EVALUATION OF MEASURES FOR THE SNOW AVALANCHE PROTECTION OF ROADS

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1. Abstract

An evaluation of protection measures at 161 avalanche road sites has been carried out. The evaluation of the 99 sites protected by snow sheds and earthworks is presented. The evaluation is based on interviews, field trips and recorded road closures before and after the protection was installed. Experience shows that the efficiency of the snow sheds is lower than required. Their low efficiency is mainly a result of the sheds being too short, poor adjustment of the sheds to the terrain and of open areas in front of the sheds. In most cases, the efficiency of earthworks is greater than 70 %. The earthworks are most effective in cases of moist and wet snow avalanches, less so for dry snow and slush avalanches

2. Introduction

The last 25 years has been an active period for avalanche protection of the Norwegian road network. The most severe types are snow and slush avalanches and rockfalls. To a lesser extent, roads have also been protected against debris flows and sediment transport in rivers.

Traditionally, the main protective measures have comprised the building of tunnels or snow sheds made of concrete. During the last two decades several alternative measures have been employed, including bridges, earthworks, supporting structures, avalanche detection and blasting techniques. The latter measures are generally less expensive and are only realistic alternatives for specific types of avalanches and types of terrain.

Last year a comprehensive study was carried out to evaluate the efficiency of the constructed measures. The main purpose of the study was to collate experiences of the different types of protection in order to improve the design of avalanche protection of Norwegian roads exposed to avalanches in future.

3. Type of protective measures investigated

The present investigation is based on interviews with local maintenance crews and supervisors, field trips to the areas in question and recorded avalanche activity both before and after the installation of the protective measures. The accuracy of the recordings varies, but it is assumed that the combination of recordings and interviews will provide the necessary accuracy to use the results statistically.

The following types of proactive measures have been evaluated:

Type	*No.*	*Description and use*
Snow sheds	62	All types of avalanches and terrain
Earthworks	37	Diverting and collecting earth dams. Earth mounds. Gentle terrain and small and medium-size avalanches
Culvert- type sheds	5	Gentle terrain and all type of avalanches
Wide road ditches	3	Small avalanches only
Supporting structures	13	Comprising nets and mainly for falling rock. Have been used for smaller snow avalanches.

Road bridges	4	Smaller and medium sized avalanches where roads cross ravines.
Relocation of roads	2	Mainly in gentle sloping terrain where the relocation may be limited in length
Blasting	5	Three types of blasting techniques, radio and cable-controlled detonation of pre-planted charges and use of cableways
Detection of avalanches	3	Avalanches are detected by geophones which switch on red lights at the roadside.
Tunnels	13	All types of avalanches
Rockfall nets	14	Protect against icefalls

The report deals exclusively with experiences of the two most extensively used types, snow sheds and earthworks.

3. Efficiency of the protective measures

3.1 Definition of efficiency

The construction of protective measures has two main purposes, to improve safety for road-users, and to reduce the time roads are closed.

Avalanche accidents fall into three groups:

Cars or pedestrians moving on the road are hit by an avalanche

Cars or pedestrians waiting for the road to be opened are hit by a new avalanche

Maintenance crew are hit by an avalanche during the opening of a road closed by a previous avalanche

Experience from Norway indicates that the proportion in each group is approx. 20, 40 and 40 % respectively. When protecting an avalanche-exposed road it is thus important to protect slopes which release snow several times during an avalanche or where the slopes are close to each other.

Similarly, a reduction in closure time is dependent on the road being protected against all avalanches which can occur during one and the same weather situation. Thus, if only two of three avalanche sites on one stretch of road are protected, this will only have a limited effect on the closure time. The best method for evaluating the efficiency of avalanche protection is to take into account both improved safety and the reduced closure time for a road section . Unfortunately, the accuracy of the recordings is too low for such efficiency to be defined. The only practical way to define the efficiency was to base the evaluation on the reduction in closures caused by the protection. The efficiency, E, is then defined as:

E=(1-((Number of closures after protection)/(Number of closures before protection)))100 [%]

3.2 Efficiency requirements

An important question when designing and evaluating protective measures is: “What is the required efficiency?” At present, there are no specific national guidelines to answer that question. The required efficiency may be stated in terms of the frequency of closures or the frequency of avalanches still closing the road following road protection

The accepted frequency of avalanches is usually dependent on the traffic volume and the importance of the road. In any case, 100 % safety from avalanches is too high a requirement. It would necessitate the adoption of too expensive solutions, leading to the protection never being built or leaving other sections with poor traffic safety unprotected.

