Density and Friction Measurements in a Flowing Dry Snow Avalanche

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ABSTRACT

Using the Revolving Door avalanche facility near the Bridger Bowl Ski Area (Dent et al 1994), measurements of density and dynamic friction in a flowing avalanche were made. Corresponding flow depths were concurrently measured using a floating arm with a small skid that rode on the surface of the snow.

Measurements of density were made using two devices; a capacitance probe (Louge et al 1996), and calibrated optical sensors that serve to measure flow velocity. The capacitance probe was constructed to measure the dialectric constant of any material that passes in front of it. Through a calibration procedure, the dialectric constant of a given type of snow can be related very accurately to the density of that snow. The capacitance probe was used in one avalanche last winter to determine the density of the snow at 1 cm and 6 cm depths within a 1.5 m deep avalanche. In addition, optical sensors were used to measure the reflectance of the snow as it passed the sensors. The reflectance measured is determined in part by the density of the snow. By proper calibration, the signals from the optical sensors can be related to the snow density. Signals from adjacent optical sensors are also cross-correlated to determine snow velocity. Last winter density and velocity measurements were made in several slides at various depths using these optical sensors. The results indicate that snow density is largest at the bottom of an avalanche, upwards of 400 Kg/m³, and in the first few centimeters from the bottom, falls off rapidly to about 300 Kg/m³. The density then continues to decrease slowly to about 250 Kg/m³ at the surface of the avalanche.

The dynamic friction coefficient at the base of two avalanches was found by measuring the shear and normal forces on a roughened 23 cm x 28 cm aluminum plate mounted flush to the running surface. Deflections of the plate were measured using strain gauges, from which the forces on the plate could be found. The ratio of the shear force to the normal force on the plate provides a measure of the friction coefficient at the base of the slide. Of the two slides measured, the drier and deeper slide had a lower coefficient of friction which allowed it to travel faster and farther.

INTRODUCTION

Improved observations of the dynamics within avalanches is required before an accurate model for determining avalanche runout distances can be made. The idea that an avalanche may move as a single mass while riding almost passively upon a thin shearing layer at its base comes from the modeling of granular materials. To complete the description of the dynamics within this shearing layer, it is necessary to obtain accurate measurements of the flow parameters such as velocity, the solid volume fraction or density and the stress ratio within this layer. This paper documents the implementation of instrumentation used to provide accurate measurements of these parameters.

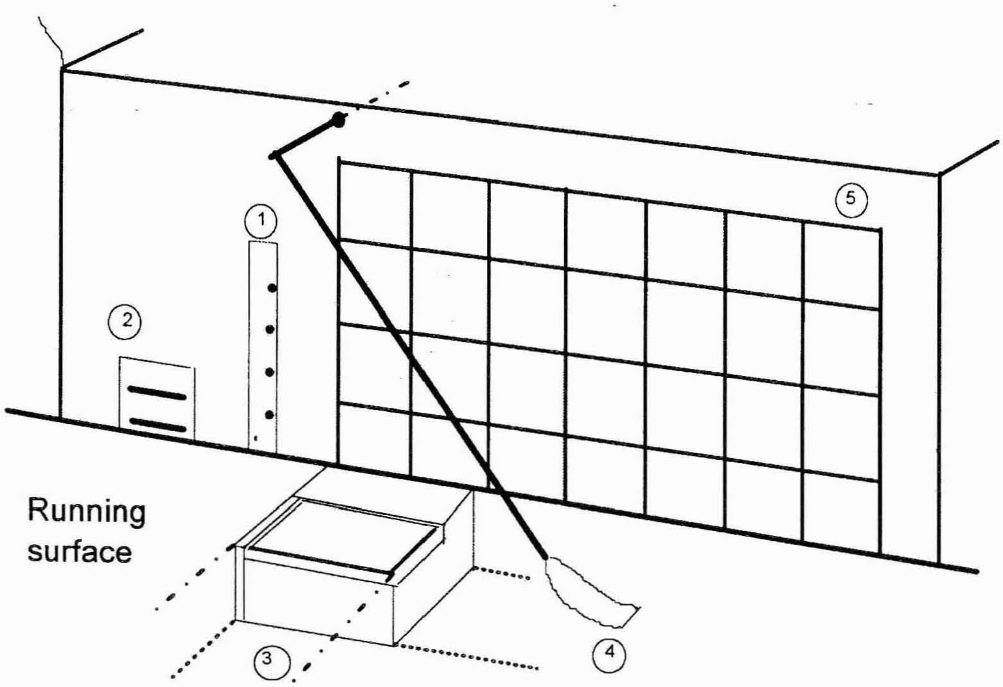

Figure 1: 1–Array of photosensors, 2–Capacitance sensors, 3– Shear plate 4– Depth gauge, 5–Acrylic observation window

