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# INFLUENCES OF SNOW SUPPORTING STRUCTURES ON THE THERMAL REGIME OF THE GROUND IN ALPINE PERMAFROST TERRAIN.

## Summary

Snow supporting structures can be located at high altitudes, in permafrost terrain, where the presence of ground ice is possible. Damages to existing structures caused by rock fall and terrain creep have occurred in the Swiss Alps. As their name suggests, the function of snow supporting structures is to retain snow in the starting zone of avalanches. Damaged structures do not function satisfactorily and repairs are expensive. Until present, it was not known whether the structures induce any modifications to the thermal regime of the ground. If ice is present in the ground, warming could lead to slope instability and hence to the occurrence of damages to structures. The foundations of the structures are 4-6 m long, and penetrate the problematic active layer of permafrost ground which can attain positive temperatures in summer and is often composed of unconsolidated sediments such as scree or glacial deposits in high alpine terrain.

The aim of this research is to determine whether steel snow supporting structures have any influence on the thermal regime of the underlying ground. The design-life of modern structures is 100 years and their presence may have an effect on ground temperature over this period of time in two distinct manners: firstly, heat may be conducted into or out of the ground through the steel components of the structures. When they are exposed to direct solar radiation, the supports can become warm (20-30°C) for short periods of time (hours). Some of this heat may be conducted into the underlying foundations and into the ground. Secondly, snow supporting structures significantly modify the spatial and temporal distribution of the snowcover. Rather than avalanching naturally, snow is retained on steep slopes and snow melt is delayed by about one month in spring. In addition, the snow pack sometimes creeps or glides downwards between rows of structures, which leads to irregular snow distribution: a gap forms below each row of structures whereas a thick, dense snowcover forms above each row. The snowcover has an important influence on ground temperature due to its insulating properties; a reduced snowcover in winter implies that heat can be evacuated from the ground efficiently. On the other hand, the presence of deep, densely packed snow above the structures in spring and early summer protects the ground from direct solar radiation and therefore prevents ground temperature from rising.

Two test sites were chosen for effecting field measurements to investigate the influences of the structures. One site is located above Pontresina (GR) and the other above Arolla (VS). Both are in permafrost terrain around 3000 m a.s.l, but have different orientations and geological conditions. The sites are characteristic steep avalanche slopes (gradients 35-40°) with a heterogeneous scree cover of varying thickness above the bedrock. Strategically located boreholes have been equipped with thermistors to a depth of 20 m and temperatures therein recorded since October 1996. In addition, ground surface temperatures are monitored, as well as snow surface temperature and air temperature. Snow distribution is registered by an automatically triggered camera. In summer 1997 experimental snow supporting structures were constructed on both sites and equipped with thermistors on their supports and along their foundations. Different types of structures were tested (snow nets and snow bridges of the conventional type as well as a newly developed „suspended sledge" system). Several types of foundations were used (micropiles, pinched tubes, steel plates, and cable anchors), and were equipped with thermistors at various depths. Parallel to these field investigations, a finite element programme developed at SLF is used to simulate the long term effects (i.e. over decades) of the snow supporting structures on the thermal regime of the ground. Data obtained in the field is used to calibrate and drive the programme. The material and thermal characteristics of the ground are derived from geotechnical and thermal borehole information.

Results of field measurements and computer simulations indicate that the modification of the snowcover by the structures has the most significant effects on ground temperature - but that these are of a seasonal nature, extremely local and that average annual ground temperature is not altered. Heat does not appear to be conducted into the ground through the steel elements of the structures, due to the fact that the contact surfaces between the steel supports and their foundations are very complex. The measurements effected also reveal that ground temperature can vary significantly at a very local scale, particularly near the ground surface. Temperature evolution is strongly influenced by factors such as grain size, ground moisture content, phase change, snow depth and type - as well as by obvious topo-climatic parameters such as orientation, altitude and geographical location. To determine the influence of engineering structures on ground temperature, such factors must be taken into account. A two year measurement period does not suffice to establish any trends and ideally, temperature measurements should be continued over longer periods of time in order to verify the hypothesis submitted here, namely, that snow supporting structures do not alter the thermal regime of the ground or induce slope instability. Damages to existing structures induced by creep exist because they were built on ice-rich, already actively creeping sediment forms such as gelifluction lobes or small rock glaciers. This type of terrain should be avoided for the construction of snow supporting structures, but in general steep scree slopes are well drained and contain little ground ice. On very steep slopes with gradients higher than the angle of repose of scree, snow supporting structures are built on bedrock which only contains ice in faults and is not subject to creep. Bedrock which is not too strongly weathered or faulted constitutes a favourable building substratum regardless of its thermal properties.

Key-words: Permafrost, snow supporting structures, unconsolidated sediments, creeping, snowcover, ground thermal regime