In the present evaluation the definition of required efficiency varies with the cost of the protective measure. Costly measures like tunnels and snow sheds are usually permanent constructions and should thus have high efficiency. In our case an efficiency of 90 % has been chosen.

Earthworks are generally much less expensive than snow sheds. Generally, the cost per meter road protection is only 5-20 % of the cost of snow sheds. One may thus accept somewhat lower efficiency due to lower investment. On the other hand, road users are only interested in the number of closures, without regard to the protective measures used. The accepted efficiency should thus not be stipulated too low. The present evaluation is based on successful protection having an efficiency rate of 70 %.

4 Evaluation of the snow sheds

4.1 Evaluated snow sheds

The extensive use of snow sheds started in the 1960's, and the average age of the 60 evaluated snow sheds is 22 years. The sheds are mostly used on low-traffic roads, where average daily traffic varies between 75 and 2000. The cost of a two-lane snow shed today is approx. USD 12,000 per meter.

4.2 Recorded efficiency

Fig 1 shows that a high percentage of the sheds do not fulfil the requirements for successful design. Only 40 % have efficiency higher or equal to 90 %, and as many as 23 % have less than 70 % efficiency. This result is unsatisfactory and clearly indicates the need for more detailed studies to find systematic weaknesses in the way we design snow sheds.

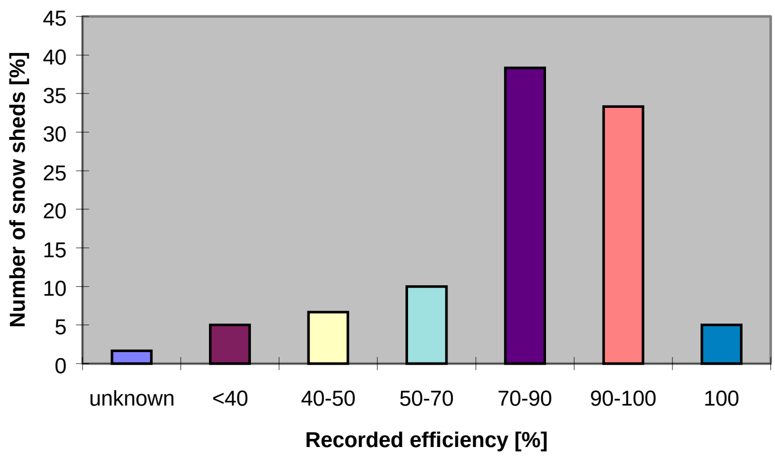

Figure 1. Recorded efficiency of the evaluated snow sheds

Efficiency is further analysed in relation to the following parameters (Figs. 2,3 and 4):
The length of the snow sheds.
Avalanche frequency.
The age of the construction.

Fig 2 clearly shows that the efficiency of snow sheds of less than 30 m in length is too low, approx. 50 %, compared with more than 80 % for longer sheds. Most of the low-efficiency snow sheds are thus found among the shortest sheds.

