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Standard Guide for Theory and Principles for Obtaining Reliable and Accurate Bulk Solids Flow Data Using a Direct Shear Cell[1]

This standard is issued under the fixed designation D8081; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Reapproved with editorial changes in November 2021.

1. Scope*

1.1 This guide covers theory and principles for obtaining reliable and accurate bulk solids flow data using a direct shear cell. It includes characteristics and limitations of the three most popular direct shear cell types: Translational (D6128), Annular (D6773), and Rotational (D6682 and D7891).

1.2 *Units*—The values stated in SI units are to be regarded as standard. No other units of measure are included in this standard.

1.3 This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

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1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D6128 Test Method for Shear Testing of Bulk Solids Using the Jenike Shear Tester

D6682 Test Method for Measuring Shear Stresses of Powders Using Peschl Rotational Split Level Shear Tester (Withdrawn 2017)[3]

D6773 Test Method for Bulk Solids Using Schulze Ring Shear Tester

D7891 Test Method for Shear Testing of Powders Using the Freeman Technology FT4 Powder Rheometer Shear Cell

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of technical terms in this standard, refer to Terminology D653.

3.2 *uniform bulk solid bed, n—in powders and bulk solids*, a specimen in a direct shear cell that has a consistent bulk density throughout the bed.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.24 on Characterization and Handling of Powders and Bulk Solids.

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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.

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

*A Summary of Changes section appears at the end of this standard

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4. Summary of Guide

4.1 The three shear cell types covered by the guide are categorized as direct shear tests in which a region of the bulk solid is sheared under a series of controlled stresses.

4.2 This guide describes the theory and principles for obtaining reliable and accurate bulk solids flow data using a direct shear cell. It also provides characteristics and limitations of each direct shear cell type to guide the user in the selection of the shear cell for a particular test.

5. Significance and Use

5.1 A large number of industrial processes involve transfer and feeding of bulk solids, and the ability of such materials to flow in a controlled manner during these operations is critical to product quality.

5.2 Direct shear cells are among the most important methods for measuring the flow properties of bulk solids in industrial applications for bulk solids handling.

5.3 Direct shear cells have many advantages over simpler methods of measuring bulk solids flow properties, but their operation is more complex and the procedures for their use must be carefully controlled to produce accurate and reproducible data.

5.4 The three most popular direct shear cell types are: Translational (D6128), Annular (D6773), and Rotational (D6682 and D7891).

5.5 From shear cell data, a wide variety of parameters can be obtained, including the yield locus representing the shear stress to normal stress relationship at incipient flow, angle of internal friction, unconfined yield strength, cohesion, and a variety of related parameters such as the flow function.

5.6 In addition, these three direct shear cells can be set up with wall coupons to measure wall friction.

5.7 When the shear cell data are combined with unconfined yield strength, wall friction data, and bulk density data, they can be used for bin and hopper evaluation and design.

6. Theory and Principles

6.1 The flow behavior of a bulk solid is fundamentally different from the flow of a fluid.

6.1.1 Bulk solid flow properties and shear behaviors are strongly dependent on the consolidation stresses applied and are minimally dependent on the strain or flow rate (under the assumption of quasi-static conditions such as flow in a bin).

6.1.2 Fluid flow, in contrast, is strongly dependent on the strain rate (where viscosity describes the relationship between shear stresses and strain rates) and is minimally dependent on absolute pressure.

6.2 When shear stresses are applied to a bulk solid, it may not immediately fail (that is, bulk solids can avoid flow under a sustained shear stress). Thus, bulk solids have the potential for arching and ratholing.

6.2.1 Newtonian and viscoelastic fluids do not behave this way and always flow under an applied shear stress.

6.3 Bulk solids can sustain a shear stress without flowing only up to a certain point. Once a bulk solid is subjected to stresses (whether by gravity or some mechanical means) that reach or exceed its yield locus, the bulk solid flows.

6.4 Determining the yield locus for a given bulk solid under conditions representative of its manufacturing process is an essential step in evaluating the flow behaviors for that process.

6.4.1 In some circumstances, this may involve testing under controlled environmental conditions, as well as holding the bulk solid under load for an extended period before shearing (a time test).

6.4.2 The yield locus for a given bulk solid is a function of many variables, including its composition, particle size and shape, moisture content, temperature, time stored at rest, and the state of consolidation.

6.5 Because bulk solid properties are highly dependent upon the degree of consolidation, the preparation of a uniform bulk solid bed (consistent bulk density throughout the bed) is the first critical step of shear cell testing.

6.6 The next stage of testing is the application of a normal stress (σ) and shear stress (τ) to the bulk solid bed to achieve steady-state shear resulting in a known state of consolidation.

6.7 The shear stress then is removed, and a reduced normal stress is applied.

6.8 A shear stress then is applied and is progressively increased until the bulk solid bed yields and begins to flow.

6.9 This procedure is repeated at several different normal stress conditions to create a yield locus plot.

6.10 To complete a full flow function analysis, the operator must determine several yield loci, which requires that the unconfined yield strength be determined under several different levels of consolidation.

6.11 Although this guide focuses on the bulk solid (particle-particle) properties, the wall (particle-wall) properties and bulk density are also important.

6.11.1 Such properties are used for bin design and also are essential when one compares different wall materials (for example, different grades and finishes of stainless steel, or the effect of plastic coatings on bulk solid flow behaviors).

6.11.2 The most fundamental property of a wall material in this regard is ϕ', the angle of friction between the bulk solid and the wall material, or, correspondingly, the coefficient of wall friction (μ_w):

$$\mu_w = \tan(\phi') = \tau_w/\sigma_w \quad (1)$$

where:

τ_w = wall shear stress and
σ_w = wall normal stress.

NOTE 1—ϕ' and hence μ_w often are a function of the applied normal stress σ_w.

7. Description of Direct Shear Cell Components and Designs

7.1 Figs. 1-3 provide schematics of the three different types of direct shear cells considered in this guide.