Long-Term Settlements of an Avalanche Gallery on Loose Soil

Walter Steiner
B+S AG, Bern, Switzerland. E-mail: w.steiner@bs-ing.ch

Michael Schulte
B+S AG, Bern, Switzerland, E-Mail: m.schulte@bs-ing.ch

Keywords: settlements, secondary settlements, silt, loosely deposited soil

ABSTRACT: An avalanche protection gallery built 1984 to 1985 on the Gotthardpass road in the central Swiss Alps suffered substantial settlement of several decimeters. The causes were determined by additional site investigations during 1987 utilizing the Marchetti Flat Dilatometer DMT (Steiner, 1994). Since construction 30 years have passed and the road and its structures have undergone a complete inspection and will be reconditioned. Within this long-term maintenance project the settlement behavior of the avalanche gallery has been reevaluated and the monitored settlements have been compared to the prediction from 1987. The settlement and deformations have followed a semi-logarithmic law with time, but differential settlements have changed. The value of the DMT measurements can be confirmed by these long-term measurements.

1 INTRODUCTION

The avalanche protection gallery "Nasse Kehle" on the Gotthardpass road, near Andermatt, in central Switzerland underwent substantial settlements and deformations since its construction in the years 1984 and 1985. The additional investigations carried out in 1987 with the flat dilatometer DMT and the experiences with these settlements were presented at the ASCE Conference on settlements at College Station (Steiner, 1994). Since construction nearly three decades have passed and changes have come also to the responsibility for the road network in Switzerland. The main national transfer roads (Nationalstrassen) are now under the jurisdiction of the Swiss Federal Government through the Federal Road Office (FEDRO). These roads will undergo in sections a systematic complete overhaul.

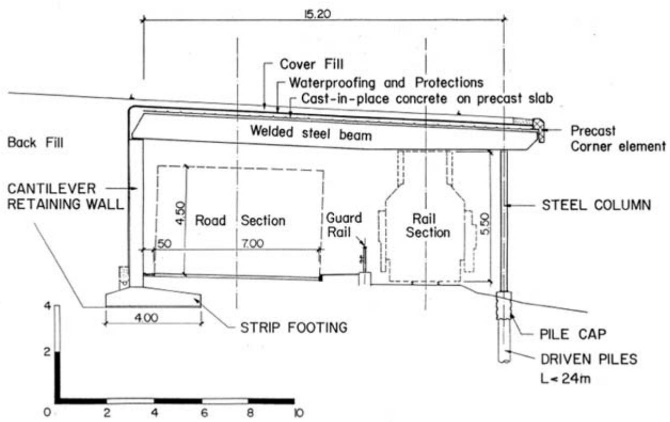

Fig. 1. Cross section of avalanche protection gallery.

Fig. 2. View of the southern end of the avalanche gallery in 2011 with retaining wall on left with heads of tieback.

2 THE AVALANCHE GALLERY

2.1 *The structure*

The structure of the avalanche gallery, shown in cross section in Fig. 1, is formed by a cantilever retaining wall on the mountainside and columns supported by driven piles on the side of the valley. Steel beams (Fig. 2) span over both railroad and road. Between the steel beams precast element covered by cast-in-place concrete complete the roof. The concrete slab is covered by a membrane (Fig. 1) overlain by a protective layer.

The avalanche gallery (Fig. 2) is 250 m long and joined in the north to an older gallery of 50 m length and to the 80 m long Tunnel Urnerloch, one of the oldest tunnels in Switzerland, left on Fig. 4 and passing through the rock ridge shown on the right of Fig. 5. To the south the valley widens to the plain of Andermatt, a glacial depression filled with up to 300 m of sediments. To the north (Fig. 5) the valley is closed with rock ridges that drop only a few meters below the level of the road and form a natural dam of the former lake.

The separation of the back wall by a dilation joint between two segments of the gallery is shown on Fig. 6; there the longitudinal differential settlement between the two sections of the retaining wall is clearly visible by the different inclination. Dilation joints of 50 mm were placed every 25 m, the reinforced foundation beam runs continuously below the wall.

