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Some observations on the design data provided by three well known devices for measuring flow properties of bulk solids

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Some Observations on the Design Data Provided by Three Well Known Devices for Measuring Flow Properties of Bulk Solids

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SUMMARY

This paper examines the flow properties of three powders determined using the traditional Jenike Direct Shear Tester and the Peschl Rotational Split Level (RSL) Shear Tester. Both instantaneous yield loci and wall yield loci measurements are compared.

In addition the critical hopper geometry parameters for mass-flow derived from the measured flow properties and bulk density measurements (made with the Jenike Compressibility Tester) are compared with the Arching Indices measured with the Johanson Hang-up Indicizer.

1 INTRODUCTION

When designing storage and handling plant for bulk solids it is well accepted that, where possible, flow property measurements should be undertaken on representative samples of the bulk solids. This is especially a requirement when there is no previous handling experience involving the bulk solids or where those experiences should not be repeated.

In Australia flow property data are normally generated using techniques that derive from those developed in the 1950's and 1960's by Andrew Jenike. He developed a Direct Shear Tester (sometimes called a Flow Factor Tester) which is used to measure yield loci (instantaneous, time and wall) for a bulk solid. These data allow estimates of the flow functions and internal friction angles to be made for a bulk solid. This information, together with measurements of the bulk density variation with consolidation stress, can be used to calculate such design parameters as mass-flow hopper wall slopes, minimum cohesive arching dimensions, critical rathole diameters and chute slope angles.

In more recent times an instrument known as the Peschl Rotational Split Level (RSL) Shear Tester has been developed and marketed by Industrial Powder Technology, Liechtenstein. A Model RO200 RSL Shear Tester has been brought to Australia by Bulk Handling Global. The authors recently had to opportunity to obtain some flow property measurements with this machine. The machine has associated computer software that controls its operation and produces the output data. Instantaneous yield loci, internal friction angles and wall yield loci are obtainable.

In the 1980's Jerry Johanson developed a suite of testers known as the Johanson Indicizers. One of the machines called the Johanson Hang-up Indicizer uses a uniaxial test cell and associated computer software to measure the Arching Index and the Ratholing Index for a bulk solid. These indices are an indication of the cohesive arching and stable ratholing capability for the bulk solid.

In this paper the authors have compared the design data developed from each of these testing machines. Three powders were used. The powders will simply be referred to as Powder 1 (a flyash) and Powders 2 and 3 (building product powders).

2 THE TESTING MACHINES

Figure 1 shows a typical Jenike Direct Shear Tester and Figure 2 shows the associated shear cell.

Fig 1 Jenike Direct Shear Tester

Fig 2 Jenike Shear Cell

The shear cell is 95.3mm internal diameter. Normal loads are applied to the lid of the cell while the recorder records associated sear forces when low speed strain is applied to the top ring of the cell. The most comprehensive descriptions of the test procedures undertaken with this machine are given in Ref 1.

The Peschl Shear Tester is shown in Figure 3.

Fig 3 Peschl Shear Tester

The data captured is fed to a laptop computer for processing. The test procedures adopted are fairly standard and automated. The procedures are outlined in Ref 2.

The Johanson Hang-up Indicizer is shown in Figure 4. This machine does not give flow properties of a bulk solid directly but provides measurements of the Arching and Ratholing Indices for a nominated bin diameter. An internal computer does on-board processing using unpublished algorithms that are understood to incorporate some empiricism. For the purposes of this comparative study the normal 5m bin diameter has been chosen and only Arching Indices (AI) have been determined. AI is an indication of the outlet dimension required to avoid cohesive arching in a conical mass-flow hopper for the bulk solid.

