Vegdirektoratet
Vegavdelingen
Geoteknikk og skred
29.08.2018

Statens vegvesen

Stavbrekkfonna glideskred

Evaluering etter tre år med målinger

STATENS VEGVESENS RAPPORTER Nr. 537

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Tittel
Stavbrekkfonna glideskred

Undertittel
Evaluation after three yeasr of monitoring

Forfatter
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Avdeling
Vegavdelingen

Seksjon
Geoteknikk og skred

Prosjektnummer

Rapportnummer
Nr. 537

Prosjektleder
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Emneord
våtsnø, glideskred, skreddeteksjon, instrumentering

Sammendrag
For å forstå den tilsynelatende uforutsigbare mekanismen i glidende snø, og for å redusere risikoen for vedlikeholdspersonell og trafikanter ved fv.63 i Breidalen i Skjåk, har vi overvåket glideskredet Stavbrekkfonna i flere vintersesonger. Vi har brukt glidesko i kontaktflaten mellom snødekke og det glatte berget under, bakkebasert InSAR-radar, timelapse fotografering og måling av snødekketemperaturer. Glideskomålinger viste seg å være et godt verktøy for å dokumentere den faktiske glidningen i et gitt punkt før skredene. Temperaturmålingene fungerer som en indikator for når skredet ventes å være nært forestående. InSAR-teknologien synes å være det mest praktiske verktøyet for en kontinuerlig vurdering av skredfaren og et varslingssystem i nær-sanntid. Foreslåtte terskelverdier innebærer at situasjonen bør følges nøye så snart hastigheten overstiger 5 cm /t. Tiltak bør iverksettes senest når hastigheten overstiger 15 cm/t.

Antall sider 8

Dato 29.8.2018

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Subtitle
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Project number

Report number
No. 537

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Key words
wet snow, glide avalanche, monitoring, instrumentation

Summary
To understand the apparently unpredictable behavior of gliding snow and to reduce the risk for maintenance staff and road users at county road 63 in Breidalen in Skjåk, we have monitored the Stavbrekka glide avalanche for several winter seasons. We have used glide shoes in the interface between the snow base and the smooth rock below, groundbased InSAR radar, timelapse photography and snow temperature measurement. Glide shoes proved to be a good tool to document the actual glide at a given point before the avalanche. Temperature measurements act as an indicator for when the avalanche is expected to be imminent. InSAR technology seems to be the most useful tool for continuous hazard assessment and a near real-time alert system. Proposed threshold values suggest that the situation should be followed carefully as soon as the velocity exceeds 5 cm/h. Action should be taken at the latest when the speed exceeds 15 cm/h.

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THE STAVBREKKA GLIDE AVALANCHE IN NORWAY – EVALUATION AFTER THREE YEARS OF MONITORING

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ABSTRACT: The Stavbrekka glide avalanche path, situated in the southern Norway mountain range, gives every spring a challenge to the seasonal opening of the tourist road between Geiranger and Strynefjellet. In order to understand the seemingly unpredictable behavior of the gliding snow and to reduce the risk for maintenance personnel and road users, the glide avalanche has been monitored for several winter seasons. The methods used have been glide shoes at the gliding base, ground based InSAR radar, time-lapse photography and snow pack temperature measurements. Last winter, the temperatures 75 cm into the ground were also logged. The measurements have given valuable insight into hazard evaluation. Threshold values for snow gliding are established based on the last three years of monitoring. Glide shoe measurements proved to be a good tool for documenting the actual glide velocities prior to the avalanche releases. The temperature measurements work well as an indicator for when the avalanche is expected to be imminent. Lastly, the InSAR technology seems to be the most convenient tool for a continuous evaluation of the avalanche hazard and a near real-time alert system. Suggested threshold values could implicate that situations should be followed carefully as soon as the velocity exceeds 5 cm/h. Action should be taken at latest when the velocity exceeds 15 cm/h.

