SOLID DOSAGE

STACKING SACKS OF POWDER FOR PROCESSING

Many powders and granular materials spend time in static storage prior to processing. They may be kept in bags, sacks, or special containers in a warehouse near the plant. Unfortunately some powders will gain significant strength over time due to the pressure caused by the stacked sacks of material, leading to a product that will not discharge from the sacks when required.

Processors have lived with this problem because they do not have a method to predict the effect of consolidation that takes place within the stacked sacks of powder. An instrument that has the ability to characterize this type of behaviour is the shear cell. An example of this instrument is shown in Figure 1. The instrument shears a small sample of the powder to measure the frictional forces acting between the powder particles during flow. When the measured force exceeds the equivalent of gravity, the powder may have gained sufficient strength over time in storage to resist moving.

Shear cells have existed for a long time. They originated in the minerals industry over 50 years ago. They are scientifically proven in an ASTM method D6128 which has become the basis for subsequent shear cell design. The basic concept is to apply pressure to a small sample of powder, then shear the particles against one another to measure the inter-particle friction. This technique is repeated at increasingly higher levels of compaction to determine the failure strength of the powder at each level of consolidating stress.

The shear cell produces a graph called the "Flow Function", which plots powder strength vs. consolidating stress. See Figure 2. Further use of this same method can show how powder gains strength over time. At each consolidating stress, the powder is sheared initially to measure its strength. Then the powder sample is allowed to remain static while the consolidating stress is still being applied. After a defined time interval – perhaps an hour, a day or a week – the sample is again sheared to measure the strength. For many powders there will be a gain in strength. This technique is called the "Time Consolidated Flow Function".

Analyzing Stacked Sacks Of Powder

The shear cell can be used to determine the consolidation pressure acting through a stack of bags on a pallet (as shown in Figure 3). The objective of this analysis is to determine the stack height above which flow problems will occur. The test technique involves use of the Time Consolidated Flow Function to quantify the gain in powder strength over time. Figure 3a shows the Flow Function curves that are measured at increasing time intervals. As the Flow Function gradient increases, the allowable height for the stacked sacks decreases, if flow problems are to be avoided.

An alternative approach is to use the shear cell to determine the pressure or stack height above which flow problems should be expected. See Figure 3b which shows the limiting stress above which the powder begins to experience a significant gain in strength. The equivalent stack height can then be determined for this situation.

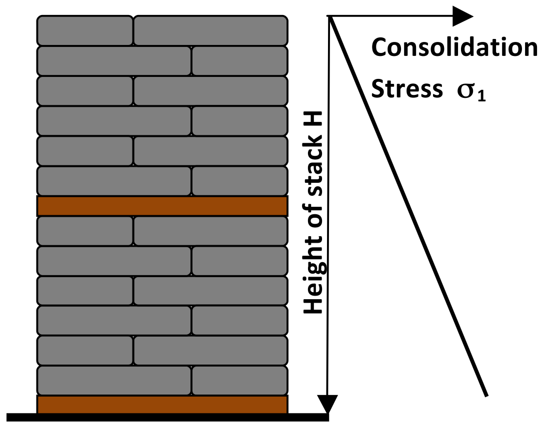


Fig 1 illustrating a stack of sacks on pallets or big bags, the vertical consolidation stress at the base of the stack of bags can be determined using the equation below:

$$\sigma_1 = \rho_b \cdot g \cdot H$$

<u>Note that this equation is valid only for flexible walled vessels (bags) and not for rigid silos</u>

Where:	σ_1	Vertical consolidation pressure in the stack of bags	Pa
	g	Acceleration due to gravity	ms^{-2}
	ρ_b	Compacted Bulk Density of the powder	kgm^{-3}
	H	Total height of the stack of bags	m

