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A Study on Backfill Properties and Use of Fly Ash for Highway Embankments

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Abstract: Fly ash a fine powder is thrown out in large quantities from thermal power plants as a waste material in a by-product of combustion of pulverized coal. The disposal of fly ash poses a serious problem considering the air, water and soil problems. The solution to this problem lies in its bulk utilization of fly ash at dumping sites. This paper is summarized with brief details of the properties and design aspects of fly ash used in highway embankments.

Keywords: Fly ash, Thermal power plants.

1. Introduction

The current total installed capacity for electricity generation in India is about 100,000 MW, 70% of which are mostly coal based thermal power plants. Because of continually increasing demand for electricity, it is estimated that an additional 100,000 MW capacity or more would be required in the next 10 years. India is strongly dependent on coal for electricity generation because it is the least expensive, abundantly available fuel (200 million tones of reserves in India). However, Indian coal has a high ash content of 35 – 50% and a low calorific value of 3,000 – 4,000 kcal/kg.

In the process, of thermal power generation the country is producing huge amount of fly ash and with the increase of the quantum of the thermal power generation, the production of this ash will more than double. In India, major problems faced by coal based thermal power plants are the handling and disposal of fly ash. The annual generation of fly ash has increased from 1 million tons in 1947 to about 40 million tons during 1994 and to about 112 million tons at present. As per an estimate of Fly Ash Utilization Program (FAUP) and Technology Information Forecasting and Assessment Council (TIFAC, India), the annual fly ash generation figures are expected to reach about 170 million tons by 2012 and 225 million tons by 2017. In order to reduce the effects of these extraneous sources on the environment, it is necessary to study its physical, chemical and engineering properties and identify the fields where it can be put to proper use and so become a resource rather than undesirable waste material.

Fly ash can be utilized in many ways in the field of civil engineering applications, roads, railways and dam embankments. Fly ashes have been used in low lying areas as structural fill for developing residential sites for mine filling. Embankments for roads and highway bridges were constructed using the fly ash to generate from coal fired power plants. Fly ash has also been used as backfill materials behind the retaining walls (Swain, 1979). Literature suggests that fly ash has been also used as geotechnical properties for supporting structural loads (Gray *et al*., 1972). Leonards & Bailey (1982) stated that load tests carried out on compacted fly ash beds show that fills materials can support large loads with small settlements.

A few major projects of fly ash are such as construction of Okhla fly over bridge in Delhi using about 4,800 tones of fly ash; construction of reinforced fly ash approaches embankment at the Hanuman statue; development for LPG plant by Indian Oil Corporation using about 300,000 tones of pond ash from National Thermal Power Corporation (NTPC), Badarpur; and Construction of approach embankment of the Nizamuddin bridge in Delhi uses about 150,000 tones of fly ash.

Embankment fill is typically an earthen material to use to create a strong stable base. Embankment fills are usually constructed by compacting earthen materials.

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Therefore, compaction and permeability properties are very important to good performance of the embankment. The shear strength and compressibility is also important measures of the compacted material. Local soil at a backfilled site may be too weak to support. For this purpose, local soil is replaced by compacted fly ash material as fill to provide the needed bearing capacity and strength. The use of fly ash in highway embankments and fills is the second highest use of this material. It behaves like a fine sand material but has a lower density (Gray *et al*., 1972). Embankments and fills are also the highest use application of bottom ash.

Bituminous (Pozzolanic) fly ash is more frequently used to construct embankments and structural backfills than sub bituminous or lignite (self-cementing) fly ash (Murthy *et al*., 2000). This is due in part to the self-cementing characteristics of the latter type, which hardens almost immediately after the addition of water (McKerall *et al*., 1982).

2. Materials and Methods

2.1 General properties of fly ash

Fly ash occurs as very fine spherical particles and is the residue of combustion of coal-originally a mixture of vegetation, clay and comprises a wide range of inorganic particles. The principal constituents of ash are silica, alumina and iron oxide. In Fig. 1, granules and cenospheres of fly ash are shown (source: www.wikipedia.com). The physical, chemical and engineering properties of fly ash are dependent on the type and source of coal, method and degree of coal preparation, handling and storage methods etc. Fly ash properties may vary due to changes in boiler load. Fly ash that is produced from the burning of lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties (ability to harden and gain strength in the presence of water alone).