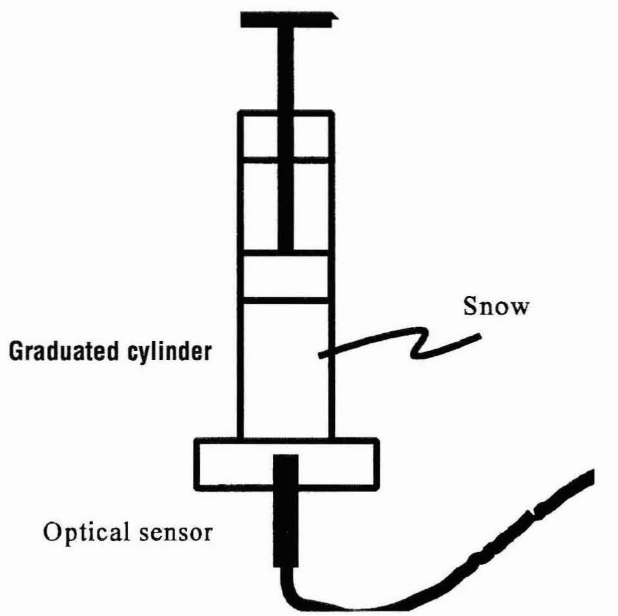

Figure 2: Snow press

EXPERIMENT

Revolving door, a small east facing avalanche path in the Bridger mountain range of Southwestern Montana has cliff bands that feed into a narrow 100m chute with an uniform slope of approximately 30° before running out into a stand of small pines. In the center of revolving door is a large boulder, behind which a small instrument shed has been built. By contouring snow in the early winter, it has been possible to release avalanches that pass next to this instrumented shed.

Preparation of the site prior to triggering of a slide first involves removing any new snow from the side of the shed exposing the top 30-40 cm of the observation window. The slope is then smoothed and contoured so that the slide will run straight and uninterrupted past the shed. Care must be taken to insure that there are no changes in slope or bumps that will disrupt the flow, causing eddies or deposition on the running surface. After the slide path is prepared, it is then instrumented (figure 1).

Densities within the avalanche were measured by two different methods. First with the use of a capacitance probe (Louge et al 1996) which measures the dielectric constant of snow passing in front of its sensors. Each sensor strip on the probe consists of a sensor, a ground and a guard. A buffer amplifier maintains the guard at precisely the same sinusoidal voltage as the sensor to protect it from any stray capacitances. In addition the sensor is connected to processing circuits using a guarded coaxial cable so that cable capacitance does not participate in the measurements. Through proper calibration this dielectric constant can be related to the density of the snow. The second method for measuring the density was with optical sensors (Dent et al 1994). Each photoelectric sensor in the array contained both an infrared light emitting diode (LED) and an infrared sensitive phototransistor mounted side by side. The phototransistor was mounted so as to measure the amount of infrared light from the LED that is reflected from objects passing in front of the sensor. This reflectance is not only a function of the snow's density, but also the snow's structure and water content. By calibrating the sensors with the snow press (figure 2) before hand, the signals can be related directly to the snow's density. Through cross correlation between adjacent optical sensors measurements of velocity at different points in the avalanche can also be obtained (Dent et al 1994).

The depth (height) of the flow is measured using a light swinging arm attached to a rotational potentiometer. As the slide passes the shed, a small skid on the arm rides on the surface of the slide rotating the arm and hence the potentiometer. Voltages proportional to the angle of rotation are then recorded. This depth gauge is calibrated by raising the skid to known heights above the running surface.

Shear and normal stresses were measured using a shear plate. The shear plate is a roughen flat 23 x 28 cm aluminum plate. This plate is rigidly mounted in a sturdy box by two cantilevered arms fitted with strain gauges in a wheatstone full bridge configuration (Figure 3). This box is mounted to the side of the shed, below the slide running surface so that the plate is flush with the surface. As the slide flows over the plate, voltages across the bridge are recorded. The recorded voltages are assumed propor-

