Bridge over troubled facets

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"What do you think about Chimo's Run?" – aggressive skier

"That surface hoar layer is probably in there." – smart skier

"Well, we haven't seen any natural activity on that layer in a couple days." – aggressive skier

"Yaaaaah, but it's probably down about 100 cm, so if we triggered it, it'll go big!" – smart skier

"Dude, there's that wind crust in there that will for sure bridge our stress!" – aggressive skier

"I don't know what that means and it sounds made up!" – smart skier

Figure 1: Mike Wheater loading the snow surface above the sensors. The sensors are mounted to long aluminum sheets which are inserted into the side of the profile. The data logger is in the black bag.

These folks are discussing how deep our stress (force) goes into the snowpack when we ski (or sled!)? How much does it depend on the kind of snow? How much snow of what kind do we need to effectively bridge a weak layer? When can we start to ski avalanche slopes with a weak layer in the snowpack? Why do we often see sudden fractures beneath crusts in stability tests and then no activity on that layer?

A few years ago, Juerg Schweizer and Bruce Jamieson (2001) investigated slab properties for a whole bunch of skier-triggered avalanche slopes. They found that most slabs are less than 60 cm thick, rarely more than 100 cm, but sometimes over 150 cm. This study provided a lot of valuable insight into the skier's impact on avalanche slopes. But, there is a lot of variation in the slab depth data, how would snowmobile-triggered slopes compare and what about the properties of those slabs?

