MITIGATION MEASURE HANDBOOK – A PRACTICAL HANDBOOK ABOUT REDUCING SNOW AVALANCHE HAZARD FOR BUILDINGS WITH AVALANCHE DEFENCE STRUCTURES

Synnøve F. Nordang[1]* and Arni Jonsson[1]

[1] *The Norwegian Water Resources and Energy Directorate (NVE), Oslo, Norway*

ABSTRACT: The Norwegian Water Resources and Energy Directorate (NVE) is responsible for the management of Norway's water and energy resources. The NVE also works to reduce the potential consequences associated with landslides and flooding, where one of the goals is to increase the knowledge about the mentioned hazards in general. This led to the initiation of a digital web-based handbook called Mitigation Measure Handbook (MMH). The digital handbook was developed by the NVE with inputs from several contributors in Norway. It gives information about structural measures such as mitigations against natural hazards. The handbook is divided into three main topics: *flooding and erosion*, *quick clay landslides*, and *natural hazard processes in steep terrain*. The last topic covers various processes like e.g. snow avalanches and slush flows. State-of-the-art knowledge is gathered for each natural hazard type with an emphasis on relating the content to Norwegian conditions and practice. Thematic modules provide practical advice for the whole process of establishing mitigation measures from the phases of planning to management, operation, and maintenance. Related modules are linked together to ease the navigation within the digital handbook. The main webpages of the topic *natural hazard processes in steep terrain* were published in November 2023. So far, a total of 20 modules are planned into this topic. Three modules related to snow avalanches and slush flows have been published. A short description on what those modules contains in relation to the strategy of the handbook is here provided. A sneak-peak into future published content is also provided. The Mitigation Measure Handbook (MMH) is addressed to a wide range of users such as engineers, municipality employees, and landowners. To reach the various audience, a special focus has been spent on development of communicative figures and videos. With the aid of this communicative content, the digital handbook is intended to increase the knowledge and quality when planning and implementing mitigation measures. The digital format and module structure will ease future revisions and improvements.

KEYWORDS: Snow avalanche, slush flow, natural hazard, mitigation, handbook.

1. INTRODUCTION

The Norwegian Water Resources and Energy Directorate (NVE) is responsible for the management of Norway's water and energy resources. The NVE also works to reduce potential consequences associated with landslides and flooding. This includes managing the Norwegian state's aid to mitigate existing buildings in hazardous areas. The NVE also has a goal to increase the knowledge about landslides and flooding in general.

For years there has been an ongoing work to mitigate existing houses and settlements in hazardous zones and areas. In the report *Floods and landslides – The need for mitigations for existing buildings (FOSS)* (NVE, 2021), a total estimation in the magnitude of 7,2 billion euros (NOK 85 billion) was revealed as necessary for the existing buildings to achieve the safety requirements following the regulations for protection against acts of nature (TEK17) (DiBK, 2017). In the context of challenges with increasing natural hazards related to changing climate, but also for the society to develop in areas restricted by hazard zones, there is a need to increase the rate of implementation of mitigation measures while ensuring good quality. One strategy to achieve this has been to increase the competence and knowledge for planning, designing, building and maintaining mitigation measures for the municipalities with the aid from consultants and contractors (NVE, 2023a). This has led to the initiation of a freely available digital web-based handbook called Mitigation Measure Handbook (MMH): https://veiledere.nve.no/naturfare/sikringshandboka/

The project with the handbook was initiated in 2018 with the aim at covering the topics *flooding and erosion*, *quick clay landslides*, and *natural hazard processes in steep terrain* following the same respective order for initiation and finalization of the handbook. During the time-period from 2020–2023, content about flooding and erosion

* *Corresponding author address:*
Synnøve F. Nordang, Section for mitigation in The Norwegian Water Resources and Energy Directorate (NVE), 0368 Oslo, Norway;
tel: +47 47840403;
email: syfn@nve.no

and quick clay landslides were finalized and published. In 2023, parts of the topic natural hazard processes in steep terrain were also published while more content are still an on-going work. This topic covers a wide range of sub-topics for processes like: snow avalanches, slush flows, surficial landslides, debris flows, and rockfalls.