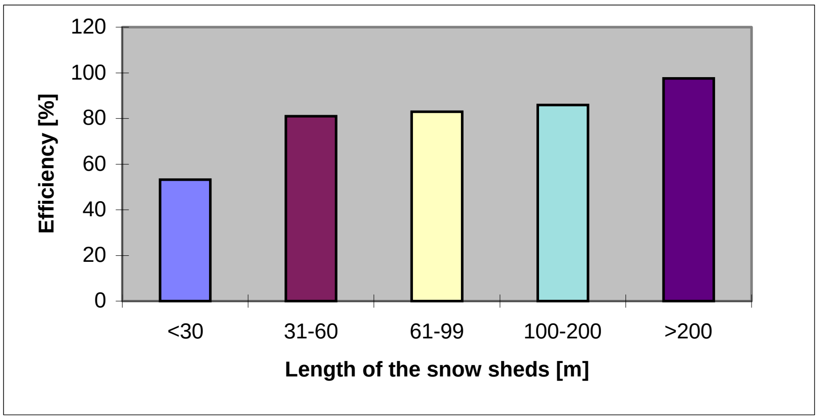

Figure 2. Efficiency in relation to length of the snow shed

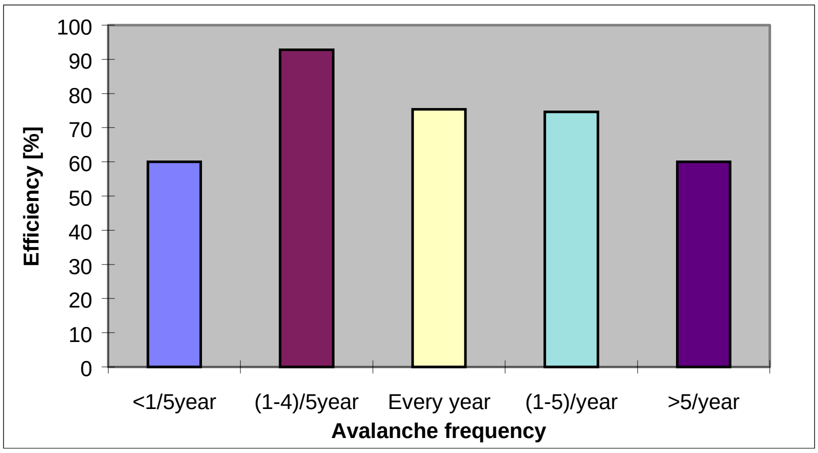

Figure 3. Efficiency in relation to avalanche frequency

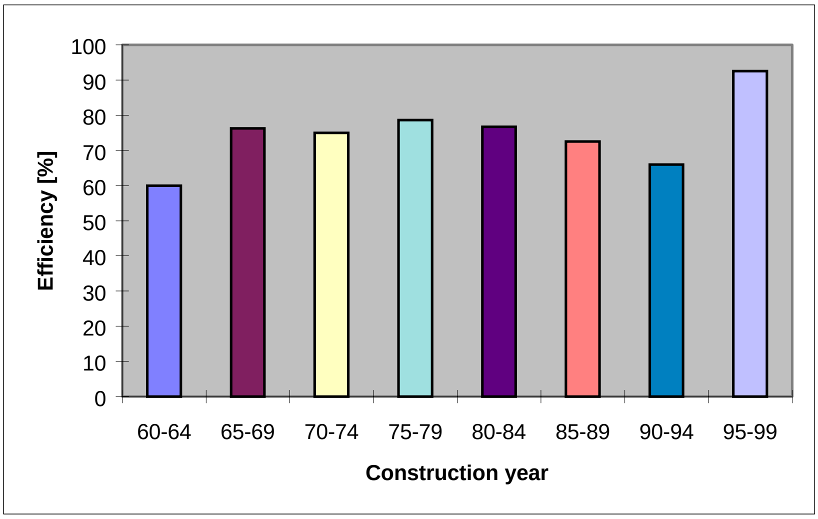

Figure 4. Efficiency in relation to construction year.

Low efficiency is also found for snow sheds protecting high-frequency avalanche sites , fig 3. The highest-frequency avalanche sites are usually found in distinct ravines with narrow and well-defined avalanche width. The results presented in figs 2 and 3 are thus correlated.

The need for carrying out evaluations is demonstrated in fig 4, showing that, since the 1960's, there has been no increase in efficiency over time. The low efficiency for the 90/94 snow sheds is the result of the building of short sheds on low-traffic roads during that period.

4.3 Evaluation of the results

The main reasons for the general low efficiency of snow sheds have been found to be:

The snow sheds are only designed for the most frequent types of avalanches. The less frequent ones then close the road at one or both ends. The reason why sheds are built too short is their high investment costs.

Poor adjustment between the terrain and the snow shed. In practice this means that deflecting earth dams and walls are lacking or are too low

A snow shed causes the avalanches to pass the road 6 m higher than before its construction. There will thus be a gently-sloping section on the roof where most avalanches are retarded and increased in width. This widening is not taken into account in the design of the sheds.

The short sheds in particular do not have enough storage capacity to handle more than one or two avalanches.

Snow sheds constructed with open pillars are often filled with snow entering from the open side.

The main conclusion is that snow sheds should be more than 30 m long at least. There should also be room for storing at least 2-3 avalanches on the roof. The terrain above the snow shed should be further channelled, combined with deflecting earth dams and walls.

Due to their low efficiency it has been necessary to rebuild 45 % of the snow sheds. The rebuilding has consisted of:

- Extensions.
- Reconstruction of earth dams and concrete walls.
- Building a dense wall on the open side
- Making drainage channels on the roof of the sheds to avoid clogged pipes underneath the sheds.

The rebuilding of the snow sheds has improved their efficiency by more than 20 % in 90 % of cases, and, in 50 % of cases, the efficiency of the reconstructed sheds has improved to 90 % or more. Generally, the rebuilding is regarded as having been successful.