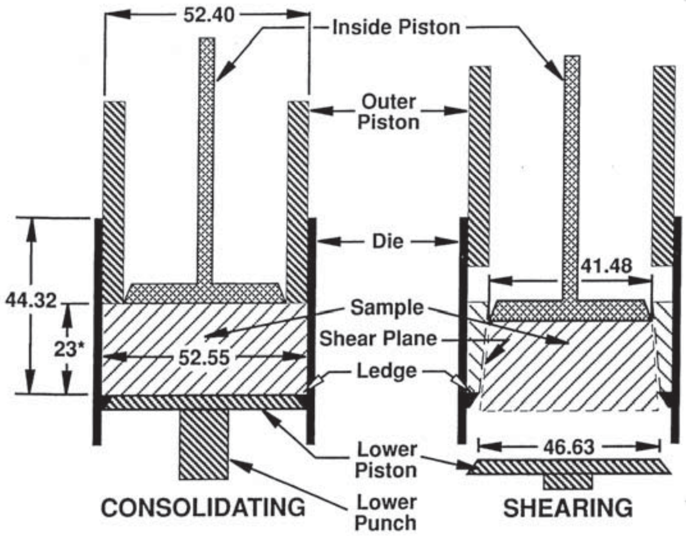

Fig 4 Johanson Hang-up Indicizer and Its Arrangement

3 EXPERIMENTAL PROGRAM

The Jenike and Peschl machines were used to measure instantaneous yield loci (IYL) for each powder and also wall yield loci (WYL) on mild steel (some rust was evident on the surface of the wall sample). The Peschl machine requires a specially prepared wall sample for WYL determinations so this sample was also used for the WYL measurements with the Jenike machine using the small 63.5mm ID shear cell.

Typical families of IYL determined with each machine are shown in Figures 5 and 6 while typical WYL are shown in Figures 7 and 8. It can be seen from Fig 5 that for the data generated from the Jenike Direct Shear Tester the Shear Consolidation Points (x) and the Shear to Failure Points (+) are indicated on the plotted loci. From Fig 6 it is seen that the experimental points are not indicated on the yield loci generated from the Peschl Tester. Experimental data points are indicated on the wall yield loci in Figs 7 (generated from the Jenike Tester) and also on the wall yield loci in Fig 8 (generated from the Peschl Tester). It will be noted that the Peschl Tester distinguishes between Static and Dynamic Friction.

