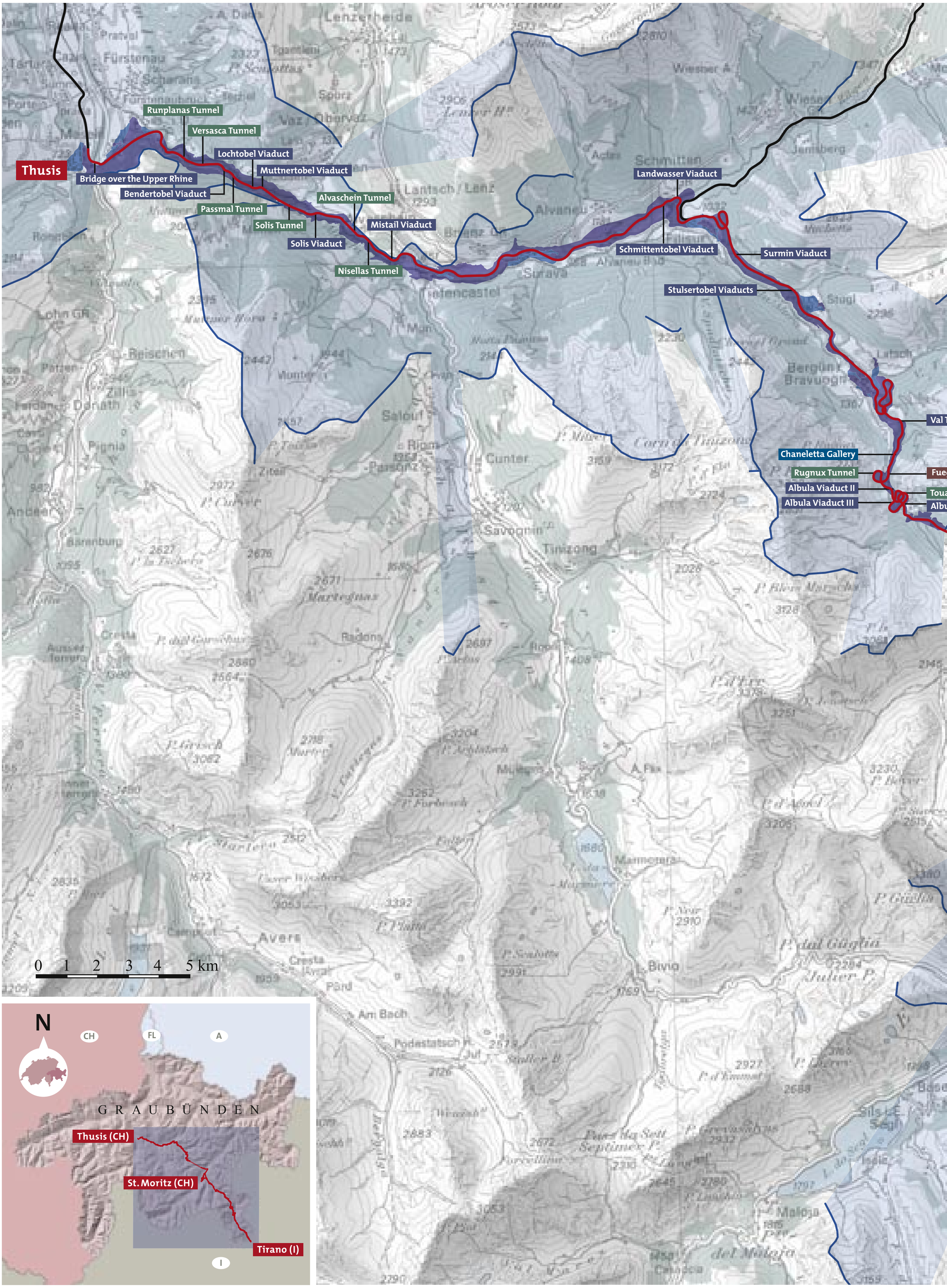
Thusis
Runplanas Tunnel
Versasca Tunnel
Lochtobel Viaduct
Bridge over the Upper Rhine
Muttnertobel Viaduct
Bendertobel Viaduct
Alvaschein Tunnel
Passmal Tunnel
Solis Tunnel
Mistail Viaduct
Solis Viaduct
Nisellas Tunnel
Landwasser Viaduct
Schmittentobel Viaduct
Surmin Viaduct
