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Standard Guide for Theory and Principles for Obtaining Reliable and Accurate Bulk Solids Flow Data Using a Direct Shear Cell¹

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.

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.

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1.5 *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.*

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D6682 Test Method for Measuring Shear Stresses of Powders Using Peschl Rotational Split Level Shear Tester (Withdrawn 2017)³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

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.

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.

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.

7.1.1 All have the same general operating principle of being able to measure the force required to shear a bulk solid bed in which a normal load has been applied.

7.1.2 The applied load or measured force can be expressed as an average stress by dividing by the cross-sectional area of the shear plane under consideration.

7.2 The translational shear cell (as described in D6128), shown in Fig. 1, has a fixed base with a movable ring above it, and both hold the bulk solid.

7.2.1 A cover that fits within the ring is used to contain the bulk solid and to provide a uniform application of the normal load (N).

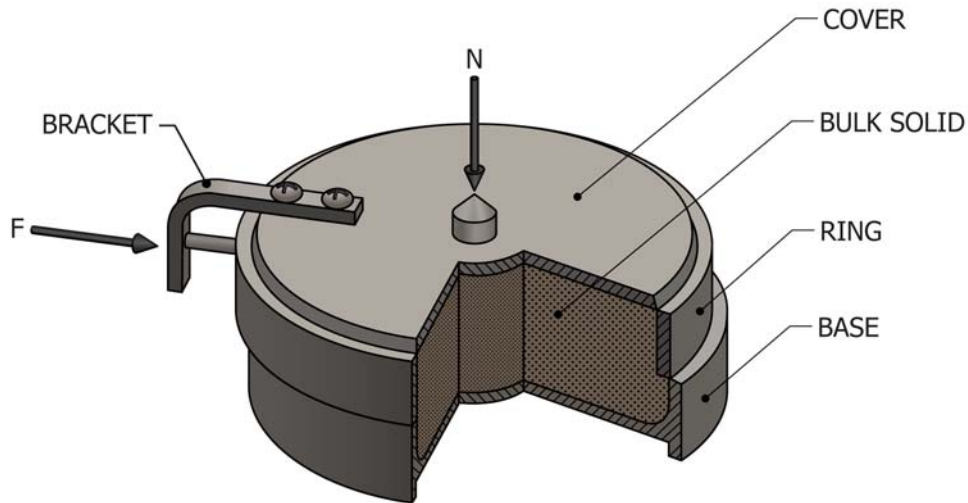


FIG. 1 Descriptive Schematic of the Translational Shear Cell (D6128)

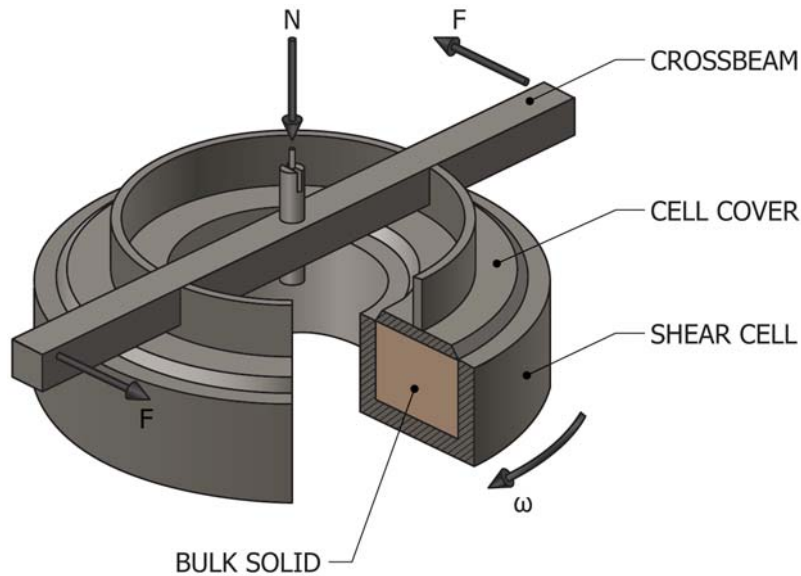


FIG. 2 Descriptive Schematic of the Annular Shear Cell (D6773)

7.2.2 The ring and cover are pushed as a unit while a load cell records the shear forces (F) that are generated.

7.2.3 The shear plane forms between the bulk solid that is contained in the base and that contained in the ring

7.3 The annular shear cell (as described in D6773), shown in Fig. 2, consists of a shear cell or base that holds the bulk solid.

7.3.1 A cover that fits within the cell is used to contain the bulk solid and to provide a uniform application of the normal load (N).

7.3.2 The cover is free to move up and down, but otherwise remains fixed in place by a load cell that measures the shear forces (F) that are generated.

7.3.3 The shear cell is rotated at a constant angular velocity (ω) to create a shear plane that forms in the bulk solid bed somewhere between the cell bottom and the cover.

7.3.4 The cover and shear cell usually have baffles or other surface features that prevent the bulk solid from sliding or shearing at the interface between the bulk solid and the cover or shear cell base.

