Quantitative Methods
of
Snow Strength Measurements

University of Utah Geography 5260

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1 List of Symbols and Notation

Symbol	Description	Units
α	Slope Angle	°
μ	Coefficient of Sliding Friction	D. L.
ρ	Density	kg/m^3
ρ_{ave}	Average Density of two or more layers	kg/m^3
T_s	Shear Strength	kPa
T_t	Tensile Strength	kPa
W_n	Weight of a single layer n	kg/m^2
W	Total weight of two or more layers	kg/m^2
A	Area	m^2
g	Gravitational Acceleration	m/s^2
L	Length	m
S_s	Shear Stress	kPa
S_t	Tensile Stress	kPa
t	Layer thickness	m
$W_{f,\ b}$	Width	m
b	Width	m

D. L. = Dimensionless

2 Shovel Shear Test

The **shovel shear test** supplements snow profile observations with information about the location where the snowpack could fail in shear. It is best applied for identification of deep unstable layers and does not usually produce useful results in layers close to the snow surface.

Although many backcountry travelers use this test to determine hazard levels in avalanche terrain based on subjective feel, i.e., "easy", "moderate", and "hard" shear forces applied to the shovel handle, it's original purpose was not intended as a guide for determining the safety of a particular slope for skiing. On the other hand, some experienced practitioners who have perfected the art of conducting the shovel shear test and relating the results to many season of avalanche observations find it to be a useful tool. It is a quick test and can be repeated in several locations on the slope of interest in a short period of time.

Figure 1 illustrates the shovel shear test and the procedures for performing the test is as follows:

1. Isolate a column in the snow pit by excavating a chimney about 0.3m (30cm) wide by 0.4m (40cm) deep as shown in the figure.
2. Mark a square with sides of 0.3m (30cm) starting at one side of the chimney.
3. Make a triangular or rectangular cut on the other size of the square about 0.4m (40cm) deep.
4. Make a vertical cut at the back of the column about 0.2m deeper than the length of the shovel ensuring that the cut extends below a suspected weak layer.

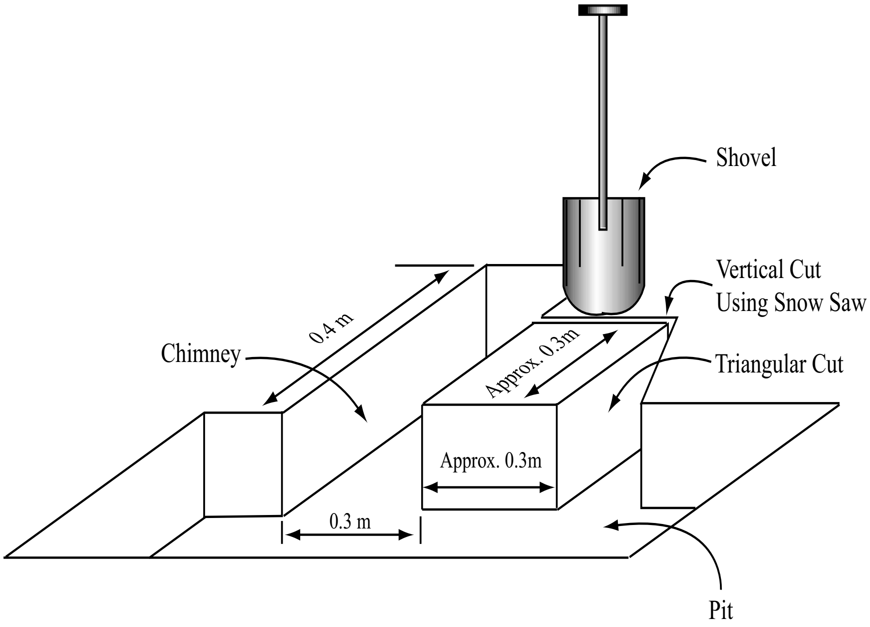

Figure 1: The shovel shear test.