5. Evaluation of the earthworks

5.1 Evaluated earthworks

The use of earthworks as a separate protection measure was first introduced in Norway in 1976. This protection included diverting earth dams, collecting earth dams and earth mounds. These measures are still the main types of earthworks used. Since then, earthworks have been used as the sole protective measure protecting several avalanche sites. This presentation is based on the evaluation of 37 different sites. The sites cover all regions of Norway and are found in different climatic conditions, varying from sea level to mountainous areas.

The average age of the protective measures is 12 years. The measures range from deflecting and collecting earth dams to earth mounds and magazines. The latter entail the excavation of wide ditches and may to a lesser extent be combined with collecting earth dams.

5.2 Recorded efficiency

The evaluation indicates that 75 % of the earthworks meet the criterion of 70 % efficiency, and more than 20 % have an efficiency rate of more than 90 % , fig 6.

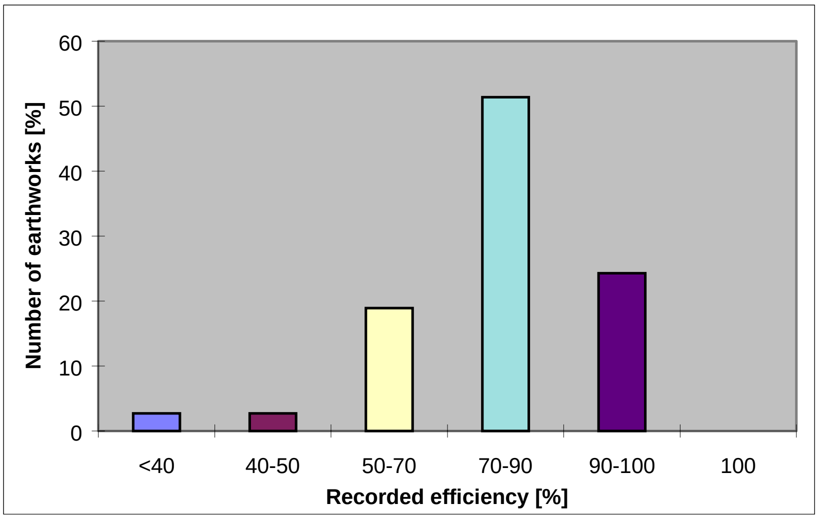

Figure 5. Recorded efficiency of the evaluated earthworks

Considering the low investments and the limited experience period, we regard this result as fairly satisfactory.

Efficiency was investigated in relation to the following parameters:
Figure 6. Efficiency in relation to avalanche frequency.
Figure 7. Efficiency in relation to the investment

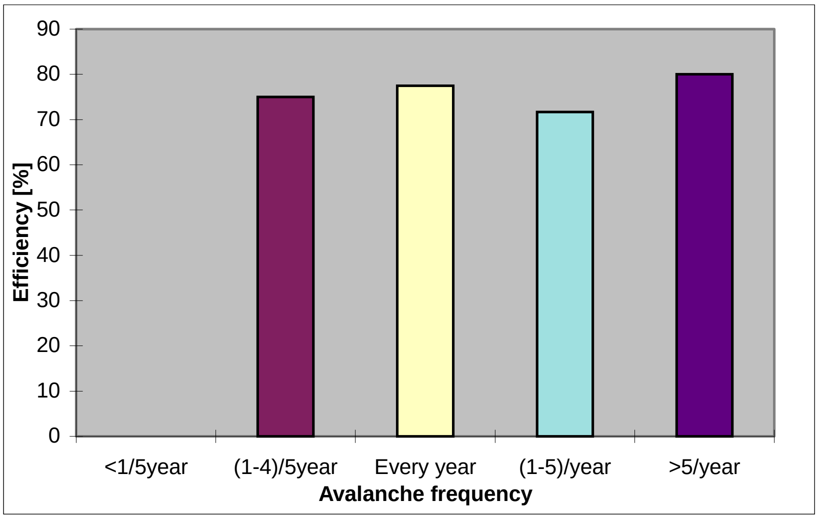

Figure 6. Efficiency in relation to avalanche frequency.

