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

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1. Scope

1.1 This guide covers procedures for the design and construction of engineered structural fills using coal combustion products (CCPs) including but not limited to fly ash, bottom ash, boiler slag or other CCPs that can meet the requirements of an engineered fill as described herein. CCPs may be used alone or blended with soils or other suitable materials to achieve desired geotechnical properties.

1.2 This guide describes the unique design and construction considerations that may apply to engineered structural fills constructed of with CCPs that have been adequately characterized as being suitable for this beneficial use.

1.3 Beneficial utilization of CCPs consistent with this standard conserves land, natural resources, and

1.4 This guide applies only to CCPs produced primarily by the combustion of coal.

1.5 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. However, when CCPs are used in saturated conditions such as ponds or impoundments, the potential for liquefaction may need to be considered.

1.6 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.

1.7 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.8 *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/C150M 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
C593 Specification for Fly Ash and Other Pozzolans for Use With Lime for Soil Stabilization
C595/C595M Specification for Blended Hydraulic Cements
C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C1157 Performance Specification for Hydraulic Cement
C1600 Specification for Rapid Hardening Hydraulic Cement
D75 Practice for Sampling Aggregates
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/D1195M 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/D1196M 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))

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[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.

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EXHIBIT
MWG902

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
D2844 Test Method for Resistance ***R***-Value and Expansion Pressure of Compacted Soils
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) (Withdrawn 2007)[3]
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
D3987 Practice for Shake Extraction of Solid Waste with Water
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
D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils
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
D5550 Test Method for Specific Gravity of Soil Solids by Gas Pycnometer
D5759 Guide for Characterization of Coal Fly Ash and Clean Coal Combustion Fly Ash for Potential Uses
D7181 Test Method for Consolidated Drained Triaxial Compression Test for Soils
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

2.3 *U.S. EPA Standard:*[5]
SW 846 Test Methods for Evaluationg Solid Waste: Physical/Chemical Methods

2.4 *OSHA Standard:*[6]
29 CFR Part 1910.1200 Hazard Communication

2.5 *AASHOTO Standard:*[7]
PP059–09–UL Standard Practice for Coal Combustion Fly Ash for Embankments

3. Terminology

3.1 *Definitions*—For definitions related to coal combustion products (CCPs), see Terminology E2201. For definitions related to geotechnical properties see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *beneficial use, n*—projects that use CCPs in a manner that meets the design specification, conserves natural resources and energy, reduces greenhouse gas emissions, and protects human health and the environment.

3.2.2 *CCP engineered structural fill, n*—engineered fill with a projected beneficial end use that is typically constructed in layers of CCPs with uniform thickness or blended with other materials and compacted to a desired unit weight (density) in a manner to control the compressibility, strength, and hydraulic conductivity of the fill and used in lieu of unconfined natural soils or aggregate.

3.2.2.1 *Discussion*—Engineered structural fills do not include base course, subbase, subgrade, utility trench backfill, and other unconfined geotechnical applications. See Terminology D653 for definitions of base course, subbase, and subgrade.

3.2.3 *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 ambient temperatures to form compounds possessing cementitious properties.

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

[4] Interim Specifications for Transportation Materials and Methods of Sampling and Testing, Part II, American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

[5] Available from United States Environmental Protection Agency (EPA), William Jefferson Clinton Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20004, http://www.epa.gov.

[6] U.S. Department of Labor, Occupational Safety & Health Administration, 200 Constitution Ave., Washington, DC 20210.

[7] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

3.2.4 *stabilized CCPs, n*—CCPs that are self-cementing alone or blended with calcium hydroxide or cementitious binder to induce or enhance a pozzolanic reaction and increase strength; use of a cementitious binder can also reduce, but will not eliminate, leaching of trace metals.

3.2.4.1 *Discussion*—See also Specification C593 and Practice D5239 for additional guidance.

3.2.5 *registered professional, n*—a person licensed, or otherwise approved by the state or local government, to manage and certify engineering or environmental projects.

3.2.5.1 *Discussion*—This professional may include, but may not be limited to, a Professional Engineer (PE) or Professional Geologist (PG).

4. Significance and Use

4.1 *General:*

4.1.1 Many CCPs are suitable materials for the construction of engineered structural fills. CCPs may be used as: structural fill for building sites and foundations; embankments for highways and railroads, road bases, dikes, and levees; and in any other application requiring a compacted fill material. Their low unit weight, relatively high shear strength, ease of handling, and compaction make CCPs useful as fill material. However, the specific engineering and environmental properties of these materials can vary from source to source and must be evaluated for each material, or combination of materials, to be used for an engineered structural fill. Information contained in Guide D5759 may be applicable to some CCPs to be used in engineered structural fills. AASHTO Standard Practice PP059-09-UL also addresses the use of coal combustion fly ash in embankments. The requirements for the type of CCPs that can be used for specific engineered structural fills may also vary because of local site conditions or the intended use of the fill, or both. Environmental considerations are addressed in Section 5.

4.1.2 CCPs can be a cost-effective fill material. In many areas, they are available in bulk quantities at a reasonable cost. The use of CCPs conserves other resources and reduces the expenditures required for the purchase, permitting, and operation of a soil borrow pit. CCPs often can be delivered to a job site at near optimum moisture content and generally do not require additional crushing, screening, or processing as compared to comparable native materials.

