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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.

D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1883 Test Method for California Bearing Ratio (CBR) 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.

[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

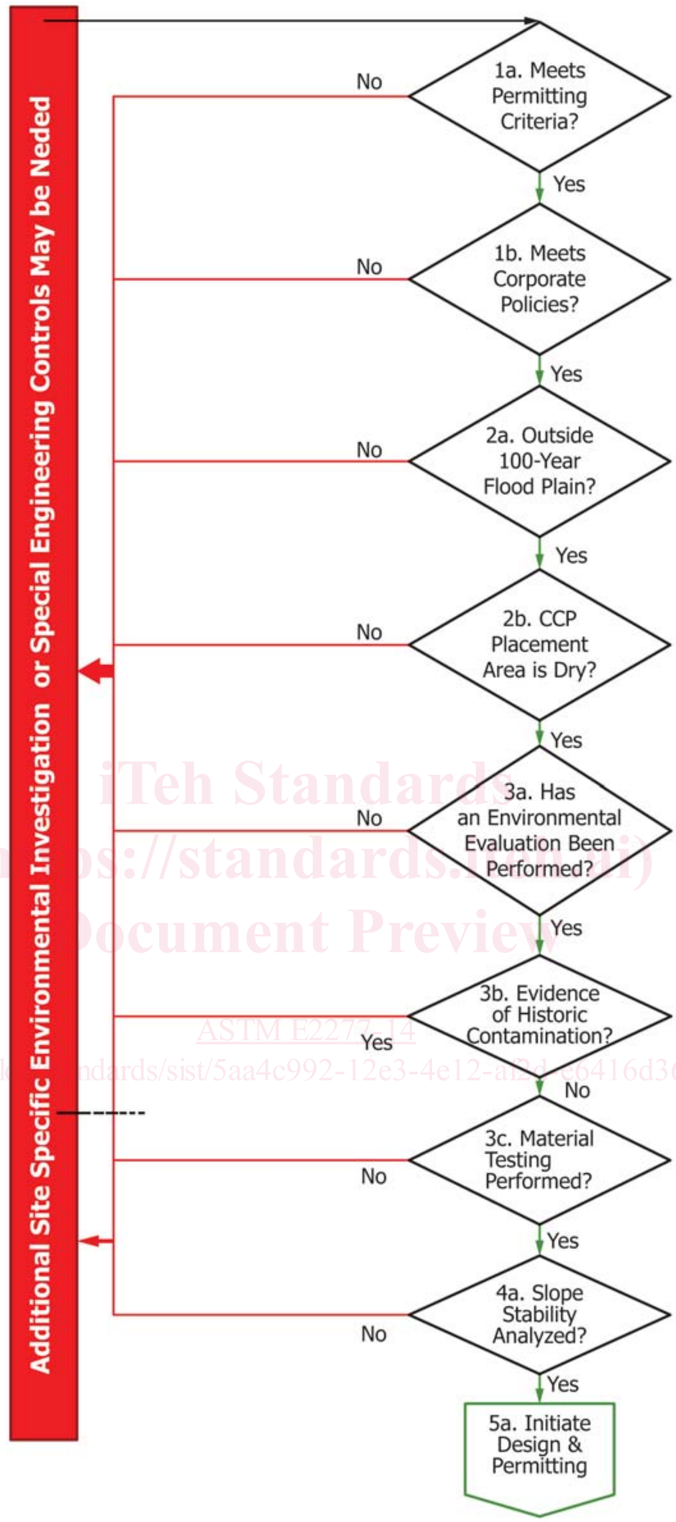

FIG. 1 Environmental Flow Chart *CCP Engineered Structural Fills*

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.