STABILITY PROBLEMS UNDER A CHAIRLIFT MIDWAY STATION IN CREEPING PERMAFROST TERRAIN, GRÄCHEN, SWISS ALPS

Marcia Phillips*[1], Florentin Ladner [2], Max Müller[3], Ulrich Sambeth [2],
Jan Sorg [4], Philipp Teysseire [5]

[1] WSL Swiss Federal Institute for Snow and Avalanche Research SLF, Davos, Switzerland
[2] Stump ForaTec AG, Nänikon, Switzerland; ulrich.sambeth@stump.ch
[3] Bergbahnen Grächen, Grächen, Switzerland; bbg.graechen@rhone.ch
[4] Leitner AG, Italy; sorg.jan@leitner-lifts.com
[5]Teysseire & Candolfi Engineering, Visp, Switzerland; ph.teysseire@t-c.ch

ABSTRACT: The mid-way 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. A few months after construction it became evident that the terrain at the mid-way station was unstable: settlement and creep occurred and cracks formed in the structure. Two 25 m boreholes were drilled near the foundations and equipped with inclinometer tubes and thermistors. The presence of permafrost with exceptionally large active layer depths and a 20 m thick talik containing water was confirmed. The deformation rates of the ground attained high values between 2002 and 2003. As a consequence, a specially developed new mid-way station had to be built in 2003. The excavation trench was lined with insulating material in order to avoid thermal disturbance of the underlying permafrost during the setting of the concrete. 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. Ground temperatures and slope deformation continue to be monitored to determine the long term evolution of the mid-way station.

Keywords: structure stability, 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. There is a mid-way station (Fig. 1) located at 2453 m at a point where the general direction of the chairlift changes by 10°. The total horizontal length of the chairlift is 2224 m and the average slope angle is 29.4°.

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 L. 1995, Phillips et al. 2003). A few months after construction high deformation rates were registered in the underlying terrain. Borehole measurements were started in 2002. For safety reasons the midway station had to be rebuilt with a specially adapted design in summer 2003. The aim of this paper is to demonstrate the problems which can be encountered when structures of this type are built in creeping mountain permafrost terrain and to indicate how the geotechnical characteristics of the ground can be monitored. Finally specially adapted engineering techniques will be presented.

Corresponding author address: Marcia Phillips, Swiss Federal Institute for Snow and Avalanche Research, Flüelastr. 11, CH-7260 Davos, Switzerland. e-mail: phillips@slf.ch, tel. +41 81

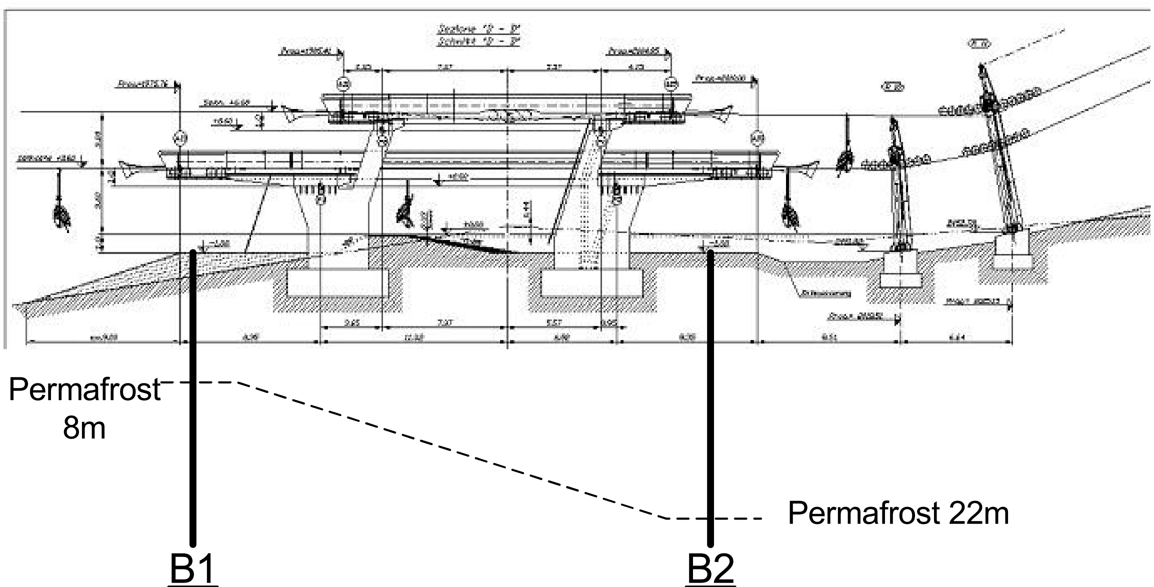

Fig. 1. Midway station of the Stafel-Seetalhorn chairlift, Grächen, Swiss Alps. The locations of boreholes B1 and B2 are shown, as well as the depth of permafrost.