In this extended abstract, an orientation of the strategies, structures and priorities that were made during the creation of the Mitigation Measure Handbook (MMH) are given. An emphasis is put on the topic *natural hazard processes in steep terrain* with snow avalanches and slush flows as examples. Further on, an overview of the planned and published content for snow avalanches and slush flows is given, providing a small sneak-peek into the handbook.

2. STRATEGIES AND STRUCTURE

The Mitigation Measure Handbook (MMH) is a practical handbook that gives information about structural measures such as mitigations against landslides and flooding. State-of-the-art knowledge and literature are gathered for each natural hazard type with an emphasis on relating the content to Norwegian conditions and practice.

When other handbooks, guidelines and content is relevant, accessible and overlapping, direct links are often provided to inform about those resources. The practical handbook is not intended to be a theoretical textbook. However, where there is a clear need and lack of knowledge, depending on the available resources, more effort is made to provide new guiding content. Otherwise, those identifications are noted as a potential future improvement and topic for research and development (R&D).

Today, the MMH is focusing on:

- some of the most common methods and measures with an established knowledge in Norway.
- physical measures that can be relevant as mitigation for buildings.

It is therefore non-exhaustive and the NVE will continue the work on improving the handbook.

Since the MMH does not have any basis in regulations, its use is facultative. However, everyone can make their own demand that it should be used in a certain project or contract. The NVE recommend using the MMH as a practical handbook. The handbook does not replace any designing standards like the Eurocodes with national annexes.

The digital handbook was developed by the NVE in collaboration with several contributors from consultant companies, other state agencies and some universities in Norway.

2.1 Digital handbook

Early in the project it was decided that the handbook should be digital in the form of a web platform. The concept with this digital format is to ease the eventual revisions and add flexibility for further development of the content when more knowledge and experience is available.

For each webpage, there is a changelog that gives an overview of the main updates. Internal procedures keep track of the different published versions through time. There are also possibilities to give feedback on the handbook.

Another advantage of having a digital web-based handbook is the various interactive ways that the content can be communicated with. For example, the content can be complemented with practical and informative videos, direct links to relevant literature, expansion boxes for secondary information and figures that can be easily zoomed in for more details. A special focus has been spent on the development of communicative figures. The figures are a mixture between technical drawings and sketches (e.g. Figure 1). All illustrative figures are free to use and can be directly downloaded from the media database and edited under the CC BY 4.0 licence (NVE, 2023b). To ease and expand the use of the figures, both raster (PNG) and vector format (SVG) is provided for each figure, which gives the user a possibility to modify and adapt the figures according to its need. So far, there are over 1000 media-objects in the MMH with over 280 of them related to natural hazard processes in steep terrain.

Even though the practical handbook is only given in Norwegian, there is various ways with today's web-browsing technology to directly translate the handbook to other preferred languages with no liability to the NVE.

2.2 Structure

The content in the handbook is organized in a matrix structure, where it starts with the three main natural hazard topics: *flooding and erosion*, *quick clay landslides*, and *natural hazard processes in steep terrain*. For each natural hazard topic, users are guided through the phases of establishing mitigation measures from: 1) *planning*, 2) *design*, 3) *construction*, and to 4) *management, operation, and maintenance (MOM)*. On the webpages for the phases, general information is provided. The information guides users to modules where

they can find more specific content. Related modules are linked together to ease the navigation within the digital handbook.

The MMH is addressed to a wide range of users such as planners, designing engineers, state agencies, construction workers, landowners, municipality employees, owners of the structural mitigations, persons that is responsible for the operation and maintenance.

3. CONTENT

The main webpages of the topic *natural hazard processes in steep terrain* including the phase-pages were published in November 2023. In this topic, 20 modules are planned so far, where 5 of them are published. All other modules are under development to a certain degree.

Here is an overview of some modules that are relevant for all the natural hazard processes in steep terrain, that includes snow avalanche and snow slush flow:

- *Modul S2.901: Dams and embankments – Design* (under development)
- *Modul S3.901: Dams and embankments – Construction* (under development)
- *Modul S4.901: Dams and embankments – MOM* (under development)
- *Modul S0.001: Anchoring of protection structures for natural hazard processes in steep terrain* (published)

As an example, an extra emphasis has been spent on the last-mentioned module, referred to as a “supporting module” covering all the phases. Early in the project, the topic was identified as a priority where more guiding content could be developed. That resulted in a 72 pages long report that describes the most used anchors for this type of construction and typical ground conditions that can be expected to encounter in Norway. It also compiles relevant standards, guides and describe methods for dimensioning these anchor types, following a Norwegian interpretation.