5. Carefully insert the shovel at the back of the column holding the handle with both hands and pull gently.
6. When the column breaks in a smooth shear plane **above** the low end of the cut, measure the location of the shear plane from the snow surface and turning the block upside down, inspect and record the snow crystal characteristics of the shear plane.
7. After a failure, or when no break occurs, remove the column to the depth of the back cut and repeat the above procedures.

3 The Loaded Column Test

This test is performed by isolating a column in the snow pit of a known dimension, usually about 30cm square, to a depth sufficient to expose layers of concern. Blocks of known density are cut from the snow pit excavation material or some other expedient source, to a dimension of 30cm square. These blocks are placed on top of the column, which has been **leveled at the top**, until shear failure occurs. By recording the height of the placed blocks and knowing their density, the shear force at failure can be determined. Figure 2 shows the loaded column test.

A handy pocket graph can be drawn for field use to calculate the centimeters of new snow at a given density required to cause the slope to fail in shear.

From Figure 2, we can calculate the **shear strength** of a weak layer as follows:

$$T_s = \left[W_{add} + b * L * \rho_{ave} * \left(t - \frac{L * \tan\alpha}{2}\right)\right] * g * \sin\alpha \qquad (1)$$

where ρ_{ave} is the average density of the snow pack to depth t, and W_{add} is the weight added by the blocks. The blocks added for weight-to-failure are generally cut from the same layer

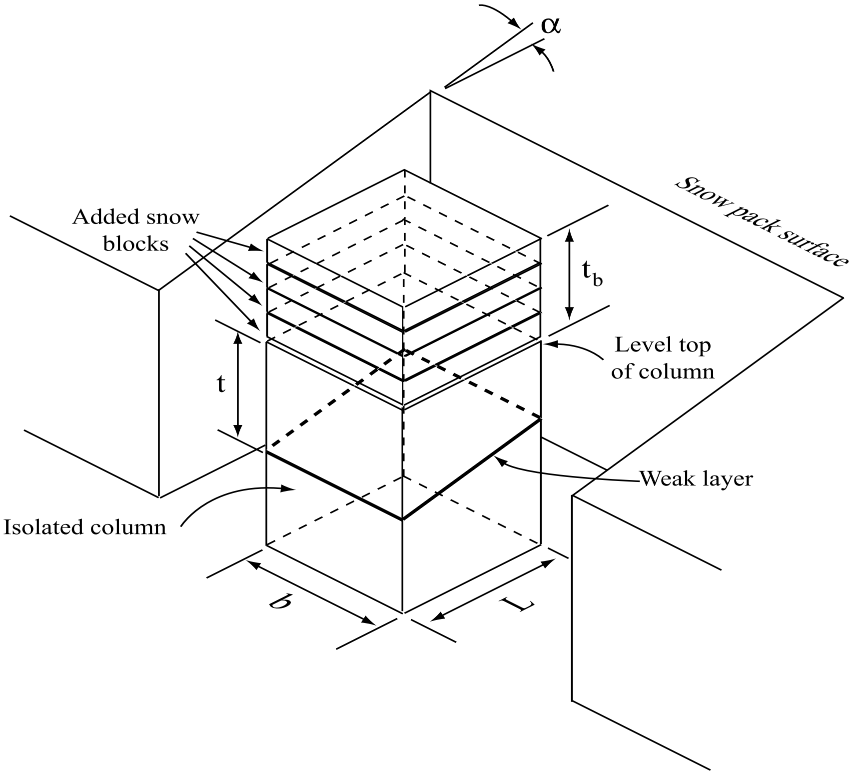

Figure 2: The loaded column test.

in the snow pack thereby having the same density. The weight of the added block then becomes,

$$W_{add} = t_b * L * b * \rho \tag{2}$$

In summary, the shear strength is the slope parallel vector of the gravitational force at failure.

