The Impact of the Sunniberg Bridge on Structural Engineering, Switzerland

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Abstract

The Sunniberg Bridge close to the village of Klosters, Switzerland, was completed in 1998 and commissioned in 2005, after having served as an access to the adjacent tunnel construction site. It has gained worldwide recognition as a symbol for technical excellence and a representative of new bridge types. The successors of the designer and the owner representative at that time retell the history of authorship, design, planning, execution, commissioning and recognition from an outsider's perspective and assess the structural behaviour in the first ten years. The impacts of the bridge on the development of bridge types, on the prestige of the various parties involved and the influence and the perception of erection costs are assessed. Finally, some issues of durability and maintenance that will occupy the responsible authorities in future are mentioned.

Keywords: bridge type; curved extradosed bridge; integral bridge; durability; inspectability.

Introduction

The Sunniberg Bridge has been mentioned in this journal on various occasions, as a novel structure close to completion[1] and as an award winner.[2] It got highly recognised internationally as a symbol of technical excellence and gave inspiration to a new generation of engineers. The authors of this article have neither been involved in the planning nor in the maintenance of the Sunniberg Bridge; however, as the successors of the main persons involved and authors of the *SEI* article of 1997,[1] they have taken the opportunity to represent the next generation of engineers, showing a high appreciation for the achievements of Prof. Em. Dr. Christian Menn as the conceptual designer and Heinrich Figi as the owner representative. Both are still active in some capacity or other, but are no longer responsible for the structure.

History

Planning

After a period of 18 years of planning, the project for three by-pass roads for the villages Klosters, Saas and Küblis was approved by the cantonal government in 1993 and 1994 and by the Federal Assembly in 1995. The last of these three by-pass roads is still under construction, and was planned to be commissioned in 2015. The Sunniberg Bridge is the best visible structure of the whole project.

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Construction

The building activities of the Sunniberg Bridge started in 1996 and lasted for 2.5 years. On 24 June 1998, the cantilevers of piers P3 and P4 were tied by the last concreting batch. The bridge was completed in autumn 1998[3] and was ready for access to the construction site of the adjacent Gotschna Tunnel. A total of 250 000 m^3 of excavation material was transported over the bridge, which can be considered as an exceptionally beautiful construction access road (*Fig. 1*). The settled construction cost amounted to CHF 20.0 Mio or 26.8 Mio US$ (exchange rate at completion).

Natural Hazards

Between 21 and 23 August 2005, the whole Alpine region experienced heavy rainfalls that led to floods. The Landquart River overtopped the banks and meandered across the whole valley floor. The Drostobel Creek coming from the Southern flank had always run along the foundations of piers P4 and P3 and brought extreme quantities of water as well. Both together eroded the stream sediments of the southern bank and uncovered the foundation of pier P3 that was situated more than 10 m above the river level (*Fig. 2*). Finally, the upper 2.5 m of the 16 m long pile shafts was exposed (*Fig. 3*). The damage to the community of Klosters/Serneus reached about CHF 40 Mio (52 Mio US$). In the aftermath, the return period of the Landquart flooding was estimated as 50–100 years.[4]

Fortunately, no settlements could be observed and the bridge could be opened to traffic as planned, as an integral part of the by-pass road of the village of Klosters. The opening ceremony took place on 9 December 2005 with the Federal Council responsible for traffic as the godfather and the Prince of Wales, who often spent skiing holidays in Klosters, as a special guest.

Ownership

In November 2004, the Swiss voters agreed on a new distribution of duties and financial loads among the Confederation and the states (cantons). As a consequence, the ownership of the national motorway network, which had been constructed by the cantons with substantial financial support from the Confederation, was transferred to the Confederation by the end of 2007. Although the road from Landquart to Davos has only two lanes, it belongs to the national network and therefore ownership of the Sunniberg Bridge was transferred as well. Since January 2008, only maintenance remains with the local authorities, commissioned by the Federal Road Office (FEDRO).