Stulsertobel Viaducts
Chaneletta Gallery
Rugnux Tunnel
Albula Viaduct II
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0 1 2 3 4 5 km
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St. Moritz (CH)
Tirano (I)
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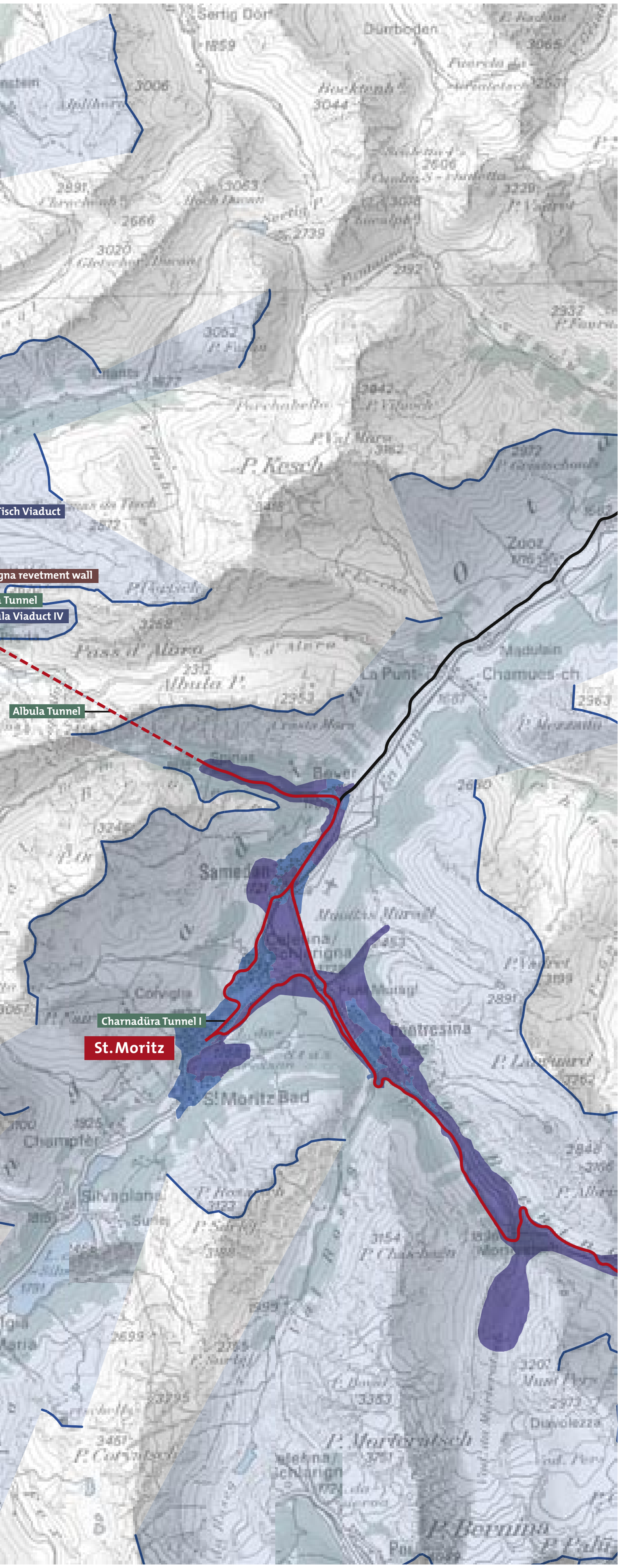