4.1.3 Use of CCPs conserves natural resources by avoiding extraction or mining of soils, aggregates, or similar fill material that also conserves energy and reduces greenhouse gas emissions.

4.1.4 The volume of beneficially used CCPs preserves valuable landfill space.

4.2 *Regulatory Framework:*

4.2.1 *Federal*—Currently, there are no federal regulations addressing the *beneficial use* of CCPs. States and local jurisdictions have oversight of CCP management and *beneficial use* activities within their states

4.2.2 *State and Local Jurisdictions*—Laws and regulations regarding the use of CCPs vary by state and local jurisdictions. It is incumbent upon the project owner and designer to determine any local or state guidance, policies, or regulations pertaining to the use of CCPs.

5. Environmental Aspects and Considerations

5.1 *General*—As part of the design phase, it is incumbent upon the designer or *registered professional* to evaluate the CCPs and to assess the site specific characteristics of a project to include appropriate measures to address potential environmental impacts. In addition to state or local guidance, screening procedures or analysis techniques should be employed as appropriate to determine, what, if any potential environmental risks need to be considered when using CCPs for engineered structural fills. Evaluation should include consideration of materials, geography, topography, hydrology, climatology, habitat, existing site conditions, and end use of the land. Fig. 1 and Table 1, depict a decision flow diagram that illustrates the potential steps for the project geotechnical and environmental evaluation.

5.2 *Materials Characterization*—Many CCP materials have been effectively used for beneficial reuse in engineered structural fills and have been shown to have little or no potential for releasing constituents to the environment when placed and compacted at the proper moisture content and with suitable engineering controls. CCPs contain constituents that may have the potential to leach into the environment if not properly managed. Factors that affect the potential of CCPs to impact the environment are the presence of constituents of concern, potential for these constituents to become available in the environment and the presence of complete exposure pathways for human or ecological receptors, or both.

5.2.1 *Safety Classification*—In consideration of the different types of CCPs that may be used in the construction of engineered structural fills the project owner and designer should prepare or obtain Safety Data Sheets (SDSs) based on the Occupational Safety and Health Administration (OSHA's) Hazard Communication Standard, 29 CFR Part 1910.1200 and consider the latest OSHA guidance. If the SDS identifies raises areas of human health or environmental concern, then the project owner or designer may need to consider additional worker safety precautions, conduct additional site specific environmental and human health investigation, or additional testing, or a combination thereof, to determine the constituents in the fill to migrate to an environmental receptor through a complete migration pathway. An SDS alone will not identify all human health and environmental concerns but may serve as a screening tool.

5.3 *Beneficial Use Site Evaluation*—The *registered professional* shall evaluate if the use of CCPs at a specific engineered structural fill project can be implemented in manner that is protective of human health and the environment. The geotechnical and environmental evaluation of the proposed site for an engineered structural fill shall include consideration of the state or local requirements for CCP use, screening procedures to determine site suitability, laboratory testing or field analysis, or a combination thereof, to determine geochemical properties of the CCPs and their compatibility to the properties of the on-site soils and conditions. The preliminary site screening or testing or both should address physical and chemical characteristics of