Fly ash consists of fine, nonplastic and powdery particles that are predominantly spherical in shape, either solid or hollow and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. A ‘cenospheres’ is a lightweight, inert, hollow sphere filled with inert air or gas, typically produced as by product of coal combustion at thermal power plants. Due to the hollow structure ‘cenospheres’ have low density and now ‘cenospheres’ used as fillers in cement to produce low density concrete.

The color of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the color of fly ash, chances of the lower carbon content (Carlson & Adriano, 1993). Porosity and Bulk density of fly ash is an important parameter, which determines the strength, compressibility and drainage characteristics of the embankment. The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area may range starts from 170m^2/kg to 1000m^2/kg (Carlson & Adriano, 1993). The particle size distributions of most bituminous coal fly ashes are generally similar to that of silt (less than a 0.075mm or No. 200 sieve). Sub-bituminous coal fly ashes are also silt-sized; they are generally slightly coarser than bituminous coal fly ashes (Di Gioia *et al*., 1972). In Table 1, normal ranges of chemical composition of Indian fly ash are given:

Table 1. Normal range of chemical composition of Indian fly ash produced from different coal types (expressed as percent by weight).

S. No.	Component	Bituminous	Sub-bituminous	Lignite
1	SiO_2	20-60	40-60	15-45
2	Al_2O_3	5-35	20-30	10-25
3	Fe_2O_3	10-40	4-10	4-15
4	CaO	1-12	5-30	15-40
5	MgO	0-5	1-6	3-10
6	SO_3	0-4	0-2	0-10
7	Na_2O	0-4	0-2	0-6
8	K_2O	0-3	0-4	0-4
9	LOI	0-15	0-3	0-5

(Table Source: www.coal.nic.in)

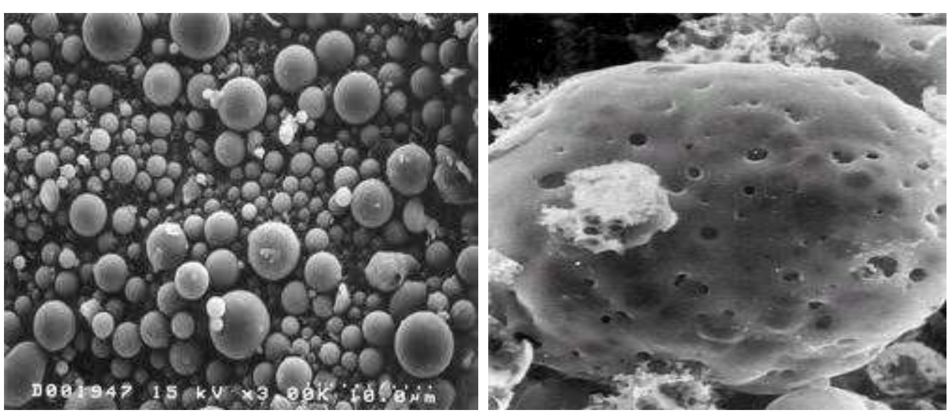

Fig. 1. Granules and hollow cenospheres of fly ash.

2.2 Types of coal ash

There are two types of coal ash produced in coal based thermal power plants, i.e. fly ash and bottom ash. Fly ash collected at the electrostatic precipitator will be fine in nature. The bottom ash collected at the bottom of the boilers will be coarse in nature and it can be handled only in the water medium initially. The bottom ash forms 15 - 20% of the total ash produced and it has good engineering properties. As a result of the nature of the two types of ash, their uses are also different.

2.3 Methodology

The grain size distribution and the specific gravity of the fly ash were determined by Sieve analysis and Pycnometer method respectively. The maximum dry density (MDD) and optimum moisture content (OMC) were determined by the Proctor test. The shear strength parameters 'c' & 'φ' of fly ash were determined by performing a direct shear test. The permeability of the fly ash is determined in the laboratory using Falling head method.

2.4 Properties of fly ash as embankment fill material

Fly ash properties are unique as an engineering material. Some of the engineering properties of fly ash that are of particular interest when fly ash is used as a highway embankment or fill material are its moisture-density relationship, particle size distribution, shear strength and permeability. Fly ash in this application must be stockpiled and conditioned to its optimum moisture content to ensure that the material is not too dry and dusty or too wet. When fly ash is at or near its optimum moisture content, it can be compacted to its maximum density and will perform in an equivalent manner to well-compacted soil. Fly ash has proved to be versatile materials with many possible applications in the highway embankment.

