sambalpur, M/s Aditya Birla (Power Plant), Sambalpur, M/s NTPC (SAIL), Rourkela. **Already 20,000 Tonnes** of fly ash has been used in the said project.

ii) **Biju Express way (Sohela to Jagdalpur):**

For the said project which is of 101 KM stretch, the tendering is in process. Around 2.5 Lakh Tonne of fly ash can be utilized in this project.

III) The other State Highway project :

- SH-15 (Sambalpur to Sonepur of 34 Km Stretch) has commenced from Augusts, 2014 and likely to be completed 24 months.
- SH-24 (Kuchinda to Bamra of 45 Km)
- SH – (Gudbhaga to Turum of 34 Km) and SH – (Bargha via Bhatili to Ambana of 35 Km) is in the pipeline.

Road Construction in Odisha

Circle	State Highway	Major District Road (MDR)	Other District Roads (ODR)
Central Circle			
Bhubaneswar	17.000	241.934	312.196
Cuttack	34.000	98.510	145.450
Jagatsinghpur	169.000	41.000	251.330
Kendrapara	70.200	46.275	387.805
Panikoili	64.500	71.500	441.362
Angul	198.300	0.000	514.780
Dhenkanal	14.000	103.400	329.563
Total	**567.000**	**602.619**	**2382.486**
Eastern Circle			
Balasore	117.850	109.300	379.610
Bhadrak	167.210	71.650	170.820
Mayurbhanj	125.500	114.600	306.150
Keonjhar	38.400	79.010	76.000
Rourkela	48.000	160.700	187.000
Sundargarh	169.780	139.040	341.460
Total	**666.740**	**674.300**	**1461.040**
Northern Circle			
Bargarh	177.000	77.592	247.100
Jharsuguda	27.940	0.000	459.021
Sambalpur	324.740	115.600	220.353
Total	**529.680**	**193.192**	**926.474**
Southern Circle			
Ganjam	328.300	53.220	744.593
Total	**328.300**	**53.220**	**744.593**
Bolangir Circle			
Bolangir	54.250	59.860	397.196
Kantabanji	109.000	126.000	298.300
Khariar	48.995	51.200	219.400
Total	**212.245**	**237.060**	**914.896**
Phulbani Circle			
Phulbani	276.740	0.000	173.170
Total	**276.740**	**0.000**	**173.170**
Jeypore Circle			
Jeypore	155.000	14.000	394.220
Kalahandi	193.455	233.160	166.350
Koraput	253.320	123.200	146.300
Malkangiri	241.920	77.700	32.600
Total	**843.695**	**448.060**	**739.470**
LWE Rayagada Circle			
Rayagada	393.400	129.800	104.320
Paralakhumundi	249.300	67.700	57.390
Total	**642.700**	**197.500**	**161.710**
Grand Total	**SH-4067.100**	**MDR-2405.951**	**ODR-7503.839**

Source: Works Deptt. Website

Around **155 Lakh Tonne** of fly ash projected that can be utilized in the Sate Project.

13.0 Conclusion:

Fly ash produced as a waste product can be a good construction material for roads and embankments. The benefits obtained due to use of fly ash as embankment fill material are well known. Adoption of ash in embankment construction will result in saving of precious topsoil besides leading to reduction in construction cost. At a time, when infrastructure development is getting top priority and construction of many road projects are being planned, greatly enhanced demand can be expected from the road sector. Unfamiliarity with the use of fly ash in road works can be overcome through demonstration projects and educating the construction agencies. But adequate attention should be paid to characterisation of fly ash and quality control during construction for better performance so that fly ash can be turned from a liability to an asset converting ash to cash.

Reference:

1. IRC:SP:58/2001
2. IRC:SP:37/2001
3. IRC:SP:89/2010
4. Works Department website
5. Paper on utilisation of fly ash in road & embankment construction by Dr. U.K. Guru Vittal, CSIR – Central Road Research Institute, New Delhi

Abbreviations:

IRC	:	Indian Road Congress
CBR	:	California Bearing Ratio
msa	:	Million Standard Axle
MDR	:	Major District Roads
MORT & H	:	Ministry of Road Transport & Highways
ASTM	:	American Society for Testing & Materials
WBM	:	Water Bound Macadam
GSB	:	Granular Sub Base

