AVALANCHE CONTROL ON NORWEGIAN HIGHWAYS INTERNATIONAL SNOW SCIENCE WORKSHOP 2023, BEND, OREGON

Tveit, Jens[1]*, Farestveit, Njål[1]

[1] *Norwegian Public Roads Administration (NPRA), Norway*

ABSTRACT: A lot have happened on avalanche control in Norway since we started to test new methods in 2010. Before 2010 the methods for avalanche control were limited to ropeways, hand charges and pre-prepared charges in the terrain. After testing both Daisybell and Wyssen avalanche tower in 2010-2012 modern systems of Remote Avalanche Control Systems (RACS) have been installed in several sites. The Norwegian Public Roads Administration (NPRA) now have experience with operational use of Daisybell, the Wyssen Avalanche tower, Gazex and O'BellX+ Double Power. This in addition to the traditional methods used for several decades. When there are several systems and methods on the market, better knowledge about the efficiency and differences of the systems are required. In November 2021 the NPRA arranged a full scale, flat field test on bare ground. The tests were carried out on one of the shooting ranges of the Norwegian army with help from explosive experts from the demolition company AF Decom. The outline for the test was to test the shock pressure from the systems and document this with pressure sensor microphones and high-speed cameras. To carry out the tests we mounted the O'BellX+ Double Power with the normal tower and made a separate tower for the explosive charges. Different types of explosives were tested out, including the new Wyssen 2K charge. The gas based O'BellX+ Double Power and Daisybell was also tested. Several avalanche sites in Norway are well suited for avalanche control. The NPRA have launched a new program for establishing active mitigation measures that includes both avalanche control and real time avalanche warning systems. In the coming years there are plans to use active mitigation methods on many avalanche sites both on county roads and highways in Norway.

KEYWORDS: Avalanche control, Avalanche mitigation, Norwegian Public Roads Administration, Norway.

1. INTRODUCTION

Norway has many roads in avalanche prone terrain. Several of these roads are in remote areas and many of them have low daily traffic. Nevertheless, these roads are important for the local communities since detours are long or not possible at all. Avalanche control have been used for decades and are important for the regularity of many avalanche prone roads. In 2010 the Norwegian Public Roads Administration (NPRA) started testing new and modern methods with the purpose of expanding the number of sites with avalanche control.

There are several different systems on the market as of 2023. To achieve better knowledge about the different systems and methods the NPRA arranged a test in the fall of 2021 where we tested systems in use in Norway today.

* *Corresponding author address:*
Jens Tveit, Statens vegvesen, Gol trafikkstasjon
Hahaugvegen 39, N-3550 Gol;
tel: +47 970 13 790; tel: +47 576 55 949
email: jens.tveit@vegvesen.no

2. IMPLEMENTATION OF NEW METHODS

Up until 2010 methods use for avalanche control on Norwegian roads was pre-prepared charges, hand charges in the field and ropeways carrying explosives to site. Because of the strict policy on explosives in Norway hand charges from helicopter and artillery are not allowed to use for avalanche control.

In the seasons 2010-2012 the NPRA tested the Wyssen avalanche tower on county road Fv53 Tyin-Årdal. The test was carried out with one single tower over two winters. Results from this test is described by Farestveit and Skutlaberg (2012). That was the start of implementation of new methods (Kristensen et. al. 2020).

2.1 Status in Norway

As of 2023 several sites are mitigated with modern Remote Avalanche Control Systems (RACS):

- Fv883 Skillefjord: 2x Gazex (2014)
- Fv53 Tyin - Årdal: 14x Wyssen towers (2016)
- Ev134 Haukelifjell: 3x Wyssen avalanche towers (2020/2022)

- Rv7 Leiro, Hardangervidda: 1x O`BellX+ (2022)
- Fv7768 Grøtfjord: 10x Wyssen avalanche towers (2022)

In addition to the permanent RACS installations there are a total of 6 DaisyBell for use by the road authorities in Norway based in Alta, Tromsø, Arnøya, Lofoten (Leknes), Leikanger and Bergen.