Specific gravity usually means Relative Density with respect to water. The term Relative Density is often preferred in modern scientific usage. A substance with a Relative Density greater than 1 will sink. In case of fly ash, specific gravity is the important properties which are used in the construction of highway embankment. Generally, Specific Gravity of Indian fly ash is low of about 2 Presence of unburnt carbon and cenospheres may be the reason for low specific gravity (Carlson & Adriano, 1993). The free lime and unburnt carbon influences the engineering properties of highway embankment fill material.

The particle size of a material can be important in understanding physical and chemical properties of fly ash. It affects the strength and load-bearing properties of rocks, fly ash and soil. Fly ash has a large uniformity coefficient consisting of silt sized particles. Fly ash is predominantly a silt-sized material. Between 60 and 90 percent of fly ash particles are finer than a 0.075mm (No. 200) sieve. As such, its particle size distribution falls essentially within the normally recognized limits for frost susceptible soils (Gray *et al*., 1971). The fine particle sizing of fly ash, together with the relative uniformity of the gradation in the coarse silt range, makes it imperative that the fly ash is handled with sufficient water to prevent dusting. Since fine-grained fly ash can be fairly easily eroded, enough moisture must also be present to support compaction equipment and to permit the material to be well densified, in order to prevent or minimize erodibility. The graph of particle size distribution of fly ash is given in Fig. 2. Sands and gravels that possess a wide range of particle sizes with a smooth distribution of particle sizes are called well graded soils. If the soil particles in a sample are predominantly in a relatively narrow range of sizes, the soils are called uniformly graded soils. If there are distinct gaps in the gradation curve, e.g. a mixture of gravel and fine sand, with no coarse sand, the soils may be called gap graded. Uniformly graded and gap graded soils are both considered to be poorly graded. There are many methods for measuring particle size distribution. The two traditional methods used in Geotechnical engineering are sieve analysis and hydrometer analysis.

Fly ash can be compacted easily at low or below the Optimum moisture content (OMC) and a minimum of about 90% relative compaction can be achieved in the field. It may be noted that fly ash exhibits high dry density and low OMC as compared to bottom ash (Gray & Lin, 1972). Fly ash has a relatively low compacted density thereby, reducing the applied loading and the resultant settlement to the supporting sub grade. In Table 2, some important backfill properties of fly ash are given.

Table 2. Backfill properties of Indian fly ash.

S. No.	Parameters	Unit	Range	Methodology
1	Clay size fraction	%	1 -10	Sieve Shaker Method *(IS:2720: Part 4, 1985)*
2	Silt size fraction	%	8 -85	''
3	Sand size fraction	%	7 -90	''
4	Gravel size fraction	%	0 -10	''
5	Specific gravity	----	1.90 - 2.55	Pycnometer Method *(IS:2720: Part 3, 1980)*
6	Maximum dry density	gm/cc	0.9 -1.6	Procter Method *(IS:2720: Part 7, 1980)*
7	Cohesion		Negligible	Direct Shear Method *(IS:2720: Part 13, 1986)*
8	Permeability	Cm/Sec	$8x10^{-6}$ to $7x10^{-4}$	Falling Head Method *(IS:2720: Part 17, 1986)*

Source: Prasad et al., 2009.