4 The Trapezoidal Tensile Test

The **trapezoidal tensile test** is used to experimentally determine the tensile strength of a particular layer. The approach is rather straight forward. The test is performed by isolating a column in the shape of a trapezoid as shown in Figure 3. A large snow saw attached to a thin sheet of low coefficient of friction (μ) material such as a plastic sheet is then used to cut through a layer of choice. The plastic sheet serves as a low coefficient of friction surface providing an easy slide path for the column when failure occurs. The cut is performed parallel to the slope angle (α) from front to back of the trapezoidal column. As the saw separates the layer, which causes the shear stress to become zero, the tensile stress within the layer will at some point cause the trapezoidal column to fail. After failure, the dimensions of the **fracture plane** are measured to determine the tensile strength of the layer. The **tensile strength** (T_t) is calculated as follows:

$$T_t = \frac{L * \rho_{ave} * g * (W_f + W_b) * (\sin\alpha - \mu * \cos\alpha)}{2 * W_b} \tag{3}$$

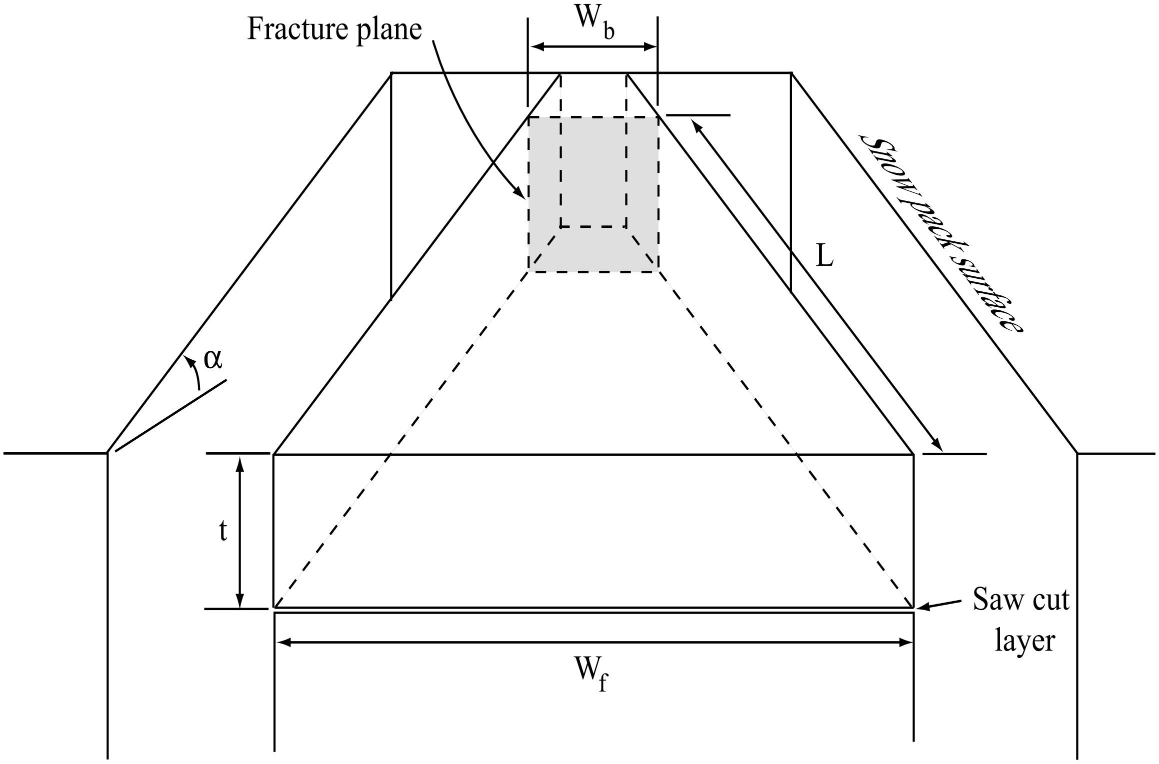

Figure 3: The trapezoidal tensile test.

where ρ_{ave} is the average density of the layer above the saw cut, μ is the coefficient of friction between the snow and the sheet inserted into the saw cut, and α is the slope angle.