Selected engineering structures on the Albula line

- Viaducts and bridges
- Tunnels
- Galleries
- Revetment walls

Core zone

- Core zone with railway and cultural landscape

Buffer zone

- Buffer zone in the near area
- Buffer zone in the distant area (backdrop)
- Horizon line

Other contents

- Other stretches of the Rhaetian Railway

Sources:
Basic map: PK 200'000 swisstopo, Wabern
Geo-data: Amt für Raumentwicklung Graubünden
Thematic data: Jürg Conzett
Design: Süsskind, SGD, Chur

2.a.4 Engineering structures on the Albula and Bernina line

The engineering structures on the Albula and Bernina railway routes are less important as individual examples, than within the scope of their mutual interplay and their relationship to a more general pattern. The decision to build these railway constructions in stone wherever possible was based on technical as well as economic and architectural factors. The successful synthesis of apparently contrary elements in opening a landscape of particular significance to tourism up to traffic was new and led to a fundamentally changed attitude to transport installations among a public that was basically critical of technical progress. The enthusiastic reception given to the railway structures discussed here by the national heritage conservation movement was quite exceptional, and its impact on other installations before the First World War was also remarkable. Another confirmation of the high quality of the engineering structures discussed here is that most of them still continue to be used for railway operation in practically unchanged form.

A statistical look at the engineering structures on the Albula and Bernina routes already shows their importance for each of these lines: the 135 bridges of the Albula railway together extend over more than 3 km, corresponding to 6.6 % of the open part of the line. A railway line is already considered to be “rich in bridges” when this proportion is a mere 1.6 %, so the density of bridges on the Albula route is exceptionally high. The tunnels on this line also make up a high proportion of its length: excluding the almost 6 km long Albula tunnel, the total length of the tunnels on this route – there are 39 of them – amounts to over 10 km, or 18.5 % of the line. The lower limit for a “tunnel-rich” route is 10 %. Although the Albula railway was designed principally to open up the tourist centres of the Engadin, its chief engineer Friedrich Hennings pointed out that it should also be seen “as part of a larger rail network… so that, after the completion of connections to Italy and the Tyrol […], it could be used to carry important transit traffic”. Great value was consequently placed on building a track with curves of relatively large radius and with comparatively low gradients: this required the construction of many tunnels and bridges along the deeply cleft terrain of the Albula valley.

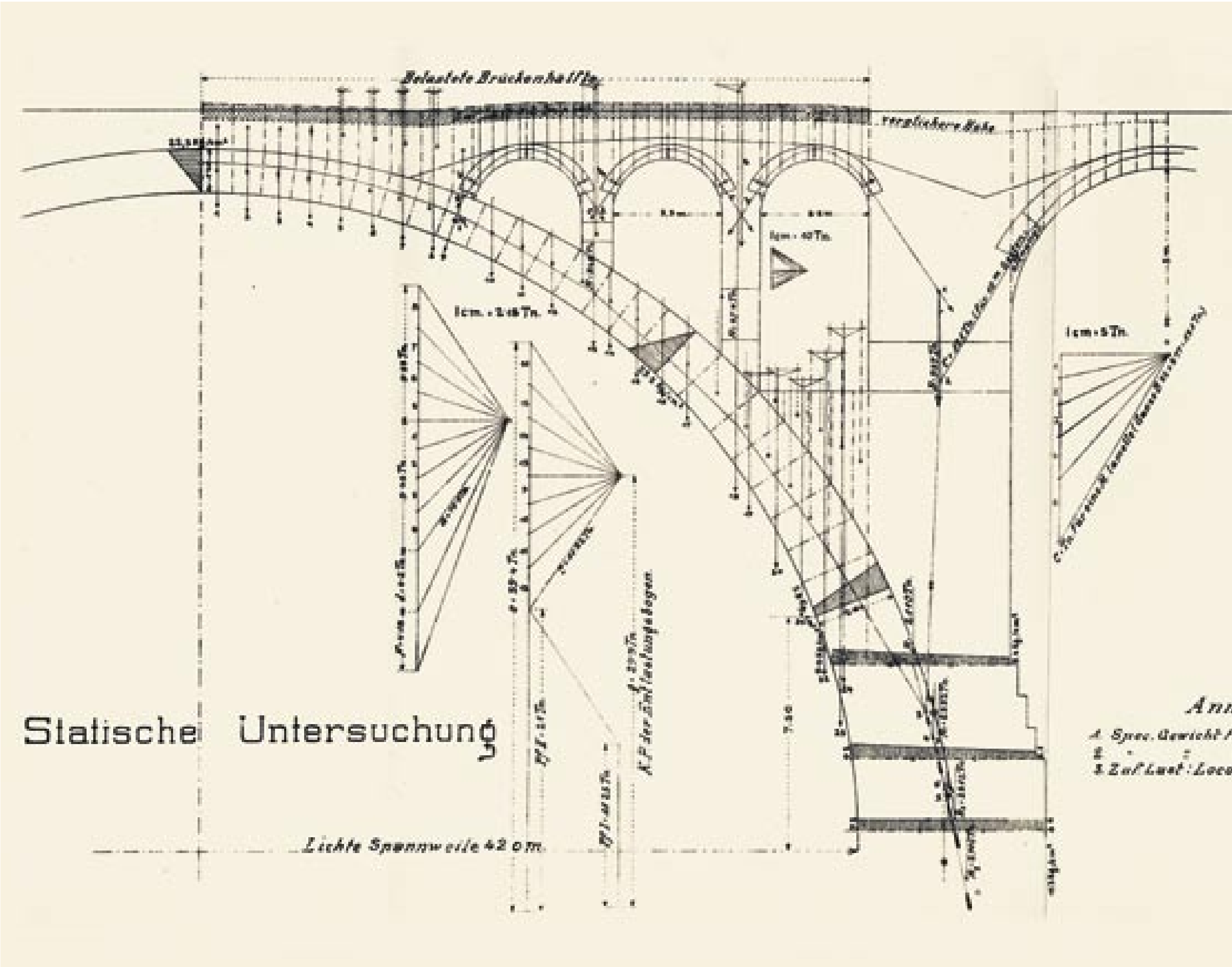
The Bernina line has a completely different character: with gradients of up to 70 ‰, the railway was operated with short, electrically driven trains. This allowed a flexible track layout that follows the terrain with narrow curves. Despite the extreme topographic conditions, the Bernina railway has few engineering structures in proportion to its length. Only 1.6 % of its route is made up of bridges and 3.65 % of tunnels.