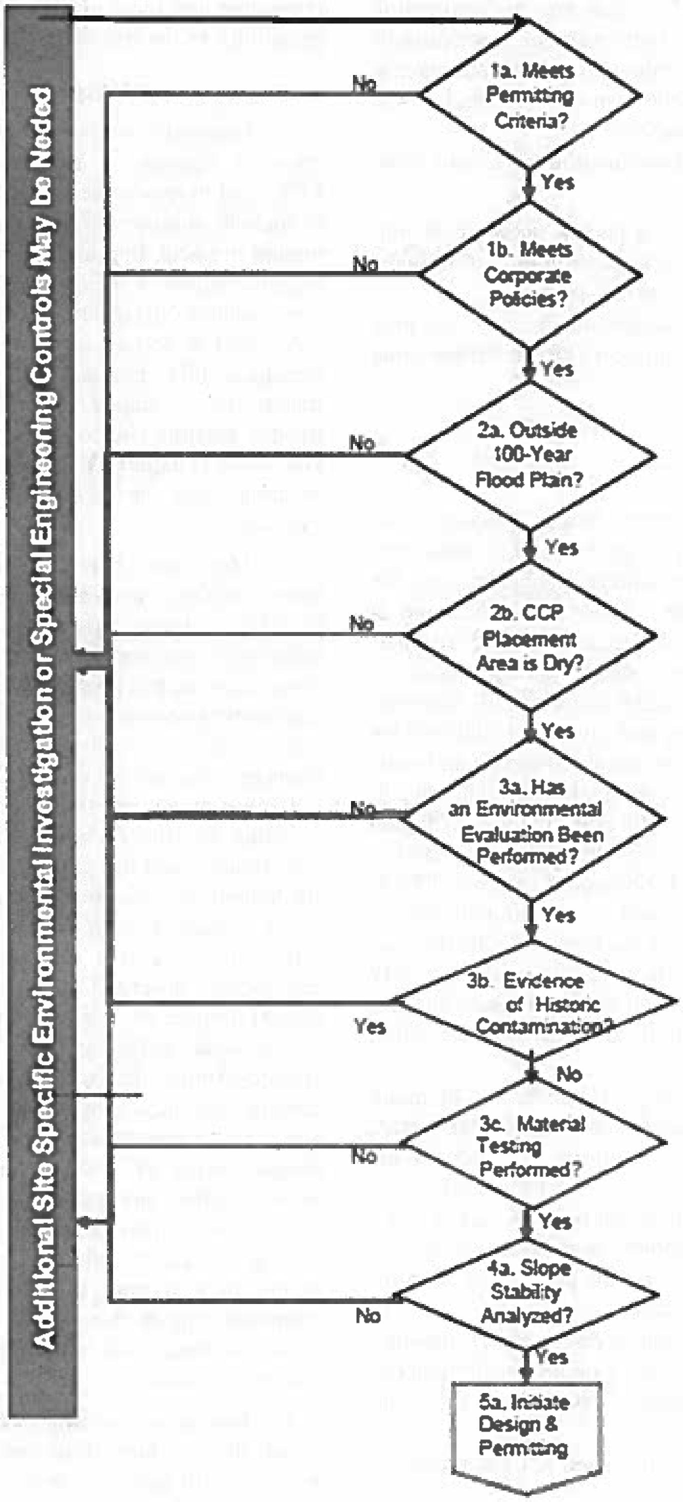

FIG. 1 Environmental Flow Chart *CCP Engineered Structural Fills*

the CCPs, leaching potential of the CCPs, the volume of CCPs to be used, and the proximity of CCPs to surface or ground water or both. The environmental evaluation may include an exposure-pathway analysis as provided in the appropriate federal, state, or local regulatory guidance. If an unacceptable risk is identified, then the *registered professional* will need to provide notice to the project owner and designer that engineering, controls, institutional controls, or other measures

TABLE 1 Coal Combustion Products (CCPs) -- Environmental Flow Chart

Each element, or step, of the CCPs Environmental Flow Chart is numbered for reference. Individual elements of the flow chart are described below and presented graphically in Figures 1a through 1c. In some cases examples are provided; these examples are not intended as exhaustive lists.

1a	**Does the Application Meet Federal/State/Local Permitting Criteria?** Develop a checklist of State and local permits and restrictions that may apply. *If Yes, proceed to 1b.* *If No, additional analysis may be required to support a variance request.*
1b	**Does the Application Conform to Company Policies?** Develop a checklist of company policies for CCP reuse and recycling that may apply to structural fill applications. *If Yes, proceed to step 2a.* *If No, additional analysis may be required to determine if an exception to the policy is warranted.*
2a	**Is the Application Outside the 100-year Flood Plain?** Placement of a structural fill containing CCPs within a 100-year flood plain potentially subjects the material to flooding, which can lead to erosion, partial saturation of the CCR, and/or stability concerns. Additional environmental evaluation and/or site engineering is warranted for applications in floodplains. *If Yes, proceed to step 2b.* *If No, additional environmental investigation and/or engineering may be warranted.*
2b	**Is the CCP Placement Area Dry and Expected to be Above the Seasonal High Groundwater Table?** Contact with water should be minimized both during placement and after project completion. Applications potentially subject to inflows other than infiltration (for example, surface water, seeps, perched water, or groundwater) require more detailed site investigation and possibly engineering controls to intercept inflows. Areas where shallow groundwater may saturate the CCP should be avoided. Site and groundwater conditions that are typically considered prior to design of engineered fills utilizing CCPs include: • Ponds, streams, and other permanent water bodies; excluding temporary ponds caused by recent rains and poor drainage. Soil Conservation Service maps can be used to depict poorlydrained soils and surface water features and can be used to supplement field inspection. • Wetlands, whether delineated or not, which can be identified by certain plant species, such as cattails, and by the presence of hydric soils or peat. • Springs, which indicate a discharge of groundwater—perched zone or water table—at the land surface. • Shallow groundwater, which can be estimated by local well logs, state reports, and literature sources. *If Yes, proceed to step 3a.* *If No, additional environmental evaluation and/or engineering design may be warranted.*
3a	**Has an Environmental Evaluation been Performed on or Near the Site?** An environmental evaluation will help identify any pre-existing environmental conditions. The extent of environmental evaluation will vary from site-to-site depending on the CCP characteristics, and a consideration of natural conditions and future use. *If Yes, proceed to step 3b.* *If No, additional environmental evaluation and/or engineering design may be warranted.*
3b	**Is there Evidence of Significant Historic Contamination?** A review of historical records and a site walkthrough will typically identify if there is evidence of significant historic contamination. It is common practice to avoid sites with historic contamination for engineered structural fills utilizing CCPs. *If Yes, additional environmental investigation and/or engineering may be are warranted.* *If No, proceed to step 3c.*
3c	**Has Leachability or Material Characterization Testing been Performed?** The CCP material is typically tested using a variety of leachability tests including the Toxicity Characteristic Leaching Procedure (TCLP) or the (Synthetic Precipitation Leaching Procedure) SPLP. Most State regulatory agencies have maximum contaminant levels (MCLs) for groundwater protection that have been identified for the use and placement of CCPs as a *beneficial use* material. For engineered structural fill projects using CCPs in States that do not have requirements, the regulatory guidelines for groundwater protection defaults to the Federal Safe Drinking Water Act (SDWA) and Federal MCLs. The type and extent of leachability or material characterization testing that is performed should be in accordance with both State and Federal drinking water standards. For CCPs that have leachate characteristics that exceed the applicable MCLs of concern, the CCP should be placed in a encapsulated or engineered system that is designed to prevent migration of constituents or to mitigate exposure. *If Yes, proceed to step 4.* *If No, additional environmental investigation and/or engineering are may be warranted.*
4	**Verify that Slope Stability Analysis of the Proposed Project has been Performed** For small sites, and for sites with flat to moderate slopes, slope stability is not typically a special concern. However, some structural fill sites may have relatively steep slopes, such as sidehill fills in steep valleys. In these cases, additional site investigation may be required to determine likelihood of water inflows that could lead to instability, and additional engineering may be required to ensure that the fill will not erode, slump, or otherwise structurally fail over time. *If Yes, proceed to step 5.* *If No, additional environmental investigation and/or engineering are typically required.*
5	**Initiate Design and Permitting of an CCP Engineered Structural** Fill The completion of the Environmental Flow Chart will typically make the project Owner, Developer and Contractor aware of Federal and State regulatory requirements that are necessary to complete a properly designed structural fill that utilize CCPs. These regulatory and permitting requirements should be followed during the design of the *CCP engineered structural fill.*