Fig. 3. Avalanche gallery seen from the south towards the ridge above the Schöllenen gorge in 2011.

Fig. 4. Avalanche protection gallery as seen from the roof of the northern railway gallery founded on rock near natural and artificial weir above the Schöllenen gorge.

Fig. 5. View over the roof of the avalanche protection gallery with the rock ridges at the gorge to the north.

Fig. 6. Retaining wall with open joint due to differential settlement and heads of tiebacks placed.

Below the steel beams the heads of tiebacks (Fig. 6; Fig. 1) placed in the year 2002 are visible. The weathering of the outside concrete is visible on the photographs.

2.2 *Underground conditions*

2.2.1 *General subsoil conditions*

The Urseren valley at Andermatt is a depression formed by glaciation in the sedimentary and metamorphic rocks wedged between two intrusive bodies in the central Alps. During the various phases of glaciation, rock was eroded down to 300 meters from the present valley surface. After the last Ice Age this depression became a lake with an overflow controlled by the rock ridge to the north of the structure (Fig. 5) at 1421 m elevation (Fig. 7). River transported sediments from the southwest filled the lake and were segregated. At the south-western shore coarse material (gravel and cobbles) was deposited. The fine fraction, formed primarily by mica, i.e. soil platelets, was transported into the lake where the sediments slowly deposited and probably formed

a loose honey-comb structure, in particular in bays in the rock wall to the north. Steiner (1994) described geologic setting and ground conditions in greater detail.
Once the postglacial lake was filled with sediments the river deposited sand and gravel (Fig. 7) that form the upper 5 to 10 meters of the subsoil.

2.2.2 *Soil conditions below the foundation*

The subsoil conditions below the gallery consist of 10 meters of fluvial gravel and sands underlain below the retaining wall by 43 m of loose silt and sandy silt. The steeply dipping (Fig. **7**) bedrock surface had been encountered at elevation 1378.5 m. The depth of the sediments below the columns is not known.

Behind the avalanche gallery slope debris had accumulated. The zone between retaining wall and slope debris was backfilled. At the southern end of the gallery a retaining dam was placed that deflects the avalanche over the gallery away from the portal. Backfill and dam created a surcharge on the subsoil their effect spreads laterally.

3 PERFORMANCE OF THE STRUCTURE

3.1 *General performance of the structure*

During the 30 years since construction the structure has been exposed to varying weather conditions and to conditions from traffic: exhaust fumes and deicing salt. The concrete surface was coated to avoid the penetration of chlorides into the concrete and create corrosion with the reinforcement. The steel beams and steel columns received a new coating after 30 years.

The inspection revealed that the structure per se had not suffered substantial damage. The concrete back wall did not show cracks. The retaining wall with the joints in the wall and continuous footing proved sufficiently flexible to accommodate the differential settlements.

3.2 *Flood wall on the river side*

A few years after construction of the avalanche gallery a major flood had occurred and the river nearly reached the level of the road. In order to prevent flooding in case of future catastrophic events a floodwall was constructed incorporating columns (Fig. 2).

3.3 *Posttensioned anchors placed in 2002*

In 2002 additional tiebacks had been placed in the retaining wall to support loads based on modified load requirements (Fig. 6, Fig. 7).

3.4 *Measurements of settlements and deformation*

Settlements continued and were monitored over the three decades since the gallery was built. However, measuring techniques changed with time. The settlement measurements, from 1984 until 1990, were carried out by leveling the height of reference bolts at the base of the retaining wall and on the pile caps below the columns. The inclination of the retaining wall was monitored by a plumb line from the top of the retaining wall; this required the use of a lift to access the upper reference point.

Later, during the 1990’s, surveying by Laser theodolites became available and displacements, not only settlement, can now be measured more easily.

The measurements obtained by different techniques and different teams had to be fitted together in order to obtain a complete picture of the settlements and deformations that the structure had undergone during three decades.