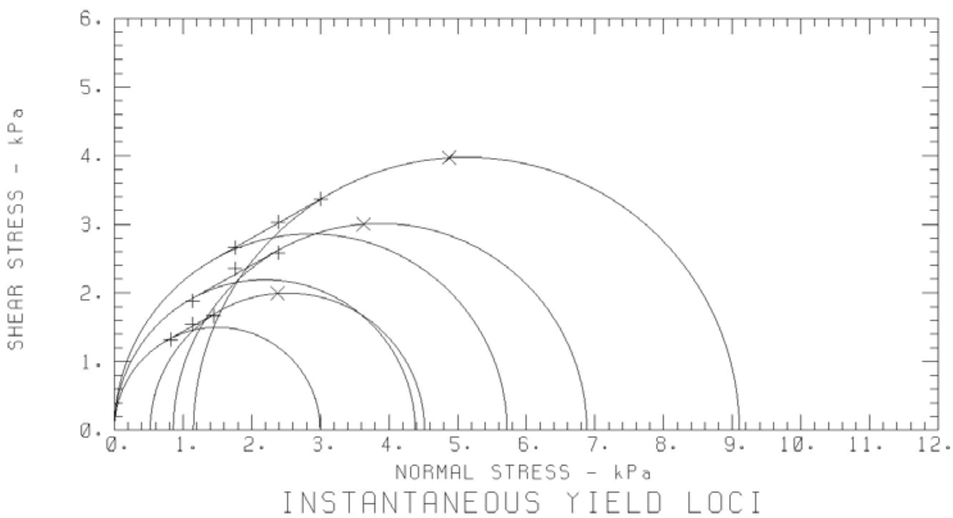

Fig 5 – Family of Yield Loci from Jenike Direct Shear Tester

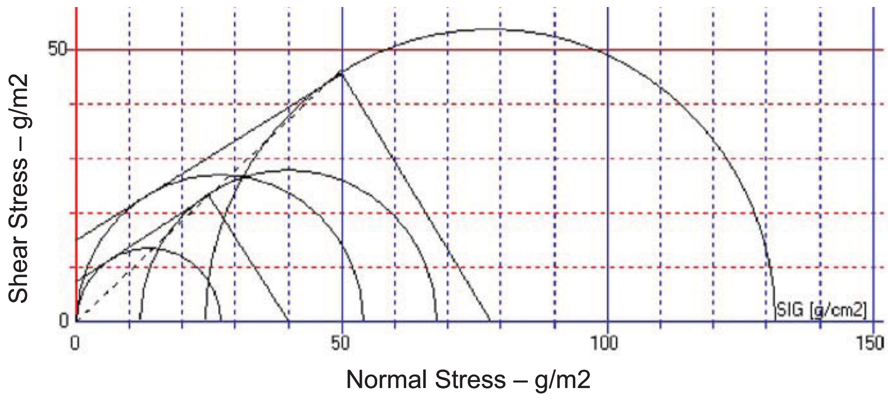

Fig 6 – Family of Yield Loci from Peschl Shear Tester

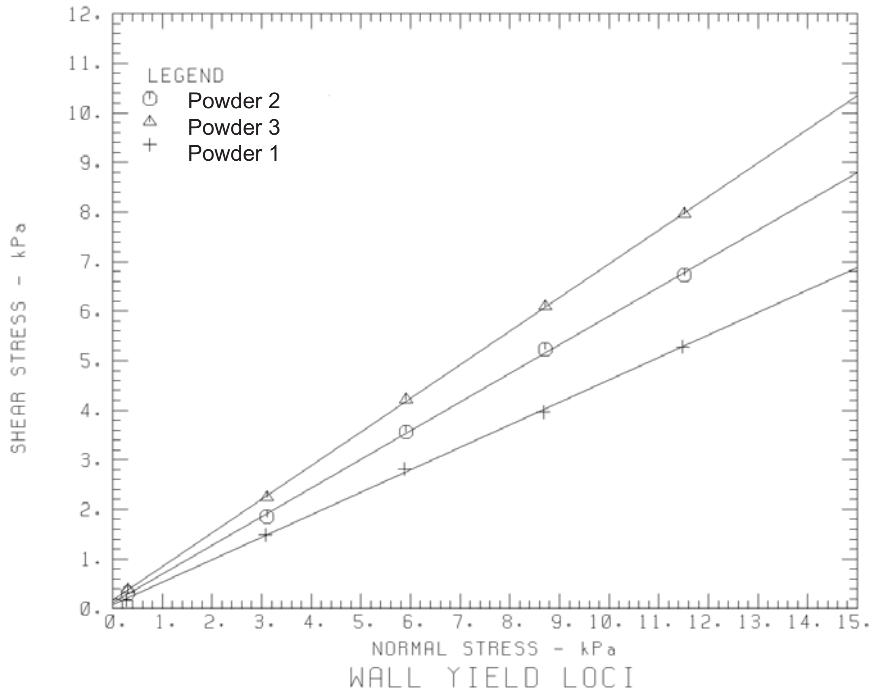

Fig 7 – Wall Yield Loci from Jenike Direct Shear Tester

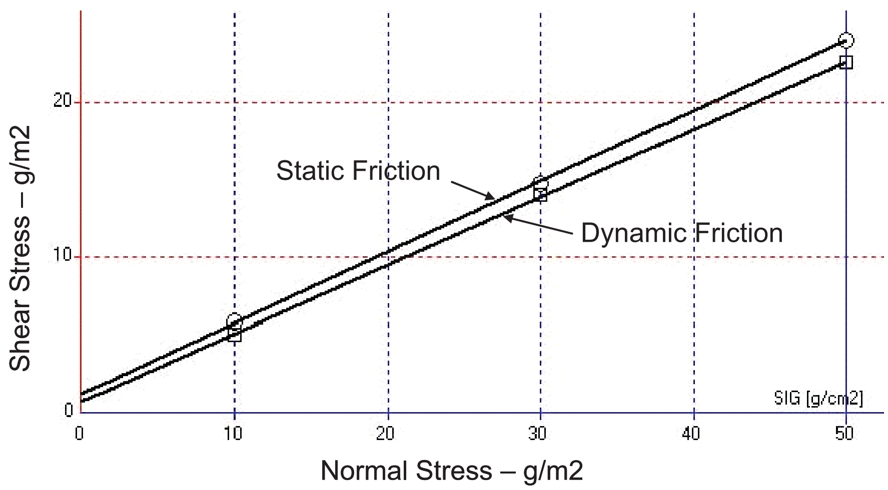

Fig 8 – Wall Yield Loci from Peschl Shear Tester

The Flow Functions that can be derived from the IYL data from each Tester are shown in Figures 9 (Jenike