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Standard Guide for Use of Coal Combustion By-Products in Structural Fills¹

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1. Scope

1.1 This guide covers procedures for the design and construction of engineered structural fills using coal combustion by-products (CCBs).

1.2 The utilization of CCBs under this guide is a component of a pollution prevention program; Guide E 1609 describes pollution prevention activities in more detail. Utilization of CCBs in this manner conserves land, natural resources, and energy.

1.3 This guide applies only to CCBs produced solely by the combustion of coal. It does not apply to ash or other combustion products derived from the burning of waste; municipal, industrial, or commercial garbage; sewage sludge or other refuse, or both; derived fuels; wood; wood waste products; rice hulls; agricultural waste; or other non-coal fuels or other such fuels blended with coal, or some combination thereof.

1.4 The testing, engineering, and construction practices for CCB fills are similar to generally accepted practices for natural soil fills. The CCB structural fills should be designed with generally accepted engineering practices.

1.5 Laws and regulations governing the use of CCBs 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 limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

C 150 Specification for Portland Cement²

C 188 Test Method for Density of Hydraulic Cement²

C 311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete³

C 595/C595M Specification for Blended Hydraulic Cements²

D 75 Practice for Sampling Aggregates⁴

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes⁵

D 422 Test Method for Particle-Size Analysis of Soils⁵

D 653 Terminology Relating to Soil, Rock, and Contained Fluids⁵

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft³ (600 kN-m/m³))⁵

D 854 Test Method for Specific Gravity of Soils⁵

D 1195 Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements⁵

D 1196 Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements⁵

D 1452 Practice for Soil Investigation and Sampling by Auger Borings⁵

D 1556 Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method⁵

D 1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56 000 ft-lbf/ft³ (2700 kN-m/m³))⁵

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils⁵

D 1883 Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils⁵

D 2166 Test Method for Unconfined Compressive Strength of Cohesive Soil⁵

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method⁵

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock⁵

D 2435 Test Method for One-Dimensional Consolidation Properties of Soils⁵

D 2850 Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression⁵

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² Annual Book of ASTM Standards, Vol 04.01.

³ Annual Book of ASTM Standards, Vol 04.02.

⁴ Annual Book of ASTM Standards, Vol 04.03.

⁵ Annual Book of ASTM Standards, Vol 04.08.

- D 2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)⁵
D 3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions⁵
D 3550 Practice for Ring-Lined Barrel Sampling of Soils⁵
D 3877 Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures⁵
D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table⁵
D 4254 Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density⁵
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils⁵
D 4429 Test Method for CBR (California Bearing Ratio) of Soils in Place⁵
D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method⁵
D 4959 Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method⁶
D 4972 Test Method for pH of Soils⁶
D 5084 Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter⁶
D 5239 Practice for Characterizing Fly Ash for Use in Soil Stabilization⁶
E 1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process⁷
E 1528 Practice for Environmental Site Assessments: Transaction Screen Process⁷
E 1609 Guide for Development and Implementation of a Pollution Prevention Program⁷
G 51 Test Method for pH of Soil for Use in Corrosion Testing⁸
G 57 Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method⁸
2.2 *AASHTO Standards*:⁹
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*—Definitions are in accordance with Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *baghouse, n*—a facility constructed at some coal-fired power plants consisting of fabric filter bags that mechanically trap particulate (fly ash) carried in the flue gases.

3.2.2 *beneficial use, n*—projects promoting public health and environmental protection, offering equivalent success relative to other alternatives, and preserving natural resources.

3.2.3 *boiler slag, n*—a molten ash collected at the base of slag tap and cyclone boilers that is quenched in a water-filled hopper and shatters into black, angular particles having a smooth, glassy appearance.

3.2.4 *bottom ash, n*—agglomerated ash particles formed in pulverized coal boilers that are too large to be carried in the flue gases and impinge on the boiler walls or fall through open grates to an ash hopper at the bottom of the boiler. Bottom ash is typically grey to black in color, is quite angular and has a porous surface texture.

3.2.5 *coal combustion by-products, n*—fly ash, bottom ash, boiler slag, or flue gas desulfurization (FGD) material resulting from the combustion of coal.

3.2.6 *drainage blanket, n*—a uniform layer of permeable material (such as sand, crushed stone, or bottom ash) installed with properly designed filter media at the base of a structural fill to maintain the fill in a drained condition.

3.2.7 *electrostatic precipitator, n*—a facility constructed at some coal-fired power plants to remove particulate matter (fly ash) from the flue gas by producing an electric charge on the particles to be collected and then propelling the charged particles by electrostatic forces to collecting curtains.

3.2.8 *flue gas desulfurization (FGD) material, n*—by-products of FGD systems that have been processed using forced oxidation or chemical fixation and stabilization to produce a soil-like material.

3.2.9 *fly ash, n*—coal ash that exits a combustion chamber in the flue gas. Fly ash is typically a pozzolan. Some fly ash also exhibits self-hardening properties in the presence of moisture.