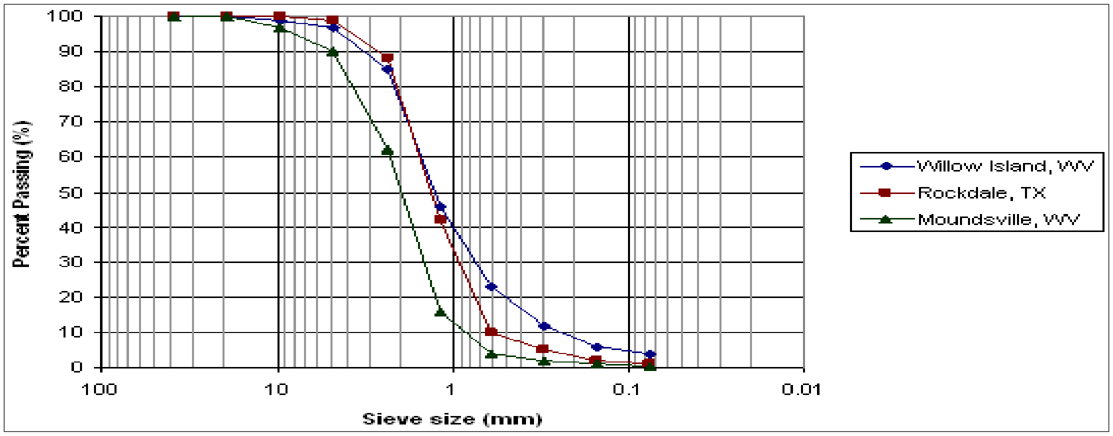

Fig. 2. Particle size distribution of fly ash.

Shear strength tests conducted on freshly compacted fly ash samples show that fly ash derives most of its shear strength from internal friction, although some apparent cohesion has been observed in certain bituminous (pozzolanic) fly ashes (Di Gioia *et al*., 1972). The shear strength of fly ash is affected by the density and moisture content of the test sample, with maximum shear strength exhibited at the optimum moisture content (Lamb *et al*., 1974). Bituminous fly ash has been determined to have a friction angle that is usually in the range of 26° to 42°. Loose ash or uncompacted fly ash has slow shear strength (Mc Laren *et al*., 1987). The shear strength of fly ash depends on many factors including the effective stress and the void ratio.

The *permeability* of a fly ash fill material is the most important property that affects the embankment construction and its performance quality. Bottom ash and pond ash being coarse grain as compared to fly ash have a higher value of permeability coefficient. The permeability of well-compacted fly ash has been found to range from 10^{-4} to 10^{-6} cm/s, which is roughly equivalent to the normal range of permeability of silty sand to silty clay soil (Di Gioia *et al*., 1979). The permeability of a material is affected by its density, degree of compaction, its grain size distribution and its internal pore structure (Hough, 1969). In addition, to fly ash consists of spherical shaped particles, the particles are densely packed during compaction, resulting in comparatively lower permeability values and minimizing seepage of water through a fly ash highway embankment (Ranjan & Rao, 2000).

3. Constructions & Design Aspects

Special concerns regarding the construction of embankments are briefly mentioned in following paragraph. Simple design and construction of embankment is shown in Fig. 3.

The original ground (site) should be leveled, sprinkled with adequate amount of water and then compacted by rolling so as to achieve 97% of Procter density. Fly ash and cover soil should be spread in layers of uniform thickness over the entire width of the embankment, by mechanical means.

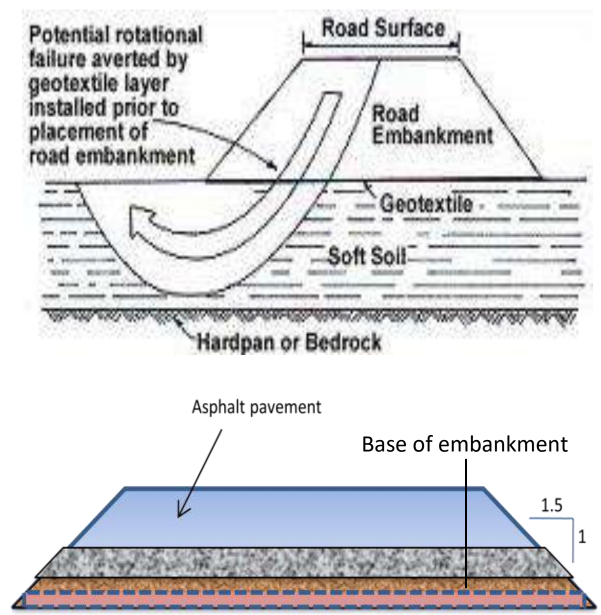

Fig. 3. Simple design of Embankment.

Water should be sprinkled uniformly over the entire embankment and moisture content of cover soil should be maintained at its optimum moisture content (OMC). Another way is to prevent the effects of water seepage in fly ash embankments is the placement of a drainage layer of well-drained granular material at the base of the embankment (Murthy *et al*., 2000). In Fig. 3, Hardpan or Bedrock place at the base of embankment. Above this, soft soil over the geotextile membrane place within a construction material. At the top of the road surface, asphalt pavement should be laid down. It consists of asphalt (used as a binder) and mineral aggregate mixed together, then laid down in layers and compacted. In highway construction, a base layer of crushed rock is usually laid down first to increase durability.

