Designation: E2277 – 03

Standard Guide for
Design and Construction of Coal Ash Structural Fills[1]

1. Scope

1.1 This guide covers procedures for the design and construction of engineered structural fills using coal fly ash, bottom ash, or ponded ash.

1.2 The utilization of coal ash under this guide is a component of a pollution prevention program; Guide E1609 describes pollution prevention activities in more detail. Utilization of coal ash in this manner conserves land, natural resources, and energy.

1.3 This guide applies only to fly ash and bottom ash produced primarily by the combustion of coal.

1.4 The testing, engineering, and construction practices for coal ash fills are similar to generally accepted practices for natural soil fills. Coal ash structural fills should be designed using generally accepted engineering practices.

1.5 Laws and regulations governing the use of coal ash vary by state. The user of this guide has the responsibility to determine and comply with applicable requirements.

1.6 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C150 Specification for Portland Cement
C188 Test Method for Density of Hydraulic Cement
C311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C595/C595M Specification for Blended Hydraulic Cements
D75 Practice for Sampling Aggregates
D420 Guide to Site Characterization for Engineering Design and Construction Purposes
D422 Test Method for Particle-Size Analysis of Soils
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3(600 kN-m/m^3))
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1195 Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
D1196 Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
D1452 Practice for Soil Exploration and Sampling by Auger Borings
D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3(2,700 kN-m/m^3))
D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1883 Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
D2166 Test Method for Unconfined Compressive Strength of Cohesive Soil
D2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D2850 Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils
D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]
D3080 Test Method for Direct Shear Test of Soils Under

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[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment and is the direct responsibility of Subcommittee E50.03 on Pollution Prevention, Reuse, Recycling, and Environmental Efficiency.

Current edition approved May 10, 2003. Published July 2003. DOI: 10.1520/E2277-03.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

Consolidated Drained Conditions

D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D3877 Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures

D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

D4429 Test Method for CBR (California Bearing Ratio) of Soils in Place

D4643 Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating

D4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating

D4972 Test Method for pH of Soils

D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D5239 Practice for Characterizing Fly Ash for Use in Soil Stabilization

E1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process

E1528 Practice for Limited Environmental Due Diligence: Transaction Screen Process

E1609 Guide for Development and Implementation of a Pollution Prevention Program[3]

E2201 Terminology for Coal Combustion Products

G51 Test Method for Measuring pH of Soil for Use in Corrosion Testing

G57 Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

2.2 *AASHTO Standards:*[4]

T 288 Determining Minimum Laboratory Soil Resistivity

T 289 Determining pH of Soil for Use in Corrosion Testing

T 290 Determining Water Soluble Sulfate Ion Content in Soil

T 291 Determining Water Soluble Chloride Ion Content in Soil

3. Terminology

3.1 *Definitions*—For definitions related to Coal Combustion Products, see Terminology E2201. For definitions related to geotechnical properties see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *internal erosion*—piping; the progressive removal of soil particles from a mass by percolating water, leading to the development of channels.

4. Significance and Use

4.1 *General*:

4.1.1 Coal ashes are suitable materials for the construction of engineered, structural fills. Coal ashes may be used as: structural fill for building sites and foundations; embankments for highways and railroads, dikes, levees; and in any other application requiring a compacted fill material. Their low unit weight, relatively high shear strength, ease of handling, and compaction all make coal ashes useful as fill material. Coal ashes may be a cost-effective fill material in many areas because they are available in bulk quantities, conserve natural resources, and reduce the expenditures required for the purchase, permits, and operation of a soil borrow pit. Coal ash often can be delivered at near optimum moisture content.

4.1.2 This guide describes the unique design and construction considerations that may apply to structural fills constructed of coal ash. The requirements for specific structural fills may vary due to local site conditions or the intended use of the structural fill, or both.

4.2 *Regulatory Framework*:

4.2.1 *Federal*—The U.S. Environmental Protection Agency (USEPA) has completed a study of coal combustion by-products for the U.S. Congress and has issued a formal regulatory determination (**1**, **2**).[5] USEPA "encourages the utilization of coal combustion by-products and supports State efforts to promote utilization in an environmentally beneficial manner" (**3**). USEPA subsequently ruled that national regulation of most beneficial uses of coal ash, including structural fills, is not warranted (**4**).