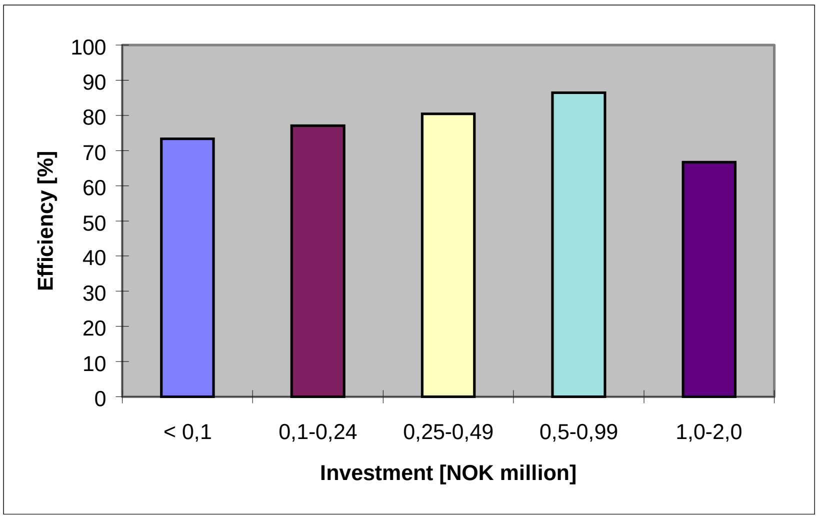

Figure 7. Efficiency in relation to the investment

Fig 6 shows that the average efficiency is more than 70 % within all frequency ranges, and it is not possible to find any trend in terms of efficiency in relation to frequency. One might, perhaps, expect somewhat lower efficiency for high frequencies due to the fact that several avalanches gradually reduce the storage capacity of the measures. The reason for the result of the investigation is probably that high-frequency sites are usually hit by small avalanches.

It is also hard to find any systematic trend in efficiency in relation to the cost of the measures. Fig 7 indicates lower efficiency for investments greater than NOK one million (USD 120,000). This is probably because very few sites were evaluated within this group, but may also indicate that earthworks should not be used to protect against large avalanches.

5.3 Evaluation of the results

Some systematic weaknesses in the evaluated earthworks were found, of which the most important are:

Earthworks are most effective in stopping densely flowing avalanches, which in practice means moist and wet avalanches. For one road section investigated in detail, 69 avalanches were surveyed. All these avalanches were big enough to close an unprotected road. They were classified into three groups and the recorded effects of the protection were:

Table 1. Efficiency of earthworks against different types of avalanche.

Type of Avalanche	Number	Road closures	Efficiency
Dry	23	6	74
Wet	39	2	95
Slush	7	3	57

The table shows that avalanches having some cohesion are most effectively stopped by earthworks, while non-cohesive avalanches consisting of dry snow or slush pass the earth dams and mounds more easily.

Earthworks built in mountainous terrain generally have low efficiency. The reason is that deep snow covers the earthworks and thus reduces their effect. Up in the mountains the percentage of dry snow avalanches is also generally high.

First generation earthworks in particular were generally too small to stop several avalanches a year. 22 % of the evaluated measures have been rebuilt and 90 % of them have improved their efficiency by more than 20 %.

6. General remarks

The main benefit of snow sheds is that they protect the roads against all kinds of avalanches and may be used in all kinds of terrain. In addition, sheds offer full protection to road-users when they are inside the sheds. Snow sheds have also proven to be highly durable. 40-year old sheds are still in good working condition.

There are, however, some disadvantages associated with the use of snow sheds. The main one is their high cost, which has too often resulted in building the sheds too short. Another disadvantage is reduced traffic safety at the entrances and inside the sheds. The light conditions at the entrances are sometimes extremely difficult, and in springtime the road inside the tunnels may be icy. In some cases it has been difficult to find a good design that meets both the requirement for proper road design and avalanche safety.

Recorded maintenance costs are limited. Some sheds have, however, been damaged by falling rocks and more powerful avalanches than expected.

Despite these disadvantages, snow sheds will continue to be important in the avalanche protection of roads in the future. However, the present way of designing the sheds needs to be adjusted. Short sheds should be avoided, and more attention should be paid to the adjustment of sheds to the terrain.

The empirical data regarding earthworks indicates that these have been fairly successful. Their relatively high efficiency combined with small investment costs should favour their use as protective structures in the future. In addition, earthworks have no negative effect on driving conditions and on traffic safety.

So far, few intensive maintenance difficulties with earthworks have been recorded. The main threat of damage comes from the eroding effects of slush avalanches. The effect of the earthworks may also be reduced in time due to sedimentation of debris in front of them.

The present evaluation will continue for at least one more year. The main emphasis will be on analysing the assembled empirical data to also cover other alternative measures and to go into more detail concerning snow sheds and earthworks. Thus, it is our hope that the evaluation will make it possible to improve our practice in the snow avalanche protection of roads in the future.