For, safe control or erosion control to construct a fly ash embankment within dikes of granular soil, which serves to protect the slopes throughout construction. Another way is to cover the slopes of the embankment with top soil. DiGioia & Brendel (1988) stated that chemical and electrical resistivity tests of some fly ashes have indicated that certain ash sources may be potentially corrosive to metal pipes placed within an embankment for drainage purpose. Provisions of metal pipes are necessary, the exterior of the pipes may be coated with tar or asphalt cement, the pipes may be wrapped with polyethylene sheeting, or the pipes can be backfilled with sand or an inert material.

4. Conclusion and Suggestion

The fly ash produced as waste materials can be a good construction material for highway or expressway embankments. Fly ash has been successfully used in more than ten highway embankments construction projects across the country. Fly ash has several advantages for the construction of embankments. The main advantages are its low unit weight and high shear strength. The pozzolanic hardening of fly ash imparts additional strength and very little settlements, making it more suitable for use in embankments. The disadvantages are due to its fine grained non-cohesive nature, is easily subject to erosion by wind or water. High winds erode fly ash and cause dust nuisance in and around the construction sites. These disadvantages can be easily overcome through the exercise of periodic checks on moisture content and density of compacted fly ash. In addition to these drawbacks, in some cases, monitoring for horizontal ground movements, settlements and pore pressure may be regularly checked at some intervals during the construction project of highway embankment.

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References

[1]. Swain, A. (1979). Field studies of fly ash in partially submerged condition. Proceedings of Symposium on Engineering behavior of Industrial and Urban fill, Birmingham, pp 14 -18.

[2]. Gray, D.H. & Y.K. Lin. (1972). Engineering properties of compacted fly ash. Proceedings of the American Society of Civil Engineers, National Water Resources Engineering Meeting, Phoenix, Arizona.

[3]. Leonards, G.A. & Bailey, B. (1982). Pulverized coal ash as structural fill, ASCE soil mechanics and foundation engineering division, Vol. 108, 517 -531.

[4]. Murthy, A.V.S.R., Guru, U.K. and Havanagi, V.G. (2000). Construction of road embankments using fly ash, fly ash disposal and deposition: Beyond 2000 AD, Narosa Publishing House, New Delhi, 198 -203.

[5]. McKerall, W.C., Ledbetter, W.B. and Teague, D.J. (1982). Analysis of fly ashes produced in Texas. Texas Transportation Institute, Research Report No. 240-1, A & M University, Texas, U.S.

[6]. Carlson, C.L. and Adriano, D.C. (1993). Environmental impacts of coal combustion residues, *J. of Environ. Quality*, 22: 227 -247.

[7]. Prasad. B., Singh, S.K. and Kumar, G. (2009). Best practices concerning fly ash with special reference to waste management. The IMEJ, 13-17.

[8]. Lamb, D.W. (1974). Ash disposal in dams, mounds, structural fills and retaining walls, Proceedings of the Third International Ash Utilization Symposium, U.S. Bureau of Mines, Information Circular No. 8640, Washington, DC.

[9]. McLaren, R.J. and DiGioia, A.M. (1987). Typical engineering properties of fly ash, Proceedings of Geotechnical practice for waste disposal. University of Michigan, Vol. 21, 22- 25.

[10]. DiGioia, A.M. & Taylor, L.R. (1979). Fly ash structural fill. Electric Power Research Institute, Report No. EA-1281, Palo Alto, California, USA.

[11]. Hough, B.K. (1969). Basic soils engineering. Ronald Press Company, New York. USA.

[12]. Ranjan, G. & Rao, A.S.R. (2000). Basic & Applied Soil Mechanics. New Age International Limited, New Delhi.

[13]. DiGioia, A.M. & Brendel, G.F. (1988). Coal ash as structural fill. International Conference on Fly ash disposal utilization, Organized by CBIP, New Delhi, India.

[14]. American Society Testing Materials (ASTM) E1861 (1997). A standard guide for use of coal combustion byproducts in structural fills. American Society for Testing and Materials, West Conshohocken, Pennsylvania, USA.

[15]. AASHTO (1986). Guide for design of pavement structures. American Association of State Highway and Transportation Officials, Washington, DC, USA.

[16]. Indian Standards (IS): 2720: Methods of Test for Soils.