will need to be evaluated and implemented to reduce this risk to an acceptable level or, if not, cease continuing with the project.

5.4 *Environmental Procedures*—A variety of technical and regulatory procedures are available to project owners and designers of engineered structural fills to evaluate the suitability of CCPs for use in a project as well as to determine if the site specific project design and location meet state and local criteria. These procedures typically consider a wide variety of criteria for identifying factors of environmental and human health concern that should be accounted for in the design and construction of a *CCP engineered structural fill* project. In addition, these procedures can be used to evaluate whether engineered solutions can be implemented to provide adequate protection for human health and the environment so that the project can proceed. It is possible that project, site location or environmental factors or both may prohibit implementation of a given project. Specific environmental guidance that pertains to the site-specific construction and placement of engineered structural fills is found in Section 9.

5.4.1 In addition to the process outlined in Fig. 1, there are other ASTM International test methods and guides can be used for the geotechnical, environmental evaluation, and civil design of engineered structural fills using CCPs. These methods are listed according their use and applicability as follows:

(1) Practice D1452
(2) Test Method D1586
(3) Test Methods D2435
(4) Test Method D2850
(5) Practice D5759

5.4.2 *Leaching Characteristics of CCPs-Test Method D3987*—Other leaching test procedures may be used provided the leaching test reasonably replicates the type of leaching expected under actual site conditions during placement and after completion of the project. Approved procedures are included in SW 846. These procedures provide data to determine potential and predict possible constituent releases. State or local agencies may have specific or preferred testing procedures that are should be used.

5.5 *Design Considerations*—Many state and local jurisdictions require that a *registered professional* be involved in the technical evaluation, siting, design, and construction of *CCP engineered structural fills*. In addition, Sections 7 and Section 8 include a list of the environmental and human health considerations across all media that should be accounted for in the engineered structural fill design process. A summary of these potential project specific factors include, but is not limited to:

Chemical composition
Leaching properties of the CCPs;
Particle size and shear strength;
Bearing capacity and settlement;
Permeability;
Moisture and density characteristics;
Site suitability and beneficial reuse potential;
Location relative to flood plain, floodways, and protected drainage areas;
Presence or absence of groundwater receptors;
Location relative to wetlands, unstable areas, and/or active faults;
Presence or absence of seasonally high groundwater table;
Site drainage and erosion control;
Protection of water resources;
Presence or absence of karst geology;
Protection of surface slopes from erosion and runoff;
Stormwater management; and
Climatic conditions including rainfall and freeze thaw impacts.

5.6 *End Use of the Land*—When designing an engineered structural fill, the end use of the land is one component that will affect the potential for the use of CCPs. For example, if a project provides for a pavement cover such as for road construction or parking, then the potential for leaching will be reduced because the low permeability cover will reduce the amount of infiltration. Similarly, the construction of buildings or structures on top of the engineered fill will reduce water infiltration. Incorporation of topsoil or groundcover on the final land surface can minimize water infiltration if properly planned and constructed. Placement of an appropriate cover over the engineered structural fill will reduce the generation of wind borne constituents and potential migration to receptors.

6. Engineering Properties and Behavior

6.1 *General*—Structural fills may be constructed with one or more types of CCPs, each of which typically exhibits unique engineering properties that shall be considered in the design of the *CCP engineered structural fill*. These general engineering properties are discussed in the following sections.

6.2 *Bulk Density*—CCPs 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 stress 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.

6.3 *Compaction Characteristics*—Most CCPs can be placed and compacted in a manner similar to soil and aggregate fill materials. Most CCPs exhibit very little cohesion and are not sensitive to variations in moisture contents as are natural cohesive soils.

6.4 *Grain Size and Gradation*—variations in grain size affect the bulk density of CCPs and gradation can change over time after successive wetting and drying cycles of the CCPs.

6.5 *Strength:*

6.5.1 *Shear Strength*—For non-self-cementing CCPs, shear strength is derived primarily from internal friction. Typical values for angles of shear strength 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 lost when the material is either dried or saturated.

6.5.1.1 Because of its irregular 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.

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

6.6 *Consolidation Characteristics*—Structural fills constructed using non- self-cementing CCPs 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 as a result of elastic deformation of the material, rather than by classical consolidation. Most deformation caused by the mass of the fill or structure thereon generally occurs during construction or during load application and the design can accommodate this deformation using traditional analytical methods.