Tester) and Figure 10 (Peschl Tester). In the Jenike Procedures all the data being used to determine the Instantaneous Yield Loci it is standard procedure to prorate the data to take account of inherent variability in experimental data. In the Peschl Procedures the data can be either 'Raw' or 'Prorated' so data has been collected using both regimes.

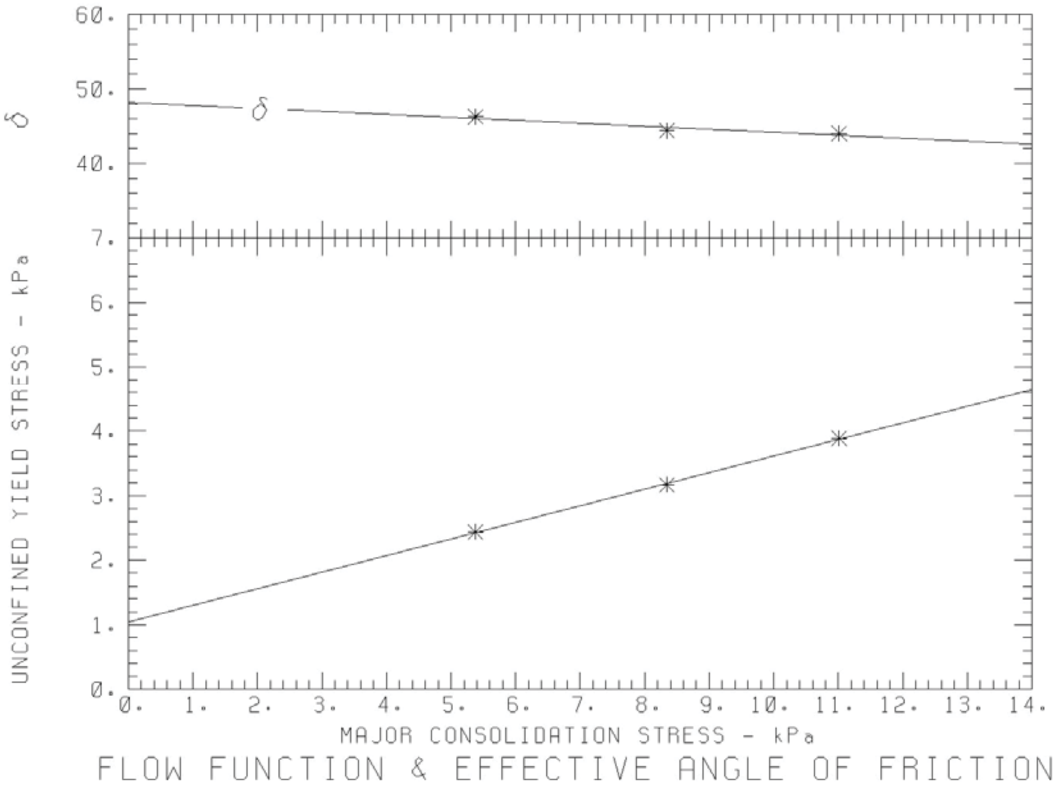

Fig 9 – Instantaneous Flow Function and Effective Angle of Internal Friction Derived from Jenike IYLs