KEYWORDS: wet snow, glide avalanche, monitoring, instrumentation

1. INTRODUCTION

The Stavbrekka avalanche path, which is a challenge to the national tourist road between Breidalen and Geiranger in Norway (County Road 63), could be classified as a *glide avalanche* according to previous publications (e.g. Mitterer and Schweizer, 2012, Höller, 2013).

The release area consists of a 150 m wide, 200 m long, 26-40° steep and fairly smooth and planar rock surface. In the spring, usually in mid-March, a glide crack appears at the upper boundary of the slab, at 1300 m a.s.l. This is the first visual prove that the glide has begun. If the conditions are favorable, the slab continues to glide on the rock surface and forms a compression zone further downslope. Because of an obstacle in the middle of the rock plane, the slab splits into two lobes in the lower part. Normally, after 1-8 weeks of gliding, the avalanches take place. Usually, two separate avalanches take place within a short time span, one from each lobe. Whether it is the eastern or western lobe that slide first, varies from year to year.

The location of the release area above the road is shown in Figure 1.

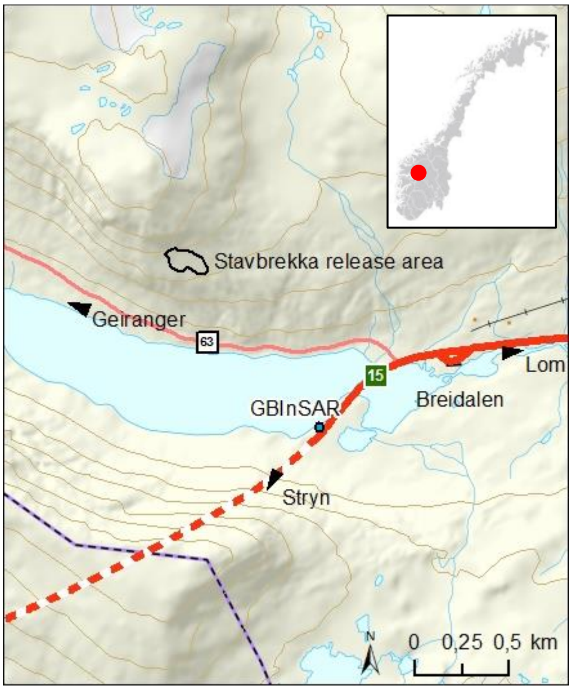

Figure 1: The Stavbrekka avalanche path is located above County Road 63 between Geiranger, Lom and Stryn in Norway.

2. FIELD MEASUREMENTS

A "glide shoe", as a method for measuring snow glide at the base of the snow pack, was first introduced by in der Gand and Zupančič (1966) and later modified by Clarke and McClung (1999) and Ceaglio et al. (2012).

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For Stavbrekka, the chosen design is previously described by Humstad et al. (2016). The original design of three glide shoes and real-time GSM transmission was from 2015/2016 reduced to *two* glide shoes and *no* transmission after operational challenges. As shown in Figure 2, the upper glide shoe (no. 1) is placed below the center of the eastern lobe, and the lower (no. 2) is close to the compression zone in front of the eastern lobe. Data loggers located in fixed steel boxes with potentiometers have draw wires connected to each glide shoe. There are no glide shoes under the western lobe.

In addition, a ground based InSAR radar (located as shown in Figure 1) provided the project with real-time monitoring (Skrede et al., 2016). The glide shoe data was then only used as a verification of other measurements, rather than an independent and operative monitoring system.