Awards

Already during construction and before being opened to traffic, the Sunniberg Bridge gained national and international recognition.

Fig. 1: Sunniberg Bridge after completion in fall 1998[3]

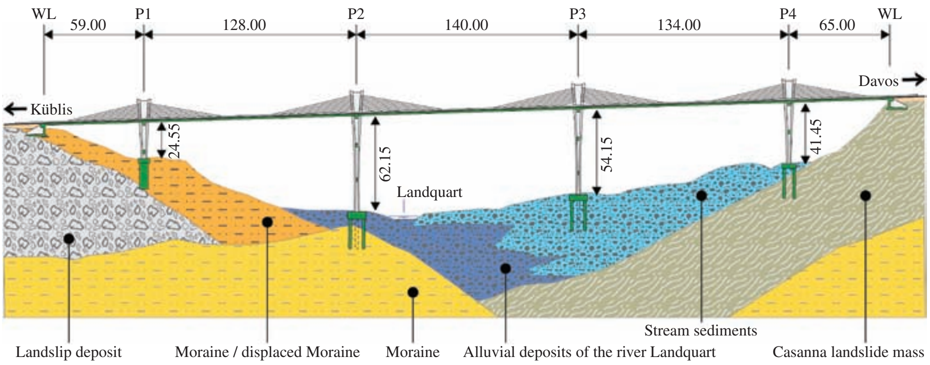

Fig. 2: Elevation with geology[3] *(Units: [m])*

For the eighth round in 2002, the competition was extended to structures in Austria and Switzerland. The high-ranked jury chaired by Prof. Dr.-Ing. Fritz Wenzel chose the Sunniberg Bridge as the winner of that round on 6 March 2003 and the ceremony took place on 9 April 2003.[5]

To commemorate 10 years of *SEI*, the editors of the journal started a survey among the readers to identify the most favourite structure published in *SEI* from 1991 to 2000. The Sunniberg Bridge was ranked no. 5.[6]

At the Annual Meetings of IABSE before the Malta Conference in 2001, the Outstanding Structure Award was handed over to Christian Menn, the designer, and Dialma Bänziger, senior partner of the engineering firm, who was in charge of the detailed design.[2] On 15 September 2001, the plaque unveiling ceremony took place at the bridge (*Fig. 4*).

In the same year, the Sunniberg Bridge received the architecture award "Gute Bauten Graubünden", promoted among others by the Cultural Heritage Association of the Canton of Grisons.

Since 1988, the publishing house Ernst & Sohn has been awarding an 'Engineer Prize' to an engineering structure in Germany every two years.

A New Bridge Type?

In the following section, the question whether Menn has promoted or even established a new bridge type in designing the Sunniberg Bridge, will be discussed.

Different parties involved in bridge innovation have different approaches: an ingenious bridge designer does not

Fig. 3: Uncovered pile cap of pier P3

Fig. 4: Plaque unveiling ceremony. From left to right: Christian Menn, Klaus Ostenfeld (former President of IABSE), Dialma Bänziger

think in categories of bridge types, but looks for the most appropriate technical solution for the given task. A university professor should have an overview on feasible bridge types, and their advantages and limits. Based on a broad knowledge, he may anticipate in what direction the development may go or even promote it. An art historian or a historian in architecture or rather engineering, finally, may identify bridge types retrospectively, identify pioneers and epigones and assign authorship accordingly. But what counts for authorship?

- An idea brought to paper and hidden in a safe?
- A proposal raised in a conference or published in a paper?
- A contribution in a design competition or a tender, either ranked second-tier or even ranked first but never executed?
- An executed project that proves to be feasible and economical or, at least, affordable?

Engineers tend to the last, but, obviously, this is the biggest hurdle and depends on many issues over which an inventor or designer has no control. With regard to the Sunniberg Bridge, all aspects of authorship can be assigned. It can also be shown, however, that only the realization of an idea covers all relevant aspects and requires the most competence.