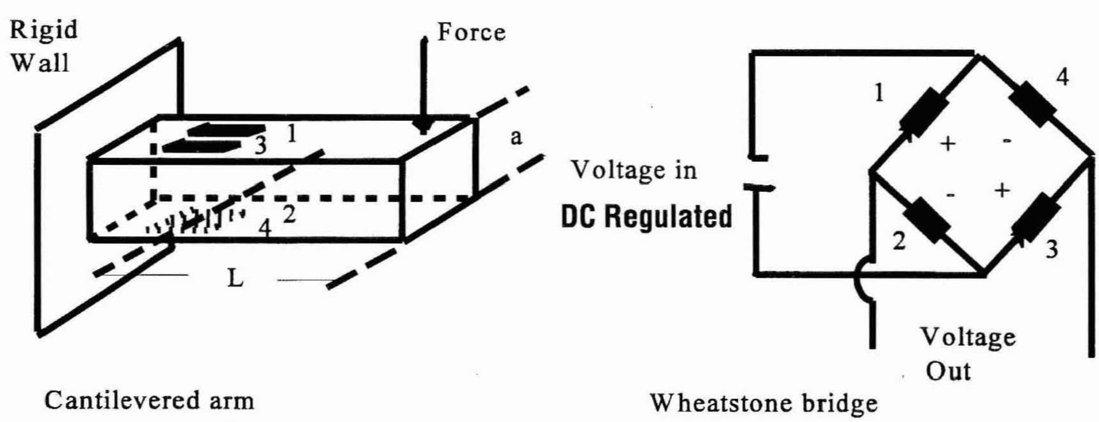

Figure 3: Cantilevered arm and bridge configuration

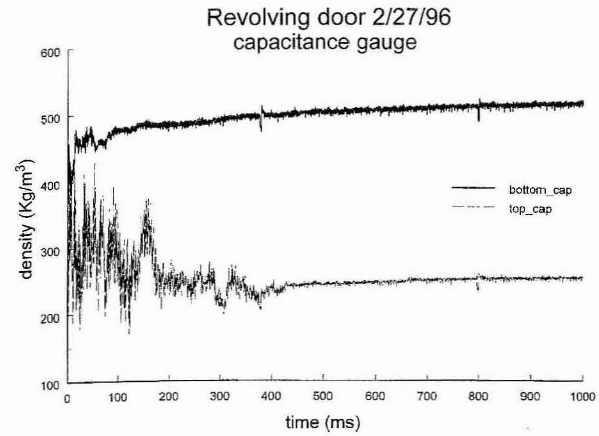

Figure 4

tional to the applied stresses. Prior to the slide the plate surface is prepared with a layer of snow and calibrated with several known weights.

Ideally, the shear angle of the snow will be equal to but not less than the slope angle keeping deposition to a minimum. A lower shear angle would cause erosion of the slope, and since the slope is artificially prepared, erosion would degrade the results.

Error is introduced in the data as the slide deposits snow on the plate. This error is due to the shear and normal components of the deposited snow's weight. This also introduces error in the flow depth measurement because the depth gauge includes in its measures the height of the deposited snow beneath the slide. It is assumed that if deposition is minimized and limited to that due to frictional deceleration then these errors are small.

RESULTS

During the winter of 1996 implementation of new instrumentation was performed for several avalanches. The optical sensors were used on all of the slides to measure velocities, but attempts to calibrated them for density measurements was only attempted once. The instrumentation for capacitance probe was only available for one slide this last winter. The shear plate was installed for our last two slides, while the depth gauge was only used for one.

Prior to the first slide on 3/27/96, a cold front came though and deposited 76 cm of new snow and dropped temperatures below 0° F with high easterly winds. Ideal avalanche conditions allowed us to release our largest slide of the season. With 6 lbs. of explosives a large slab was released running approximately 1.5 m deep and traveling up to 8 m/s. The capacitance probe and the optical sensors measuring velocity, were the only instrumentation applied to this slide. The capacitance sensors measured densities at only 1 cm and 6 cm above the slide running surface. The data shows that the density at 1 cm above the running surface was in the range of 450 Kg/m^3 and quickly decreasing to about 300 Kg/m^3 at 6 cm. This indicates that the density of the slide quickly decreases in the first few centimeters and then decreases very little toward the surface of the slide. Although on a whole there was little deposition on the running surface with this slide, the data indicates that the sensors were quickly buried. The bottom sensor was covered in less than a tenth of a second, while it took about a half of second to cover the top sensor. This was due to deceleration of the slide.