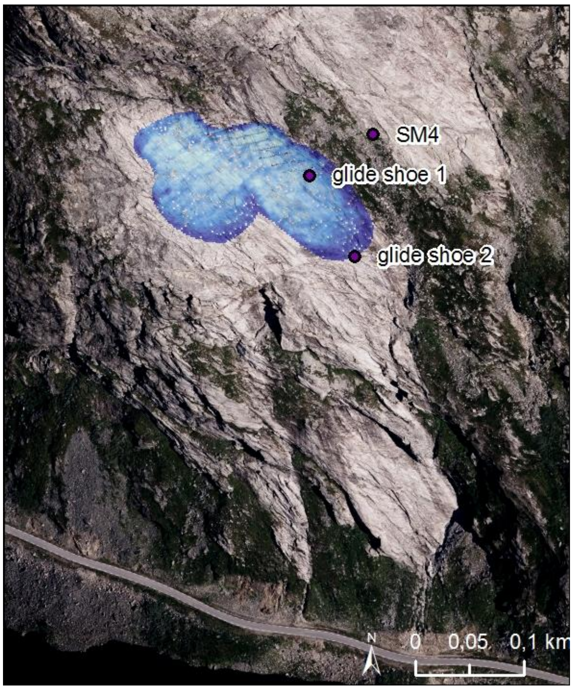

Figure 2: The field set-up around the Stavbrekka glide avalanche path shown on an aerial photo. The road is below. The blue shades correspond to areas with gliding snow in 2016. The upper limit correspond to the glide crack location, the lower limit correspond to the compression zone.

A sensor of the "SM4" type is located approx. 100 m east of the eastern lobe (see Figure 2). It consists of a series of digital thermistors mounted with a fixed distance of 20 cm on a vertical pole. This sensor was used to log the temperatures in air and snow. Measurements from the thermistors were logged with 10 minutes interval and saved to an internal memory and transferred to a central computer with GSM, according to descriptions presented by Ingólfsson et al. (2012).

Glide avalanches may occur both in warm and cold snow packs. The former is caused by melting of snow from the surface and down. The latter is believed to be caused by melting from the ground and up through the snow base. This may occur in certain cases, even though the snow surface may be cold (Clarke and McClung, 1999). So far, only warm glide is observed in Stavbrekka. However, to evaluate the possibility of a cold glide, the SM4 was modified in 2017/2018 to measure temperatures both in the ground, snow and air. Four thermistors were places into a narrow borehole in the rock, in addition to the 22 thermistors above the ground (measuring temperatures in snow or air, depending on the actual snow depth).

3. DATA FROM GLIDE SHOES

In 2016 the velocity reached maximum 47.5 cm/h at the upper glide shoe before the draw wire broke less than ten minutes before the avalanche took place on May 7 (see data in Figure 3). In 2018, the velocity at the upper glide shoe reached 20.5 cm/h before the draw wire broke less than 30 minutes before the avalanche took place in April 20.

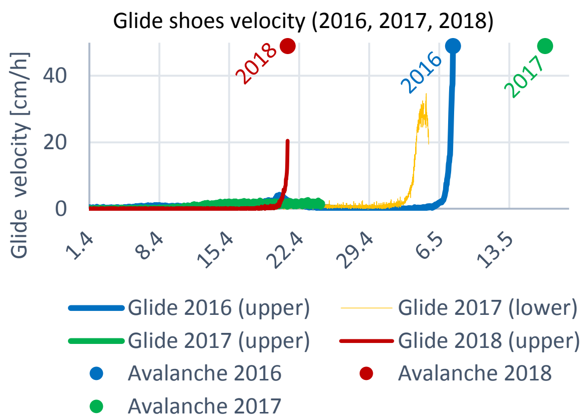

Figure 3: Monitored velocities at the upper (2016, 2017, 2018) and lower (2017) glide shoes combined with dates for the avalanches in the eastern slab.

In 2017 both glide shoes failed long before the avalanche. The data series from the upper glide shoe failed as much as three weeks before the avalanche took place in May 16. In addition, the lower glide shoe failed two weeks before the avalanche. When the data series stopped, the upper and the lower glide shoe had reached 2 cm/h and 35 cm/h respectively without any avalanche. Note that the spring of 2017 was a special one with much longer glide displacement than the normal situation. Actually, for both 2016 and 2018, the lower glide shoe had no movement at all, as it was believed to be located below the compression zone of the slab.