4.2.2 *State and Local*—Laws and regulations regarding the use of coal ash vary by state and locality.

4.3 *Economic Benefits*—Coal ash can be a cost-effective fill material. In many areas, it is available in bulk quantities at a reasonable cost. Use of coal ash conserves natural resources and reduces the expenditures for the purchase, permits, and operation of a soil borrow pit.

5. Engineering Properties and Behavior

5.1 *General*—Fly ash and bottom ash exhibit distinct engineering properties and behavior as described below. The engineering properties and behavior of ponded ash may be similar to fly ash or bottom ash, depending on the ratio of each in the ponded ash.

5.2 *Unit Weight*—Many coal ashes have relatively low unit weights. The low unit weight of these materials can be advantageous for some structural fill applications. The lighter weight material will reduce the load on weak layers or zones of soft foundation soils such as poorly consolidated or landslide-prone soils. Additionally, the low unit weight of these materials will reduce transportation costs since less tonnage of material is hauled to fill a given volume.

5.3 *Strength*:

5.3.1 *Shear Strength*—For non-self-cementing fly ash and bottom ash, shear strength is derived primarily from internal friction. Typical values for angles of internal friction for non-self-cementing fly ash are higher than many natural fine-grained soils. These ashes are non-cohesive and although the ash may appear cohesive in a partially saturated state, this effect is completely lost when the material is either completely dried or saturated.

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[4] Interim Specifications for Transportation Materials and Methods of Sampling and Testing, Part II, AASHTO, 444 North Capitol St., N.W., Suite 225, Washington, DC 20001.

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

5.3.1.1 Due to its angular shape, the shear strength of bottom ash is typically greater than fly ash and is similar to the shear strength of natural materials of similar gradation. However, friable bottom ash may exhibit lower shear strength than natural materials of similar gradation.

5.3.2 *Compressive Strength*—Self-cementing fly ash experiences a cementing action that increases with time. Because the hydration of dry self-cementing fly ash commences immediately upon exposure to water, higher compressive strengths will be attained when the fly ash is placed and compacted immediately following addition of water. If too much time lapses, the fly ash particles can become cemented in a loose state, reducing the compacted density and strength.

5.4 *Consolidation Characteristics*—Structural fills constructed of fly ash typically exhibit small amounts of time-dependent, post-construction consolidation. This is because excess pore water pressures dissipate relatively rapidly, and thus, most of the embankment settlement or deformation occurs due to elastic deformation of the material, rather than by classical consolidation. Most deformation due to the mass of the fill or structure thereon generally occurs during construction.

5.4.1 Bottom ash is usually a free-draining material that can be compacted into a relatively dense, incompressible mass. For these reasons structural fills constructed of bottom ash also typically exhibit small amounts of time-dependent, post-construction consolidation or deformation, with most deformation occurring during construction.

5.4.2 Self-cementing fly ash typically exhibits minimal post-construction consolidation or deformation due to cementing and solidification of the fly ash.

5.4.3 Some self-cementing fly ash may swell with time. Section 6.3.8 provides guidance on evaluating the swelling potential of self-cementing fly ash.

5.5 *Permeability*—The permeability of non-self-cementing fly ash is similar to values observed for natural silty soils.

5.5.1 Self-cementing fly ash is relatively impermeable, with permeability values similar to natural clays.

5.5.2 Bottom ash is typically as permeable as granular soils of similar gradation.

5.6 *Liquefaction and Frost Heave*—Fine-grained, non-cohesive materials such as fly ash are susceptible to liquefaction and frost heave when saturated. For this reason, fly ash fills are designed to be well drained or are located in areas where they are not subject to saturation or infiltration by surface or ground water. Self-cementing fly ash is not susceptible to liquefaction.

5.6.1 Bottom ash is not typically susceptible to either liquefaction or frost heave. However, some of the finer bottom ash materials may behave quite similarly to fly ash and would require the same consideration for design as fly ash fills.