3.1 Snow avalanche

For snow avalanches, the following modules have been planned or are published up to this point:

- *Module S1.300: Possible measures against snow avalanches* (under development)
- *Module S1.301: Snow avalanches – Basis for dimensioning defence structures* (published)
- *Module S2.305: Supporting structures – Design* (under development)
- *Module S3.204/S3.305: Rockfall fence and supporting structures – Construction* (under development)
- *Module S4.305: Supporting structures – MOM* (not started)

In Figure 1, an example of a communicative illustration is given. As earlier mentioned, some of the most relevant structural measures for buildings and common methods with an established knowledge in Norway is displayed in this figure.

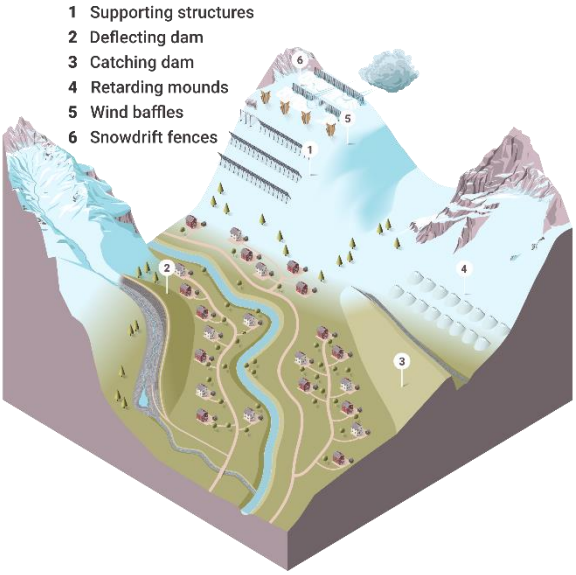

Figure 1: Sneak-peek of the illustrative figure in module S1.300 that gives a rough overview of possible structural mitigation measures against snow avalanches.

A combination of mitigations measures that acts together is sometimes required to reduce the hazard to a sufficient level. So far, only supporting structures and dams have been prioritized with custom modules that detail the phases of designing, construction and management, operation, and maintenance (MOM). That is because those structural measures could be sufficient as mitigation for settlements and buildings alone. Regarding mounds, wind baffles and snowdrift fences are often used as secondary and supplementing measures. They are therefore only mentioned with a short description in *module S1.300: Possible measures against snow avalanches*. To complement the text about snowdrift fences, direct links to more literature are provided to the user, e.g. work of Tabler (2003) that is an open available and relevant resource.

In *module S1.301: Snow avalanches – Basis for dimensioning defence structures* in the chapter about *Dimensioning snow height* for support structures, more resources were spent to propose a procedure based on guidelines from the Alpes (Margreth 2007; Margreth et al., 2008), but

adjusted to Norwegian conditions. When estimating the snow height, it is important to also consider the various snow distribution from wind drifting snow. This effect can also change after the installation of the supporting structures since they can affect the wind locally and accumulate some more snow than before installation (Figure 2).

Figure 2: Distribution of snow in release areas when support structures are in place. (Photo: Arni Jonsson)

In the chapter *Parameter properties of snow in the release area*, there is also a discussion and guidance on the choices of parameter values of density (ρ), glide factor (N) and height factor (f_c) that can used as a starting point for Norwegian conditions.

As there already exist books and literature covering the chapter *Methods for calculating avalanche dam heights* (e.g. European Commission et al. 2009), the strategy in this chapter is more to give an introducing overview of the simplified classic method from estimate of energy height (h_u) and the use of shock theory and Froude numbers (Fr).

There is also in chapter *Expected values for the velocity of the avalanche flow* given a short summary of a more recent study and approach from Gauer et al., (2023) that provides a rough expected value of velocity for dry avalanches. The method is based on velocity measurements along avalanche paths that is related to the well-known alfa-beta method. This method could be used as a control to more detailed calculations with dynamic models and is therefore a supplementary method. Further on, with some assumptions made for a catchment dam, a simple equation to estimate the required effective embankment height (H_{eff}) as an indication of the feasibility of such a mitigation measure is also provided.