Hence, in order to define certain threshold values, the data from the upper glide shoe seems most reliable. However, the varying velocities between the glide shoes and previous InSAR measurements at several spots on the slab (Humstad et al., 2016, Skrede et al., 2016), suggest that different spots on the slab needs different threshold values.

4. TEMPERATURE STUDIES

A study of the ground temperatures in 2018 documents, as expected, that the temperature increases with increasing depth. The ground was frozen down to approx. 50 cm depth in the coldest period in the beginning of April. As the ground was frozen at 15 cm depth also when the snow got isothermal, the ground did apparently not contribute to the melting. Consequently, the glide that started in mid-April, and the subsequent avalanche on April 20, must be regarded as a warm event caused by melting solely from the surface.

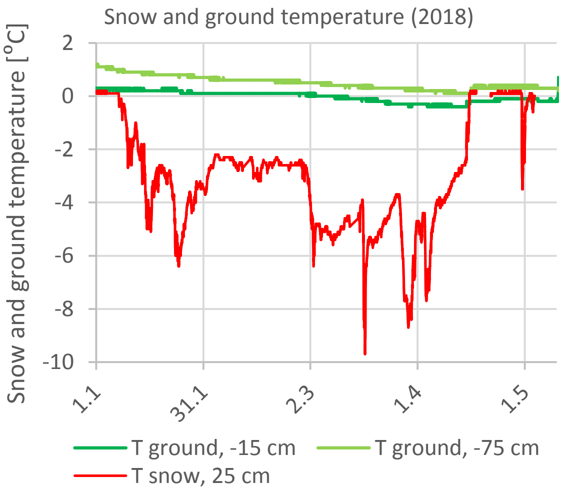

Figure 4: Temperatures at two depths in the ground and one height in the snow pack in 2018

Some temperature measurements in air and snow pack from 2016 and 2018 are presented in Figure 5 and Figure 6. The snow height of 120-125 cm (blue line) is chosen because this is about in the middle of the snow pack where the snow is assumed to be at its coldest state before it gets isothermal (i.e. wet throughout the snow pack). When this height remains at 0 °C, we have a practical indication that the snow is isothermal.

In order to relate the temperatures to the glide behavior of the snow slabs, we have added the corresponding glide shoe velocity for both plots.

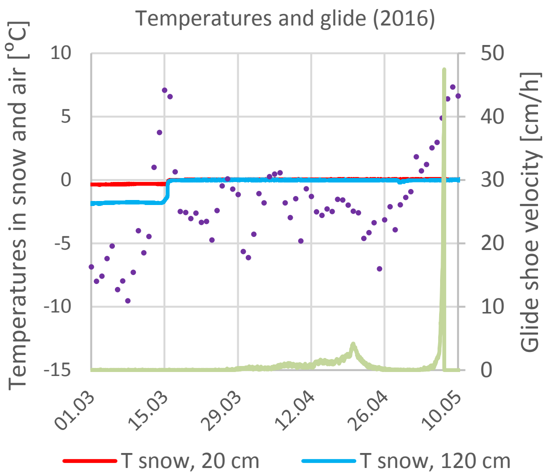

Figure 5: Temperatures from SM4 sensors and glide velocity from upper glide shoe in 2016

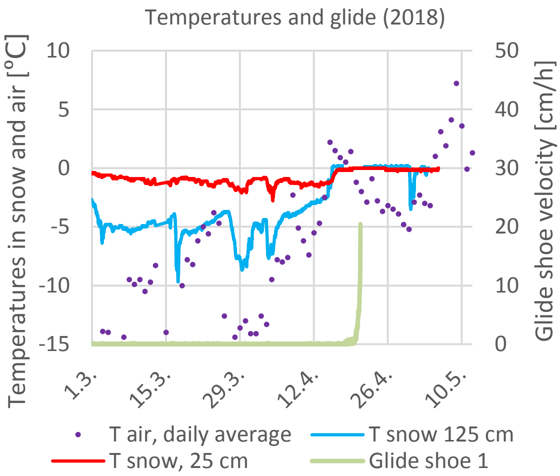

Figure 6: Temperatures from SM4 sensors and glide velocity from upper glide shoe in 2018