6. Testing Procedure

6.1 *General*—Testing requirements are determined based on site conditions, knowledge of the coal ash, intended use of the fill, and local requirements.

6.2 *Sampling*—Practice D75 or Test Method C311 as appropriate, and Guide D420 with sample extraction conducted in accordance with Practice D1452, Test Method D1586, or Practice D3550, as appropriate.

6.3 *Physical and Engineering Characteristics*:

6.3.1 *Grain-Size Distribution*—Test Method D422. For fly ash, a substantial portion of the material will be finer than the No. 200 sieve and hydrometer analyses will also be required. Use distilled water in the hydrometer test with a deflocculating agent added to prevent fly ash from forming flocs. Self-cementing fly ash[es] may require use of alcohol or other nonreactive solution in place of the standard solution used. Fly ash often has a relatively uniform particle size and precautions against overloading sieves are warranted. Specimen loss through dusting can also be a problem. Specific gravity may vary with particle size. Specific gravity values used in hydrometer analyses should be appropriate to the portion of the sample being tested.

6.3.2 *Specific Gravity*—Test Method D854. For some fly ash, a significant portion of the particles may have a density less than water and float. Agitation of the slurry may be needed to keep the particles in suspension so that the average specific gravity can be obtained. Alternately for this ash and self-cementing fly ash, Test Method C188, which uses kerosene as the fluid, may be used.

6.3.3 *Water Content*—Test Method D2216. For self-cementing fly ash consider lowering the drying temperature to 140°F (60°C) to avoid driving off the water of hydration.

6.3.4 *Compaction*:

6.3.4.1 *Fly Ash*—Test Method D698 or D1557. For dry self-cementing fly ash, the time interval between wetting and compaction in the laboratory should be similar to that anticipated during construction to account for the influence of the rate of hydration on compaction characteristics.

6.3.4.2 *Bottom Ash*—Test Methods D4253 and D4254 may be used for the determination of maximum and minimum density of coarse-grained bottom ashes that do not exhibit a moisture-density relationship.

6.3.5 *Strength*:

6.3.5.1 *Shear Strength*—Test Method D3080. This test is preferred because it models the drained conditions that typically exist in a structural fill constructed of coal ash. The method is modified in that the shear box is not to be filled with water.

6.3.5.2 *Compressive Strength of Non-Self-Cementing Fly Ash*—Test Method D2850. Compact specimens to the unit weights and water contents required by the project compaction requirements.

6.3.5.3 *Compressive Strength of Self-Cementing Fly Ash*—Test Method D2166. The unconfined compressive strength at various ages is used to evaluate short-term and long-term strength development.

6.3.6 *Hydraulic Conductivity*—Test Method D5084. Hydraulic conductivity is used to estimate the quantity of infiltration for designing underdrains.

6.3.7 *Compressibility*—Test Method D2435. Samples should be prepared at the degree of compaction specified for construction and at the optimum water content determined by the compaction test. This is because fly ash tends to lose surface stability in the field when compacted at water contents greater than the optimum for compaction. Coal ash consolidates rapidly, therefore compressibility typically is not a design concern. Because of the non-cohesive nature of some coal ashes, extra care in sample handling is needed.

6.3.8 *Swelling*—Test Methods D3877, for self-cementing fly ash. Reactions producing the expansive properties may not commence for a period of more than 30 days after initial ash hydration. The test procedures must address this delayed reaction. The procedure should be modified to extend the wetting and drying cycles to a frequency determined by a qualified design engineer.

6.4 *Chemical Characteristics*—Chemical analyses are routinely conducted by many coal ash producers and are communicated to users of this material by means of a Material Safety Data Sheet (MSDS) or some similar communication. For the structural fill designer these results provide information on characteristics that may need to be considered in design, particularly with regard to assessing chemical interaction between fill and other materials or structures. Tests for soluble species may also be required by local regulatory agencies.

6.4.1 *Chemical Composition*—Test Methods C311 is often used to determine the major chemical constituents.

6.4.2 *pH*—Test Method D4972 or Practice D5239. The pH of the coal ash may vary with age, water content, and other conditions.