The engineering structures, especially the bridges, are a characteristic element along the Albula route, both in terms of building technology and from the viewpoint of travellers. Hermann Behrmann, author of a travel guide published in 1908, felt a new type of “travel magic” in the Albula valley: “despite being uncommonly susceptible to natural beauty, […] I was often enough diverted away from even the most magnificent landscape by the details of the railway installations”. On the Bernina route, in contrast, the engineers made a point of avoiding engineering structures as far as possible. The economic reasons for this approach

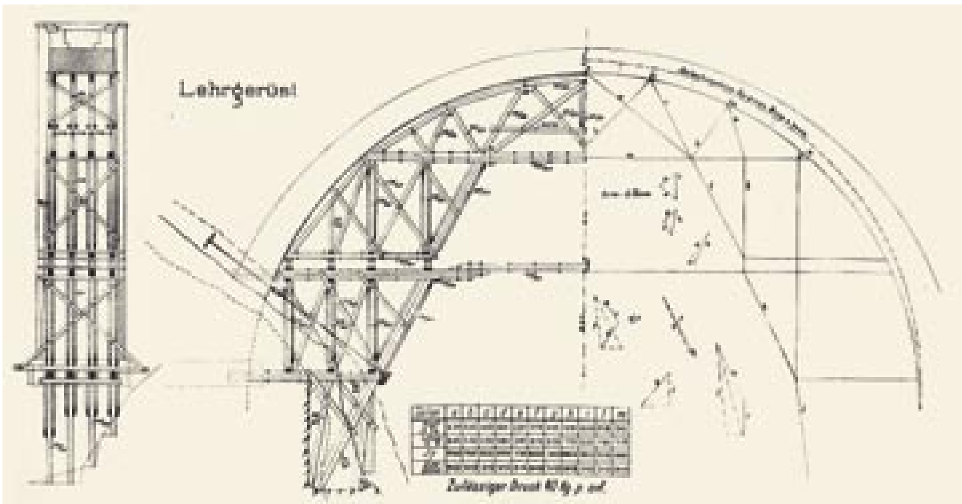
Albula line > The 42 m span of the Solis Viaduct under construction.
Rhaetian Railway