5 The Flatjack Shear Test

"Flatjacks" have been used in experimental geology to measure changes in the earth's stress and to apply stress for experimental purposes to large in-situ rock masses (Swolfs, et al. 1975). Their application to snow mechanics required a total redesign of the technique for a media where much lower stress must be applied and measured. A **flatjack** is a flat slender fluid-filled bladder, which when inserted into a slot, can be pressurized to apply stress to the material surrounding it. The pressure of the fluid in the flatjack can be related to the stress in the surrounding material. For the technique discussed here, a common sphygmomanometer of the type used by medical personnel to measure the blood pressure of a patient was used. The rubber bladder was removed from the fabric "cuff" and a new nylon case was made. Fiberglass cards were inserted on each side of the bladder to maintain a uniform plane to apply stress to the snow and prevent the bladder from taking on the round shape of a balloon or from taking on some other shape dictated by regions of different hardness in the snowpack. A small nylon bag was also tied around the rubber bulb hand pump to prevent snow and ice from affecting the operation of the check valve. The pressure gage, calibrated in $mm - Hg$ was not modified but the readings need to be interpreted to calculate the correct stress applied.

After identifying the weak layer with a **shovel shear test**, a block should be cut slightly

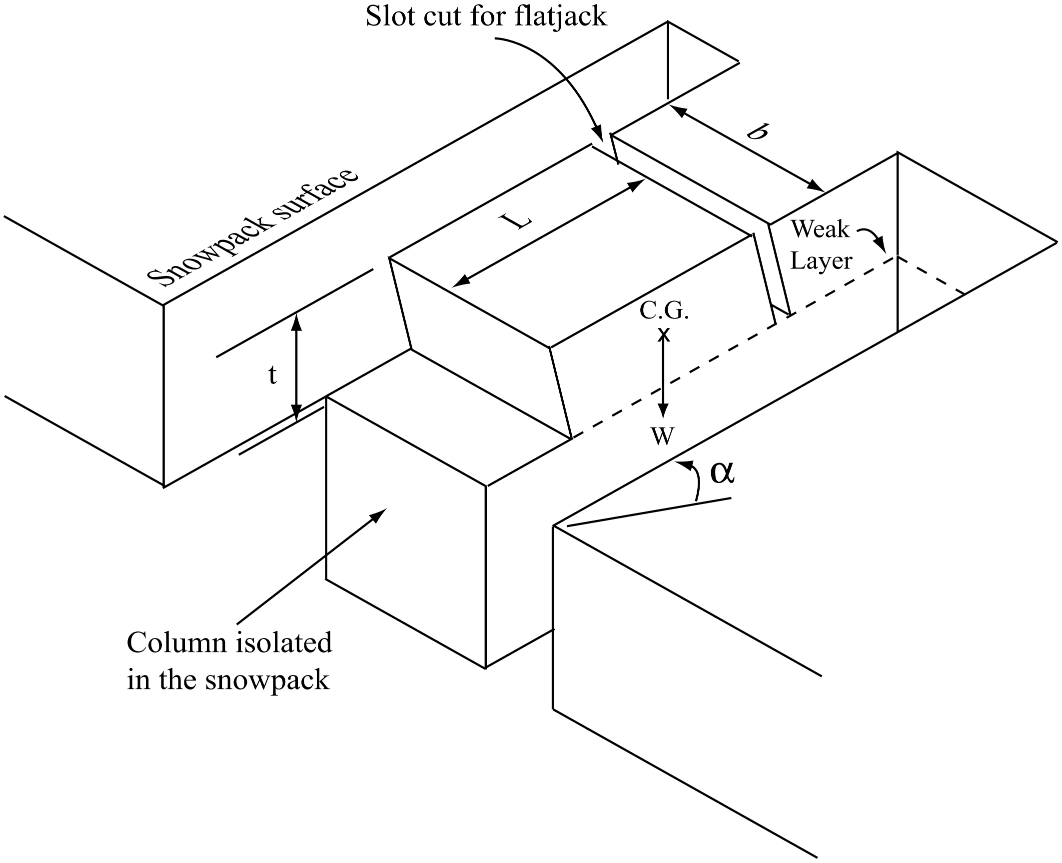

Figure 4: The flat jack shear strength test.