2. INITIAL SITE CHARACTERISTICS

The chairlift midway station is located at 2453 m and oriented NW, near the lower limit of alpine permafrost (Keller et al., 1998). Before construction in 1997 the presence of permanently frozen ground was suspected but not verified. 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. 2). No ice was visible and the ground did not appear to be frozen but was cold. Any existing voids in the ground were filled with building materials such as fleece, gravel, rocks and concrete but no thermal insulation was installed between the concrete supports and the ground.

Fig. 2. Construction pit (August 2003), showing the foundation and earthy to blocky ground material in the sides of the trench (5 m deep).

3. STRUCTURAL PROBLEMS

A few months after construction cracks were observed in the concrete supports and in the ground 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. 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.

As the chairlift is only used in winter, it was possible to effect geometrical corrections for that period of time. In the course of the following two years it nevertheless became clear that the means of correction were too limited and that new solutions had to be found. A monitoring system had to be installed to obtain the necessary geotechnical information.

4. MONITORING METHODS

Two 25 m boreholes (B1 and B2, Fig. 1) were drilled just above and below the midway station in October 2002. 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 during drilling at 15-17 m depth in both boreholes.

The boreholes were equipped with inclinometer casings to allow terrain deformation to be measured. In November 2002 they were also fitted with thermistor chains to monitor ground temperature.

4.1 Deformation measurements

Lateral movements of the ground are measured by inserting an inclinometer in the borehole casings. The first survey establishes the initial profile of the casing and subsequent surveys reveal changes in the profile if ground movement occurs. Displacement profiles of this type are useful for determining the magnitude, direction, depth and rate of ground movement. The inclination is measured by two force-balanced servo-accelerometers: one for measuring tilt in the plane of the inclinometer wheels and the other for measuring tilt in the perpendicular plane. The measurement range of the inclinometer is 0°-30° and the whole system has a precision of +/- 0.15 mm m^{-1}.

4.2 Ground temperature measurements

As permafrost is a thermal phenomenon (ground temperature <0°C, regardless of ice content), long-term temperature measurements in boreholes are the most reliable means of determining the presence and thermal state of permafrost. Ground temperature can be monitored at different depths and the thickness of the active layer (topmost layer of ground which melts in summer and which is potentially unstable) and of the permafrost body can thus be determined. In addition, it is possible to identify the presence of layers of unfrozen ground (taliks) in the permafrost. The data obtained helps to interpret lateral and vertical ground movements. Any thermal effects induced by the presence of a structure and by the artificial modification of the ground and of the snow cover in its surroundings can also be identified.

Ideally, boreholes should be drilled and equipped with thermistors at least one year before construction. This allows to establish the original thermal regime of the ground and then to monitor the effects of the curing of the concrete, a process which releases large amounts of heat and which can lead to melt of permafrost ice. As the boreholes were drilled in 2002, five years after initial construction, this was not possible. Measurements were however carried out in one borehole (B2, upper borehole) during the second construction phase of the midway station in 2003.

The temperature measurements were effected by the Swiss Federal Institute for Snow and Avalanche Research (SLF). Both boreholes were equipped with 12 YSI 44008 thermistors in November 2002. They were installed at 0.25, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0 and 24.0 m depth. The thermistors were calibrated in the cold laboratory using an ice-water mixture at 0°C. They have a precision of +/- 0.01 °C but in combination with a Campbell CR10X data logger their field precision is at least +/- 0.1°C. The data logger is powered by two 12 V batteries. Temperatures are measured hourly and the daily mean is registered in the data logger.

5. TECHNICAL SOLUTIONS

A long-term solution had to be found in 2003. The location of the midway station could not be altered due to the position of all the other pylons and the direction of the cable. The construction of a new, specially designed midway station was necessary so the concrete structure of the old station was destroyed and removed completely.

Several technical solutions were designed by Leitner AG in which criteria such as technical function, longevity, construction and maintenance costs were taken into account in various combinations. The final solution was chosen by the owner (Bergbahnen Grächen), the chairlift constructor (Leitner AG) and various experts involved.

5.1 Static system

The new structure had to be supported and positioned in such a manner that terrain movements (up to about 3 m in any direction) can be taken into account without incurring damage. The new shifting device is located entirely underground. Transverse girders transfer the load of the new midway station to two concrete supports. The distance between the axes of the two supports is 15 m. The total loads (dead and live load) are 2323 KN and 2452 KN respectively, which corresponds to a mean foundation pressure of approximately 55 N mm^{-2}. The ground plates are 1 m thick. The two concrete supports are carried by a 20 m long T-shaped girder (see Fig. 3). The girder has three point bearings (two upslope and one downslope), which can slide horizontally in order to allow displacement of the entire midway station. The two upslope bearings are fixed whereas the downslope bearing can move freely. The T-girder can be displaced or uplifted hydraulically and steel plates can be inserted. The point bearings can therefore be relieved and repositioned.

