Construction of Fly Ash Roadway Embankment in Illinois

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Electrostatically precipitated fly ash is a readily available source of structural fill in many metropolitan areas of the United States. A site was chosen by the Illinois Division of Highways near a large power plant for both a trial embankment and a highway embankment constructed with fly ash. A methodology for construction of fly ash embankments was developed that included spreading fly ash in thin lifts, scarification, and compaction by a vibratory roller. A clay seal was used to aid in confining the fly ash during construction and to provide a means of supporting vegetation. The performance of this roadway embankment has been satisfactory in respect to both structural stability and aesthetics.

Much fly ash is produced annually in the United States, as elsewhere in the world. Disposal of this fly ash not only has become an increasing burden on the producer of the fly ash (primarily, the power industry) but also results in a cost ultimately transferred to the power consumer. Superficially, fly ash may be considered as the waste product of a procedure necessary to reduce pollutants in the air and thus help to preserve our environment and as a waste product by its origin suspect and deserving of no more than careful disposal. However, the transportation engineer may, when faced with increasing shortages of building materials, choose to explore and evaluate the potential of fly ash as an engineering asset.

In urban areas particularly, earth borrow is often in scarce supply and available only at premium cost. Often these same urban areas are served by large power-generating stations that consume great quantities of coal and consequently produce great quantities of fly ash. A favorable combination of circumstances is created, provided the technology is available, for the use of fly ash in structural fill.

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CONSTRUCTION OF TEST EMBANKMENT

In spring 1965, the Illinois Division of Highways, in cooperation with the Commonwealth Edison Company and the Chicago Fly Ash Company, planned and supervised the construction of a trial fly ash embankment on a site adjacent to an electrical generating plant at Waukegan, Illinois.

The trial embankment was 61 m (200 ft) long, 12 m (40 ft) wide, and 1.8 m (6 ft) high and was constructed primarily to develop a construction methodology for future use of electrostatically precipitated fly ash in state projects.

The fly ash used consisted of two types: a stockpiled fly ash (approximately 60 days old) used in the lower 1.2 m (4 ft) of embankment, and a considerably younger silo-stored fly ash used for the upper 0.6 m (2 ft).

Initial procedures consisted of dumping the fly ash in 15.2-cm (6-in) loose lifts from tandem dump trucks, grader spreading, and compacting by means of a 9072-kg (10-ton) self-propelled pneumatic roller. Because of the formation of a crust and the presence of large lumps of hardened fly ash from the stockpiles, compaction of the full lift depth was apparently not possible. The value of further efforts, with disking and sheepsfoot tamping roller compaction, also proved to be dubious because the tamping roller tore the surface and did not provide any substantial increase in compaction.

At this point, procedures were altered to include rotary tilling, scarification, and six to eight passes with the pneumatic-tired roller. This sequence of operations proved successful in obtaining at least 85 percent relative compaction (AASHTO T-99) and was continued to completion of the embankment.

The effect of compaction at moisture contents both above and below optimum moisture (±25 percent), as determined by AASHTO T-99, method C, was also evaluated. Attempts at significantly low moisture contents (optimum ± 13 percent) were totally ineffective; the roller lost mobility, and dusting was a severe problem to personnel and equipment. The most effective range of compaction moistures was from optimum + 8 percent to optimum + 4 percent; this provided compaction in a narrow range

of from 85 to 88 percent. Other observations included the tendency of the fly ash to harden with age, that is, gain strength with time; a relatively high apparent permeability in respect to other similarly graded natural soils; and the inability of fly ash to support vegetation.

ENGINEERING PROPERTIES OF FLY ASH

There are several significant properties of fly ash that must be considered when it is used in structural fills or roadways. Individual fly ash particles are spherical in shape, generally solid, though sometimes hollow. In bulk quantities, fly ash possesses a silty texture, a specific gravity somewhat less than that of naturally occurring soils, and no plasticity.

Fly ash exhibits shear characteristics similar to those of a cohesionless soil, a significant undrained angle of internal friction (+25 deg), and a minimal cohesion intercept in a dry condition (1). A latent strength development or age-hardening process does often occur because of inherent pozzolanic activity within the fly ash.

The gradation of the fly ash used in this project is as follows: 19 percent sand, 71 percent silt, and 10 percent clay. It is nonplastic, has a maximum density of 1362 to 1474 kg/m^3 (85 to 92 lb/ft^3), and has an optimum moisture of from 20 to 26 percent. The California bearing ratio (CBR) for three conditions of fly ash is as follows: 20 percent for unsoaked, 2 percent for soaked, and 5 percent for swell. In that the CBR seems to be reduced as the fly ash swells when it is soaked, zones known to become saturated would most likely not be considered for placement of fly ash.

