THE STABILITY WHEEL: AN INTUITIVE AND DIDACTIC DECISION-MAKING FRAMEWORK

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ABSTRACT: The Stability Wheel is an intuitive and didactic decision-making framework which incorporates the findings from anti-crack theory by Heierli et al. (2008) into classroom and field practice. The Stability Wheel is a visual representation of the slab avalanche release model. Specifically, it distinctly represents the likelihoods of Trigger, Propagation, and Slip in addition to the Structural Weaknesses identified as lemons by McCammon and Schweizer (2002) or yellow flags by Jamieson and Schweizer (2005).

KEYWORDS: Decision making, avalanche education, anti-crack theory, terrain management

1. INTRODUCTION

Perhaps the most important development in slab avalanche release models was the novel anti-crack theory work by Heierli et al. (2008). Although prior models proposed shear fracture mechanisms, the work by Heierli et al. (2008) showed that fracture mechanics, specifically anti-cracks, provide a much more thorough and fitting model. Anti-crack theory maintains that the release of a slab avalanche is a result of three distinct events. First, a mixed-mode fracture is triggered naturally or by human activity. Following that, the fracture nucleates and propagates along the weak layer. Finally the slab either sticks or slips based upon whether crack-face friction exceeds the gravitational force on the slab. The Stability Wheel's role in decision-making is to identify the likelihood of the three events critical to the release of a slab avalanche: trigger, propagation, and slip. Determination of these probabilities is based on field stability tests. The result is a framework that is didactically intuitive, grounded in science, and is easily applicable to decision making in terrain selection.

2. STABILITY WHEEL REPRESENTATION

A significant portion of the Stability Wheel's success is owed to its straightforward and intuitive presentation. The Stability Wheel is presented as a circle divided into three portions equal parts plus a smaller circle embedded inside. Figure 1 below shows the Stability Wheel.

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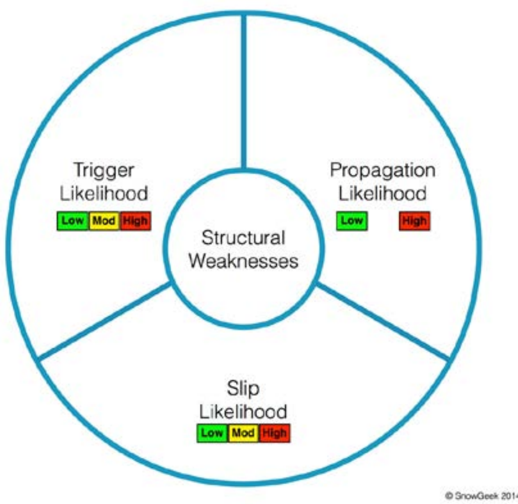
Fig. 1: Stability Wheel Graphic



The upper left third is reserved for the trigger likelihood, the upper right third for propagation likelihood, the lower third for slip likelihood, and the inner circle for the count of structural weaknesses.

3. DETERMINING EVENT LIKELIHOODS

1.1. Determination of Trigger Likelihood

The first event responsible in the release of a slab avalanche is the initiation of a mixed mode fracture. This fracture can be initiated by natural or human triggers. The likelihood is determined to be low, moderate, or high.

Determination of trigger likelihood falls entirely on performing stability tests. These likelihoods are drawn from the Compression Test, the Extended Column Test outlined by Simenhois and Birkeland

(2006), or variants of these such as the Baby Burp and Loaded Column Test found in the *Snow, Weather, and Avalanche Guidelines* (2010). These tests are performed by impacting the snowpack thirty times, the first ten from the wrist, the next ten from the elbow, and the final ten from the shoulder. If the test produces active results between the first and tenth impacts, then trigger likelihood is high. Likewise active test results from impacts eleven through twenty are assigned a moderate trigger likelihood. As may be guessed, impacts twenty-one through thirty are assigned a low trigger likelihood.

1.2. Determination of Propagation Likelihood

The second event responsible in the release of a slab avalanche is fracture nucleation commonly known as propagation. The likelihood is determined to be either low or high.

Determination of propagation likelihood primarily comes from the results of the Extended Column Test and Propagation Saw Test. The Extended Column Test reports one of three possible results, ECTX for no fracture, ECTN for fractures without propagation, and ECTP for fractures with propagation. In the case of an ECTN or ECTX propagation likelihood is considered low. In the case of an ECTP, propagation likelihood is high. Test results for the Propagation Saw Test are reported in form PST X/100 where X represents the number of centimeters cut before the initiation of a self-propagating fracture. Results are considered positive if X <= 50 and negative if X > 50. Positive results correspond to high propagation likelihood while negative results correspond to low propagation likelihood.

