First Experiences in Applying the Swiss 'Guideline to Account for Avalanche Hazard of Ropeways in Ski Areas'

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Abstract

Ropeways in ski areas are often exposed to avalanches. The new ropeway guideline fixes principles and procedures how to account for avalanche and snow pressure hazards. The two main subjects of the guideline define firstly standards to determine the avalanche and snow pressure forces acting on the structures, and assure secondly safety for the public. To ensure structural integrity, the guideline defines 'normal' and 'accidental' design avalanches, as well as static snow pressure, which have to be considered in the structural analysis. Temporary safety measures are a commonly used method to avoid avalanche hazards on ski-runs. However, avalanche incidents on ski runs show that there is always a residual danger, which cannot be neglected. Therefore, for exposed areas where people gather (e.g. terminal stations), the guideline requires an additional safety margin: it must be ensured that spontaneous avalanches with a return period of 10 years will not reach these areas. Ten years application of the guideline in consulting work for new and existing ropeways show that the defined standards can be regarded as appropriate for the vast majority of cases. The winter 2008/09 provided some avalanche events that allowed for a first full-scale test of ropeways designed according to the guidelines. We will show typical examples of hazard assessments and proposed safety measures for ropeways.

Key words: avalanche protection, avalanche defence, snow pressure, ropeway

1. INTRODUCTION

In 1999, a first draft of a 'Guideline to Account for Avalanche Hazard of Ropeways in Ski Areas' was issued by the the Swiss Federal Office of Transport and the WSL Institute for Snow and Avalanche Research SLF, Davos. In 2006, a revised version was released for consultation by the industry (BAV-SLF, 2006). The guideline considers two peculiarities of ropeway installations in alpine terrain. On one hand, rope-ways are often built in areas of frequent avalanches – this is a case not covered by the current design standards (SIA261; CEN13107). These codes generally consider avalanches as rare, and thus accidental actions. On the other hand, applying the same standards as for hazard evaluation in residential land-use (BFF-SLF, 1984) may not be appropriate for rope-ways. During periods of imminent avalanche danger it is easier to close down a ski area in comparison to evacuate a residential area.

The guideline firstly defines how the structural safety of the ropeway has to be ensured. Secondly, it sets the standards to guarantee avalanche safety for the public. This requires to check not only the avalanche hazard along the ropeway itself, but also the overall avalanche situation of the ski runs connected to the ropeway.

2. SAFETY REGULATIONS FOR THE STRUCTURAL SYSTEM OF ROPEWAYS

In accordance with the principles that are set in the Swiss Standard for actions on structures (SIA261, 2003), two cases of avalanche action are defined: First, extreme avalanches with a return period of 100 to 300 years are considered as an 'accidental action'. Second, smaller avalanches with a return period of 10 to 30 years are considered as normal, 'variable action'(see table 1). The calculation of these design avalanches follows the same rules as used in land-use planning (see Salm et al. (1990)). Dense and/or powder avalanches have to be considered when evaluating the hazard. During the avalanche event, it is assumed

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Table 1: Standards to determine the actions for the design of ropeway installations

importance of the ropeway:	principal		peripheral	
object:	station	pylon	station	pylon
hazard scenario	**applicable return period T (years)**			
extreme avalanche (accidental action)	300	100	100	100
height of the natural snow cover during the avalanche event	30	30	30	30
normal avalanche (variable action)	30	10	10	10
height of the natural snow cover during the avalanche event	30	30	30	30
snow pressure (variable action)	30	30	30	30

that the natural snow cover at the object equals the maximum snow cover with a 30 year return period.

Furthermore, we distinguish between 'principal' and 'peripheral' ropeways. This accounts for the fact that, compared to a principal installation, a peripheral installation is less important and can be closed down easier during imminent avalanche danger. Additionally, even minor damage to a principal installation may cause a high financial loss.

Snow pressure is taken into account as a variable action. The design snow pressure is calculated with a 30-year snow height. The guideline allows the avalanche expert to define whether avalanches can coincide simultaneously with snow pressure.

Figure 1 shows the characteristic load distribution for dense flow and powder snow avalanches, and snow pressure.

3. SAFETY REGULATIONS FOR THE SKI AREA TERRAIN

Guaranteeing an acceptable risk to skiers addresses largely different aspects than ensuring structural integrity of the ropeway. For example, during extreme avalanche situations, no skiers will normally be endangered because the ski area will be closed. On the other hand, even a small snow slide can be a large hazard for a skier. Such small avalanches can occur even when the avalanche hazard level is moderate. The avalanche service of a ski area is responsible for the safety of the skiers due to his liability for premises (Verkehrssicherungspflicht, see Stiffler (2002)). Hazardous areas are secured by artificial release of avalanches and, if necessary, closure of endangered areas. All these measures rely on the correct assessment of avalanche hazard. The importance of the safety measures is illustrated by the fact that on average about five persons are hit by avalanches on ski runs per year and every fourth year, a person is killed (data from the SLF avalanche database 1985/86 to 2008/09, see also SLF (1951–2009)).