6.4.3 *Resistivity*—Test Method G57, a field test, is used to measure coal ash resistivity as an indicator of possible corrosion potential for embedded metals. An alternate laboratory procedure is AASHTO Interim Method of Test T 288. Likely field water contents should be considered in assessing test conditions and results. Field water contents in drained coal ash fills are likely to be close to the optimum water content for compaction. AASHTO Interim Methods of Test T 289, T 290, and T 291 provide measurements of the pH, water-soluble sulfate ion content and water-soluble chloride ion content of the coal ash that are useful in evaluating corrosion potential. Test Method G51 is also used to determine the pH of soil for use in corrosion testing.

6.4.4 *Sulfate*—Sulfate content as determined from the coal ash chemical analysis by Test Method C311, or other method is used in a preliminary assessment of the potential for sulfate attack on concrete. As with corrosivity, likely field water conditions and variations in concentrations with time should be considered.

7. Design Considerations

7.1 *General*—The design process and procedures are similar to those normally followed for cohesionless natural soil materials. Cohesion developed by self-cementing fly ash can also be considered in the design of fill slopes and determination of bearing capacity. Refs (**5-9**) provide additional information regarding laboratory testing, design, and construction procedures.

7.1.1 The ultimate end use of the site can present special design considerations. For example, fly ash is not an appropriate medium for septic systems. A thicker soil cover may be appropriate depending on the planned end use of the site. Deed restrictions may be warranted in some instances.

7.2 *Site Characterization*:

7.2.1 *General*—The siting and design of a coal ash structural fill requires the same characterization of site conditions that is typically required of earthwork construction projects of similar size. The geologic and hydrologic conditions at the site must be understood to determine design parameters for the structural fill. In addition, consideration of environmental resources at or near the site is required to avoid or minimize negative environmental consequences. Practices E1527 and E1528 may be applied whenever a real estate transaction is involved.

7.2.2 *Geologic and Hydrologic Investigation*—A subsurface investigation may involve a review of available information about the site, a site reconnaissance by a geologist or engineer, and extraction of soil and rock samples for classification and testing, depending on the size and intended use of the structural fill. Guide D420 provides guidance for conducting subsurface investigations.

7.2.3 *Environmental Resources*—Many sensitive environmental resources such as wetlands, floodplains, rare and endangered species, and cultural resource areas are afforded protection by Federal, state, and local regulations and ordinances. Appropriate action should be taken to comply with the requirements of the regulatory agency having jurisdiction at the structural fill site.

7.3 *Site Preparation and Internal Drainage*—Some structural fills constructed of non-self-cementing fly ash must be well drained because of the sensitivity of the material to the flow of water (that is, piping). Problems such as slope stability, liquefaction, and frost heave that may result from saturation of the fly ash are thus avoided. When necessary, a drainage blanket can be used to provide internal drainage and serve as a capillary barrier. Coal ash should be placed in areas where it is not subject to saturation by surface or ground water to avoid this concern.

7.3.1 *Site Preparation*—Site preparation involves grading and drainage improvements required prior to placement of coal ash. Surface drainage is diverted and controlled. Erosion and sedimentation controls are installed. If needed, wet areas are allowed to drain and dry. Unsuitable materials such as vegetation and topsoil are removed and the subgrade is prepared. Provisions to stockpile any soil needed for final cover are included.

7.3.2 *Site Drainage*—Provisions for positive site drainage are essential if the structural fill is to be reliably maintained in an unsaturated condition. Drainage of seeps and springs encountered during construction should be provided for in design of a site drainage system. A series of perforated pipe drains or aggregate-filled trenches are commonly used for this purpose. These systems are flexible and can be expanded in areal extent as needed to accommodate conditions encountered during construction. Adequate filter protection of drains to ensure long-term, maintenance-free performance should be included. Any provisions needed to control site ground-water levels through collection and drainage should be included in the design.

7.3.3 *Drainage Blanket*—For non-self-cementing fly ash, a drainage blanket of free-draining material may be used. The drainage blanket also serves as a barrier to capillary saturation.