Historical photograph of the Solis Viaduct, in the foreground the road bridge over the Albula river.
Rhaetian Railway

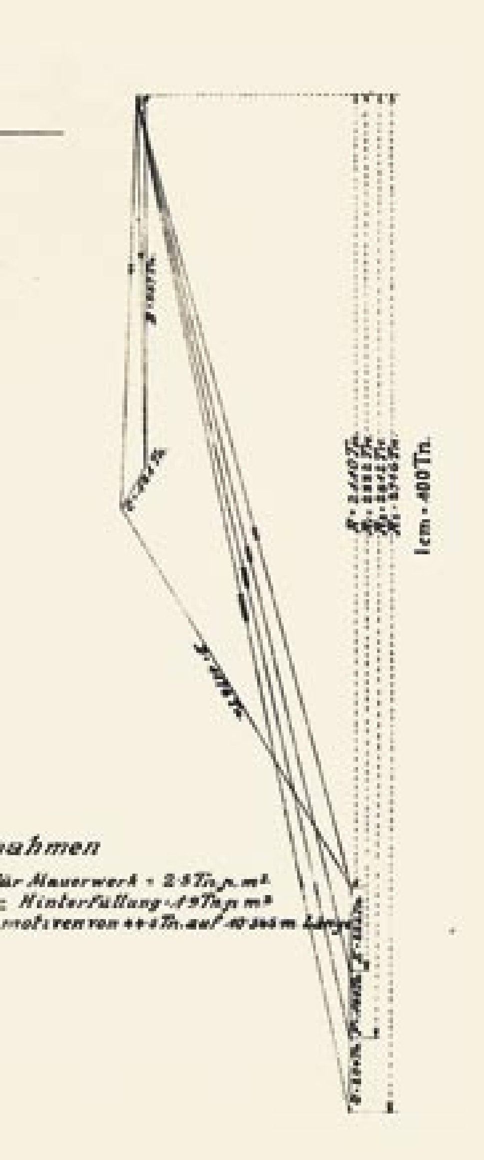
Solis > The Solis Viaduct is still in its original state.
T. Keller