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

3.2.11 *pozzolans, n*—siliceous or siliceous and aluminous materials that in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

3.2.12 *stabilized CCBs, n*—CCBs that are blended with a cementitious binder to induce or enhance a pozzolanic reaction.

3.2.13 *structural fill, n*—an engineered fill with a projected beneficial end use that is typically constructed in layers of uniform thickness and compacted to a desired unit weight (density) in a manner to control the compressibility, strength, and hydraulic conductivity of the fill.

3.2.14 *thixotropic, adj*—the property of a material that enables it to stiffen in a relatively short time on standing, but upon agitation or manipulation to change to a very soft consistency or to a fluid of high viscosity, the process being completely reversible.

4. Significance and Use

4.1 *General*—The CCBs can be effective materials for the construction of engineered, structural fills. The CCBs may be used as: structural fill for building sites and foundations; embankments for highways and railroads, dikes, and levees.

⁶ Annual Book of ASTM Standards, Vol 04.09.

⁷ Annual Book of ASTM Standards, Vol 11.04.

⁸ Annual Book of ASTM Standards, Vol 03.02.

⁹ Available from the American Association of State Highway and Transportation Officials, 444 N. Capitol St., NW, Washington, DC 20001.

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 CCBs useful as fill material. The CCBs may be a cost-effective fill material in many areas because they are available in bulk quantities and reduce the expenditures required for the purchase, permits, and operation of a soil borrow pit. Also, because CCBs are abundantly produced by-products, their use in large-volume applications such as in the construction of structural fills provides an outlet for material, provided that the CCB is environmentally and geotechnically suitable for the desired use.

4.1.1 Fly ash is typically a pozzolan, however, certain fly ash and FGD by-products may exhibit self-hardening properties as well. The laboratory testing and design considerations for self-hardening and non-self-hardening CCBs vary in some instances. Guidance is provided in Sections 6-9.

4.2 *Engineering Properties and Behavior*—The CCB structural fills may be constructed with fly ash, bottom ash, boiler slag, FGD material, or combinations thereof. Each of these materials typically exhibits general engineering properties that must be considered in the design of a CCB structural fill. These general engineering properties are discussed in the following sections; however, it should be noted that the specific engineering properties of these materials can vary greatly from source to source and must be evaluated for each material, or combination of materials, to be utilized for a structural fill.

4.2.1 *Unit Weight*—Many CCBs 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.

4.2.1.1 Fly ash is typically lighter than the fill soils it replaces with unit weight ranging from about 50 to 100 pcf (8 to 16 kN/m³).

4.2.1.2 Bottom ash is also typically lighter than coarse-grained soils of similar gradation.

4.2.1.3 Boiler slag is typically as heavy, if not heavier, than natural soils of similar gradation.

4.2.1.4 The FGD materials are also relatively lightweight, with unit weights ranging from about 50 to 100 pcf (8 to 16 kN/m³).

4.2.2 *Compaction Characteristics*—Most CCBs can be placed and compacted in a manner very similar to soil and aggregate fill materials. In fact, most CCBs exhibit very little cohesion and are not as sensitive to variations in moisture content as natural soils.

4.2.2.1 Fly ash and FGD material are typically placed and compacted in a manner similar to non-cohesive fine-grained soils. Smooth drum vibratory rollers typically compact these materials most effectively. Although not always, fly ash and FGD material typically exhibit a measurable moisture-density relationship that can be utilized for compaction quality control. It should be noted that fly ash and FGD material that exhibit self-hardening properties must be compacted soon after the

addition of water. Compaction criteria are usually not specified for FGD material that exhibits thixotropic properties.

4.2.2.2 Bottom ash is generally placed and compacted in a manner similar to non-cohesive coarse-grained soils or fine aggregate. Smooth drum vibratory rollers typically are most effective for the compaction of these materials. Bottom ash may or may not exhibit consistent moisture-density relationships.

4.2.2.3 Boiler slag is generally placed and compacted in a manner similar to non-cohesive coarse-grained soils or fine aggregate. Smooth drum vibratory rollers typically are most effective for the compaction of these materials. As with bottom ash, boiler slag may or may not exhibit consistent moisture-density relationships.

4.2.3 *Strength*:

4.2.3.1 *Shear Strength*—For non-self-hardening fly ash and bottom ash, shear strength is derived primarily from internal friction. Typical values for angles of internal friction for non-self-hardening fly ash are higher than many natural 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.

(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.

(2) The shear strength of boiler slag may be higher than that of natural materials of similar gradation, in part due to the typically angular shape and hardness of the particles.

4.2.3.2 *Compressive Strength*—Self-hardening and stabilized CCBs and FGD material undergo a cementing process that increases with time. Hydration of dry self-hardening CCBs commences immediately upon exposure to water and can cement the CCB particles in a loose state, reducing the compacted density and strength. Compressive strengths in excess of 1000 psi can be achieved if the CCBs are compacted immediately after incorporation of water.

4.2.4 *Consolidation Characteristics*—Structural fills constructed of fly ash or FGD material 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.

