The Mattertal and Zermatt Railway and Funicular Companies as Construction Pioneers in Mountain Permafrost of the Swiss Alps

[1] **Christen Baumann,** [2] **Willi In-Albon,** [3] **Lorenz King**

[1] CEO Zermatt Bergbahnen; [2] Leiter Infrastruktur Matterhorn Gotthard Bahn, Brig;
[3] Permafrost Monitoring Research Group, Justus Liebig University Giessen, Germany

Zermatt is a touristic centre in the Alps with all together 14,000 beds and more than 1.8 million official overnight stays per year (cp. location map to the right). The necessary infrastructure consists of installations that often reach into permafrost areas, from the sporadic zone at about 2600 meters up to the continuous permafrost zone above 3400 meters a.s.l. The surrounding high mountain ranges often reach above 4000 meters a.s.l., and this results in a dry and sunny climate with a high glacier equilibrium line. The unglaciated permafrost areas thus have a large vertical extension.

The infrastructure erected in the permafrost areas consists of: (a) hotels, restaurants, mountain huts; (b) station buildings of railways, funiculars, ski lifts; (c) other related constructions as pylons, tunnels, elevators, shelters for vehicles, workshops etc., and (d) subsurface water pipes for drinking water and artificial snowing of ski-runs, sewage, communication and electricity lines. Engineering geologists as well as the responsible persons for this infrastructure have become increasingly interested in the distribution and the characteristics of permafrost in the Zermatt area, as there have been problems due to permafrost degradation. Good knowledge of the permafrost environments, suitable construction designs and careful maintenance of installations is compulsory in this fragile ecosystems strongly influenced by climate warming.

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The Matterhorn Gotthard Bahn

The Matterhorn Gotthard Bahn (fusion of Brig-Visp-Zermatt-Bahn and Furka Oberalp-Bahn in 2003) leads from the Rhone valley through the deeply entrenched Matter valley to Zermatt, located at 1605 meters a.s.l. It is in some steeper sections a cogwheel railway. Along its track, natural hazards range from avalanches to mudflows and rock-falls. Some of these hazards may be connected with permafrost degradation due to climatic warming, resulting in a rise of the lower permafrost limit in the steep upper slopes of the valley. The railway track from Visp to Zermatt leads over 9 bridges and through 16 tunnels and galleries, many of them have been built as protection devices against the mentioned hazards, ensuring safety for the traffic.

Cogwheel-railway Gornergrat Bahn

The mountain crest Gornergrat (about 3100 m a.s.l.) may be reached from Zermatt by a 9.3 km long cogwheel-railway. It went into operation on August 20, 1898 and was the first electric cogwheel-railway in Switzerland. The first ski season in Zermatt was as early as 1927/28. Due to the climatic conditions, permafrost has developed naturally in the railway dam of the uppermost part (Figure 2).

Figure 1: The Kulmhotel Gornergrat was opened in 1910, above the top-station of the Gornergratbahn. In the year 1985 two astronomic observatories were added to the northern and southern towers, built on permafrost. To the right, a funicular constructed in 1957 leads to Hohtälli (3286 m) and Stockhorn (3407 m). Ice-filled bedrock joints at the construction sites prove the existence of permafrost, there. The prominent peak of Matterhorn (4478 m) is seen in the background.

Funicular Kleinmatterhorn

This funicular reaches up to 3820 m a.s.l. and was constructed in 1981. It arrives at a tunnel cut in the northern wall of the mountain top (cp. Figure 3). At its southern exit the ski run starts down to Zermatt.

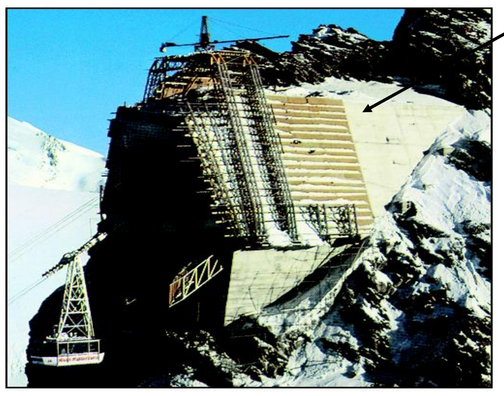

Figure 3: Construction of the tunnel entrance to the peak station Kleinmatterhorn at its northern rock-wall (3820 m a.s.l.)