3.2 Slush flow

For slush flows, the available state-of-art and experience with mitigation measures is a lot more limited in Norway compared to snow avalanches. The number of modules and their content is consequently less extensive:

- *Module S1.500: Possible measures against slush flows* (published)
- *Module S1.501: Slush flows – Basis for dimensioning defence structures* (under development)

Several different slush flow mitigation solutions have been proposed, theoretically discussed and planned during the past 30 years in Norway. However, it is partly unknown whether those suggestions have been implemented, and there is even less information available to as whether those possible mitigations had the desired effect (Klima 2050, 2022). In *module S1.500: Possible measures against slush flows*, the strategy was to initially give a brief overview of some typical organisational and emergency measures (e.g. Figure 3 and Figure 4). Then, the main emphasis is put on some current permanent structural mitigation measures that has been suggested, planned or built for protection of settlements to our knowledge (Figure 5).

Figure 3: A snow avalanche went into the river Driva in 2018 and formed a plug of snow/ice that dammed the water in the river by 5–6 m. As an emergency measure, a temporary road was made down to the snow/ice plug, so that a trench could be dug in the plug to get a controlled emptying of the dammed river. (Photo: Simon Joachim Oldani, NVE)

Figure 4: Is a print-screen from a video that NVE made from the emergency measure described in figure 3. The video is made for communicative purposes and is linked up in module S1.500 trough YouTube. (Video: NVE, YouTube)

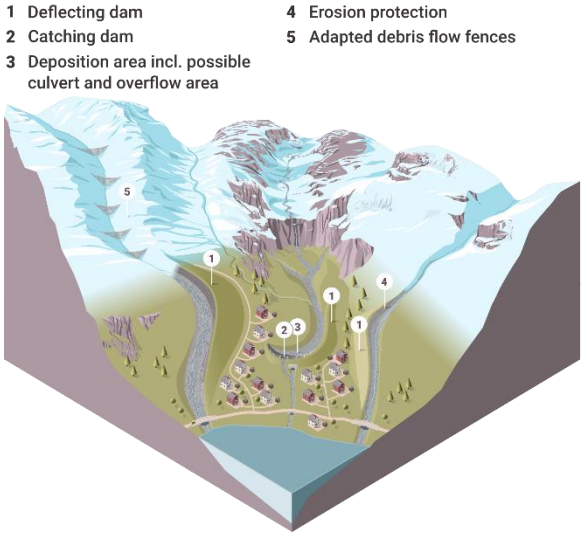

Figure 5: Some possible and relevant structural protective measures against slush slows in the release and run-out area. As illustrated, it is often a combination of several different types of measures that together form a mitigation system.

As showcased in Figure 5, many of the permanent structural mitigation measures against slush flows are also used as protection against other types of natural hazard processes in steep terrain such as snow avalanches and debris flows. However, the protection measures must often be adapted to the special properties of slush as a material, so the design will normally be different (Tomasson & Hestnes, 2000; Klima 2050, 2022; Hestnes & Sandersen, 2000).

For mitigation measures where there might be little documented practical experience and research are also briefly described. They are complemented with direct links for further information for the user to deepen into the concept.

Also, to extend the examples of possible mitigation measures or systems against slush flows, some measures built to protect settlements in Iceland are also showcased.

An original unique example case is given in Figure 6. Here the upper part of the protection system has an open draining catching dam (approx. 5 m high) with the purpose of slowing down parts of the slush, but where the water can flow more freely and through the dam. Under and through the draining dam, a closed drainage ditch of boulders has been laid. A smaller deflecting dam just downstream steers the masses that pass the open draining catching dam and towards the other bigger deflecting dam that leads the slush flow down to a large storage and catching dam. At the bottom of this catching dam, which is about 7–8 m high, there is a culvert that leads water through the dam, but there is also an overflow channel at the top of the dam that is erosion protected down to a new culvert with a grate and a small dam.