6.6.1 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 or load application.

6.6.2 Self-cementing fly ash typically exhibits minimal post-construction consolidation or deformation as a result of cementing and solidification of the fly ash.

6.6.3 Some self-cementing fly ash may swell with time. In 7.3.8, guidance is provided on evaluating the swelling potential of self-cementing fly ash.

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

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

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

6.8 *Liquefaction and Frost Heave*—Fine-grained, non-cohesive materials such as fly ash are susceptible to liquefaction and frost heave when saturated. When used in ponds or embankments, additional design analysis of underlying soils conditions and potential water ingress may be required to ensure degradation does not occur over time.

Note 1—Fly ash fills are normally designed to be well drained or are located in areas where they are not subject to saturation or infiltration by surface or ground water.

6.8.1 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.

6.9 *Erosion Characteristics (Piping)*—Non-self- cementing fly ash can be subject to internal erosion because of 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.

7. Testing Procedure

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

7.2 *Sampling*—Practice D75 or Test Method C311 as appropriate, and Guide D422 with sample extraction conducted in accordance with Practice D1452, Test Method D1586, or Practice D3550, as appropriate.

7.3 *Physical and Engineering Characteristics:*

7.3.1 *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.

7.3.2 *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.

Note 2—Other tests, such as Test Method D5550, may be more applicable to certain types of CCPs.

7.3.3 *Water Content*—Test Method D2216. For CCPs consider lowering the drying temperature to 140°F (60°C) to avoid driving off the water of hydration.

7.3.4 *Compaction:*

7.3.4.1 *Fly Ash—Test Method D698, D1557, or D5759*—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.

7.3.4.2 *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.

7.3.5 *Strength:*

7.3.5.1 *Shear Strength Characteristics*—The shear strength properties of CCPs can be tested using the following test methods:

(1) Test Method D2850
(2) Test Method D4767
(3) Test Methods D7181

7.3.5.2 *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.

Note 3—Relative humidity in curing conditions may affect the test results.

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

Note 4—Relative humidity in curing conditions may affect the test results.

7.3.6 *Hydraulic Conductivity*—Test Method D5084. Hydraulic conductivity is used to estimate the potential infiltration for designing underdrains.

7.3.7 *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.

7.3.8 *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 shall 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.

7.4 *Chemical Characteristics*—Chemical analyses are routinely conducted by many CCPs producers and are communicated to users by means of laboratory data, a SDS, or similar documents. 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 interactions with other materials or structures, including weathering processes, at the project site. Tests for soluble species may also be required by local regulatory agencies. An analysis of the chemical composition of CCPs, including trace elements of CCPs, may be required. State or local jurisdictions may require testing of CCPs to determine elemental totals or leachability or both of specific constituents. In some states, this testing may be required of the product containing CCPs, such as in the case of stabilized applications.

7.4.1 *Chemical Characteristics*—Test Methods C311 and Specification C618 are often used to determine the major chemical and physical characteristics of CCPs for use in concrete and may also provide insight into the potential reactions when used in engineered structural fills. Testing would typically be done to demonstrate that CCPs would not leach chemical constituents at levels above federal Maximum Contaminant Levels (MCLs) or at levels specified by state or local agencies. Testing may be performed by the generator, user or independent third party. Individual states may require testing for specific parameters such as total composition or leachability of specific metals or other elements.

7.4.2 *pH— Test Method D4972 or Practice D5239*—The pH of CCPs may vary with age, water content, and other conditions such as carbonation, acid ingress, oxidation, and leaching. The designer or *registered professional* should determine the likelihood of these factors and any impact they may have on the project.

7.4.3 *Resistivity*—Test Method G57, a field test, is used to measure CCPs' 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 CCPs fills are likely to be close to the optimum water content for compaction. In the United States, 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 CCPs that are useful in evaluating corrosion potential. Test Method G51 is also used to determine the pH of soil for use in corrosion testing.

7.4.4 *Sulfate*—Sulfate content as determined from the CCPs chemical analysis by Test Method C311, or other method is used in a preliminary assessment of the potential for sulfate attack on concrete if any. As with corrosivity, likely field water conditions and variations in concentrations with time should be considered. See also 8.7.2.

8. Design Considerations

8.1 *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. References (1-5) provide additional historical information regarding laboratory testing, design, and construction procedures.

8.2 *Site Characterization:*

8.2.1 *General*—The siting and design of a CCP 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.

8.2.2 *Geologic and Hydrologic Investigation*—A subsurface investigation may involve a review of available information about the site, a site reconnaissance by a *registered professional*, and extraction of soil and rock samples for classification and testing, depending on the size and intended use of the structural fill.

8.2.3 *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 must be taken to comply with the requirements of the regulatory agency having jurisdiction at the structural fill site (See Section 5.)

8.3 *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 internal erosion from 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 can thus be avoided. The results of leaching tests may warrant specific methods for placing CCPs to minimize the potential for impact on the environment. When necessary, a drainage blanket can be used to provide internal drainage and serve as a capillary barrier. CCPs should be placed in areas where they are not subject to saturation by surface or ground water to avoid this concern. It may be necessary to specify a minimum separation between the bottom of the CCPs in a structural fill and the seasonal high water table.