The decisive criteria for repositioning of the midway station are safe cable guidance and the limitation of forces to acceptable values. The indicators for the reliable running of the station are summarized in a control plan (according to the Swiss standards for continuous ropeways).

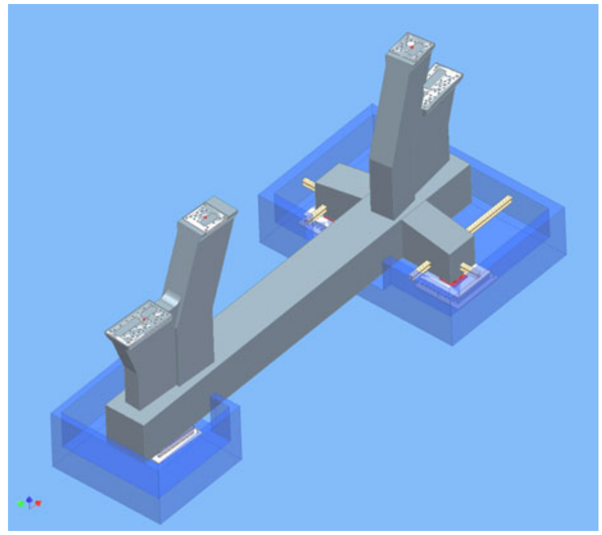

Fig. 3. Structure of the new midway station showing the two concrete supports (upslope support on the right), connected by the T-girder which rests on the 3 point bearings.

5.2 Substructure

The substructure of the new midway station consists of 1 m of reinforced earth consisting of soil material replacements with two layers of reinforcing nets. A layer of insulating material (Misapor) with an insulation coefficient of 0.091 W mK^{-1} was installed between the reinforced earth and the ground plate, in order to prevent transfer of hydration heat into the permafrost during the curing of the concrete (watertight B40/35 concrete) and any subsequent heat transfer between the structure and the ground.

6. MONITORING RESULTS

6.1 Deformation measurements

The deformation measurements in the boreholes were effected by Stump ForaTec AG. The initial surveys were made in October 2002 and repeat surveys in March, May, July and December 2003. The results of the surveys in borehole B1 (located in the more unstable terrain downslope of the midway station) are shown in Fig. 4 (cumulative displacement). The displacement of the ground is very irregular. There is not one sharply defined sliding plane but complex translational and rotational movements, probably due to a combination of the local geology and the presence of frozen ground.

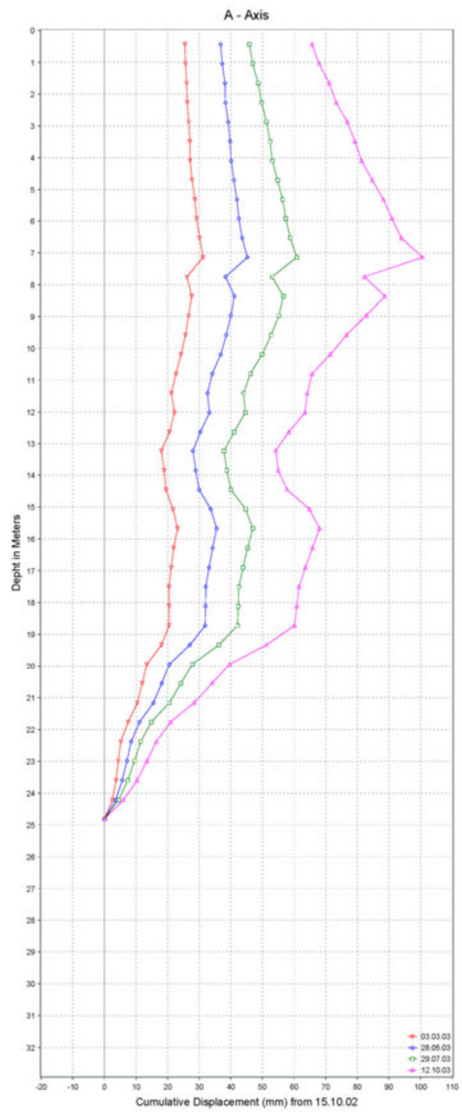

Fig. 4. Horizontal deformation (cumulative, in mm) in borehole B1 (3.3.2003, 28.5.2003, 29.7.2003, 12.10.2003, from left to right).

6.2 Temperature measurements

The temperature data indicate that the thermal regime of the ground is of a very particular nature: whereas the active layer in the lower borehole B1 is almost 8 m thick and the ground is permanently frozen to the base of the borehole, the upper borehole B2 has a 22 m unfrozen talik, below which the ground is frozen. Neither borehole reaches the base of the permafrost body (Fig. 5).