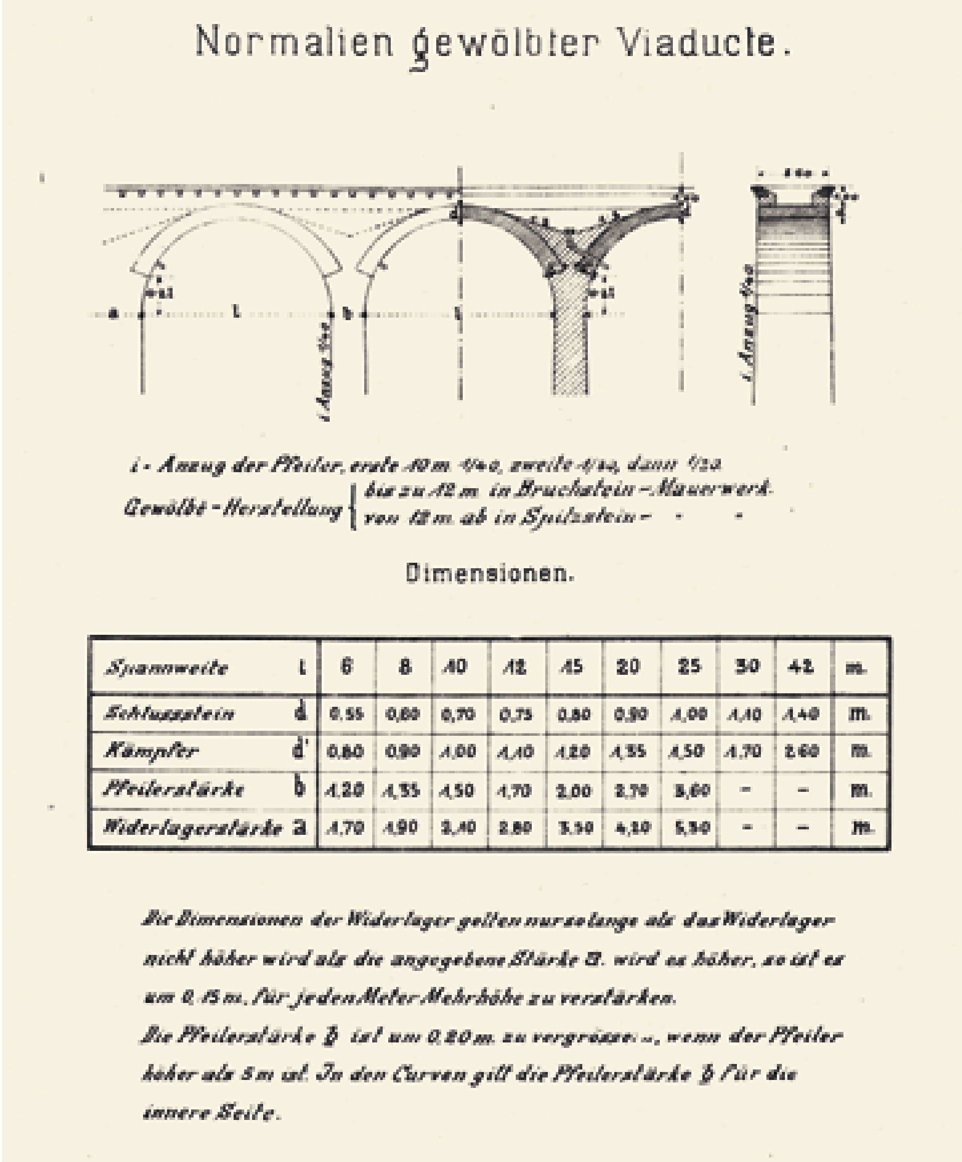


Solis Viaduct > Testing the statics.



Solis Viaduct > Plan of the framework.





Normalien gewölbter Viaducte.

i = Anzug der Pfeiler, erste 10 m 1/40, zweite 1/30, dann 1/20

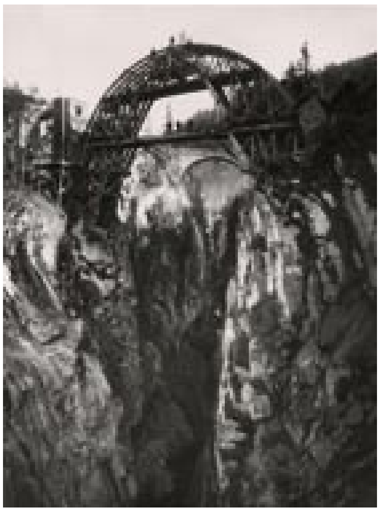
Gewölbe-Herstellung { bis zu 12 m in Bruchstein-Mauerwerk. / von 12 m ab in Spitzstein- " "

Dimensionen.

Spannweite	l	6	8	10	12	15	20	25	30	42	m.
Schlussstein	d	0.55	0,60	0,70	0,75	0,80	0,90	1,00	1,10	1,40	m.
Kämpfer	d'	0,80	0,90	1,00	1,10	1,20	1,35	1,50	1,70	2,60	m.
Pfeilerstärke	b	1,20	1,35	1,50	1,70	2,00	2,70	3,60	–	–	m.
Widerlagerstärke	a	1,70	1,90	2,40	2,80	3,50	4,20	5,50	–	–	m.

Die Dimensionen der Widerlager gelten nur solange als das Widerlager nicht höher wird als die angegebene Stärke a. wird es höher, so ist es um 0,15 m. für jeden Meter Mehrhöhe zu verstärken.
Die Pfeilerstärke b ist um 0,20 m. zu vergrössern, wenn der Pfeiler höher als 5 m ist. In den Curven gilt die Pfeilerstärke b für die innere Seite.

Albula line > Standards for ached viaducts.