8.3.1 *Site Preparation*—Site preparation involves grading and drainage improvements required before placement of CCPs. 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. Depending upon the size of the project, it may be advisable to construct the structural fill in phases or zones to address any risk factors associated with construction.

8.3.2 *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.

8.3.3 *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. Bottom ash often has a suitable particle size range to serve as a drainage blanket. Sand, gravel, or other aggregate can also be used depending upon the gradation of these materials. Adequate filter protection such as a geotextile between the fill and drainage blanket shall be considered and included to ensure satisfactory long- term performance. The drainage blanket should be designed so that the outlets will remain freely drained. Including outlet pipes with rodent screens is one method that is often satisfactory.

8.4 *Surface Cover and Drainage*—Provisions shall be made for controlling erosion of CCP structural fills. Because of its fine-grained, non-cohesive nature, non-self-cementing fly ash is readily eroded. Unprotected, compacted CCPs are erodible when exposed to surface runoff or high winds. Erosion control is normally accomplished by controlling surface run-on and run-off and by establishing permanent cover with compacted stone, pavement, or soil and vegetation. Construction of the fill in phases or zones may be an effective way to control erosion processes.

8.4.1 *Cover*—Effective cover to control erosion can be either pavement or soil depending upon the final use of the surface. Surface configuration should include provisions for controlled, positive drainage of surface runoff. Minimum slopes to prevent ponding both on surfaces and in drainage ways of approximately 1 to 3 % are desirable so that settlement and minor surface variations can be accommodated.

8.4.2 *Soil Thickness/Vegetation*—The required thickness of soil cover varies and will depend upon site use, climate, and the type of vegetation to be established. The most important consideration is to control wind and water erosion of the surface. On sites where erosion potential is small, 6 in. (150 mm) of cover may provide protection, but 1 ft (0.3 m) is probably a practical minimum thickness in most cases. Where erosion potential is greater, or deeper rooted vegetation (such as tree planting) is planned, greater thicknesses may be warranted. In some cases, fly ash/soil blends are used as part of the cover to reduce the need for soil borrow. In these applications, testing of the blend to determine its suitability as a growing medium should be conducted.

8.4.3 *Surface Drainage*—Positive surface drainage is needed to prevent ponding that can lead to erosion problems. Suitable channel linings designed to accommodate storm flows without damage are needed. Slopes on surface areas and in drainage channels should be sufficient to prevent ponding and avoid long-term maintenance problems. Drainage discharges must be designed and constructed to be consistent with water quality permits.

8.5 *Structural Performance*—To perform satisfactorily, any fill material must shall support its own mass, that of the loads to be placed on it, and have acceptable settlement. Each of these aspects is analyzed as part of the design process.

8.5.1 *Slope Stability*—Embankment slopes should be stable and able to stand without slumping or sliding. Stability analyses should consider static, dynamic, and seismic loadings, and seepage forces, as appropriate. Desired factors of safety typically range from 1.0 (seismic) to 1.5 (static), but shall be increased as the level of uncertainty increases. Stability of exterior slopes, foundation soils and embankment combined, and cover soils should be analyzed.

8.5.2 *Bearing Capacity*—The ability of the fill to support structures bearing on or within the fill can be calculated by conventional procedures used for natural soils.

8.5.2.1 *Footings*—Ultimate bearing capacity analysis is appropriate for footings bearing on compacted CCP structural fills. The analysis is simplified by the drained, non-cohesive nature of the fill (except for self-cementing fly ash). The relatively low unit weight of CCPs as compared to natural soils should be considered in the analyses. Footings that are wider than the thickness of the fill below the footing or that are located near the edge of slopes may require special consideration.

8.5.2.2 *Slabs and Pavements*—The ability of the fill to support slabs and pavements to be located on the fill surface can be assessed by standard pavement design procedures and by determining the modulus of subgrade reaction by Test Methods D1195/D1195M or D1196/D1196M, or bearing ratio by Test Methods D1883, D4429 or D2844, as appropriate.

8.5.3 *Settlement*—As with any fill material, settlement as a result of consolidation and compression of the fill and the underlying materials should be considered in design. Settlement may adversely affect project performance if not considered in design. Conventional methods of analysis used with natural soils are appropriate.

8.5.4 *Lateral Earth Pressure*—Conventional methods of analysis of lateral earth pressure can be used for CCPs considering that the material is cohesionless (except for self-cementing fly ash) and has a lower unit weight than many natural soils.

8.6 *Compaction*—Proper and uniform compaction (including control of molding water content) of CCPs placed in the structural fill increases the strength of the material, reduces the compressibility, and produces a relatively uniform structural fill. CCPs are readily spread and compacted by conventional construction equipment; vibratory compactors operated at or near resonant frequency are particularly effective.

8.6.1 *Fly Ash*—Because it is fine-grained, fly ash exhibits compaction behavior under static compaction similar to natural soils in that compaction is sensitive to molding water content. Most fly ash has a well-defined compaction relationship, that is, for a given static compactive energy, there exists optimum water content at which compaction of the fly ash will achieve the maximum dry unit weight. Attempting to compact fly ash above the optimum water content results in displacement of the fly ash and limited densification is attained. Using static compaction, the compaction of fly ash with water contents below the optimum water content requires more compactive effort to achieve desired results. However, the compaction of fly ash below the optimum moisture content is not especially sensitive to variations in water content when using vibratory compactors operated at the resonant frequency. Thus, fly ash that is several percent below the optimum water content can be readily compacted using vibratory compactors operated at the resonant frequency. Compaction characteristics of dry fly ash can change depending on coal type origin and water content.