The second slide recorded was on 3/19/96. It was on a sunny day with approximately 20 cm of new snow from two days prior. The warm weather was stabilizing the snowpack. The shear plate and the optical velocity sensors were the only instrumentation applied to this slide. Four pounds of explosive were used to trigger a relatively small slide traveling at around 6 m/s with very small powder cloud. The bulk of the slide passed the shed in about 1.3 seconds, reaching an estimated maximum depth of about 30 cm before stalling out high in the runout zone. The estimated flow depth for this slide was taken from video and checked with measurements of the normal stress combined with an approximation of the slide average density. In this case a smaller sluff arrived at the instrument shed first and was over taken by the main slide. This can be seen in the plate data (Figure 4). The plate data also shows that both the normal and shear stresses continue decreasing once the slide has come to a stop. It is believed that this is caused by the plate slowly slipping back to its unstrained position and sintering of deposited snow bridging the plate. It can be seen in Figure 5 that the shear to normal stress ratio (S/N) remains high throughout the

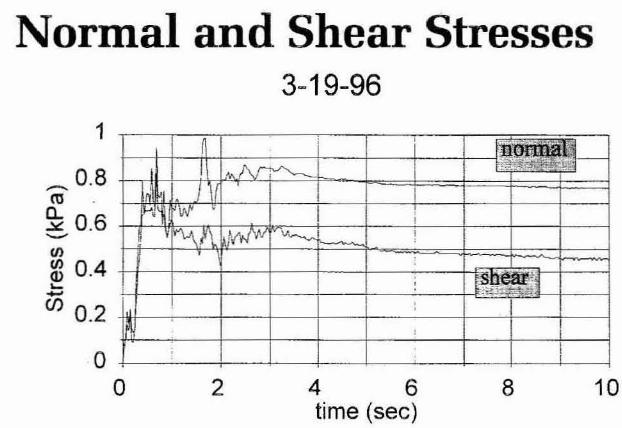

Figure 5

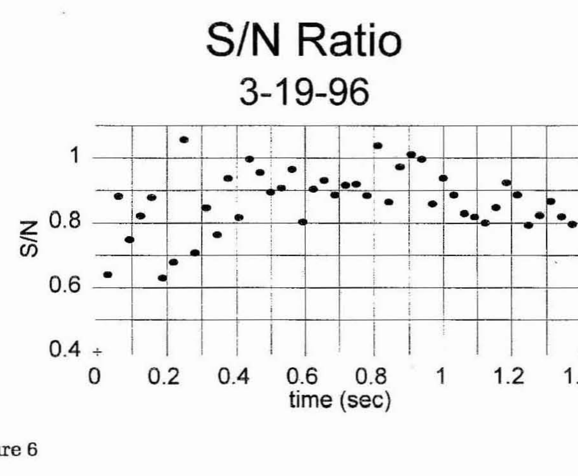

Figure 6

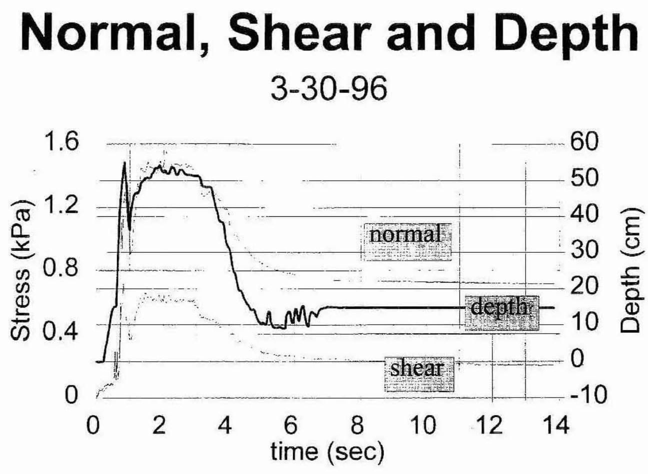

Figure 7

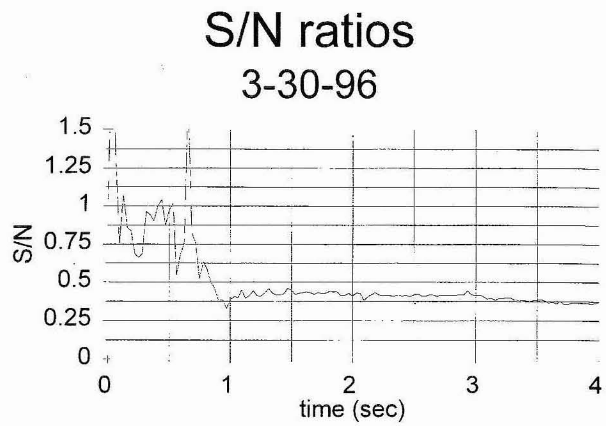

Figure 8

slide, averaging about .85. Approximately 15-20 cm of snow was deposited on the running surface by the slide due to poor slope preparation prior to the slide.