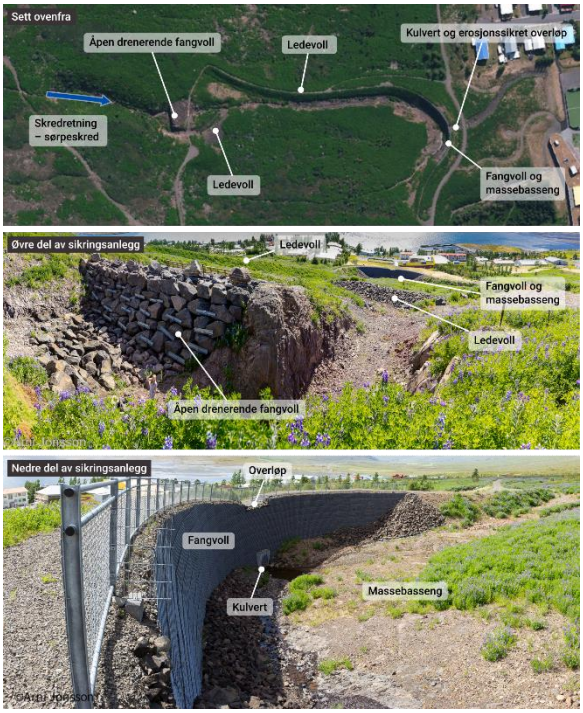

Figure 6: Slush flow protection system at Búðarlækur in Fáskrúðsfjörður, eastern Iceland. Aerial photos are taken from SDI Iceland – National. (Photo: Arni Jonsson, NVE)

4. CONCLUSION

With the aid of this communicative content, the digital handbook is intended to increase the knowledge and quality when planning and implementing mitigation measures. The digital format and module structure will hopefully ease future revisions and improvements. More modules related to natural hazard processes in steep terrain will be made available once finalized.

ACKNOWLEDGEMENT

We would like to thank everyone that has contributed and helped to create the Mitigation Measure Handbook (MMH). This includes many persons from different sections in NVE and some external contributors from the Norwegian Geotechnical Institute (NGI), Multiconsult, HNIT Consulting Engineers, Skred AS, Rambøll, the Norwegian Road Administration, the Norwegian University of Science and Technology (NTNU) and the Geological Survey of Norway (NGU). NVE and Klipp og Lim AS have been responsible for the graphic design of illustrations and images.

REFERENCES

DiBK: Byggteknisk forskrift (TEK 17) – Veiledning om tekniske krav til byggverk, 2017.

European Commission, Directorate-General for Research and Innovation, Issler, P., Gauer, P., and Jóhannesson, T.: The design of avalanche protection dams – Recent practical and theoretical developments, edited by: Issler, P., Gauer, P., and Jóhannesson, T., Publications Office, https://doi.org/doi/10.2777/12871, 2009.

Gauer, P., Body, N. S., and Aalerud, A. H.: What avalanche observations tell us about the performance of numerical models, in: Proceedings, International Snow Science Workshop, Bend, Oregon, 120–127, 2023.

Hestnes, E. and Sandersen, F.: The main principles of slushflow hazard mitigation, International Symposium Interpraevent, 267–280, 2000.

Klima 2050: Sørpeskred. Egenskaper, historikk og sikringsløsninger, SINTEF Akademisk forlag, 2022.

Margreth, S.: Defense structures in avalanche starting zones – Technical guideline as an aid to enforcement, Federal Office for the Environment, Bern. WSL Swiss Federal Institute for Snow and Avalanche Research SLF, Davos, 1–134 pp., 2007.

Margreth, S., Burkard, A., and Buri, H.: Beurteilung der Wirkung von Schutzmassnahmen gegen Naturgefahren als Grundlage für ihre Berücksichtigung in der Raumplanung TEIL B: LAWINEN, 2008.

NVE: Flom og skred – sikringsbehov for eksisterende bebyggelse (FOSS) : beskrivelse av metodikk og resultater, Norges vassdrags- og energidirektorat, 2021.

NVE Fotostream – The Mitigation Measure Handbook: https://nve.fotoware.cloud/fotoweb/archives/5028-Sikringsh%C3%A5ndboka/.

Sikringshåndboka: https://veiledere.nve.no/sikringshandboka/om-sikringshandboka/, last access: 14 August 2024.

Tabler, R. D.: Controlling Blowing and Drifting Snow with Snow Fences and Road Design, 2003.

Tomasson, G. G. and Hestnes, E.: Slushflow Hazard and Mitigation in Vesturbyggd, Northwest Iceland, in: Nordic Hydrology, Reykjavik, Iceland, 399–410, 2000.