In ski areas the guideline distinguishes between ski runs, areas where people accumulate (stations, snow-bars etc.), and evacuation routes. In order to minimise risk to the public, the following standards are set:

- The avalanche safety of ski runs is primarily ensured by artificial release and closures. In order to guarantee the efficiency of these measures, tracks must not cross areas, where avalanche safety is difficult to achieve. For example, such areas may be below hanging glaciers, where avalanches can release anytime without warning, or directly below large cornices.
- For areas where people gather, the damage potential is much higher than for a ski track. Therefore, in addition to the temporary measures the avalanche service can provide, the guideline foresees an extra safety margin. This margin is enforced by restricting gathering areas to be outside the run-out of avalanches with a natural return period of 10 years. When there is no opportunity to place stations at safe locations, the skier accumulation areas have to be protected by structural measures as dams or snow supporting structures.
- The operator of the installations has to ensure that evacuation routes, e.g. for passengers from blocked chair lifts, are accessible without avalanche hazard throughout the operating hours of the ropeway.

The safety measures have to be summarised in a safety concept and the work of the avalanche service has to be documented continuously. The documentation encompasses the assessment of the avalanche danger, the safety measures initiated, results of the artificial release, closure and opening of ski-runs and

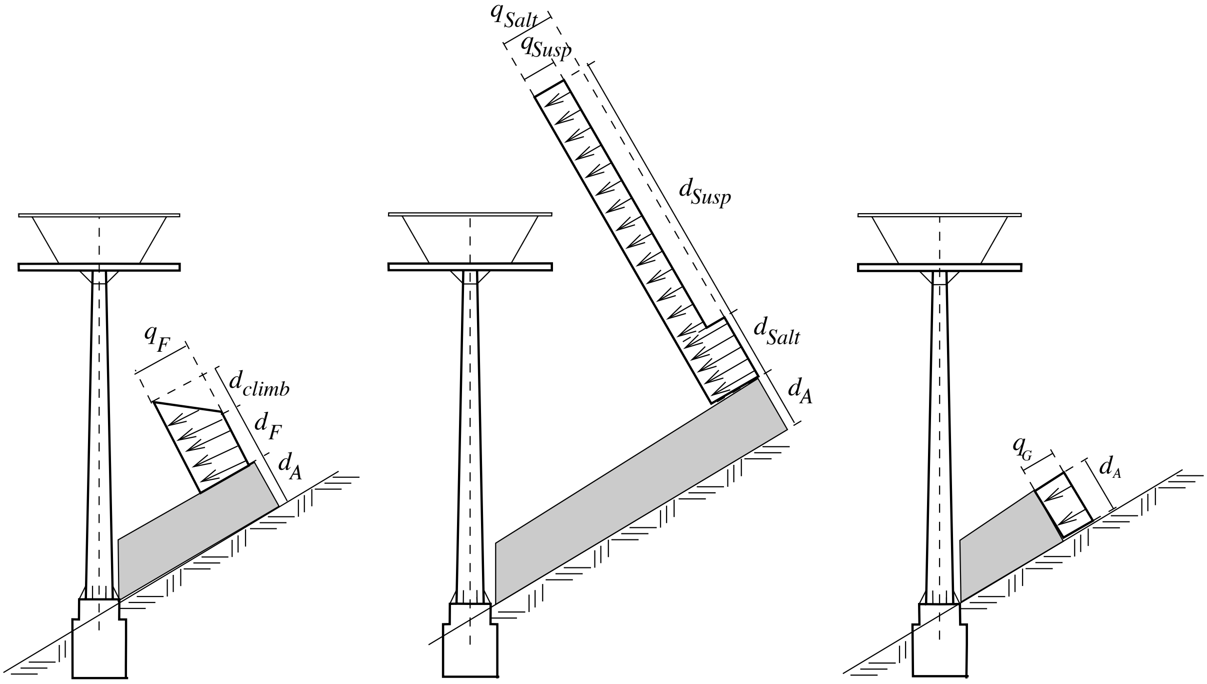

Figure 1: Load distribution on a ropeway pylon due to a dense flow avalanche (left), a powder snow avalanche (centre), and to static snow pressure (right).

d_a, d_F, d_{climb}, d_{Salt}, and d_{Susp} correspond to the perpendicular height of the snow cover, the flow depth and flow height of the dense avalanche, and the height of the saltation and suspension layers of the powder avalanche. q_F and q_{Salt} are the reference values $\rho_F {v_F}^2$ and $\rho_{\text{Salt}} {v_{\text{Salt}}}^2$ for the avalanche pressure in the dense avalanche, and the saltation layer avalanche pressure. q_{Susp} is the dynamic pressure $\rho_{\text{Susp}} {v_{\text{Susp}}}^2/2$ in the suspension layer (powder cloud), and q_G is the quasi-static snow pressure. ρ and v are the density and velocity of the respective avalanche layers.

installations and finally the documentation of all avalanche events.