8.6.2 *Bottom Ash*—Bottom ash is typically free-draining, ; therefore, unless saturated, the moisture content of this material has little influence on its compaction characteristics. Simply wetting the bottom ash sufficiently to prevent bulking will promote adequate compaction.

8.6.3 *Other CCPs (including boiler slag and FGD materials)*—can be placed using similar methods as bottom ash and fly ash, but additional testing may be required to evaluate optimum moisture, maximum density and strength characteristics for the materials to be used.

8.6.4 *Placement of CCPs*—CCPs should be placed in loose layers of uniform thickness or blended with soils or other suitable materials to achieve the compaction required. Each layer should be compacted to the required density because strength is derived from internal friction and this value is dependent on the relative compaction/unit weight of the CCPs. A maximum layer thickness is usually specified to ensure that the required density is achieved through the full depth of the layer. Control of layer thickness is not as important for self-cementing fly ash because additional strength is derived from the cementitious products formed during the hydration process.

8.6.5 *Degree of Compaction:*

8.6.5.1 *Fly Ash*—A typical requirement is that the fill be compacted to a minimum of 95 to 100 % of the maximum dry unit weight, in accordance with Test Method D698, or 90 to 95 % of the maximum dry unit weight in accordance with Test Methods D1557. Similar requirements are usually applied for the slopes and adequate performance of foundations, structures, roadways, and so forth, will dictate the degree of compaction needed.

8.6.5.2 *Bottom Ash*—Granular bottom ash is typically compacted to 70% relative density, in accordance with Test Method D4254.

8.6.6 *Compaction Specifications*—Compaction specifications may dictate either the construction method to be used or the performance standard to be attained.

8.6.6.1 *Performance Specifications:*

(1) Fly Ash—The compaction criteria are typically expressed as a percentage of the maximum dry unit weight, in accordance with Test Methods D698 or D1557 and at molding water contents that do not exceed the optimum water content plus a given percentage and that prevent dusting during placement and compaction. When using static-type compaction, an allowable range of water contents is also usually specified so that the material will be in the range in which the required unit weight can be readily achieved. Fly ash has a tendency to be displaced under the mass of the compactor when placed above the optimum water content. Specifications requiring placement over a range of water content less than the optimum water content will control this phenomenon.

NOTE 5—Experience has shown that vibratory compactors can achieve the required degree of compaction over a wide range of water contents, but not excessively wet, of the optimum water content.

(2) Bottom Ash—Performance specifications for bottom ash typically specify the compaction criteria as a percentage of the relative density in accordance with Test Method D4254, and may require use of vibratory compaction equipment.

(3) Other CCPs —Performance specifications for other CCPs and CCP blends, additional testing may be required. Other CCPs , including boiler slag and FGD materials), can be placed using similar methods as bottom ash and fly ash, but additional testing may be required to evaluate optimum moisture, maximum density and strength characteristics for the materials to be used.

8.6.7 *Dust Control*—Dusting does not occur during placement and compaction of CCPs when the molding water content of the CCPs is sufficient to achieve the desired degree of compaction. CCP surfaces exposed to the sun and wind can dry out and become susceptible to dusting. Dusting can be controlled by wetting the CCPs, applying a dust suppressant, constructing wind screens, or by placing the final soil cover. Construction in phases or zones may also reduce the need for additional dust control as the total volume of CCPs exposed may be less than if doing the project as a single area.

8.7 *Protection of Embedded Materials*—When materials are to be embedded in the structural fill, it is prudent during design to assess whether any deleterious reactions are likely to occur. Specifically, the potential for corrosion of pipes, conduits, and other metal structures should be evaluated. Concrete structures such as culverts, footings, and retaining walls should be evaluated for sulfate attack.

8.7.1 *Corrosion Protection*—Low resistivity is commonly used as an indicator of the corrosion potential of soil or aggregates. Field tests with CCPs have shown that additional contributing factors are high or low pH, high soluble sulfate and soluble chlorides, and partially saturated field moisture embedded material. Appropriate test methods are described in 7.4.3. The standards used by the local or state transportation agency for evaluating corrosion potential of soil fill may be used as a reference.

8.7.2 *Sulfate Attack on Concrete*—Sulfate attack on concrete in CCPs fills has received attention because of the sulfate content in some CCPs. The sulfate exposure is considered severe when the water soluble sulfate in soil (or ash) exceeds 0.20 % by weight, or when sulfate in water exceeds 1500 ppm. As with corrosion, other factors such as moisture will be contributing factors. Also as with corrosion, there is a need to assess sensitivity and lifetime of the structure, and the difficulty of replacement or repair. If sulfate exposure is a concern, the use of blended or sulfate-resistant cements such as those described in Specifications C595/C595M, C150/C150M, C1157 and C1600, or application of polymer or bituminous coatings may provide protection.

8.8 *Radionuclides*—As with other structural fill materials, certain radioactive elements are known to occur naturally in

CCPs. The model standards and techniques for controlling radon are recommended for new building construction, where needed.