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

4.2.4.2 Self-hardening fly ash and FGD material typically exhibit minimal post-construction consolidation or deformation due to cementing and solidification of the CCBs.

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

4.2.5.1 Self-hardening fly ash and FGD material are relatively impermeable, with permeability values similar to natural clays.

4.2.5.2 Bottom ash and boiler slag are typically as permeable as granular soils of similar gradation.

4.2.6 *Erosion Characteristics*:

4.2.6.1 *Internal Erosion (piping)*—Non-self-hardening fly ash is subject to internal erosion due to its fine-grained, non-cohesive nature. Internal erosion can be controlled by providing adequate surface water controls to minimize infiltration and by providing internal drainage when warranted.

(1) Bottom ash and boiler slag typically are well graded and capable of being compacted to a stable mass. These attributes usually preclude any problems arising from internal piping of material.

(2) Self-hardening fly ash and FGD material are usually not subject to internal erosion.

4.2.6.2 *Surface Erosion*—All CCBs may be eroded by wind or water and require use of erosion controls similar to those commonly used on earthwork construction projects.

4.2.7 *Swelling*—Some self-hardening CCBs may swell with time. Paragraph 6.3.9 provides guidance on evaluating the swelling potential of CCBs.

4.2.8 *Liquefaction and Frost Heave*—Although fine-grained and non-cohesive materials such as fly ash are susceptible to liquefaction and frost heave when saturated, these problems are readily controlled by design practices that allow for drainage away from the ash fill. Because of its sensitivity to moisture, it is standard practice to design fly ash fills to be well drained. Typically, drainage blankets to provide internal drainage and serve as a capillary barrier are included at the base of fills. Also, locating fills in areas where they are not subject to saturation or infiltration by surface or ground water is normally considered in design. Self-hardening and stabilized fly ash and FGD material are not susceptible to liquefaction.

4.2.8.1 Well-compacted bottom ash and boiler slag are not typically susceptible to either liquefaction or frost heave. However, some of the finer bottom ash materials may behave quite similarly to that of fly ash and would require the same consideration for design as fly ash embankments.

4.3 *Environmental Considerations*

4.3.1 *Regulatory Framework*:

4.3.1.1 *Federal*—The U.S. Environmental Protection Agency (USEPA) has completed a study of CCBs for the U.S. Congress and has issued a formal regulatory determination (1,2).¹⁰ The EPA “encourages the utilization of coal combustion by-products and supports State efforts to promote utilization in an environmentally beneficial manner” (3). There is currently no regulatory program at the Federal level that regulates the use of CCBs in structural fills.

4.3.1.2 *State and Local*—There is considerable variation in state-mandated permitting and other regulatory requirements.

¹⁰ The boldface numbers in parentheses refer to a list of references at the end of this guide.

Some states have specific beneficial use provisions, while other states have no regulations addressing beneficial use.

4.3.2 *Water Quality*—The design and construction of CCB structural fills should consider the potential impacts on ground water and surface water to ensure protection of human health and the environment.

4.3.2.1 The CCB structural fills should typically be designed to provide separation between the CCB fill material and the seasonal high ground water table. Measures taken to protect both ground water and surface water include proper compaction to reduce permeability and erosion and placement of suitable cover material to minimize infiltration and erosion. Structural fills should also be sloped to encourage runoff while minimizing erosion concerns.

4.3.3 *Air Quality*:

4.3.3.1 *Dust Control*—Dusting must be controlled during placement of CCBs in structural fills in order to avoid fugitive dust and to protect workers. See 9.2.1 for recommended dust control measures.

4.3.3.2 *Radionuclides*—As with other structural fill materials, certain radioactive elements are known to occur naturally in CCBs. The model standards and techniques for controlling radon in accordance with Ref (4) are recommended for new building construction, where needed.

4.4 *Economic Benefits*—The use of CCBs in structural fill can have economic benefits. These benefits are affected by local and regional factors including production rates, processing and handling costs, transportation costs, availability of competing materials, environmental concerns, and the experience of materials specifiers, design engineers, purchasing agents, contractors, legislators, regulators, and other professionals.

4.4.1 The CCBs can be a cost-effective fill material. In many areas, it is available in bulk quantities. Use of CCBs reduces the expenditures for the purchase, permits, and operation of a soil borrow pit.

5. Site Characterization

5.1 *General*—The siting and design of a CCB structural fill requires the same characterization of site conditions that is typically required of earthwork construction projects of similar size. An investigation of the geologic and hydrologic conditions at the site is required 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 E 1527 and E 1528 may be applied whenever a real estate transaction is involved.

5.2 *Geologic and Hydrologic Investigation*—Subsurface conditions at the site must be understood. This typically involves a review of available information about the site, a site reconnaissance by a geologist or geotechnical engineer, and extraction of soil and rock samples from the subsurface for classification and testing. Guide D 420 provides guidance for conducting subsurface investigations.

5.3 *Environmental Resources*—Many sensitive environmental resources such as wetlands, floodplains, rare and endangered species, and cultural resource areas are afforded