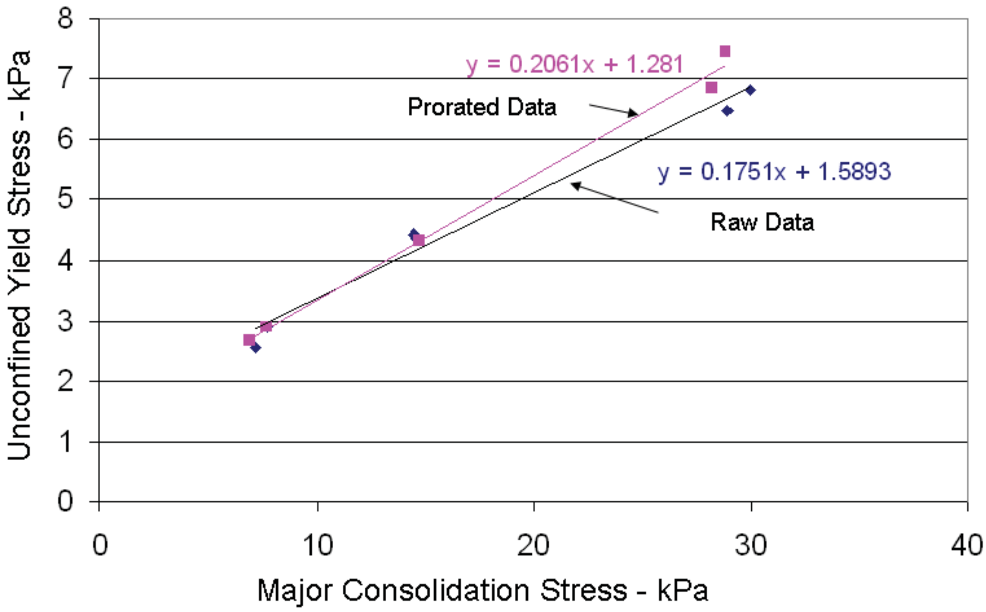

Fig 10- Instantaneous Flow Functions Derived from Raw and Prorated Data from Peschl IYLs

3 EXPERIMENTAL RESULTS

Instantaneous flow functions and wall yield loci data were collected for the three powders using the Jenike and Peschl Testers. The data are summarised in Table 1. Bulk density of the three powders was measured using the Jenike Compressibility Tester.

Table 1 – Flow Property Parameters Measured on Three Powders with the Jenike and Peschl Testers

Powder	Machine	Parameter		Value/Equation
1	Jenike	1	Inst Flow Function	$0.31+0.59\sigma_1$
		2	Effective Angle Intl Friction	$53.89-0.36\sigma_1$
		3	Wall Friction Angle	24.3°
	Peschl	4	Inst Flow Function - Raw	$0.93+0.19\sigma_1$
		5	Inst Flow Function - Prorated	$0.46+0.23\sigma_1$
		6	Effective Angle Intl Friction	38.4°
		7	Wall Friction Angle - Dynamic	23.7°
		8	Wall Friction Angle - Static	24.5°
	Jenike Compress	9	Bulk Density	$913.13(\sigma_1/5.939)\hat{}\ 0.0870$
2	Jenike	1	Inst Flow Function	$1.53+0.20\sigma_1$
		2	Effective Angle Intl Friction	$55.82-1.19\sigma_1$
		3	Wall Friction Angle	30.0°
	Peschl	4	Inst Flow Function - Raw	$1.31+0.17\sigma_1$
		5	Inst Flow Function - Prorated	$0.49+0.21\sigma_1$
		6	Effective Angle Intl Friction	44.2°
		7	Wall Friction Angle - Dynamic	29.1°
		8	Wall Friction Angle - Static	29.4°
	Jenike Compress	9	Bulk Density	$1361.39(\sigma_1/5.939)\hat{}\ 0.0529$
3	Jenike	1	Inst Flow Function	$1.04+0.26\sigma_1$
		2	Effective Angle Intl Friction	$48.20-0.40\sigma_1$
		3	Wall Friction Angle	34.2°
	Peschl	4	Inst Flow Function - Raw	$1.28+0.21\sigma_1$
		5	Inst Flow Function - Prorated	$1.59+0.18\sigma_1$
		6	Effective Angle Intl Friction	45°
		7	Wall Friction Angle - Dynamic	33.1°
		8	Wall Friction Angle - Static	33.3°
	Jenike Compress	9	Bulk Density	$1259.64(\sigma_1/5.939)\hat{}\ 0.0706$