4. CURRENT EXPERIENCE APPLYING THE GUIDELINE

4.1. Overview

The SLF applied the guideline in consulting practise for ten years. We compiled a data set consisting of 50 chairlifts, gondola lifts, aerial tramways, or funiculars. As the data covers a substantial fraction of all ropeways that were built or renewed during this period, the sample can be considered to be quite representative for Switzerland.

Out of 513 examined pylons, in 368 cases (72%) we found no, or just a negligible, avalanche hazard, and no relevant snow pressure. At 83 pylons (16%), we estimate that just minor reinforcements are necessary to meet the standards (resulting action on the pylon 20 to $60\,\mathrm{kN}$). At 32 pylons, a massive reinforcement of the pylon is required to withstand the predicted avalanche forces (resulting action on the pylon $> 60\,\mathrm{kN}$). In 8 cases, the resulting snow pressure exceeded $60\,\mathrm{kN}$, requiring massive reinforcements, although there was no large avalanche hazard for the pylon.

Out of 105 examined stations, 5 stations are in the perimeter of avalanches with a return period of 10 years, so protective measures as earth dams, or snow supporting structures are required. Even in extreme avalanche situations, 97 stations will not be reached by the design avalanches with a substantial intensity. Only one station we examined is exposed to very large avalanche pressures, resulting in the construction of massive protection measures.

4.2. Example of a station heavily exposed to avalanches

In 2006, the chairlift 'Vaduzer Täli' was constructed. It's top station is situated at the base of a steep cirque. The location is regularly reached by avalanches. At the station, avalanches with a return period of 100 years have a velocity of $17\,\mathrm{m/s}$ and a flow height of

Figure 2: Top Station of the Chairlift 'Vaduzer Täli' on April 7, 2009. The Station is protected by a 3.5 m height curved earth dam, and the structure itself is designed to a maximum impact load of 86 $\mathrm{kN/m^2}$.

Figure 3: Foundation of pylon 7 of the 'Pleus' chairlift, Elm in spring 1999. Snow pressure has dislocated the anti-avalanche by some 8 m. The slope at the pylon is 28°, compared to other situations not really steep.

1.5 m. Thus, the station had to be protected by a massive concrete shelter. Avalanches with a return period of 10 years can also reach the station. To meet the standards, a protective dam has been built. Te total cost of the protective measures were about 1.3 M€.

In Winter 2009, which was rich in snow in this area, between mid-February and end of March, several artificially release avalanches did reach the station. Figure 2 shows the situation on April 7, 2009. One avalanche started at the position of the photographer, overflowed the concrete roof of the station and deposited up to 2 m of snow on the roof. A second avalanche from the lower left overflowed the protective dam and deposited about 2 m of snow at the exit of the station. We estimate the return period of the released avalanches to be between 5 and 10 years. For spontaneous avalanches with the same size, the return period is estimated to be some 30 years. Of course, in extreme situations, much larger avalanches have to be expected.

4.3. Example of a severe snow pressure situation

In Winter 1998/99, extreme snow heights in much of the Alps contributed to high snow pressure loads, provoking the destruction of some ropeway pylons. Margreth (2007) has analysed cases with extreme snow pressure. Figure 3 shows an incident in Elm, where the back-calculated forces acting on the pylon have been at least 470 kN. These forces could be reproduced by snow-pressure calculations only when we chose very conservative parameters in the calculations. The avalanche expert estimated the return period of the snow pressure situation to be at least 50 years.

5. CONCLUSIONS

The application of the guideline over the last ten years shows that for the majority of the investigated ropeways the proposed standards could be implemented easily and without causing much additional cost. No damage was observed at ropeways designed according to the guidelines. We believe the main advantage of the guideline is that it sets a definite safety level for all installations.

There is some criticism suggesting that the safety levels are too conservative. The primary argument of the critics is that there exist many pylons which are not reinforced, but for all that, they have not suffered any damage for several decades. However, as the examples in this paper have shown, there *are* rather high uncertainties in the design approach. This justifies the definition of a safety margin. The main uncertainty in the application of the guideline is the calculation of the avalanche and snow pressure actions. In particular, the evaluation of the snow pressure on a pylon is difficult due to the uncertainties in the selection of parameters and boundary conditions of snow creep calculations.

Finding a better approach to assess the avalanche and snow pressure actions on a pylon, and defining a design level that is both, safe and economic, is still an open challenge.

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