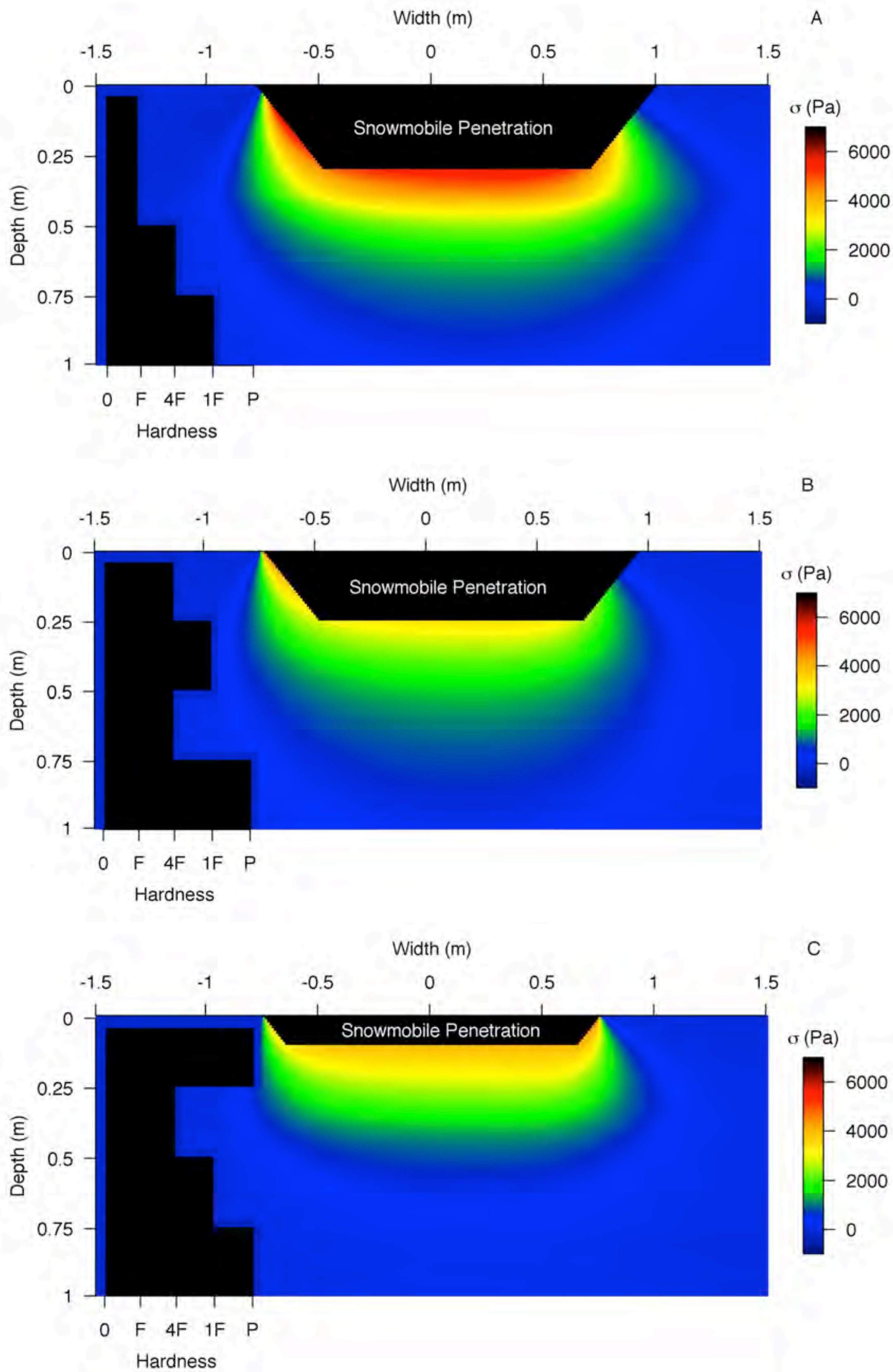

Figure 2: The plot shows calculated stress values that are ***calibrated*** *to match measurements of a snowmobile (σ is the symbol for stress). The data are grouped into three "typical" snow resistance profiles shown on the left of each plot. Plot A for "soft", B for "medium" and C for "supportive". The black near the surface of the plot represents the average snowmobile penetration into the snow cover.*

Well, to shed some more light on how skiers and sledders impact the snow, we've been placing sensors at different levels in the snowpack and recording the force that a skier or sledder transmits as they pass over them (see Figure 1 of Mike Wheater skiing over the sensors). Not everyone loves boxplots as much as researchers, so we made some colourful pictures of the numbers for snowmobile measurements (Figure 2). The pictures are separated into three "typical" snowpack resistance profiles: soft, medium and supportive. The hardness profile is shown on the left of the graph. The plots are made for a 35° slope (that is why the bulbs are shifted to the right slightly).

We see the stress bulb for the "soft" profile about 75 cm into the snowpack, whereas the bulb for the "supportive" profile about 35 cm into the snowpack. The average penetration of the sled is shown as black at the top of the bulb and, as expected, the "soft" profile allows more penetration compared to the "supportive" profile. Looking at these plots it becomes obvious that our stress bulbs start beneath our sled or skis. So, if it's over-the-head 50 cm ski pen then the stress bulb starts at 50 cm and goes deeper from there (minus some stress being absorbed by deforming the powder). This whole idea of harder snow supporting and spreading skier and sledder stress is not new and many folks call it bridging. Most Rockies ski enthusiasts keenly evaluate bridging as the season progresses until those pesky depth hoar layers are buried deep enough.

So, how much snow of what type do we need to bridge a weak layer? Many experienced ski gurus have an intuitive answer for this question which, as always, depends on many factors. In casual conversation with many ski guides, the answer to this question varied greatly. Based on the stress measurements and using skier stability indices (Föhn 1987, Jamieson 1995), we arrived at a bridging index value of 130 for skiing. The bridging index is simply the thickness of layer times the hardness (1 for Fist, 2 for 4 Finger, 3 for 1 Finger, etc).

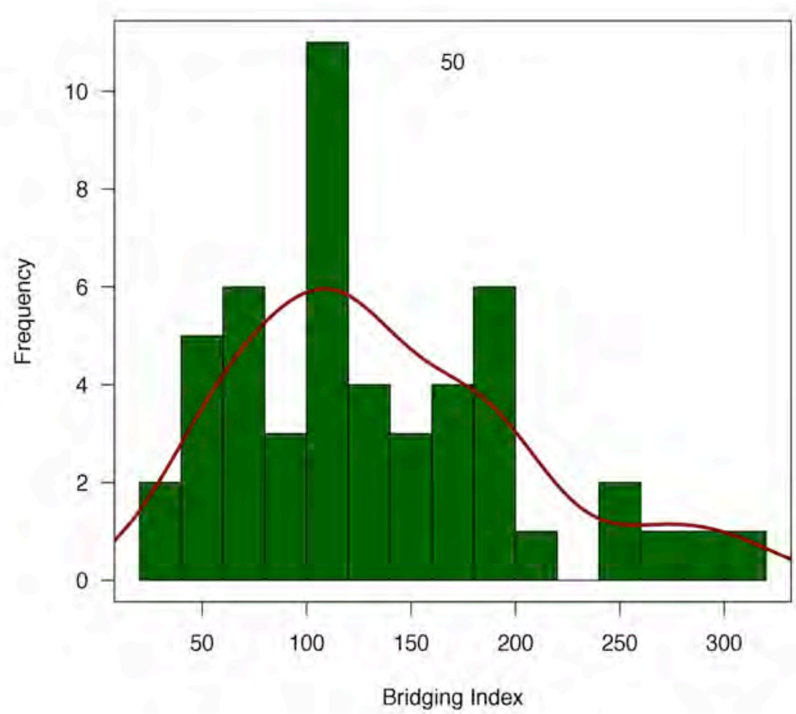

Figure 3: Frequency of bridging index values for 50 skier triggered avalanches (Sc and Sa). Only avalanches size 2 or larger are shown.