1.3. Determination of Slip Likelihood

The third and final event responsible in the release of a slab avalanche is the gravitational force exceeding the crack-face friction that causes the slab to slip. The likelihood is determined to be low, moderate, or high.

Slip likelihood is determined through a combination of Q scores from Compression and Extended Column Tests as codified by a combination of Johnson and Birkeland (2002) and Herwijnen and Jamieson (2004). Q1 sudden collapse or sudden planar scores correspond to high slip likelihood. Q2 corresponds with moderate slip likelihood. Q3 corresponds to low slip likelihood.

4. STRUCTURAL WEAKNESSES

At the center of the Stability Wheel are structural weaknesses. They are placed at the center to represent that they affect the likelihoods of trigger, propagation, and slip. The structural weaknesses in the Stability Wheel are a combination of lemons and yellow flags. The structural weaknesses used in the Stability Wheel are:

- Weak layer depth is 1 meter or less
- Weak layer thickness is 10cm or less
- Hardness difference between the slab and weak layer is 1 or more steps
- Hardness difference between the weak layer and bed surface is 1 or more steps
- Weak layer is a persistent grain type
- Difference in grain size between slab and weak layer is 1mm or more

Based on those studies, we place low danger with one to two structural weaknesses, moderate danger with three structural weaknesses, and high danger with four or more structural weaknesses.

5. DECISION-MAKING

The Stability Wheel very easily lends itself to making terrain management decisions even for novices such as graduates of avalanche Level 1 courses. By using tests to determine the likelihoods of trigger, propagation, and slip, it removes the doubt at the very least in determining what the conditions are, leaving only the question of what to do about them. Since a slab avalanche requires all three components, it is often sufficient to mitigate one factor, but we teach to mitigate two or more to protect against human error and spatial variability.

1.1. Mitigating Trigger Likelihood

The first event which can be mitigated is the initiation of the mixed mode fracture. Techniques we teach to mitigate this are based on avoiding areas of stress that would facilitate the initiation of a mixed mode fracture. Practical examples include:

- Avoid shallow areas such as rocks and trees to avoid impacting deep weak layers
- Prevent loading the slope with more than one person
- Avoid slope convexities, and loaded areas

1.2. *Mitigating Propagation Likelihood*

The second event which can be mitigated is the propagation of the fracture. Unlike trigger or slip likelihood, this factor is more difficult to mitigate for prevention. Instead the primary mitigation taught is in managing consequences. Under high propagation likelihood conditions we teach to avoid slopes with significant consequences such as large alpine bowls.

1.3. *Mitigating Slip Likelihood*

Slip likelihood is the most important factor to mitigate. Slope angle is determined entirely by the traveler's choices, and as is well understood, slope angle plays a critical role in the release or arrest of slab avalanches. Didactically, this is the primary feature which is emphasized in selecting safe terrain during periods of avalanche instability.

1.4. *Philosophy*

The overarching philosophy of the Stability Wheel is to to understand the fracture mechanics of slab avalanches, and use that knowledge to mitigate the likelihoods of trigger, propagation, and slope through terrain selection.

6. CONCLUSION

The origins of the Stability Wheel trace back to the mid 2000s. The idea to use a circle to present principal factors in slab avalanche release originates from the presentation of stability as combination of strength, energy, and structure by McCammon and Sharaf (2005). Although the Stability Wheel continued to change and evolve, it was not until 2008 when the concept finally took the form presented here. The final changes were a direct result of combining the years of experience in education and guiding of Santiago Rodriguez with the Anti-Crack Theory presented at ISSW 2008 by Joachim Heierli and later published as a doctoral thesis.

The Stability Wheel has been used with great didactic success in the education of approximately 600-700 students in Avalanche Level 1, 2, and 3 courses. These courses were run in areas including Idaho, Oregon, California, Colorado, Nevada, Chile, Argentina, Hungary, and Austria by SnowProject, SnowGeek, the National Ski Patrol, and/or Silverton Avalanche School.

The Stability Wheel is a successful example of a greater education ideology: create tools that promote active, scientific observation of avalanche conditions which combined with an understanding of underlying science helps students to make informed and intuitive decisions.

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