Everyday work of an avalanche engineer – Calculation of avalanche loads and protection of small objects in avalanche paths like ropeway towers

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ABSTRACT
The complexity of avalanches especially the interaction with objects like masts or buildings are not sufficiently described in the current guidelines. Therefore, engineers need to utilize scientific approaches or to develop individual solutions. This paper discusses the current Standards for avalanche loads and demonstrates a design of a general avalanche load profile. Furthermore, a special solution of a wedged ropeway tower is shown and approaches towards an improvement for avalanche protection measures for ropeway towers are discussed.

1. INTRODUCTION
Ropeways usually make high alpine terrain accessible and are, thus, frequently built in avalanche prone areas. The towers act as narrow obstacles for the avalanche. The avalanche engineer has to investigate the avalanche hazard and to design a realistic avalanche load profile. The structural engineer has to consider the loads in his calculation in order to make the towers safe against avalanches. However, the complexity of avalanches, especially the interaction of an avalanche with objects like masts or buildings is not sufficiently described in current national guidelines which leads to individual approaches. The main challenge is to find the optimal tower shape which provides a minimum contact area and a maximum cost-effectiveness. One of the major steps in this working process is to draw an avalanche load profile that is as realistic as possible. Furthermore, we developed an optimized tower shape against the avalanche impact.

In this paper, we present our approach resulting from practical experience in a number of ski resorts and daily discussions with other avalanche experts.

2. STANDARDS FOR AVALANCHE LOADS
The Austrian standards for the calculation of avalanche loads on obstacles (ONR 24805) and the Swiss guidelines for the consideration of snow loads and avalanche loads on ropeways (Margreth et al. 2015) are used do distinguish between loads of the gliding snow mass, the dense flow part, the fluidized part and the powder part. The interaction of these different load types and the temporal occurrence are not defined in these standards and must therefore be defined by the avalanche expert.

3. APPROACH TO THE PROTECTION OF ROPEWAY TOWERS AGAINST AVALANCHES/ AVALANCHE LOADS

3.1 Design of a “Realistic” avalanche load profile

Avalanches are dynamic processes with a complex flow behaviour that cannot be described in a simple way. Structural engineers need concrete load specifications of avalanche impacts for the dimensioning of endangered objects. The challenge for avalanche engineers is the transmission of the complex avalanche impact in a realistic, comprehensive and understandable way.

The loads on masts and buildings can be split into the creeping or gliding snowpack, the dense flow part, the fluidized layer and the powder part. Each of these loads is subdivided into different load types (e.g. the dense flow part is divided into the dynamic flow pressure along the flow depth and the flow pressure along the climbing height that decreases linearly). We assume that loads of the gliding snow mass, the dense flow, the fluidized layer and the powder part appear at the same time. Overlapping loads are not added, but the highest load value on each point along the tower is selected (the thick black dashed line in figure 1). With this approach we can provide an avalanche load profile that corresponds to all appearing load types and is applicable for narrow objects like masts as well as for wall-like structures (e.g. buildings). The figure 1 shows the load profile considering all load types.