Bedrock temperatures as low as –12°C were reported during the construction (Keusen & Haeberli 1983). The same temperature was measured in the near surface rock material of the northern rockwall below the mountain top in a diploma study. The measured MAAT here, however, was –8°C in the years 1998/99, and bedrock temperatures have risen even to –3 to –2°C at several localities in the tunnel area. This is due to heating and to the heat brought into the tunnel by the more than 490,000 visitors per year. Additional heat is created by almost 70,000 elevator movements per year, transporting tourists to the mountain top. In summer 1997, meltwater created problems when re-freezing in the elevator shaft (King et al. 1998). In view of the considerable temperature rise in the bedrock, temperatures are monitored since 1998 at ten places in order to take countermeasures if necessary.

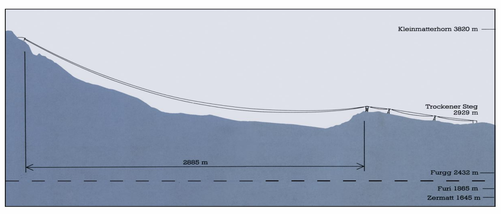

Figure 4: The funicular Kleinmatterhorn leads from areas of discontinuous permafrost at Trockener Steg (2929 m) to continuous permafrost (3820 m). Between the third mast and the mountain top, the construction spans a horizontal distance of 2885 meters!

Figure 5: Kleinmatterhorn (3883 m a.s.l.) with funicular pylons at 3012 m and 3025 m a.s.l, the pylon in the foreground has been constructed on bedrock covered with ice-rich moraines. The ground-ice has completely disappeared during the last 20 years. The insertion shows the tunnel cut through the mountain top.

Funicular Furggsattel

This funicular, constructed in 2002 is just another example of many further installations erected on permafrost. It went into operation in november 2003.

Figure 6: The top station Furggsattel is anchored deep into the perennially frozen bedrock. It is located at the mountain crest (background) that also marks the Swiss-Italian border.

Figure 7: Same location as above, during construction in 2003.

Figure 8: The new Furggsattel (6 persons) glacier chairlift leads from Trockener Steg (2929 m a.s.l.) to the crest of Furggsattel at 3351 m a.s.l. It guarantees year-round skiing, as the ski-run leads mainly over the glacier Oberer Theodul. Twelve masts out of 17 have been constructed on the glacier with special devices for adjustment to the glacier movement. The building in the foreground receives the passengers from Furgg (2432 m).

Figure 2: The Gornergratbahn (GGB) in its uppermost section at an altitude of about 3000 meters a.s.l. Discontinuous permafrost is encountered here, 700 meters above the tree-line. The panorama shows (from left to right) the mountain peaks Matterhorn (4477 m), Dent Blanche (4357 m), Ober Gabelhorn (4063 m), Zinalrothorn (4221 m) and Weisshorn (4505 m)

Zermatt Bergbahnen

The Zermatt Bergbahnen constructed a large number of funiculars and chairlifts during the last 50 years. Permafrost has been encountered e.g. at the stations of Stockhorn (3407 m), Hohtälli (3286 m), Rote Nase (3250 m), Furggsattel (3351 m), and last but not least Kleinmatterhorn (3820 m). These constructions always demanded special precautions in order to cope with permafrost. During the last years, most of the installations were upgraded to modern standards, with new funiculars, chairlifts, and other structures such as new masts, shelters for vehicles, and workshops, often built on permafrost.

Figure 9: The station Trockener Steg during construction phase in summer 2003 (cp. Figure 8).

Table 1 shows altitudes and mean annual temperatures (MAAT). Human activities as well as a further climatic warming will influence active layer processes, and may affect the foundations of installations. Particularly the pylons of the funiculars react most sensitive to the movement caused by permafrost creep or degradation, causing great hazards. Regular geodetic controls ensure safe traffic conditions.

Table 1: Examples of installations on permafrost in the Zermatt area, with altitudes and expected MAAT. Widespread permafrost has been encountered at all altitudes above 3300 meters a.s.l. At Stockhorn station, a permafrost thickness of about 170 meters is verified by deep drilling and longterm permafrost monitoring during the European project PACE (Permafrost And Climate Change).

Name (station)	Altitude (m a.s.l.)	MAAT (°C)
Kleinmatterhorn	3820	-7,2
Stockhorn	3407	-4,9
Furggsattel	3351	-4.6
Cogwheel-railway Gornergrat	3090	-3,0
Trockener Steg	2939	-2,2

Conclusion

Degradation of permafrost due to climatic change and the influence of human activities is a serious challenge to touristic installations. Scientists working in permafrost areas therefore have the duty to give the necessary information to the managers of these installations and the authorities, so that facilities built on permafrost can be properly maintained.

Further information and contacts:

www.bergbahnen.zermatt.ch
www.mgbahn.ch
www.gornergrat.ch
www.uni-giessen.de/akn