The effects of the thermal disturbance caused by construction work in 2003 can be seen in Fig. 5, where the overall mean temperature in both boreholes is shown (for 7.11.2002 to 16.8.2004) and the mean values for the period 7th November to 16th July in 2002-2003 (before construction) and 2003-2004 (after construction) respectively. In both boreholes the ground was warmer after construction, below about 4 m depth. In B1 the permafrost table was about 0.5 m and in B2 1.0 m lower than before. In addition, after construction the temperature curve comes very close to 0°C at 15 m depth in B1.

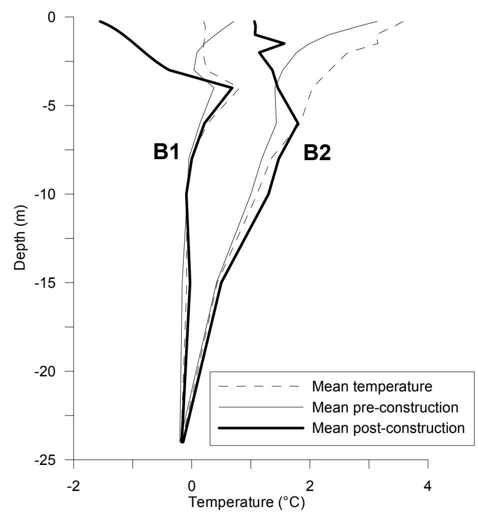

Fig. 5. Mean vertical temperature profiles in boreholes B1 and B2, and mean temperatures before and after construction of the new midway station for the period November 7th to July 16th in 2002-2003 and in 2003-2004 respectively.

7. DISCUSSION

The borehole temperatures clearly indicate that the thermal regime of the ground has been modified artificially by the removal and addition of ground material, the curing of concrete without any underlying insulation and general disturbance caused by the presence of large excavations in summer (in particular during the exceptionally hot summer 2003). It is difficult to predict the evolution of the permafrost temperatures and ice content at this site in the future. Unfortunately the ice content of the permafrost is not known, so it is not possible to foresee how much settlement and deformation could actually occur. The general evolution of the permafrost here now strongly depends on the duration of the snow cover, snow depth in winter, air temperature and ground water content.

Until present the terrain deformations have occurred in a continuous manner and not abruptly, implying that repositioning of the new midway station can be planned in advance. It has not yet been necessary to reposition the station because the position of the cable entering and exiting the station at all 4 points has remained practically unchanged.

8. CONCLUSIONS

The midway station of the chairlift in Grächen is the first known case in the Swiss Alps of a large concrete structure which had to be entirely rebuilt due to stability problems induced by rapid permafrost creep and settlement. The case illustrates the necessity of undertaking geotechnical investigations before construction in potentially problematic terrain and of developing appropriate technical solutions in advance (e.g. Steiner et al. 1996, Hamre et al. 2000). In the present case the solution found appears to be ideal for the problematic geotechnical site characteristics. Geotechnical monitoring at the site will be pursued to allow detection of any further modifications of temperature or stability which could have an influence on the stability of the structure.

9. ACKNOWLEDGEMENTS

Stefan Margreth and Walter Ammann are thanked for carefully reading the manuscript and making constructive suggestions for improvement.

10. REFERENCES

Hamre D., McCarty D.K., Long E. L., Yarmak E., 2000. Ice Engineering for Rock Glaciers. In Proceedings of the International Snow Science Workshop ISSW, October 1st-6th, Big Sky, Montana. p. 433-438.

Keller F., Frauenfelder R., Gardaz J.-M., Hoelzle M., Kneisel C., Lugon R., Phillips M., Reynard E., Wenker L., 1998. Permafrost Map of Switzerland. In Proceedings of the Seventh International Conference on Permfrost, 23-27 June 1998, Yellowknife, Canada. Eds. Lewkowicz A., Allard M. Collection Nordicana. p. 557-562.

Phillips M., Margreth S., Stoffel L., Ammann W.J., 2003. Development and testing of Swiss guidelines for the construction of snow-supporting structures in creeping alpine permafrost terrain. Proceedings of the 12th Panamerican Conference on Soil Mechanics and Geotechnical Engineering, MIT Boston, June 2003. Vol. 2, 2603-2610. Eds. P.J. Culligan, H.H. Einstein, A.J. Whittle.

Steiner W., Keusen H.-R., Graber U. (1996). Construction in Rock at 3550 meters elevation (Jungfraujoch Switzerland). Eurock ’96.

Stoffel L., 1995. Bautechnische Grundlagen für das Erstellen von Lawinenverbauungen im alpinen Permafrost. Report No. 52, Swiss Federal Institute for Snow and Avalanche Research SLF, Davos.