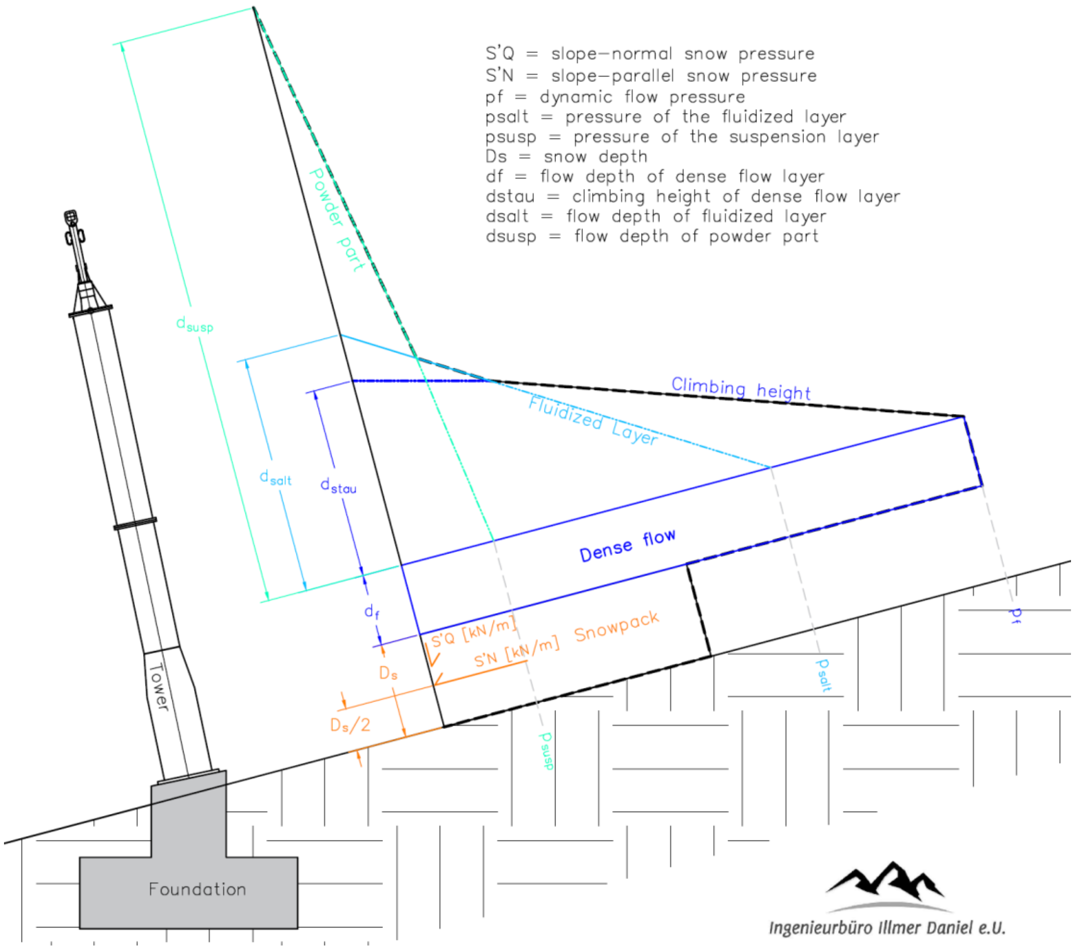

Figure 1 Avalanche load profile on a tower considering all load types (snowpack, dense flow, fluidized layer and powder part)

3.2 Effect of circular cylinder and splitting wedge on avalanche dynamic

The first focus is on the calculation of the climbing height hdyn of the dense flow part on towers that cannot be described realistic with the equations used in practice. The equations in ONR 24805 (2010) for the dynamic flow pressure p_f as for the climbing height of the dense flow part h_{dyn} are the same for circular cylinders and for wedged obstacles.

$$p_f = c_d \frac{\rho_f \cdot v_f^2}{2} \qquad (1)$$

$$h_{dyn} = \frac{v_f^2}{2 \cdot g \cdot \lambda} \cdot f_{b/d_f} \qquad (2)$$

The drag coefficient cd is the same for circular cylinders as well as for wedged objects (cd = 1.5 for the dense flow regime according the recommendations in Jóhannesson et al. (2009) and ONR 24805 (2010)). Equation 2 in ONR 24805 (2010) for the calculation of the climbing height hdyn does not contain any value for the shape of the obstacle and considers just the avalanche type by the variable λ and the obstacle width. Also the slope inclination has not been considered in the equations.

We suppose that the obstacle shape has a crucial influence on the resulting pressure and especially on the climbing height of the avalanche. Equation 2 (climbing height hdyn) results in unrealistic high values for the climbing height in case of high flow velocities. For example a fast avalanche (v_f=25m/s, d_f=1m, cd=1.5) and a narrow obstacle (b=1m) lead to a climbing height of 15m. This seems not to be realistic. Practical observations support our theory that obstacle shape does influence climbing height with lower heights in wedged-shaped object compared to cylindrical objects probably due to a “splitting effect” on the avalanche (figure 2 and 3).

Figure 2 Avalanche impact on a circular cylinder tower. Photo by NGI

Figure 3 Train with a snow plow in action. TNT Channel – YouTube (2016)

3.3 Optimized design of ropeway towers – "wreath construction"

Ropeway towers usually need to be built in steep terrain in avalanche-prone areas. Our solution for an optimized avalanche protection measure for a ropeway tower is to raise a wedge-like wall around the avalanche exposed side as shown in Figure 4 ("Wreath" construction). The construction material can be concrete, steel or a steel-wood-combination. Such constructions have already be implemented in ski areas.

3.4 Approach for a design of a tower construction based on the shape of the snow plow of the train in figure 3

Figure 5 shows a more complex wedged tower protection which is integrated in the foundation, similar to the form of the snow plow in figure 3. The construction includes a wedge-shaped concrete-shaft with a concrete or steel plate on top. It can be assumed that the avalanche is split by the wedge and climbs up to the level of the energy height. The level of the energy height is reached after the tower. The steel mast of the tower is not reached by the dense flow part of the avalanche. The shaft height above ground must overtop the snow surface, the dense flow height and a safety supplement.