wider than the bladder and long enough to assure that the block's center of gravity is behind it's front edge. With the snow removed on booth sides of the block, a saw cut can be made down the back of the block perpendicular to the slope and down to the weak layer. The bladder is then inserted in the slot made by the saw and positioned so the bottom edge of the bladder is just above the weak layer. The bladder is now pumped up slowly while the pressure gage is watched closely. As the pressure increases, some compression of the snow will take place causing slight drops in pressure but eventually the pressure will increase and shear failure along the weak layer will take place. The maximum pressure reached, and the bladder-slot thickness just before failure must be recorded. A diagram of this test is shown on the following page.

The **shear strength** determined from flatjack data is,

$$T_s = \left(\frac{P_i * C_{Hg} * A_{flatjack}}{b * L}\right) + t * \rho_{ave} * g * \sin\alpha \tag{4}$$

where P_i is the interface pressure exerted by the flatjack, $A_{flatjack}$ is the area of the flatjack (usually taken as 0.033 m^2), and C_{Hg} is the conversion factor from $mm - Hg$ to N/m^2 (i.e., Hg x 133.3 $= N$). P_i can be selected from the curves presented below after measuring the thickness of the flatjack bladder when shear failure is induced.

Important points to remember

- The faces of the block to be placed in shear are cut normal to the slope.
- The test block must be long enough for the center of weight to pass within the area in shear, as illustrated in the Figure 4.
- ρ_{ave} is the average density from the surface to the weak layer.

5.1 Calibration of the flatjack

The calibration of the flatjack must be performed carefully to ensure consistent results. The relationship between the pressure in the bladder and the force applied to the block of snow should depend simply on the area of the bladder; however, as the bladder expands it stretches and some of the pressure is resisted by the tension in the bladder. This needs to be considered when calculating the true force applied to the snow block. The calibration curves for the flatjack are shown below[1].