3.4.1 *Observed settlements*

The compiled settlements along the back retaining wall are presented in Fig. 8. and for the columns in Fig. 9. The first measurements of the settlement of the retaining wall were carried out on May 29, 1985, when only the northern part of the wall was complete. The second measurements presented from October 31, 1985 indicate settlements of the southern end of 120 mm and the different behavior of this part of the construction. At the end of construction settlement had reached 350 mm. These observations led then to the decision to carry out additional site investigation (Steiner, 1994) applying the flat dilatometer DMT.

Settlements continued as extrapolated and the settlements reached 550 mm during 2012, an increase by 50 percent since end of construction, equivalent to the predictions carried out in 1988. Settlements of the footings of the columns have reached 300 mm in 2012 (Fig. 9) and had nearly doubled since the last measurements after construction.

The settlement below the piles was relatively larger after 1990 than the settlements below the retaining wall. Based on these observations one has to assume that the stress redistribution in the deeper parts of the sediments has taken substantially longer. These measured settlements now correspond better to the settlements computed by elastic analyses. The analyses carried out in 1987 had resulted in an overprediction by 50 % of the measured settlement, this difference has now decreased.

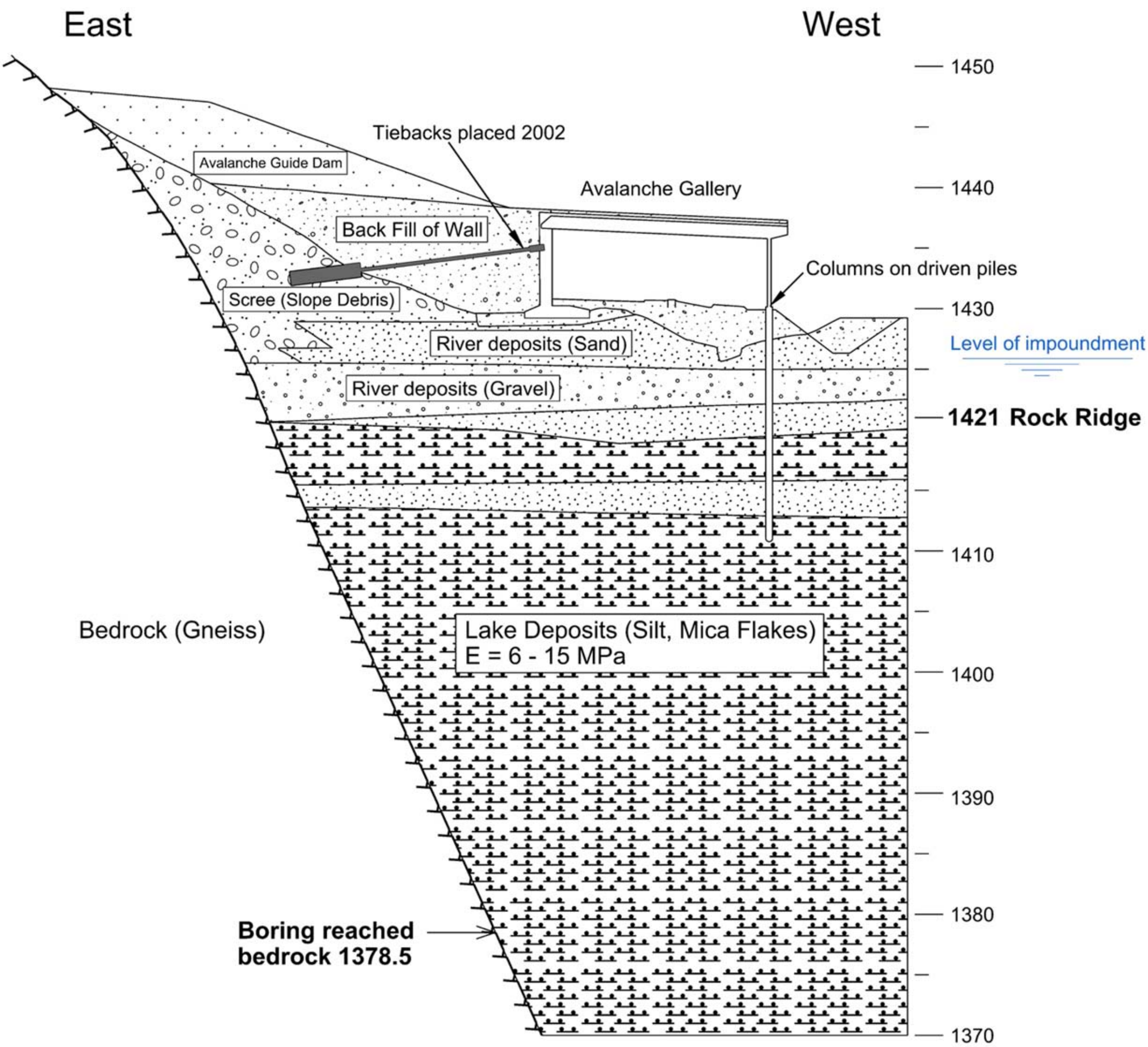

Fig. 7. Cross section with conditions of underground and backfilling at the southern end of the avalanche gallery.

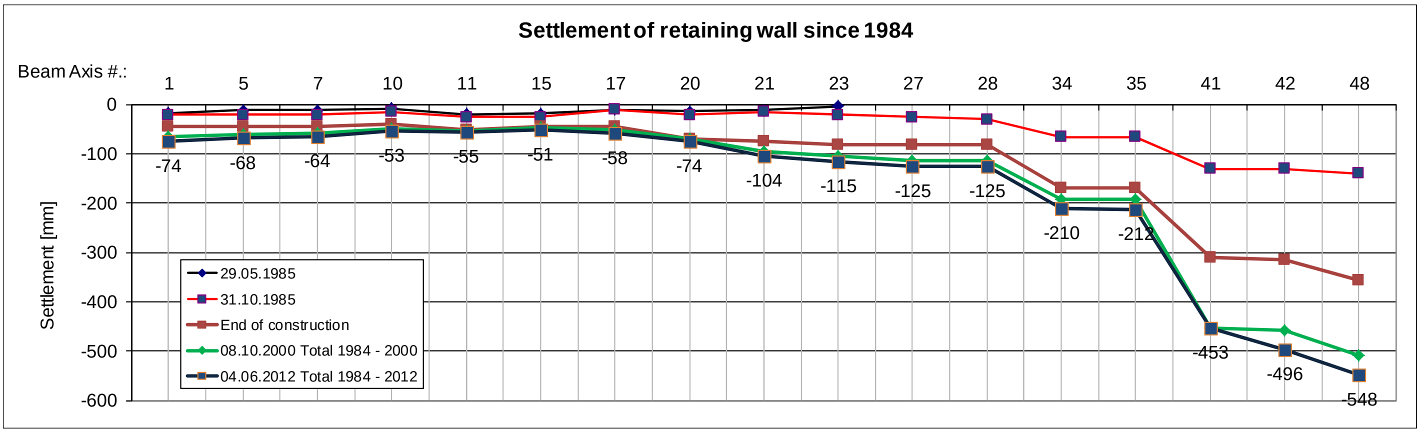

Fig. 8. Settlements of back wall of avalanche gallery from north to south, from 1984 until 2012