Extradosed Bridges

Term

The term "extradosed bridge" is normally traced back to Jacques Mathivat[7] who defined this type and proposed it for the Arret-Darre Viaduct in 1988, which, however, was finally built with a more conventional system. Mathivat positioned extradosed bridges between cantilevered bridges with internal prestress below the running surface and cable-stayed bridges with a pylon height to span ratio of about 1/5 and maximum cable stresses of 40–45% of ultimate strength. For extradosed bridges, he proposed a pylon height to span ratio of about 1/15 and a maximum cable stress of 65% of ultimate strength like in internal prestress. He also referred to the Ganter Bridge by Menn (*Fig. 5*), but did not consider it as an extradosed bridge, because the tendons—although shaped the same way—are encased in concrete and cannot be replaced. He stated that on the Ganter Bridge, the concrete had been placed after stressing of the cables, and by this showed that he ignored why the cables had been encased, namely to follow the horizontal curvature of the bridge.[7] Bridges with tendons above the running surface and encased in concrete are also called "fin plate bridges"[8], "finback bridges"[7] or "finback-bridges".[9]

The term "extradosed bridge" was adopted from the French "pont extradossé", not only in English but also in Spanish and other Romanic languages, but not in German. As a consequence, the authors of papers on the Sunniberg Bridge did not call it an extradosed bridge, but a cable-stayed bridge, also in publications in English.[1,10] According to the first criterion formulated by Mathivat[7] however, the Sunniberg Bridge with a pylon height to span ratio of 15/140 m = 1/9.3 is an extradosed bridge, even if according to Baumann[11] the tendons have only been stressed to a level not to exceed 50% of ultimate strength in the serviceability stage. It is not the first extradosed bridge ever built; the Odawara Blue Bridge completed in 1994, and other bridges[12,13] were already based on the concept of Mathivat, in Japan.

Precursory Schemes

Christian Menn proposed an extradosed bridge concept in his presentation at the first session of the IABSE Symposium Zurich as early as September 1979[14] and called it "cable-stayed ribbon".

Fig. 5: Ganter Bridge by Christian Menn

He stated: "… often new ideas reach a break-through only with large delay, and for large structures it can be found again and again that extrapolations are preferred to innovations. As an example, traditional free-cantilevering beam bridges have been proposed for spans up to 300 m, although progress shows that in a span range beyond 200 m cable-stayed bridges with prestressed concrete are more economical. [...] For a very high bridge, a cable-stayed ribbon on massive stiff pylons would be superior to a traditional beam bridge with slender piers sensitive to wind and a girder with constant depth" (translated from German).

The sketch he added was of a fan type cable-stayed scheme with a trapezoidal hole in the pylon to have access to the anchorages of all tendons (*Fig. 6*).

In spring 1979, Santiago Calatrava had completed his studies in Civil Engineering at ETH Zurich with a thesis on a bridge over the Acleta gorge close to Disentis in the Grisons, supervised by Menn. In summer 1979, he visited the Southern ramp of the Gotthard motorway where the construction of the Biaschina Viaduct was going on. He sketched his own ideas for the design of the bridge. In fall 1979, he started working as an assistant and doctoral student at the Architecture Department of ETH Zurich. As he states in Ref. [15], Menn asked him to provide sketches for a bridge on tall pylons to cross a deep valley, to be integrated in his presentation at the IABSE symposium mentioned earlier. The sketches in 1979 by Calatrava for all three tasks contained finback and extradosed solutions but were not published until 2004.[15] For that booklet, models were built and photographed to illustrate the designs (*Fig. 7*). Compared to the shape of the final design of the pylon of the Sunniberg Bridge, however, none of those proposals made a comparable aesthetic impression with regard