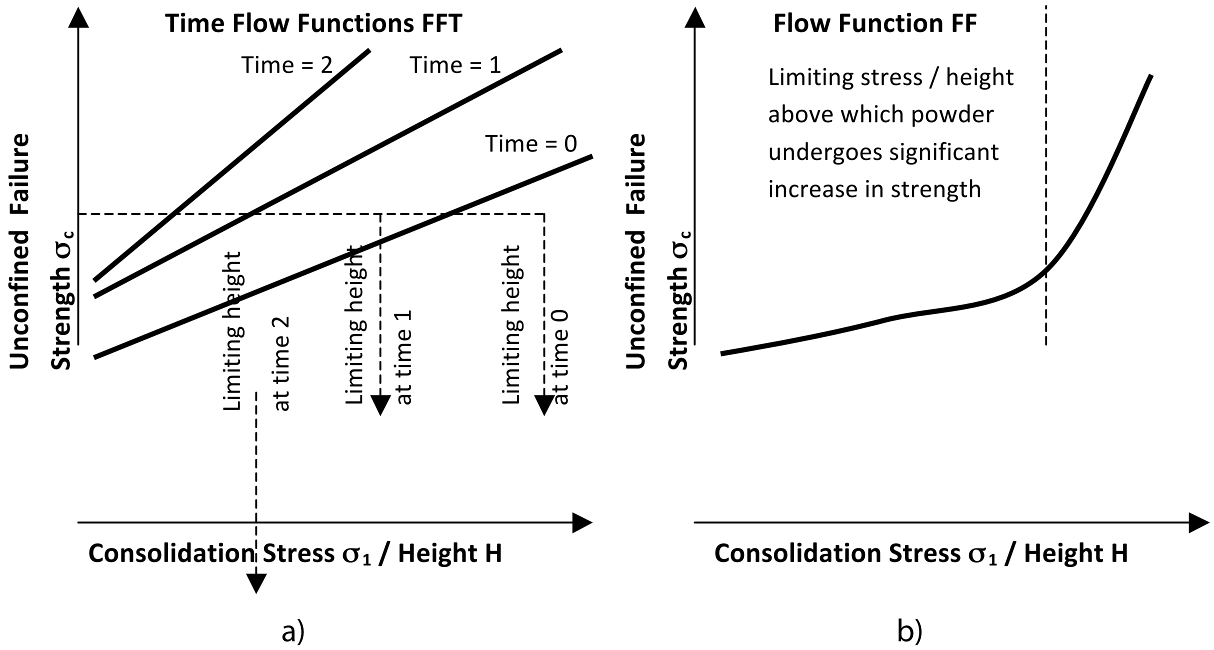
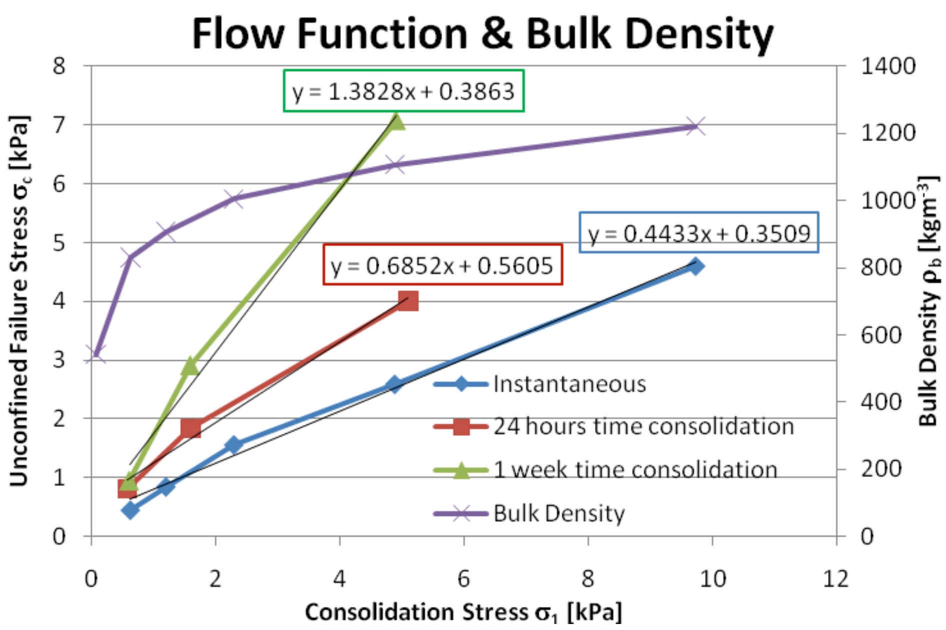


Fig 3a Instantaneous and Time Consolidated Flow Functions for a powder

Fig 3b) Flow Function illustrating limiting stress /stack height above which material undergoes a rapid increase in strength

Example Calculation

See the graphs below for the Time Consolidated Flow Function of a powder exhibiting sever gain in strength. The objective is to calculate the limiting safe stacking heights as a function of storage time. (Note that this is an approximate calculation). The flow function of a material has been measured for instantaneous and two time consolidation periods of 24 hours and 1 week. The flow functions and bulk density function are presented below. To determine the maximum stacking heights as a function of storage time, first estimate the maximum unconfined failure strength for which there is an equivalent "arching dimension" value that quantifies the maximum height for stacking.



Assume that the maximum arching dimension (stacking height) is 0.5m for reliable flow into the process. Use the following equation to determine the maximum level of unconfined failure strength, assuming the maximum measured bulk density in this case is 1200kgm^{-3}.

$$\sigma_c = \frac{B \cdot \rho_b \cdot g}{2000}$$

Thus

$$\sigma_c = \frac{0.5 \times 1200 \times 9.81}{2000} = 2.9$$

To determine the limiting consolidation stress that can be achieved at each time period, substitute the limiting unconfined failure strength into the flow function equations in the above figure.

$$\sigma_1 = \frac{\sigma_c - c}{m}$$

Thus for instantaneous conditions

$$\sigma_1 = \frac{2.9 - 0.3509}{0.4433} = 5.75$$

Where m is the gradient and c is the intercept of the best linear fit flow function.

The limiting stack heights are calculated by rearranging the hydrostatic stress equation to make the height the subject and solving for the consolidation stress and maximum bulk densities for each of the relevant time periods. For the instantaneous condition, the limiting stack height is

$$H = \frac{\sigma_1}{\rho_b g} \qquad \text{Thus} \qquad \boxed{H = \frac{5.75 \times 1000}{1200 \times 9.81} = 0.49}$$

For instantaneous conditions the limiting stack height is 0.49m. The limiting consolidation stresses and equivalent stack heights for 24 hour and 1 week storage times are presented in table 1 below.

	Instantaneous (time = 0)	24 hour static storage	1 week static storage
Consolidation stress s1 [kPa]	5.75	3.41	1.89
Height of powder H [m]	0.49	0.29	0.16

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December 10, 2013