9. Construction

9.1 *General*—Construction procedures for CCPs structural fills are similar to conventional earthwork operations. Routine methods used with soil fills to control dusting, erosion, and sedimentation are similarly required. Depending upon the size of the project, it may be appropriate to construct the fill in phases or zones to reduce the total area open to the elements. Public access to the site should be restricted during construction by means of no trespassing signs, temporary fencing, and gates, as appropriate.

9.2 *Weather Restrictions*—Construction should be suspended during severe weather conditions. Operations may proceed during moderately wet periods by reducing the amount of water added at the plant or job site to compensate for precipitation. Dry CCPs can also be disked into excessively wet CCPs or other suitable soils or materials to reduce the water content to an acceptable level. Because fly ash obtained directly from silos or hoppers dissipates heat slowly, it may be placed during cold weather. If frost penetrates the surface a few inches, it can be removed from the surface or recompacted upon thawing and drying.

9.2.1 *Dust Control*—Dust control measures routinely used on earthwork projects are effective in minimizing airborne particulate at CCPs fill sites. Typical controls include avoiding hauling on completed ash surfaces; use of wind breaks; moisture-conditioning of the CCPs; wetting or covering of exposed CCPs surfaces; chemically treating CCPs surfaces; and paving, wetting, and covering of high-traffic haul roads with coarse materials.

9.2.2 *Erosion Control*—It is incumbent upon the *registered professional* to determine if stormwater or erosion permits, or both are required depending upon the site conditions. CCPs typically do not require additional sedimentation and erosion control measures beyond those normally used for soil fills in accordance with state and local requirements.

9.3 *Source and Delivery*—CCPs are typically supplied from sources containing little or no extraneous or deleterious material. Non-self-cementing fly ash and bottom ash are usually hauled in covered dump trucks with tightly sealed tailgates. These CCPs may be conditioned with water at the plant, if necessary. Self-cementing fly ash is hauled in pneumatic tank trucks and conditioned with water at the project site or may be partially conditioned and hauled in covered dump trucks to the project site. Care should be taken to not overfill the trucks so that spillage does not occur. Adequate measures shall be taken to ensure proper water content when using fly ash or bottom ash that has been stored in landfills, ponds, and lagoons. Trucks should be spray-cleaned with water at the plant to reduce spillage and dust during transport. Provisions should be made for cleaning of public roads in the event spillage does occur.

9.4 *On-Site Storage*—Limit on-site storage of CCPs to the minimum quantity required to maintain the construction schedule. For stockpiles, provide sedimentation and erosion controls in accordance with state and local requirements. Self-cementing fly ash that is not partially conditioned should be stored dry in pneumatic tank trucks or in suitably protected storage silos. Precautions normally taken for bulk storage of cement and lime may be required.

9.5 *Site Preparation*—The base of the fill should be stripped of vegetation and organic soils. The subgrade should be compacted to the desired dry unit weight and underdrains installed, when required.

9.6 *Placement and Compaction*—Place CCPs in uniform layers or blended not exceeding the thickness specified. The CCPs shall be spread uniformly; otherwise, the compaction equipment will ride on uneven hard spots in the fill, resulting in softer areas between the high spots. Tracking the CCPs with a dozer or truck before compaction will facilitate compaction to the required density. Typically, a CCPs fill is compacted with a vibratory or pneumatic-tired roller. Fill should not be placed on saturated or frozen material. If water shall be added to obtain optimum water content condition, allow adequate time for the entire lift to equilibrate, yet compact before the surface dries out. Water should be sprayed uniformly.

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

9.6.1.1 Fly ash is typically placed and compacted in a manner similar to non-cohesive fine-grained soils. Smooth drum vibratory rollers and pneumatic-tired rollers typically compact fly ash most effectively. Although not always, fly ash typically exhibits a measurable moisture-density relationship that can be used for compaction quality control. Note that fly ash that exhibits self-cementing properties shall be compacted soon after the addition of water.

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

9.7 *Cover*—Structural fill slopes should be covered with soil and revegetated as soon as practicable following the fill placement operations. Top surfaces should also be covered or paved promptly to reduce infiltration of precipitation and runoff into the fill and to minimize surface erosion.

9.8 *Quality Control*—Quality control programs for CCPs structural fills are similar to quality control programs for earthwork projects. These programs typically include visual observation of CCPs placement operations, supplemented with laboratory and field testing to confirm that the structural fill is constructed as designed. The testing requirements will vary depending on whether a method specification or performance specification is used.

9.8.1 Visual observations are typically made to verify lift thickness, the number of passes of the compactor on each lift, and the behavior of the CCPs under the weight of the compaction equipment. Laboratory compaction tests (Test Methods D698, D1557, D4253, and D4254) are performed to establish baseline data needed to control compaction in the field. Field unit weight and water content tests are conducted regularly on compacted lifts to verify that the required degree of compaction is achieved. Test Methods D1556, D2167, or D2922 may be used to determine the field unit weight. Test Methods D2216 or D4959 may be used to estimate the water content.

Note 6—To obtain representative in place moisture and density measurements, it may be necessary to field calibrate test results to develop a site-specific moisture density offset.

9.8.2 It is prudent to maintain daily job logs documenting site conditions, weather, and work activities. Water content and unit weight tests should be taken as specified by the design engineer and whenever visual observations indicate the desired degree of compaction is possibly not being achieved.

10. Keywords

10.1 bottom ash; CCPs; coal ash; embankment; environmental considerations; fly ash; resource conservation; structural fill; utilization

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