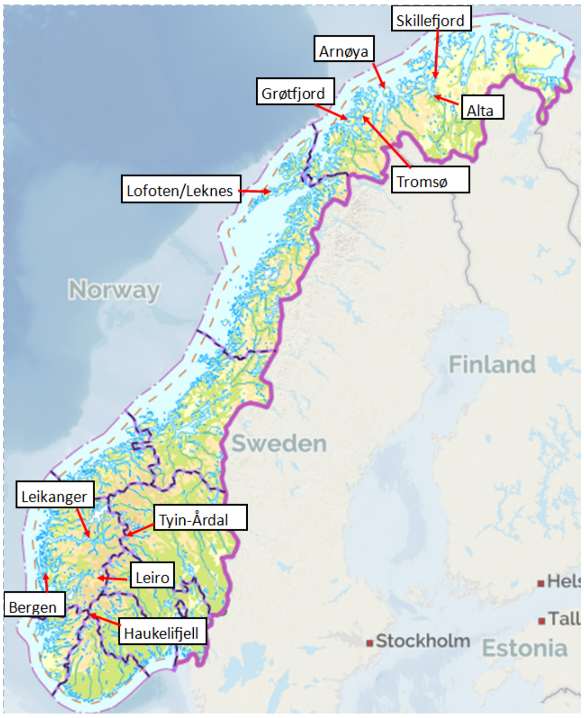

Figure 1 - Map over location for modern RACS and DaisyBell bases.

2.2 Future plans

Since avalanche control has proven to be a cost-effective measure for avalanche mitigation there are plans to expand the number of installations in the coming years. The NPRA have started an internal project to look at all the known avalanche prone roads to decide if it is well suited for avalanche mitigation by active methods such as real-time warning systems or avalanche control. The project was initiated in 2022.

3. TESTING OF DIFFERENT SYSTEMS

The systems in use today use different methods for triggering avalanches. There are several types of explosives in use in addition to gas mixtures. Tests comparing gas and solid explosives have been carried out earlier, described by for example Simioni and Schweizer (2018) and Seitz (2021). It is not known that the new O`BellX+ and the Wyssen 2K are tested at the same site before.

To expand the knowledge on the different systems, the NPRA arranged a test in the fall of 2021. The test was carried out in cooperation with explosive experts from the demolition company AF Decom.

3.1 Test site and instrumentation

The test was carried out on the Rena shooting range of the Norwegian army in the start of November 2021. To ensure the exact same conditions for all measurements the test was on bare ground in a flat field.

The test site was equipped with a tower to place the explosives on a rope. The O`BellX+ tower was mounted as on a real avalanche site. The DaisyBell was operated from a crane on a truck. The height over ground for all systems was approximately 4,5 meters except for some tests of Daisybell on 1 meter over the ground. Figures 2-6 shows an overview over the test setup.

Figure 2 - Temporal tower for testing explosives. Photo: N. Farestveit, NPRA

Figure 3 - O`BellX+ with tower. Photo: J Tveit, NPRA

Figure 4 - Testing of DaisyBell from a crane. Photo: J Tveit, NPRA

For measurements of the shock pressure air blast sensors of the type Sigicom infra S10 and S11. Air blast sensors was placed out on a line on the following locations:

- MP01: Vertical at -10 meters. S11
- MP02: Horizontal at 0 meters. S11
- MP03: Horizontal at 10 meters. S11
- MP04: Vertical at 19 meters. S10
- MP05: Horizontal at 20 meters. S10
- MP06: Horizontal at 30 meters. S10
- MP07: Horizontal at 40 meters. S10
- MP08: Horizontal at 50 meters. S10

All measurements were carried out in a straight axis from the detonation point.

Figure 5 - Sensors at 0 meters. Photo: N Farestveit, NPRA

Figure 6 - Overview over the test site. Shock pressure sensors shown with red arrows. Photo: AF Decom

3.2 <u>Tested systems</u>

The outline for the test was to get data from several systems and methods in use today. The following list describes the different tested systems:

- TNT: 1 kg, 1,7 kg, 5 kg and 10 kg.
- Dynamite: 5 kg.
- Wyssen 2K: Appr. 4,5 kg.
- Daisybell: Gas mixture of Hydrogen and Oxygen. 5 sec fill time.
- O'BellX+: Gas mixture of Hydrogen and Oxygen. 21 sec fill time.
- Emulsion explosive: 5 kg.