The third slide was on 3/30/96. Again the shear plate and velocity sensors were used on this slide with the addition of the depth gauge and an attempt to calibrate the photosensors for density measurements. This slide was triggered on about 28 cm of new snow and conditions were drier than the previous slide. The slide was larger than the previous slide and had a substantial powder cloud. The leading edge of the slide was moving fast, reaching speeds up to 12 m/s during a surge, taking about 4 seconds to pass the shed before running far into the runout zone. It was observed and recorded that the depth gauge was kicked up in the initial wave front of the slide before settling down and riding smoothly on the slide surface. This slide also deposited about 15 cm of snow on the plate. For this drier slide, the S/N ratio was much lower for the majority of the slide because the normal stress was much larger than the previous slide, while the shear was about the same magnitude. An attempt calibrate the optical sensors to measure densities was also tried on this slide. The data gives conflicting results with measurements of the densities measured in the deposition after the slide. The densities measured with the optical sensors show lower densities near the bottom of the slide. This may in part be attributed to leakage of infrared through the slide surface. The sensors at 10.5 cm above the running surface measured the density of about 280 Kg/m^3 (Figure 9). The data shows that as the sensor became uncovered at around 4 seconds the reflectance increased, increasing the recorded density. The measuring of density using the optical sensors requires further investigation.

Due to the amount of deposition upon the plate there are doubts as to whether these measurements represent the true shear layer S/N ratios and actual slide depth. Since

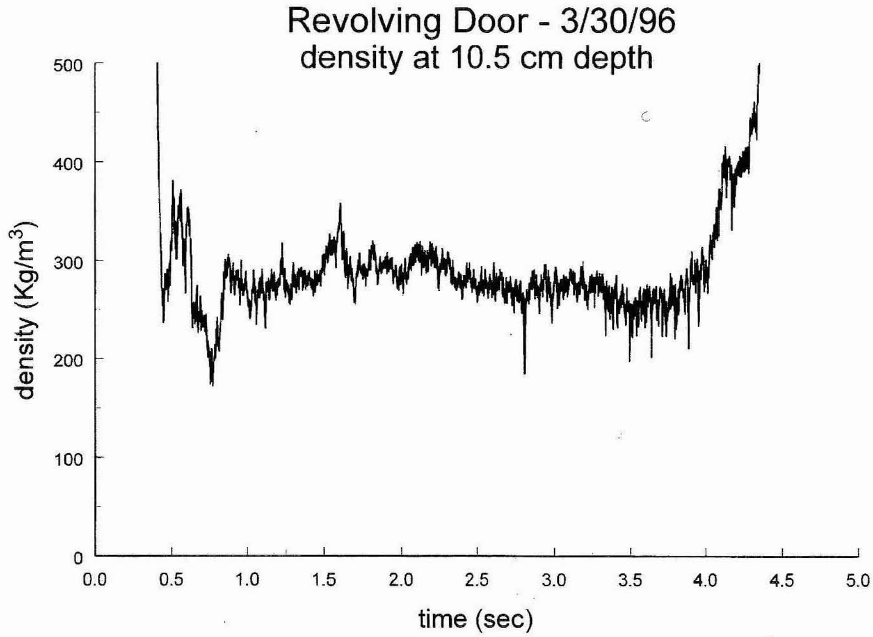

Figure 9

the two slides deposited similar amounts of snow though at different rates, there is the possibility for comparison. Intuitively one would expect that the drier and deeper slide would have a lower S/N ratio allowing it to travel faster and further. Improvements to measurements of both the S/N ratio and the slide depth can be obtained by insuring that the slide encounters no obstructions down slope of the plate limiting deposition to that caused by frictional deceleration only.

In the future it may be possible to calculate the rate of deposition from velocity sensors along with density measurements and subtract its normal and shear components from those recorded by the shear plate to obtain a more accurate measurement.

With all of the instrumentation in place and working correlation between the slide parameters can be made allowing for a plot of the S/N ratio against the velocity normalized by the density and normal shear stress. This curve should give tremendous insight to the dynamics and the relationship of the flow parameters within actual avalanches, hopefully leading to a better model for determining runout distances.

CONCLUSIONS

The increased flow distances of dry snow avalanches appears to be connected with the lower S/N ratios that result at the slide's base.

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