Annexure-I

Geotechnical Tests of Fly Ash Carried out as per IRC:58;2001

Sl. No.	Name of the Thermal Power Plants	Test Carried out by	Parameters (Unit)									
			Specific gravity	Plasticity	Max. Dry Density (g/cc)	Optimum Moisture content (%)	Angel of Internal friction (0 deg)	Permeability (Cm/sec)	Cohesion (KN/m2)	Compression Index (Cc)	Coefficient of consolidation Cv (cm2/sec)	Soluble Sulphate (So3 g/l)
1	**Bhushan Power & Steel Ltd., Sambalpur**	Bhagabati Ana Labs Pvt. Ltd., Hyderabad **Dt:04.03.14**	2.05	Non Plastic	1.07	34	33	$8x10^{-5}$	Negligible	0.12	$1.81x10^{-3}$	1.9 Max.
2	**Bhushan Steel Ltd., Dhenkanal**	MMT, Bhubaneswar **Dt:24.02.14**	1.92	Non Plastic	0.97	24	38	5.5x10-5	Negligible	-	-	0.168
3	**Bhushan Energy Ltd., Dhenkanal**	IMMT, Bhubaneswar **Dt:24.02.14**	1.92	Non Plastic	1.10	27	38	$5.6x10^{-5}$	Negligible	-	-	0.177
4	**JSPL, Angul**	NIT, Rourkela **Dt:06.03.14**	2.46	Non Plastic	1.17	42	28.8		Negligible		$25x10^{-4}$	-
5	**Jindal Stainless Ltd, Kalinga Nagar**		2.04	Non Plastic	1.23	31.5	114 (Wrong Value - Check)	1.18×10^{-4}	Negligible	0.10	1.84×10^{-4}	1.3

	Annexure-I											
	Geotechnical Tests of Fly Ash Carried out as per IRC:58;2001											
Sl. No.	**Name of the Thermal Power Plants**	**Test Carried out by**	**Parameters (Unit)**									
			Specific gravity	**Plasticity**	**Max. Dry Density (g/cc)**	**Optimum Moisture content (%)**	**Angel of Internal friction (0 deg)**	**Permeability (Cm/sec)**	**Cohesion (KN/m2)**	**Compressi on Index (Cc)**	**Coefficient of consolidati on Cv (cm2/sec)**	**Soluble Sulphate (So3 g/l)**
6	**SMC Power Ltd., Jharsuguda**	Bhubaneswar Test House **Dt.07.10.13**	2.086	Non Plastic	1.314	22.12	28	4.0×10^{4}	0.18	0.38	1.9×10^{-5}	1.0 gm/Litre
7	**Aarti Steel Ltd., Cuttack**	Orbit infrastructure Consultancy & Research Pvt. Ltd. , **Dt. 15.11.13**	2.85	Non Plastic	1.865	17.8	-	-	-	-	5.4×10^{-3}	-
8	**FACOR POWER, Bhadrak**	Research Development & Quality Promotion (R&B), Bhubaneswar, **dt. November, 2013**	-	-	1.505	24.5	31	-	-	0.2	-	-
9	**Tata Sponge Iron Ltd., Keonjhar**	Geotechnical Section, Jamshedpur **Dt.09.05.12**	2.61	Non Plastic	1.42	26	29.7	0.47×10^{-4}	0.7	0.212	4.69×10^{-2}	-

Annexure-I

Geotechnical Tests of Fly Ash Carried out as per IRC:58;2001

Sl. No.	Name of the Thermal Power Plants	Test Carried out by	Parameters (Unit)									
			Specific gravity	Plasticity	Max. Dry Density (g/cc)	Optimum Moisture content (%)	Angel of Internal friction (0 deg)	Permeability (Cm/sec)	Cohesion (KN/m2)	Compression Index (Cc)	Coefficient of consolidation Cv (cm2/sec)	Soluble Sulphate (So3 g/l)
10	**Vedanta (CPP), Jharsuguda**	CSIR- Central Road Research Institute, New Delhi, **Dt. September, 2011**	2.07	Non Plastic	-	-	31.7	5.3×10^{-5}	-	-	-	1.1
11	**HINDALCO, Sambalpur**	CPRI, Banglore, **Dt. June, 2008**	2.24	Non Plastic	0.95	-	-	-	-	Compressive Strength 85 kg/cm2	-	0.23