4. RESULTS

The compilation of results is shown in Table 1 and 2. Note that due to limitations with the air blast sensors the peak value is about 20 000 Pa. Values near 20 000 Pa are most likely higher.

Table 1 - Results from tests carried out. Table shows measurements in Pa in a given distance from the detonation point. (Values over 19 000Pa are most likeley higher due to limitations of the measuring devices). Table continues in table 2.*

19m Vertical	10m*	0m*	-10m Vertical	System
5980	8960	19600	7550	ObellX+ (Gas)
3820	3870	15900	2790	Daisybell (Gas)
6180	19700	19200	18900	TNT 5 kg
6200	19300	20200	19000	TNT 10 kg
6282	18500	19600	17400	Wyssen 2K appr 4,5 kg
6310	19400	19800	18000	Emultion 5 kg
6230	19300	19200	16500	Dynamite 5 kg
6280	14700	19300	9500	TNT 1 kg

Table 2 - Results from the tests continued from table 1.

50m	40m	30m	20m	System
1470	1930	2680	4350	ObellX+ (Gas)
682	930	1180	1910	Daisybell (Gas)
3630	4970	6300	8220	TNT 5 kg
5200	5650	6460	8220	TNT 10 kg
2990	4090	5640	8260	Wyssen 2K appr 4,5 kg
3110	4380	5890	8300	Emultion 5 kg
3590	4730	6050	8420	Dynamite 5 kg
2140	3010	4080	6550	TNT 1 kg

5. DISCUSSION

As shown in table 1 and 2 there are differences in the shock pressure from the different systems, and for the different amounts of explosives. The sensors do not read values more than 20 000 Pa. For an optional new test, it should be considered usage of sensors that record higher values. Nevertheless 20 000 Pa is a high value, and it is considered of limited interest to record values higher than that.

For every ten meters there are horizontal measurements of shock pressure, and in two locations there are vertical measurements of shock pressure; wall mounted at -10 meters and vertical mounted at +19 meters.

These tests show the distribution of shock pressure along one axis from the detonation point in a horizontal plane. In a real avalanche starting zone the distribution of force will be different. The 360-degree angle of impact on explosives will provide more energy to the areas behind the installation in steep terrain. The more directed explosion of the O`BellX will probably provide more energy downhill than recorded on a flat field.

5.1 Explosives

All the explosives were detonated from a rope on the temporal tower. These charges have a 360-degree line of sight. The results show that the higher quantity of explosives, the higher the air pressure becomes (Table 1 and 2). The Wyssen 2K charge, 5 kg dynamite and 5 kg TNT all have air pressures at between 8200 Pa-8420 Pa at 20 meters from the detonation point (figures 7-9). While the time the high air pressure is kept up are a bit longer on dynamite compared to the Wyssen 2K, it is significantly longer on TNT.

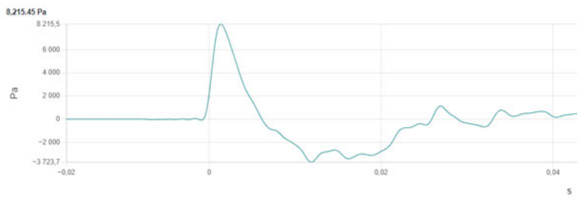

Figure 7 - Shock pressure wave from the Wyssen 2K charge at 20 meters from detonation point. Peak at 8215 Pa.

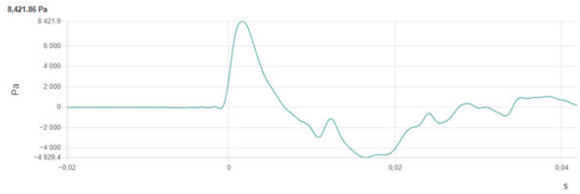

Figure 8 - Shock pressure wave from 5kg dynamite charge at 20 meters from detonation point. Peak at 8421 Pa

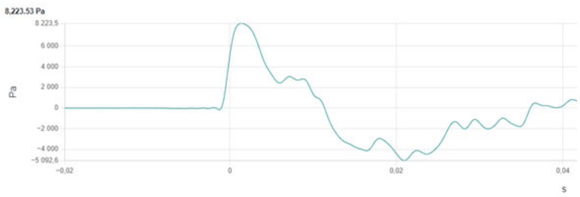

Figure 9 - Shock pressure wave from 5kg TNT charge at 20 meters from detonation point. Peak at 8223 Pa