Using the above data mass-flow hopper geometry parameters have been calculated using the traditional Jenike techniques to establish conical hopper wall slopes and minimum outlet diameters to avoid cohesive arching. In addition the Johanson Hang-up Indicizer was used to measure the Arching Indices for each of the three powders. For these measurements a nominal bin diameter of 5m was specified.

The results of the mass-flow hopper geometry parameter calculations and Arching Index measurements are summarised in Table 2.

Table 2 – Hopper Geometry Parameters and Arching Index Measurements

Powder	Machine	Parameters Utilised	Hopper Half Angle - deg	Minimum Outlet Diameter - mm	Arching Index Range – mm
1	Jenike	1, 2, 3, 9	18.0	335	
	Peschl	4, 6, 7, 9	19.0	365	
		4, 6, 8, 9	17.5	365	
		5, 6, 7, 9	18.5	205	
		5, 6, 8, 9	17.5	205	
	Johanson				340
2	Jenike	1, 2, 3, 9	14.0	350	
	Peschl	4, 6, 7, 9	11.5	290	
		4, 6, 8, 9	11.0	290	
		5, 6, 7, 9	11.5	125	
		5, 6, 8, 9	11.0	125	
	Johanson				220-240
3	Jenike	1, 2, 3, 9	5.0	280	
	Peschl	4, 6, 7, 9	6.0	315	
		4, 6, 8, 9	6.0	315	
		5, 6, 7, 9	6.0	370	
		5, 6, 8, 9	6.0	370	
	Johanson				160-240

4 CONCLUDING REMARKS

The following comments are made concerning the results presented in this paper:

- The Jenike and the Peschl Testers purport to provide the same range of flow properties for a bulk solid.
- The processing of the results from the Jenike Tester follows manual procedures. Normally the Instantaneous Yield Loci are presented as a 'family' of loci as they should relate to each other (ie they are not independent of each other).
- The processing of the results from the Peschl Tester is carried out in the accompanying computer software and similar 'family' relationships do not appear to be employed.
- While the hopper half angles from both the Jenike and Peschl machines are very comparable there are significant differences in the hopper outlet diameters (cohesive arching dimensions) calculated from the flow properties.
- The hopper outlet diameters predicted utilising the raw and prorated flow functions from the Peschl Tester can also show significant differences.
- The Arching Indices measured with the Johanson Hang-up Indicizer were generally smaller than the Hopper Outlet Diameters calculated from the Jenike data and the Peschl raw data.
- While the output from the three test machines considered in this paper purport to give precise values for hopper half angles and cohesive arching dimensions care should be exercised in assuming that the values are absolute.

5 REFERENCES

1. IChemE, 'Standard Shear Testing Technique for Particulate Solids Using the Jenike Shear Cell'. IChemE, 1989, 46 pages.
2. Industrial Powder Technology, 'Operating Manual for IPT-Peschl RSL Shear Tester'. IPT, 2005, 37 pages.