CHEMICAL PROPERTIES OF FLY ASH

The primary constituents of the fly ash used on this project were oxides of silica (45 percent), iron (19 percent), and lesser percentages each of aluminium, sodium, calcium, magnesium, and potassium. The presence of variable quantities (5 to 7 percent) of unburned carbon in the fly ash was noted throughout construction, and on at least one occasion an even higher carbon content was suspected because of the black color, and the fly ash was rejected.

The combination of available lime (CaO, MgO), ash pozzolans, an alkaline environment, and moisture may produce the apparent age hardening of the fly ash. The fly ash here had a pH of 10 and sufficient available lime to appear on the surface after drying. Recent use of certain western coals (Wyoming and Montana) in Illinois has produced fly ash with accelerated pozzolanic activity, apparently because of the higher natural lime content of the coal.

CONSTRUCTION OF HIGHWAY EMBANKMENT

In 1972, a contract was let by the Illinois Division of Highways to construct a major highway improvement between Grand and Greenwood avenues in Waukegan, 64 km (40 miles) north of Chicago. The portion of improvement covered here is now known as the Melvin E. Amstutz Expressway.

The proposal for the project included 2.33 km (1.45 miles) of four-lane concrete pavement with concrete median, the 188 080-m^3 (246 000-yd^3) embankment for which was to be constructed from one of the alternate materials, including fly ash.

The fly ash construction alternate was chosen by the contractor because a nearby power plant offered an available source of material, at a cost savings. The types of fly ash available were the same as those used in the test embankment phase, i.e., stockpiled and silo-stored material.

The height of the embankment was nominally 1 m (3.3 ft), except in the ramp areas at Grand and Greenwood avenues, where fills in excess of 8.5 m (28 ft) were constructed.

Site Conditions

The site conditions consisted of approximately 1980 m (6500 ft) of swampy vegetation to be removed to an average depth of ±0.6 m (±2 ft) underlain by clean sand (Figure 1). The removal areas were then to be backfilled to an elevation of 0.6 m (2 ft) above the mean water table with a porous granular backfill. The mean water table at this location is controlled entirely by the adjacent Lake Michigan.

Fly Ash Handling

Particular problems were encountered in handling the drier (±8 percent moisture), silo-stored material. As when used previously, this silo-stored material created a severe dusting problem during dumping and manipulation and required large quantities of water to bring it to compaction moisture, especially on hot, windy days.

When the stockpiled material arrived at the job site, its moisture content ranged from 12 to 40 percent; consequently, the material presented fewer problems in respect to blowing and compaction. Exceedingly large lumps of hardened fly ash from the stockpile were routinely broken up at the loading site by an end loader (Figure 2).

Manipulation of the fly ash after it was spread on grade by trucks (Figure 3) consisted of blading the fly ash in 15-cm (6-in) lifts (Figure 4), water spreading it if necessary, and disking it to achieve uniformity of moisture content and reduce the effects of lensing and crusting (Figure 5).

Lensing (the formation of small, shallow, transverse shear cracks) and crusting of the surface are considered detrimental, and disking or tilling through the loose lift into the surface of the preceding compacted lift is seen as a practical means of eliminating any adverse effects of lensing.

Field Compaction

The contractor was not bound to a particular means of compaction but was given some degree of flexibility, provided that a relative compaction of 85 percent (AASHTO T-99, method C) was attained on each lift. He chose to use a vibratory, single steel drum, 9072-kg (10-ton) roller (Figure 6). This roller performed adequately and often attained compaction well in excess of 85 percent with as few as two passes. Previous findings about the required range of compaction moisture were somewhat verified, although the response of stability and density at moisture contents in excess of optimum appeared to be much more sensitive with vibratory compaction than with pneumatic-tired roller compaction.

A 2.4-m (8-ft) envelope of cohesive soil was placed on the outside of the embankment to serve as an erosion protection device and to provide a means of vegetation support (Figure 7). This envelope also provided the secondary benefit of containing the outside edges of the embankment, thus allowing complete compaction at this point.

Figure 1. Roadway profile.