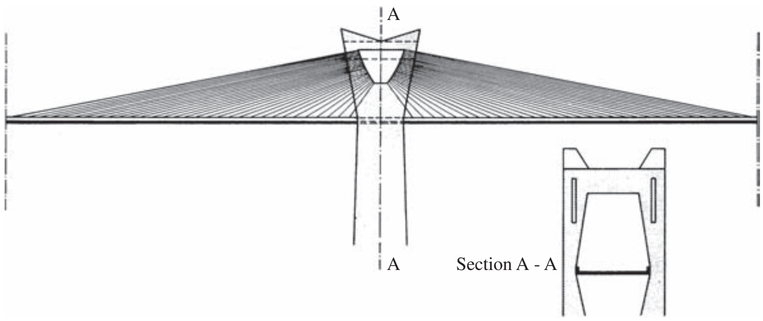

Fig. 6: Cable-stayed ribbon proposed by Menn in 1979[14]

(a) (b) (c)

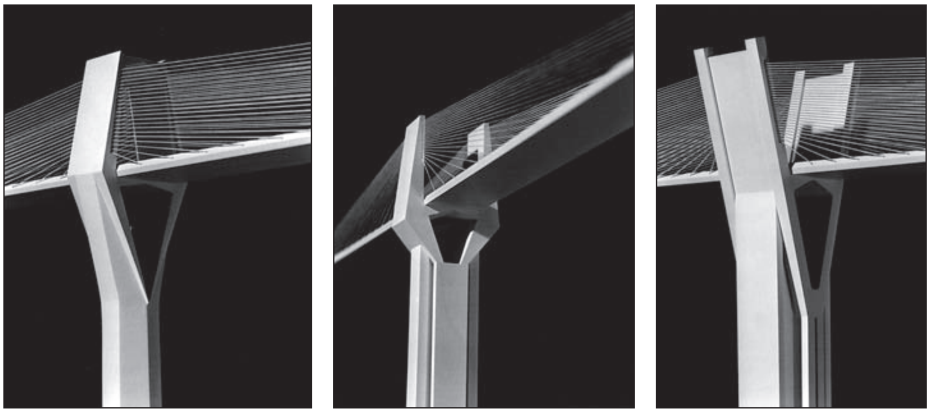

Fig. 7: Models of sketches by Calatrava[16]; (a) Biaschina Bridge, (b) and (c) variants for a bridge with tall pylon

to slenderness and detailing level (*Fig. 8*).

Curved Extradosed Bridges

Menn was not satisfied with the fin plate solution for the Ganter Bridge. As reported, he improved the concept for the Poya Bridge in Fribourg, again a bridge high above the valley where ordinary pylons would have increased the height of the structure even further. Being a member of the jury of the design competition in 1989[17] however, he had no opportunity to influence the submitted proposals.Nevertheless, he worked out and published a proposal on his own[18] that already looked quite similar to the later Sunniberg Bridge (*Fig. 9*). Although the Poya Bridge might have been straight in a plane, he slightly inclined the pylons transversally for aesthetic reasons.

In the Sunniberg project, the rules were less strict than in an anonymous design competition. Three engineering firms had been commissioned to study four different concepts and work out proposals. Again, Menn was a member of the judgement committee and none of these proposals could convince him. An architect and fellow juror encouraged him to come up with his own design. Menn's proposal was convincing not only for aesthetic reasons, but also because the larger spans had a significantly reduced environmental impact, in comparison with the other concepts. The locations of the foundations were well accessible and required only a minimum of cleaning works in the forested slopes. The owner agreed to have this proposal also worked out to a preliminary design stage by one of the teams, to be comparable with the submitted ones. Finally, the owner invited two of the teams to tender for the detailed design works. By further inclining the pylons transversally, it was possible to keep the stay cables outside the clearance, although the horizontal radius amounted to only 503 m.