6 Acknowledgments

1. Russo, Robert S., Alta Ski Lifts Co., Alta, Utah.

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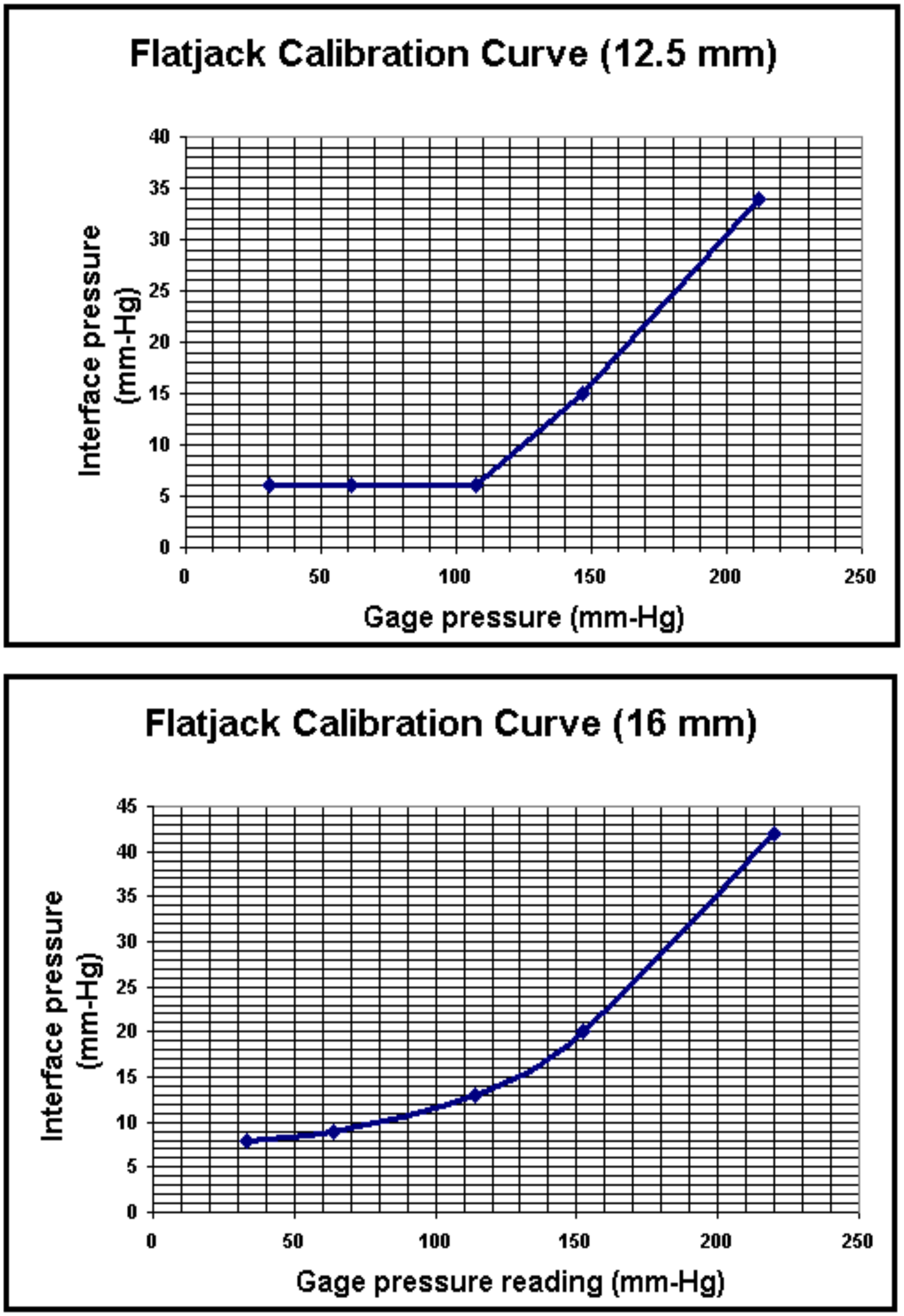
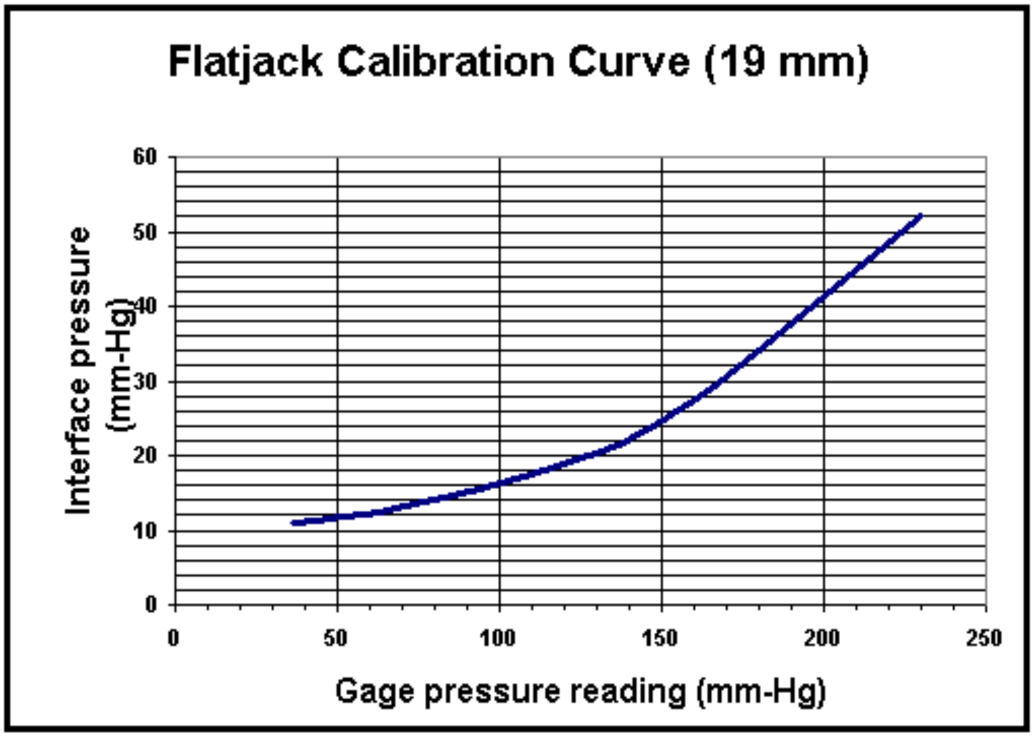
[1] The results and curves of the calibration tests were performed by Robert S. Russo.