To realize the described approach in 3.3 and 3.4 it is very important that the flow direction is clear, otherwise the wedge acts like a rectangular obstacle.

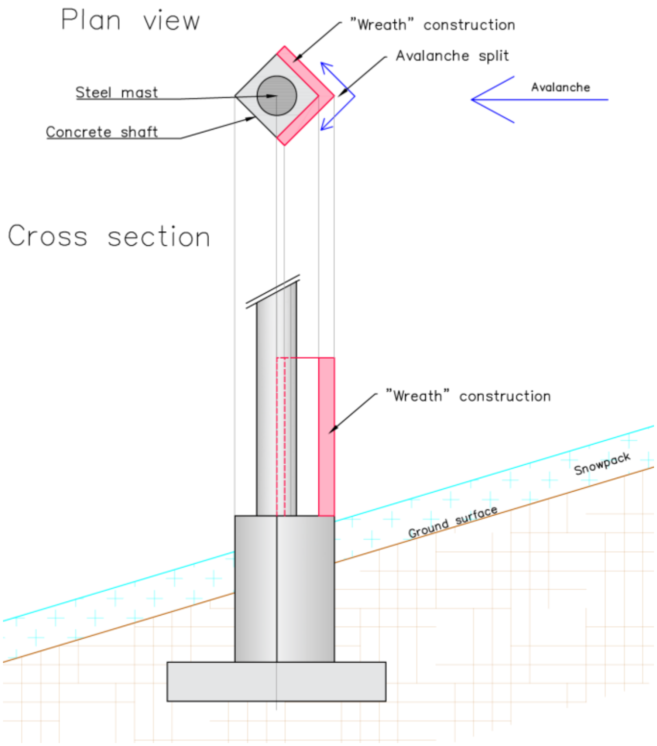

Figure 4 Wedged structure around the avalanche exposed side ("Wreath" construction) on a ropeway tower.

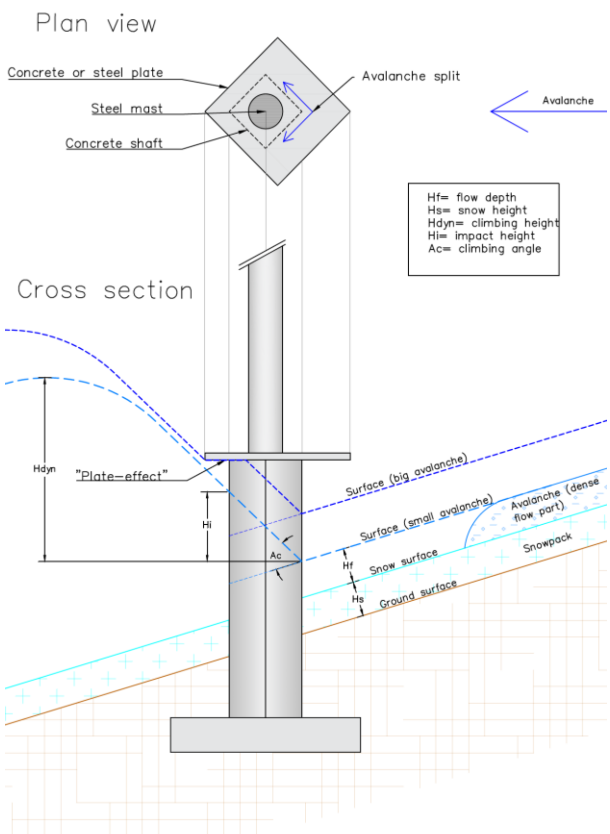

Figure 5 Approach of an improved ropeway tower

4. CONCLUSION

Loads of avalanches can be huge and the interaction with obstacles complex.

Our observations and experiences show that the behaviour of the dense flow part of the avalanche is not the same for circular cylinder as for wedged obstacles. The Austrian and the Swiss guidelines do not distinguish between these obstacle shapes regarding the dense flow regime.

For small objects in avalanche paths like ropeway towers and for high flow velocities we recommend to design the objects as wedged structures and the surface of the wedge as smooth as possible. However, one of the most important requirements to realize wedged structures is a clear flow direction of the avalanche.

The theoretic results and approaches of this paper should be proved with field tests or laboratory experiments. Heil (2017) researched the flow behaviour of snow in a rotating drum. The experiment setting could be adopted by inserting obstacles in the rotating drum. The pressure and the climbing height for different obstacle shapes could be measured.

Field tests could as well be performed on snow-covered lakes. A construction at the front of a snowmobile should constitute obstacles in different shapes: circular cylinder, rectangular and wedge as “narrow obstacles” and walls (straight and inclined) to represent the effect of catching dams and deflecting dams.

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