Fig. 8: Pylon of Sunniberg Bridge

Fig. 9: Menn's proposal for the Poya Bridge in Fribourg[18]

Integral Bridges

Until recently, it was almost a paradigm that concrete bridges of a certain length have to be articulated to control and reduce stresses caused by restrained deformations. The resulting expansion joints need repetitive maintenance, are a source of noise and discomfort for users and a weak point in the effort to keep chloride-charged runoff away from structural elements. Integral bridges have neither joints nor bearings at their ends, but the girder is rigidly connected to the abutments. To what length integral bridges are feasible depends on the local seasonal temperature difference, on the required comfort for the running surface and on some detailing issues. As a tendency, the maximum length of bridges to be built as integral increases from values of 30–60 m in the past to 150 m and more in future.[19]

The Sunniberg Bridge is an integral bridge although its length amounts to 526 m. This is possible only because the bridge is curved, and strains caused by seasonal temperature changes, creep and shrinkage are taken by radial movements. To follow this movement without excessive restraint, the piers have to be flexible in the transverse direction. In the same way, the girder acts as a horizontal arch from abutment to abutment for wind and earthquake actions.

This solution reduced maintenance needs significantly and justified the higher erection cost. To avoid expansion joints as well as repeated pavement maintenance at the bridge ends, a force of about 9.5 MN at the serviceability level[11] had to be tied back and led into the ground by base friction of the abutments. Although these reach a considerable length of 12.50 and 13.30 m, respectively, they are perfectly hidden in the ground (*Fig. 10*).

Structural Design

The different steps that led Christian Menn to the design of the Sunniberg Bridge should not impair his achievements, but should exemplify how only a long-lasting endeavour to answer the relevant questions can lead to such a bridge design. Structural design, however, covers all phases from

(a) (b)

Fig. 10: Abutment without (a) bearing and (b) expansion joints

preliminary design to detailing and finally execution and quality control. That is why the contribution of all other parties involved in the different planning and execution phases also need to be acknowledged.

Impact on Prestige and Paradigms

Eighteen years after the first publications of the project[20], 17 years after its completion and 10 years after its commissioning, the impact this structure has had on the prestige of the various involved parties and the paradigms of the bridge engineering community can now be estimated.

Profession

The Swiss Federal Technical University (ETH) in Zurich has been the teaching and research domain of Christian Menn for 22 years and is the alma mater of almost all the civil engineers who have been involved in the project. Photographs of the bridge are widely used to characterize the achievements of the graduates of ETH and to advertise and illustrate the civil engineering curriculum of ETH.

Building Technique and Materials

Structural concrete as a building material and construction technique has also profited. The Sunniberg Bridge demonstrates that concrete—although being a bulky material—can be used to build elegant and light structures.

The bridge has also been used by many different companies such as contractors and suppliers of stay cables to advertise and market products such as reinforcing steel, waterproofing, etc.

Justified Extra Costs for Good Design

The Sunniberg Bridge played an important role in bridge engineering in the perception and acceptance of extra costs for good design.

Famous bridges of the past such as the Salginatobel Bridge could often prevail against their competitors because they had been the most economical solution under the given circumstances and thus won the call for bids. This reasoning also became a paradigm in the education of structural engineers. In the first edition of his reference book[21], Menn estimated that the additional costs to improve the aesthetic quality for the given spans would be at the most 1–2% of the total building costs. He considered extra costs of 5–7% as adequate to increase the spans in order to get an aesthetically more convincing concept. In the third edition[22] brought out together with Prof. Eugen Brühwiler from EPFL, the authors considered extra costs of 5% for large bridges and 15% for medium bridges as justified to increase the aesthetic quality. “If these limits are exceeded, the design is inappropriate and should be abandoned.” They admit, however, that for smaller structures such as pedestrian bridges, the extra costs may reach 100% of the costs of the most economical project.

For the Sunniberg Bridge, the costs of the preliminary concepts were estimated on a common basis.[23] The cheapest project with two end spans of 47.5 m and seven inner spans of 62.5 m was judged as not compatible with the environment. A conventional free-cantilevering design with estimated costs of CHF 15 Mio served as reference instead. The judgement committee accepted additional costs of 15% for the cable-stayed proposal and proposed it for execution.[24] Menn considers these extra costs as justified in the special case, being still below the average costs per length of the whole by-pass road project.[25] This is not surprising because 64% of the total length of the road consists of a tunnel. The settled construction costs for the bridge in 1998 amounted finally to 133% of the reference conventional design of 1995.