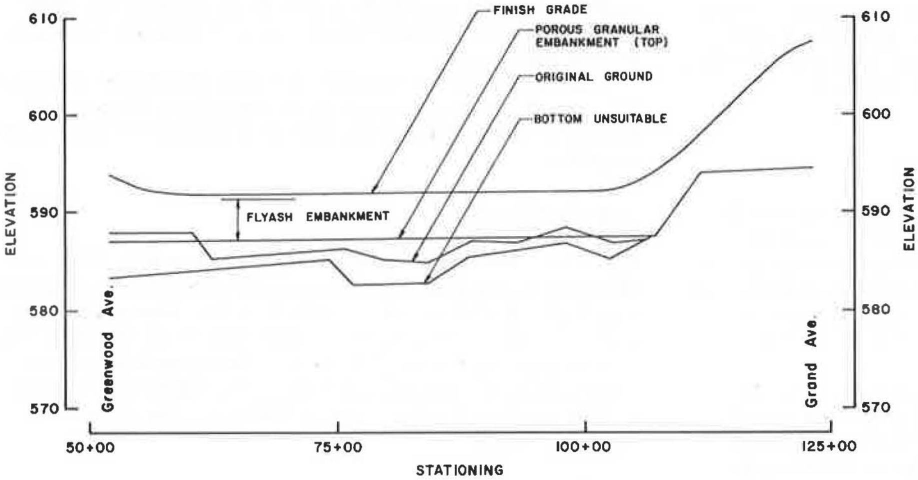


Figure 2. End loader breaking up hardened fly ash from stockpile.

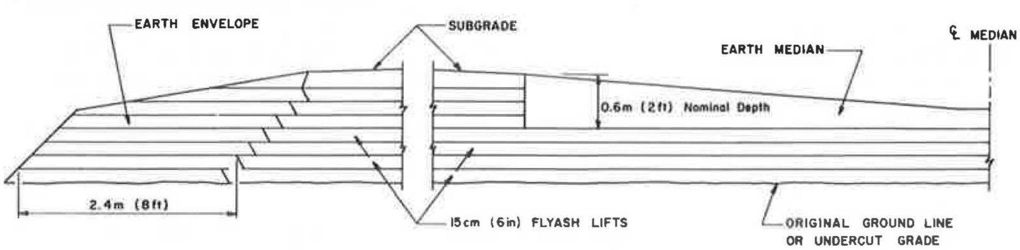
Figure 3. Spreading fly ash on grade.

Figure 4. Blading fly ash in lifts.

Figure 5. Disking fly ash.

Figure 6. Single steel drum roller.

Figure 7. Section of fly ash embankment.



Other Observations

Because of an apparent high permeability and often a high demand for water when fly ash is compacted, contractor operations were often unimpeded by moderate rainfall. Even after periods of heavy rain, work could resume much sooner than would be possible with more cohesive soils.

Freezing occurred to a depth of 45.7 cm (18 in), less than one-half of the 107 cm (42 in) normally expected in this area. During the thawing period, instability of this zone was evident because of the formation of ice lenses that prevented the downward flow of water. However, when thawing was complete, suitable stability was restored in 2 to 3 days.

Erosion of exposed fly ash was severe because channels several meters deep were developed during heavy storms on unprotected slopes. After periods of heavy rainfall and on drying, free lime appeared on the surface, accompanied by the development of longitudinal tension cracks in roller wheel tracks.

There is no evidence at this time of slope or subgrade instability. Slopes as steep as 2:1 are performing satisfactorily. Instrumentation has been installed, in both the high embankment areas and subgrades, to measure settlement, frost depth, and capillary rise. Because of the recent mild winter in this area and a relatively short period of observation, no significant trends have been observed.

CONCLUSIONS AND RECOMMENDATIONS

1. Electrically precipitated fly ash is an acceptable alternative to naturally occurring soils in both subgrades and fills above the water table.
2. Methods of construction control, such as compaction in thin lifts, scarification of the preceding lift surface, and compaction to at least 85 percent relative compaction, may be essentially those used for natural soils.
3. Compaction characteristics of fly ash are similar to those of noncohesive soils and are more responsive to vibration than to kneading or tamping.
4. Variations in standard densities of fly ash should be expected and provided for in control procedures.
5. Provisions must be made in contracts for the use of large quantities of water, as a means of controlling dusting and obtaining compaction.
6. Environmental hazards, real or purely speculative, must be solved or fly ash use may never reach its full potential. Dusting is a real problem, particularly to contractor's equipment. Groundwater pollution by fly ash is currently in the speculative category, and its significance can only be assessed by realistic laboratory and field measurements on a case-by-case basis.

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REFERENCE

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