5.2 Gas Mixtures

The DaisyBell are designed to be operated underneath a helicopter. The detonation is straight down, but the records show that some force is applied sideways as well. However, at approximately 40 meters from the detonation point the air pressure is slightly under 1000 Pa. The O`BellX+ is inclined slight forward so that the explosion is directed with most force along the axis of the device. Tests with an experimental Gazex (Simioni et.al. 2016) show that there is no lateral decay of the impact within an opening angle of approx. 70 degrees. The decline of air pressure in the different horizontal axis was not measured in our study but is a point of interest for further work.

The gas-based systems have a similar wave form as the explosives with a sharp increase of air pressure followed by a drop and a longer phase with underpressure (figures 10-11). The time with high air pressure is slightly lower than for the Wyssen 2K and dynamite.

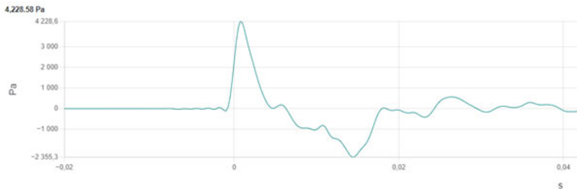

Figure 10 - Shock pressure wave from a standard 21 second filling O`BellX+ at 20 meters from detonation point. Peak at 4228 Pa

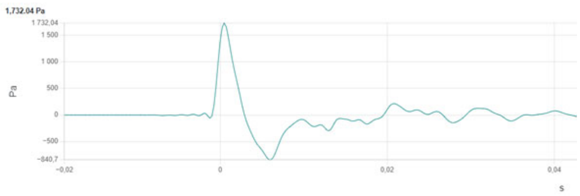

Figure 11 - Shock pressure wave from a standard 5 second filling DaisyBell at 20 meters from detonation point. Peak at 1732 Pa

6. CONCLUSIONS AND FURTHER WORK

All the systems show a shock pressure similar to or above 1000 Pa about 40 meters from the detonation point. The DaisyBell gives high values directly underneath the point of detonation, but the shock pressure falls significantly even with short distances. Therefore, it is important to use multiple shots in a potential avalanche starting zone to hit the right spot.

The O`BellX+ show lower shock pressure values than explosives at distances, but at the point of detonation the sensor peaks and that gives a shock pressure of ≥ 20 000 Pa.

The wave form is about similar on the gas-based systems and explosives, however TNT keeps up the shock pressure for a longer time than the other systems.

6.1 Further work

Points of interest for further work are to examine the effect of different horizontal angles. The gas-based systems have a directed explosion, and it is of interest to see how the shock pressure varies with both distance and angle.

Further it is of interest to perform the test in cold weather with snow on the surface. The temperatures should be like in a real event for avalanche triggering in Norway, between -15 to -20 degrees Celsius (5 to -4 degrees F).

There will also be of interest to implement a test on a slope inclined as a starting zone for avalanches.

ACKNOWLEDGEMENT

Thanks to the Norwegian Army for supplying the test site, to Jarle Bøckman at AF Decom for the execution of the test and Bengt Ole Norman and Sindre Linstad formerly at Visinor for supplying the tower and fundaments for the test site.

REFERENCES

Farestveit, N., Skutlaberg, S.: The results from two years of testing the Wyssen Avalanche Tower in Norway, in: Proceedings of the International Snow Science Workshop, Achorage, Alaska, 2012, 657-661, 2012.

Kristensen, L. et.al.: Preventive snow avalanche release: Summarizing report, Statens vegvesens rapporter nr 623. 2020. Only in Norwegian

Seitz, B. K.: Measuring Explosive Airblast of Remote Avalanche Control Systems, Master thesis Montana State University, Bozeman, Montana, 2021.

Simioni S., Schweizer, J.: Comparing two methods of artificial avalanche triggering: Gas vs. solid explosives, in: Proceedings of the International Snow Science Workshop, Innsbruck, Austria, 2018, 158-161, 2018.

Simioni S. et.al.: Artificial avalanche release: Flat field experiments using a gas exploder, in: Proceedings of the International Snow Science Workshop, Breckenridge, Colorado, 2016, 405-409, 201