In the meantime, the importance of pure construction costs has been relativised by several issues:

- Life-cycle costs. By considering the repetitive costs during use and the final costs for dismantlement at the end of the structure’s working life, the higher initial costs may be justified. The fact that bearings and expansion joints could be avoided in this case, justifies some extra costs in the construction phase.
- Signature bridges/signature spans. The case of Bilbao, where an industrial town gained international renown with the construction of a museum by a world-famous architect, influenced also the bridge design. Nowadays, it is generally accepted that a whole bridge or a single span of a long bridge is more expensive than the most economical solution, if its shape is unique and has a recognition value and by this enhances the reputation of the owner as well as the tourism value and prosperity of the region. Sunniberg has anticipated and exemplified the term signature bridge.

Fig. 11: Train to Davos passing by the Sunniberg Bridge

Fig. 12: Swiss Alpine half marathon crossing the Sunniberg Bridge

Crossing and Passing By

Once each year, at the end of January, the town of Davos becomes the centre of global publicity, when opinion leaders and politicians meet at the World Economic Forum. The closest international airport is Zurich and weather conditions do not allow helicopter transport all the time. That is why most participants travel with earthbound transport, either by train or by car or coach. In both cases, they are in touch with the Sunniberg Bridge. On the road, they cross it and by rail they pass by and have a perfect view from different angles (*Fig. 11*).

Davos also hosts other events of considerable relevance. Since 1986, the Swissalpine Marathon is organized with different categories for beginners and amateurs as well as for professionals of all ages. The K21 race is a half marathon over 21 km. From 2007 to 2013, the route was from Klosters over the Sunniberg Bridge to Davos. Crossing the bridge in a crowd just after the start produces a feeling similar to that experienced in the famous New York City Marathon (*Fig. 12*).

Professional and Touristic Excursions

Grisons, the mountainous canton in the southeast of Switzerland has a large concentration of structures from distinguished bridge engineers like Johannes Grubenmann, Richard La Nicca, Robert Maillart, Walter Versell, Christian Menn, Jürg Conzett and others.

Engineering students and bridge engineers travel to this part of Switzerland to visit the Salginatobel Bridge by Robert Maillart, a Historic Civil Engineering Landmark designated by the American Society of Civil Engineers in 1990, along with the Sunniberg Bridge. As the two bridges are only 23 km away from each other, it is easy to visit both on the same day.

Heritage for the Next Generation?

For the next generation of professionals, besides prestige and recognition all relevant issues for maintaining and preserving the bridge have to be considered.

Accessibility for Inspections

As no provision has been made for monitoring, technical inspections are the main tasks needed for an early identification of durability issues. Of main structural relevance are the midspan sections (where the deck is not compressed by the reaction of the stays), the condition of the tendon's anchorages and the highly stressed parts of the piers. While the midspan sections are rather easily accessible, the stays are a considerable obstacle for reaching the anchorages. This task is solved by using a lifting basket, which requires closing the bridge for traffic and an extremely precise handling of the basket (*Fig. 13*). Different from ordinary girder and arch bridges, the piers cannot be reached by conventional equipment from the bridge deck.

Inspections could have been simplified significantly by providing movable inspection platforms in every span. It is understood that this solution was studied in the detailed planning phase but was dropped because of costs and aesthetic reservations. The task remains for a future project to design monolithic bridge ends and intermediate supports in such a way that the platforms can be integrated and placed if not needed or removed.

Maintenance

The bridge deck is situated about 1050 m above sea level, which means that a large amount of yearly precipitation falls as snow, temperatures are generally low at all seasons, and icy conditions are fought with de-icing salt (*Fig. 14*).

Snow clearance is mainly carried out at night by removing snow laterally, not only by means of ploughs but also by blowers. Short obstacles along the road such as the pylons or prohibited zones like passing roads underneath are signalled by small signs (visible in *Fig. 13a*) and can be avoided by turning the exhaust tube of the snow blower. The stays, however, being along considerable parts of the bridge length, cannot be spared; they are hit by the snow stream and part of it rebounds, but no difficulties have been reported so far.