What does bridging index of 130 mean? It can represent an infinite number of hardness profiles, but here are some examples:

- 50 cm fist, 40 cm 4F
- 20 cm P, 20 cm 4F
- 10 cm F, 20 cm 4F, 30 cm 1F

Investigating a little further, we pulled a bunch of old ASARC profile data from skier-triggered slopes and looked at the bridging index. Figure 3 shows the frequencies of bridging index values for skier accidental and ski-cut avalanches Sz. 2 and larger. The middle of the bridging index values is about 130, but what about all those larger values to the right of 130? Those would probably be larger avalanches as well! As a first pass this concept shows promise, but needs some more investigating. More to come!

For now, let's fast forward a little in time. Let's assume we have a good idea how much snow of what type it takes to bridge a weak layer. We are out skiing and we're pretty sure we have enough bridge above our weak layer, but we better do a quick test to make sure. We dig out a small hole, cut a 30 cm x 30 cm column and start tapping away. POP! What the #$%#? Sudden fracture on those facets under the crust.

Scott Davis and Bruce Jamieson were chatting in Penticton this spring about this hypothetical scenario. For many good reasons, in all our snowpack tests (CT, ECT, PST, DT, ST, RB… wow there are a lot!) we isolate a column of some size. This cutting of the snow when isolating a column has the effect of eliminating the bridging strength of the layers. Consequently, there are many situations where we get sudden results, often under a crust, but don't see avalanches on the layer. Over coffee this morning, Bruce remembered a well-developed facet layer under a 20 cm hard crust in the North Columbias. The layer was producing sudden fractures, but the guides were skiing steep open terrain without triggering avalanches. Figure 4, shows some stress measurements from within stability tests. In some we isolated the normal 30 cm x 30 cm column and some we only isolated the front wall, leaving three sides intact. We see more stress in the isolated columns than the un-isolated ones, which is one reason why sudden results sometimes occur in snowpack tests but the adjacent slope can't be triggered.

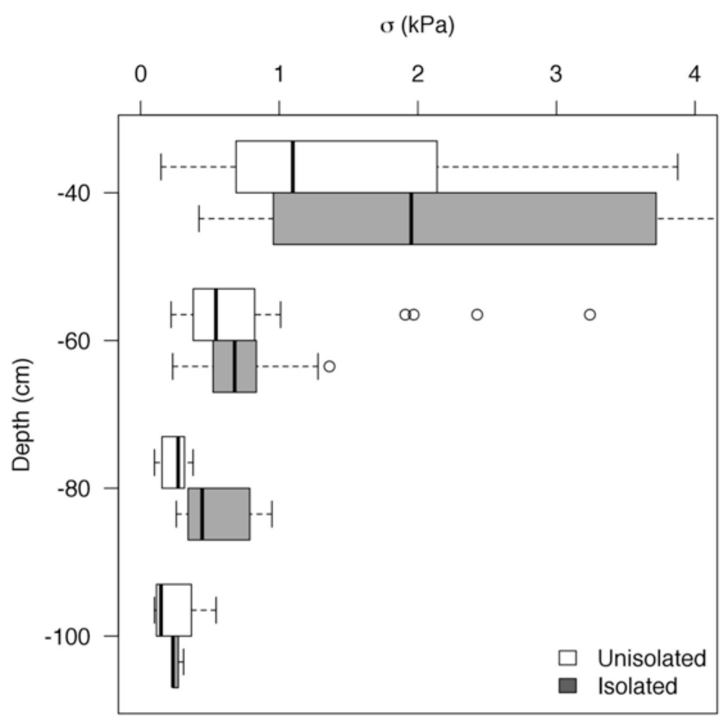

Figure 4: Stress (σ is the symbol for stress) at various depths for isolated and un-isolated columns. The measurements are from a test similar to the compression test where we tap on the top of the column. The black line in the boxes is the middle value and the boxes are the half of the values.

The concept of bridging is an important one to understand, although the usual caveat about the highly spatially variable snowpack applies. Even if we figure out how much snow is needed for effective bridging, thin spots with much less bridging are always lurking. Much of the data shown here is preliminary and is presented to spark discussion and thought (don't take the 130 number as gospel!). Currently this is an active research topic, so expect more information in the near future.

For further reading, there is a more detailed paper submitted to this year's ISSW in Grenoble.

References

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