Flatjack Calibration Curve (12.5 mm)

Flatjack Calibration Curve (16 mm)

Figure 5: Calibration curves for bladder thickness at shear frame (12.5mm and 16mm)



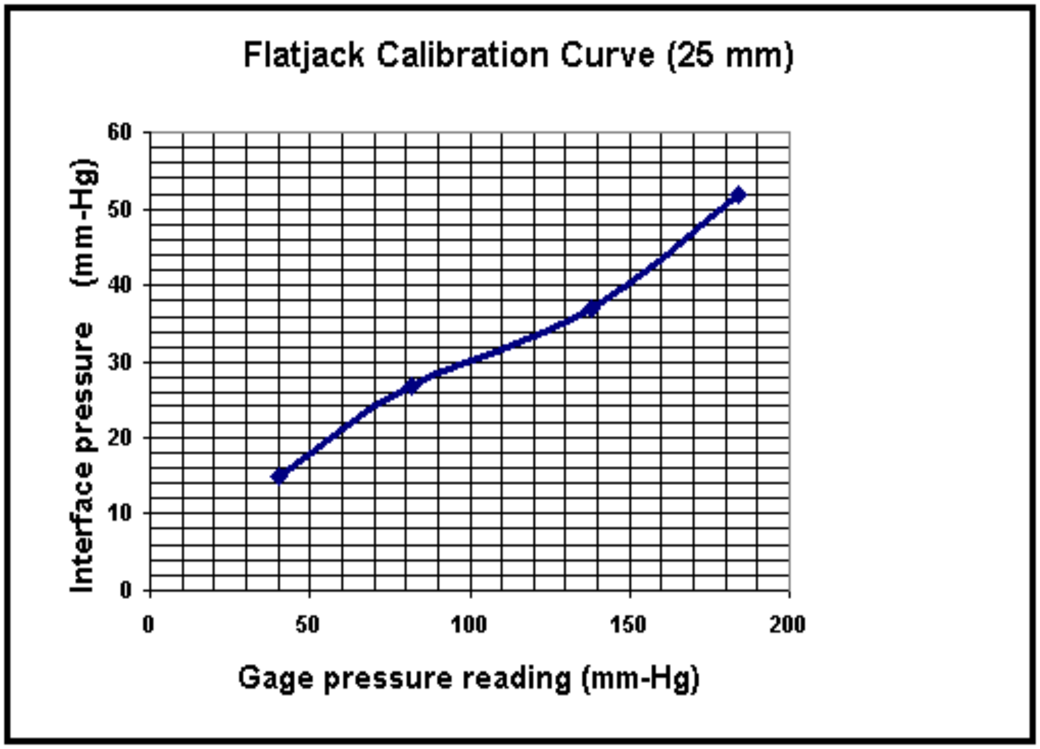


Figure 6: Calibration curves for bladder thickness at shear frame (19mm and 25mm)