The yearly flushing of the drainage system can be carried out easily in combination with the cleaning of the adjacent Gotschna Tunnel, where the road section is taken out of service anyway.

During the first years in service, the water froze in the sewage, since the seepage water from the Gotschna Tunnel also flows through those pipes. In order to avoid damages, a heating system for the pipes was installed.

Durability

The importance of durability was already identified during the design

(a) (b)

Fig. 13: Access to bridge deck soffit by a lifting basket, (a) manoeuvring between the stays, (b) room needed for the traffic space

Fig. 14: Sunniberg Bridge in winter

Fig. 15: Soffit of the bridge deck with ducts for wiring and sewage, de-watering drainage pipes and anchorages of the stay tendons (from left to right)

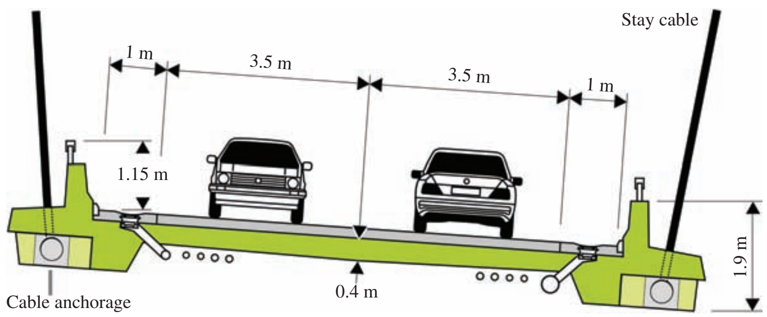

Fig. 16: Cross-section of the bridge girder, inclined by 7% because of the curved horizontal road alignment

phases, which led to several extra provisions:

- Spall drains as well as inlet shafts are placed not only at the inner and lower edges but also at the outer and higher edges of the deck plate. Thus, melting water from snow removed by ploughs at the outer edge does not flow across the carriageway (*Fig. 16*).
- The waterproofing layer is drained by inlets at its lowest part in the cross-section. The drainage pipes are placed in the edge beam and protrude some centimetres in order to drop the chloride-charged water well below the structure (*Fig. 15*). In case these tubes congest because of icing, there is the danger of the water reaching the structural concrete in a crucial part of the cross-section.
- The stay cables can be replaced.
- Reinforcing steel with high resistance for chloride-induced corrosion (material number 1.4003) was used for the stirrups in the parapets that are exposed to de-icing salt.

The challenge remains to make sure that the connections from tendons to anchorages also remain watertight and that the corrosion protection remains functional, in particular for all steel elements that are exposed to de-icing salt.

Conclusions

The Sunniberg Bridge has become an icon of Swiss engineering, standing for high performance, quality and elegance, perception of structural engineering, an object inspiring admiration, even an incentive for today's younger generation at the stage of making career choices.

The Sunniberg Bridge is a pioneering work in various aspects. First experience has been gained during construction and with the first decade of use, more will be gained in the future. All experiences—good and bad ones—should be discussed, not to accuse or blame, but to learn from the past for the future and to encourage young engineers to pursue a similar career.

Acknowledgements

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SEI Data Block

Owner (since 2008):	Swiss Confederation, Federal Road Office (FEDRO), Bern
Client:	Cantonal Highway Administration Grisons, Chur
Conceptual design:	Prof. Dr. Christian Menn
Detailed design:	Bänziger + Köppel + Brändli + Partner, Chur
Total bridge length (m):	526
Total bridge width (m):	12.38
Spans (m):	59, 128, 140, 134, 65
Horizontal radius (m):	503
Concrete (m^3):	8500
Reinforcing steel (t):	1250
Prestressing steel (t):	50
Structural steel (t):	240
Stay cables (t):	320
Concrete for bored piles (m^3)	500
Formwork (m^2)	17 500
Total costs (USD million):	26.8
Service date:	December 2005