The data show that the snow pack was warmer before wetting in 2016 (compared to 2018) because the temperature difference between the lower (20 cm) and the upper (120 cm) thermistor was less in 2016 until all snow was wet. Also, the air temperature dropped quickly and remained low for several weeks after wetting in 2016. As much as 7-8 weeks were needed in order to accelerate the snow pack (see Figure 5). But when the air temperature exceeded 0 °C both night and day, the avalanche took place in just a few days.

In 2018, the snow pack was much colder the last period before the snow pack got isothermal. But as the air temperatures remained high also the first days after complete wetting, the glide accelerated much quicker, and the avalanche took place just a few days after the snow got isothermal (Figure 6).

5. OTHER RESULTS

In addition to the methods described in this paper, also other methods have been used in Stavbrekka. For instance, Venås (2015) tracked pixels on time-lapse photos of wooden sticks placed on top of the gliding snow pack. The same process was repeated and presented together with glide shoe data from 2016 by Humstad et al. (2016). These analyses showed good correspondence of glide behaviour based on how it was seen from above (on images) with how it was measured from below (by glide shoes).

Ground based InSAR radar used in 2016 gave velocities of 40-60 cm/h at different spots on the slab prior to the avalanche. The InSAR radar measured the same deformation as the glide shoe 1 on the same coordinates. Higher deformation was found further up on the slab, and lower deformation further down (Skrede et al., 2016, Humstad et al., 2016). Ground based InSAR was also used in 2018, but the results are yet not analysed.

6. SUGGESTED THRESHOLD VALUES

Data from the glide shoes are difficult to use for real-time monitoring as long as the logging unit is buried below 2-4 m of dense, wet and moving snow. Such conditions apply strain on cables and other equipment that may be put under the snow, and wireless transmission through snow is challenging. Data from glide shoes have, however, proved to be fairly realistic and reliable and well suitable for post-avalanche analysis. They therefore serve as a good basis for setting threshold values for other systems located above the snow, from which near real-time data transmission is much easier.

The crucial prediction to make, is when the avalanche is likely to occur. Although the exact prediction is obviously impossible, different precautions could be made whether you have indications if the avalanche is likely to occur in *a few weeks*, *a few days*, *a few hours* or at *any moment*. If we use the glide velocity from 2016 and 2018 together with the exact timing of the avalanches (at May 7 at UTC 09:10 in 2016 and April 20 at UTC 20:30 in 2018), we could illustrate a "countdown", in retrospect, to when the avalanches took place. This is done in Figure 7.

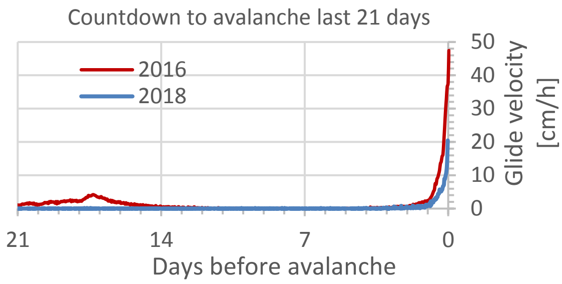

Figure 7: Glide velocity at glide shoe 1 the last 21 days, in retrospect, prior to the avalanches in 2016 and 2018

Figure 7 shows that a small peak of 3.5 cm/h occurred 17 days before the avalanche in 2016. This didn't lead to any avalanche, probably because the air temperature fell considerably after the peak (see Figure 5). Still, peaks like this should lead to some increased awareness, as a precaution.