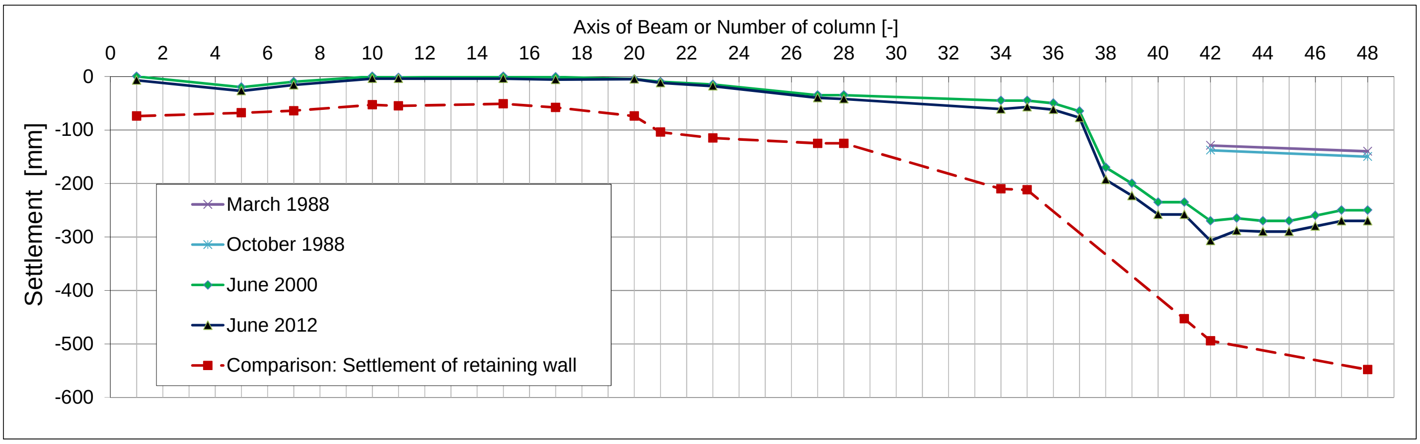

Fig. 9. Settlement of columns from 1986 until 2012 and comparison with retaining wall.

3.5 *Horizontal deformations*

Horizontal deformations were more difficult to monitor. Initially in 1985 the deviations from a plumb line along the back wall were monitored, which indicated essentially no tilt of the back wall or in the maximum of one to two centimeters over 6 meters height, i.e. 1/500 tilt.

3.5.1 *Measured horizontal deformations*

With the laser measurements the resulting horizontal displacements could be directly obtained. The observed horizontal displacements were in the range of a few dozen millimeters, the retaining wall thus essentially continued to settle vertically. The total horizontal deformations could not be determined.

3.5.2 *Observation of tieback forces.*

In 2002 tiebacks were placed every 3 m in the upper part of the retaining wall. The development of the forces has been observed with seven force measurement cells. These measurements indicate a decrease of the forces with time (Table 1).
The tieback forces have generally decreased with time, this means that the retaining wall has not moved away from the slope, but has tilted slightly towards the fill, eastwards.

Table 1. Development of tieback forces

Tieback	Force	2002	Force	2005	Force	2007
Number	kN	%	kN	%	kN	%
1	254	100%	223	88%	218	86%
18	247	100%	170	69%	167	68%
38	255	100%	189	74%	185	73%
53	300	100%	280	93%	276	92%
62	353	100%	335	95%	329	93%
77	352	100%	332	94%	327	93%
86	250	100%	172	69%	158	63%

This corresponds also to the expected soil movement as the backfill of the retaining wall is the surcharge that causes the settlement and the settlement must be largest beneath the fill. The southernmost tieback (#86) shows the largest decrease in force. The length of the tiebacks is variable between 10 and 20 m and the shortening of the cables leads to a reduction of the anchor forces in the elastic range of the steel. The posttensioning strain lies below the elastic strain limit of approx. 0.2 % of the steel cables, thus the strain caused by stress reduction is estimated 0.08 %. Displacements on the top of the back wall (Fig. 7) are estimated as being in the order of 8 to 20 mm towards the back fill; these displacements are being judged, to be caused by the larger settlement of the ground below the backfill behind the retaining wall.

4 EVALUATION OF SETTLEMENTS

4.1 *Development of settlements*

The observed settlements in 2012 have been compared to the predictions made in 1987 for the year 2013 and they agree well. In section 48 settlements of 550 mm were predicted, increased from 450 mm in 1990. In section 42 settlements of 460 mm were measured corresponding to the earlier predictions.

4.2 *Evaluation of settlements for wall*

The observed settlements at the southern end in sections 42 and 48 have been analyzed and used to predict future settlements of the retaining wall (Fig. 10) in a logarithmic scale with time. The year 2012 corresponds to about 10000 days and 40000 days to the year 2094, roughly a century after construction. For 2094 a settlement of 720 mm is predicted for section 48, corresponding to another increment of 170 mm from 2012.

In section 42 additional settlements of 150 mm are predicted, thus reaching about 610 mm in 2094.