7.4 The rotational shear cell (as described in D6773 and D7891), shown in Fig. 3, has a base and ring that hold the bulk solid.

7.4.1 A loading lid that fits within the ring is used to contain the bulk solid and to provide a uniform application of the normal load (N).

7.4.1.1 The loading lid is free to move up and down, but otherwise remains fixed in place, connected to a load cell that measures the shear forces (F) that are generated.

7.4.2 The shear cell base then is rotated at a constant angular velocity (ω) to create a shear plane that forms in the bulk solid bed somewhere between the ring and the base.

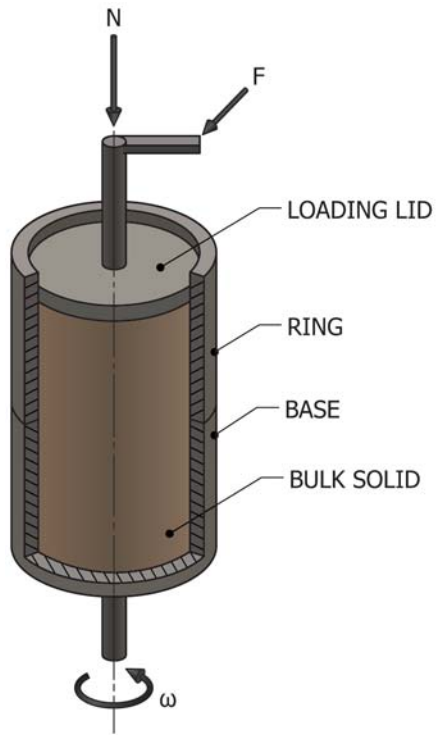


FIG. 3 Descriptive Schematic of the Rotational Shear Cell (D6682 and D7891)

7.4.2.1 Alternatively, the base can be fixed and the lid can be rotated to create the shear plane in the bulk solid specimen.

7.4.3 The ring and base usually have surface features that prevent the bulk solid from sliding at the bulk solid-surface interface.

7.5 Characteristics and limitations of the four shear cell testers considered in this Guide are listed in Table 1.

8. Keywords

8.1 annular shear tester; bulk solid; cohesive strength; flow function; Freeman Technology FT4 Powder Rheometer Shear Cell; internal friction angle; Jenike shear cell; kinematic wall friction angle; Peschl Rotational Split Level Shear Tester; powder; rotational shear tester; Schulze Ring Shear Tester; translational shear tester; unconfined yield strength; wall friction; yield locus

TABLE 1 Characteristics of Various Direct Shear Cells Used for Testing Bulk Solids

Characteristic	ASTM Standard			
	D6128	D6682	D6773	D7891
Type	Translational	Rotational	Annular	Rotational
Commercially available	No	No	Yes	Yes
Operation	Manual	Semi-automatic	Automatic	Automatic
Required operator training	Significant, so results are more operator-sensitive than those testers described in D6773 and D7891	Significant, so results are more operator-sensitive than those testers described in D6773 and D7891	Less significant, so results are less operator-sensitive than those testers described in D6128 and D6682	Less significant, so results are less operator-sensitive than those testers described in D6128 and D6682
Sample size required	Requires new specimen for each test point, so larger sample required than those testers described in D6682, D6773 and D7891 when using shear cells with same volume.	Smaller compared to tester described in D6128	Smaller compared to tester described in D6128	Smaller compared to tester described in D6128
Maximum allowable particle size of specimen	5 mm	2.4 mm	Monosize particles: 5 mm Broad size distribution: 10 mm	1 mm
Need for preconsolidation step	Required	Not required	Not required	Not required
Time required to run test	Longer than those testers described in D6682, D6773 and D7891, since preconsolidation step is required	Shorter than tester described in D6128, since preconsolidation step is not required	Shorter than tester described in D6128, since preconsolidation step is not required	Shorter than tester described in D6128, since preconsolidation step is not required
Homogeneity of shear deformation	High, since shear deformation of specimen does not vary with radius in cell	Low, since shear deformation of specimen varies dramatically with radius in cell	High, since shear deformation of specimen varies only slightly with radius in cell	Low, since shear deformation of specimen varies dramatically with radius in cell
Performance if sample requires large shear strain to reach steady state	Poor, since travel of shear cell is limited	Good, since infinite travel of shear cell is permitted	Good, since infinite travel of shear cell is permitted	Good, since infinite travel of shear cell is permitted
Location of wall friction coupon	Below test cell, which is consistent with most industrial applications	Below test cell, which is consistent with most industrial applications	Below test cell, which is consistent with most industrial applications	Above test cell, which is inconsistent with most industrial applications. Due to segregating nature of some bulk solids, differences in wall friction angles may be observed.
Effect of grain orientation of wall friction coupon	Can be captured	Cannot be captured	Cannot be captured	Cannot be captured
Testing at high or low temperatures	Possible	Difficult or impossible	Difficult or impossible	Difficult or impossible

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