If we combine velocity data with experience from road operation and necessary preparation time for taking action, we could suggest some threshold values and indicators as shown in Tbl. 1 and Figure 8.

Tbl. 1: Suggested glide threshold values

Alert level	Approach to avalanche probability	Glide [cm/h]	Other indicators
-	Stable	0	No visual indication
0	In a few weeks	> 0	Glide crack appears, and snow is getting isothermal
1	In a few days	> 0.5	Isothermal snow. Air temperature exceeds 0 °C both day and night.
2	In a few hours	> 5	
3	Any moment	> 15	

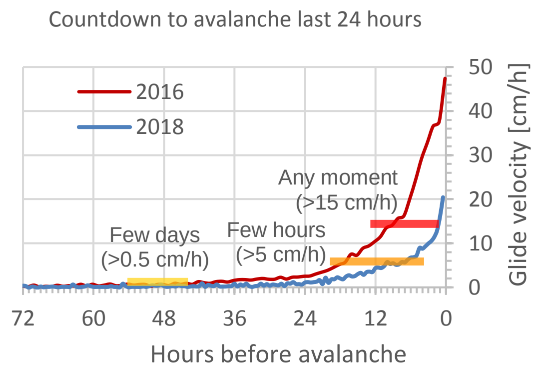

Figure 8: Suggested threshold values (from tbl. 1).

7. DISCUSSION

Threshold values suggested in this paper are based on the velocity measured in the center of the eastern lobe. Velocities could be different at other points of the slab, and this has to be accounted for and adjusted carefully if future alert system is be implemented for other points. And velocity is, after all, measured under few events, and only two seasons gave useful information. More experience in the years to come could lead to adjusted threshold values. Moreover, glide velocity [cm/h] is only *one* parameter describing the glide dynamics. More studies could reveal if total glide [m] or acceleration [cm/h^2] could be additional, and even more useful, parameters. This should be evaluated in the future.

The suggested indicators are based on behavior under warm conditions (surface melting). In the more unlikely event of glide under cold conditions (base melting), the behavior would be different and the temperature indicators would not be valid.

Temperature measurements are done outside the slab. Temperature conditions and also snow depth inside the slab could be a bit different. In addition, the SM4 sensors are mainly made to measure temperatures buried in the snow pack. Sensors recording temperatures in free air are not fully shaded and ventilated, and they could be affected by solar radiation. This, however, compensates to some extent for the effect of solar radiation (and melting) of the snow surface at the same time, which is not possible to derive only from standardized air temperature measurements.

It is also important to notice that glide avalanches in one location could be very different from other locations. The Stavbrekka glide avalanche, for instance, has a much slower deformation than the average glide avalanche in steeper terrain (e.g. Feick et al.,2012). One should therefore be careful when transferring knowledge from one path to another.

8. CONCLUSION

Useful information of the glide behaviour over the last three years are found. Although more experience is needed, threshold values based on glide velocity and indicators based on temperatures and visual observations could be used to design an alert system. Such a system should be improved continuously for future data and experience.

In a real-time alert system, the measurements and data logging should be done from *above* the snow surface and account for spatially variations on the slab. Comparison with glide shoe velocity in a single point *below* the snow will ensure more reliability.

As future work, the undocumented InSAR data collected in 2018 should be analysed and compared with the 2018 glide shoe data.

The users of any alert system based on the concept described in this paper, should be aware of the limitations that are pointed out.

ACKNOWLEDGEMENTS

Thanks to the staff at POLS Engineering and Cautus Geo AS for good data collection and the Norwegian Water Resources and Energy Directorate for providing additional InSAR data. Thanks to the NIFS Natural Hazard programme (2012-2016) for initiating the test and for the Norwegian Public Roads Administration for financing the test over the last three years.

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Postboks 6706 Etterstad 0609 OSLO
Tlf: (+47) 22073000
publvd@vegvesen.no

ISSN: 1893-1162

vegvesen.no

Trygt fram sammen