For the two sections 42 and 48 the following correlations were determined for the settlement of the wall:

$$\text{Settlement (42)} = -215.5 * \log_{10}(\text{Days}) + 382 \text{ mm} \quad (1)$$

$$\text{Settlement (48)} = -256.6 * \log_{10}(\text{Days}) + 452 \text{ mm} \quad (2)$$

In section 48 the layer of silt is 44 m thick (Fig. 7) and in section 42 estimated as about 36 m. This results in a coefficient of secondary consolidation $c_s = 0.6$ % per log cycle of days.

The constant value corresponds to the initial settlements and agrees to the ones that were computed during construction with the moduli obtained from DMT in 1987.

4.3 *Evaluation of settlement for columns 42 and 48*

The settlement behavior was also evaluated for columns 42 and 48 that illustrate the width and depth effect of the load (Fig. 10)

For the two sections 42 and 48 the following correlations were determined for the settlement of the columns:

$$\text{Column (42)} = -188.4 * \log_{10}(\text{Days}) + 452 \text{ mm} \quad (3)$$

$$\text{Column (48)} = -130.6 * \log_{10}(\text{Days}) + 261 \text{ mm} \quad (4)$$

The rates of secondary settlement are smaller for the columns than below the retaining wall.

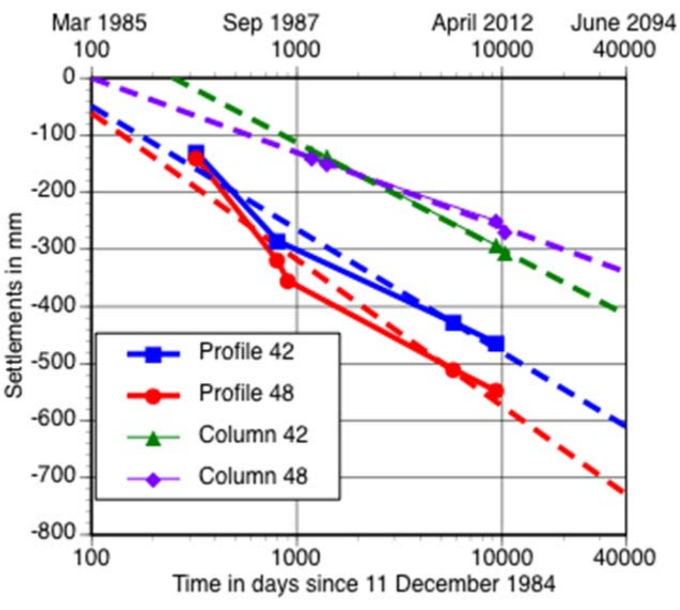

Fig. 10: Observed settlements of back wall and columns in section 42 and 48 and extrapolation.

5 CONCLUSIONS

The use of the flat dilatometer DMT in 1987 has greatly assisted in the explanation of the causes of the large settlements. The continued monitoring over 30 years has given new insights in the settlement behavior of subsoil and the structure. The structure had been designed with dilation joints in the back retaining wall such that the deformations could be accommodated by the structure without any further damage.

In retrospect one has to conclude that the large settlements would have been difficult to avoid or preventive measures, like preloading to be taken. The secondary settlement due to rearrangement of the loosely deposited mica flakes are to slow.

Load with a rather small foot print and not extreme height had a quite far reaching effect. Such deposits may also be present in other valleys in the Alps or other mountain ranges and this case history may furnish some information to other cases where fills may experience substantial settlement.

6 ACKNOWLEDGMENTS

The authors thank the Swiss Federal Road Office (FEDRO), *Bundesamt für Strassen ASTRA*, subsidiary Zofingen for the permission to publish the experience. They also thank to their colleagues of the Engineering Joint Venture for their support and collaboration.

7 REFERENCES

Steiner, W. (1994). “Settlement of an avalanche protection gallery founded on loose sandy Silt”. *Proc. Settlement '94, ASCE Conference on Vertical and Horizontal Deformations of Foundations and Embankments*, New York, 207-221.