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Monitoring and reconstruction of a chairlift midway station in creeping permafrost terrain, Grächen, Swiss Alps

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Abstract

The midway station of a chairlift located in the ski resort Grächen (Swiss Alps) was originally built in 1997 at 2453 m ASL in alpine permafrost terrain. The chairlift conveys 300,000–330,000 passengers every winter season and constitutes an important link between two cable cars in the ski area. In winter 1997–1998, it became evident that the terrain at the mid-way station was unstable: one of the two concrete foundations started to creep and settle rapidly and cracks formed in the structure. To investigate the properties of the ground, two 25 m boreholes were drilled near the foundations and equipped with inclinometer casings and thermistors. The presence of permafrost with an exceptionally thick active layer and a 20-m talik containing water was confirmed. The horizontal and vertical deformation rates of the ground attained very high values between 2002 and 2003. As a consequence, and in the interest of the safety of the passengers, the original midway station had to be destroyed and a specially developed new station was built in 2003. The excavation trench was lined with insulating material in order to avoid thermal disturbance of the underlying permafrost by hydration heat. The new foundation consists of a concrete T-girder with three point bearings. Repositioning of the entire structure in response to creep is possible, due to the unique character of the structural bearings which can be raised or lowered using hydraulic cylinders and steel plates. The thermal regime of the entire structure, ground temperatures and slope movements continue to be monitored to determine the long-term evolution of the mid-way station.

Keywords: Structure stability; Mountain permafrost; Terrain deformation; Chairlift midway station

1. Introduction

The Stafel–Seetalhorn chairlift was built in 1997 in the Swiss ski resort Grächen by the company Leitner AG. The chairlift starts at 2208 m and culminates at 2867 m on the Seetalhorn. There is a mid-way station located at 2453 m at a point where the general direction of the chairlift changes by 10°. The midway station is 23 m long at ground level, 36 m long at the top and has two concrete supports (Fig. 1). The chairlift only has one cable loop, so in order to enable this change of direction, the chairs have to be uncoupled from the cable and then recoupled, which allows passengers to leave or get onto the chairlift at the midway station. The chairs' velocity is therefore reduced

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to 0.6 ms^{-1} and then accelerated to 5 ms^{-1} again, which is the speed of the cable. The velocity of the chairs travelling downhill is reduced to 2.5 m s^{-1} and no passengers are carried in this direction. The total horizontal length of the chairlift is 2224 m and the average slope angle is 29.4°. It has 4-person chairs (bubbles), can convey 1200 passengers per hour and 300,000–330,000 passengers are transported per winter season.

The midway station is built on mountain permafrost which is potentially problematic because ice in debris on slopes tends to creep or can melt, both of which lead to structural instability (Haeberli, 1992; Stoffel, 1995; Phillips et al., 2003). The presence of water, ground ice and creeping sediments beneath the midway station rapidly led to structural stability problems a few months after construction. In order to monitor the development of the problem, borehole measurements were started in 2002 (Fig. 2). Terrain deformation rates were so high that for safety reasons, the midway station had to be rebuilt with a specially adapted design in summer 2003. The aims of this paper are to demonstrate the problems which can be encountered when structures of this type are built in creeping mountain permafrost terrain, to indicate how the geotechnical characteristics of the ground can be monitored and to show how structure stability problems can be overcome with specially adapted engineering techniques.

2. Initial site characteristics

The chairlift midway station is built on moraine-type material (fine grained to blocky) and is surrounded by steep, blocky scree slopes. The site is at 2453 m and oriented NW, near the lower limit of alpine permafrost (Keller et al., 1998). The likelihood of permafrost occurring is underlined by the presence of an active rock glacier (a typical permafrost feature consisting of a mixture of creeping rocks and ice) located about 200 m NE of the midway station and extending below it to 2380 m.

Before construction of the midway station in 1997 the presence of permanently frozen ground was suspected but not verified, as there was no time planned for long-term monitoring. There were also no existing reference values allowing to determine slope movements with geodetic measurements. The site was not considered to be ideal but its position was determined according to the position of the other pylons and the necessity to change the general direction of the cables at this point. During construction, a large pit was excavated and the ground was observed to consist of small rocks and earthy material (Fig. 3). No ice was visible and the ground did not appear to be frozen but was reported to be cold. However, no measurements were effected to determine ground temperature. Any existing voids in the ground were filled with building materials such as synthetic fleece, gravel, rocks and concrete but no layer of thermal insulation was installed between the concrete supports and the ground.

3. Structural problems

The chairlift was first put into service in December 1997. The foundations consisted of two shallow concrete footings. In February 1998 cracks (a few millimeters wide and several decimeters long) were observed in the concrete supports and in the ground (approximately 5–10 cm wide and several meters long) at the midway station. Leitner AG immediately verified the cable forces and they corresponded to the prescribed values. In October 1998, theodolite measurements showed that since construction, the upper concrete support had moved about 2.5 cm (15–20°) and the lower one 12 cm (30°). The displacement of the lower support was therefore significantly higher, which eventually led to an unforeseen load situation on the two pylons because they were joined by the 36-m-long stiff upper structure. The cracks in the concrete were repaired and plates were installed between the cable guides to compensate the difference. The cause of the problems was not yet known.

The creep movements were most evident at the points where the cable entered and left the midway station. As the chairlift is only used in winter, it was possible to effect geometrical corrections for that limited period of time. In the course of the following 2 years it nevertheless became clear that the means of correction were too limited and that new solutions had to be found. However, the necessary geotechnical information was not yet available and so a monitoring system had to be installed.

4. Monitoring methods

Two 25-m boreholes (B1 and B2, Figs. 1 and 2) were drilled just above and below the midway station in October 2002. They were drilled destructively and small amounts of ground ice were observed in B1 (mainly below 16.5 m depth). It is possible that there is ice in the ground at shallower depths directly under the midway station. As the boreholes were drilled destructively and not cored, the volumetric ice content of the ground is not known. A layer of humid ground was observed at 15–17 m depth in both boreholes.

The boreholes were equipped with inclinometer casings (71 mm diameter) to allow terrain deformation and settlement to be measured. In November 2002 the