Solis Viaduct > The daring framework was built by the legendary bridge builder Richard Coray in 1901. Rhaetian Railway

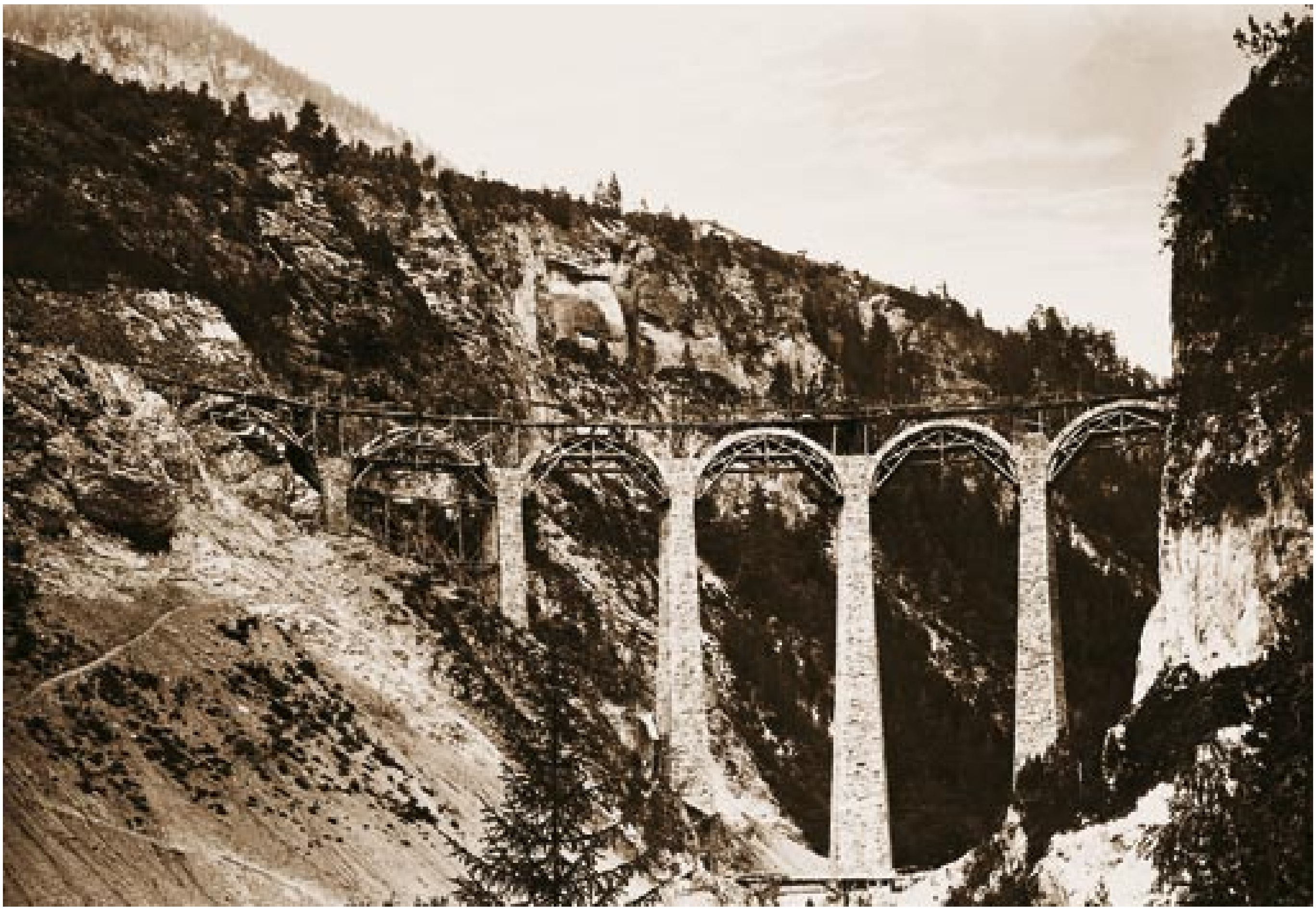
All the plans on this double page are taken from: FRIEDRICH HENNINGS: *Albulabahn. Denkschrift*, Chur 1908.

are evident, but it also reveals the will to preserve the landscape and as far as possible not to encroach upon it with "engineering art" in the form of conspicuous buildings.

Engineering structures along the Albula route

Bridges

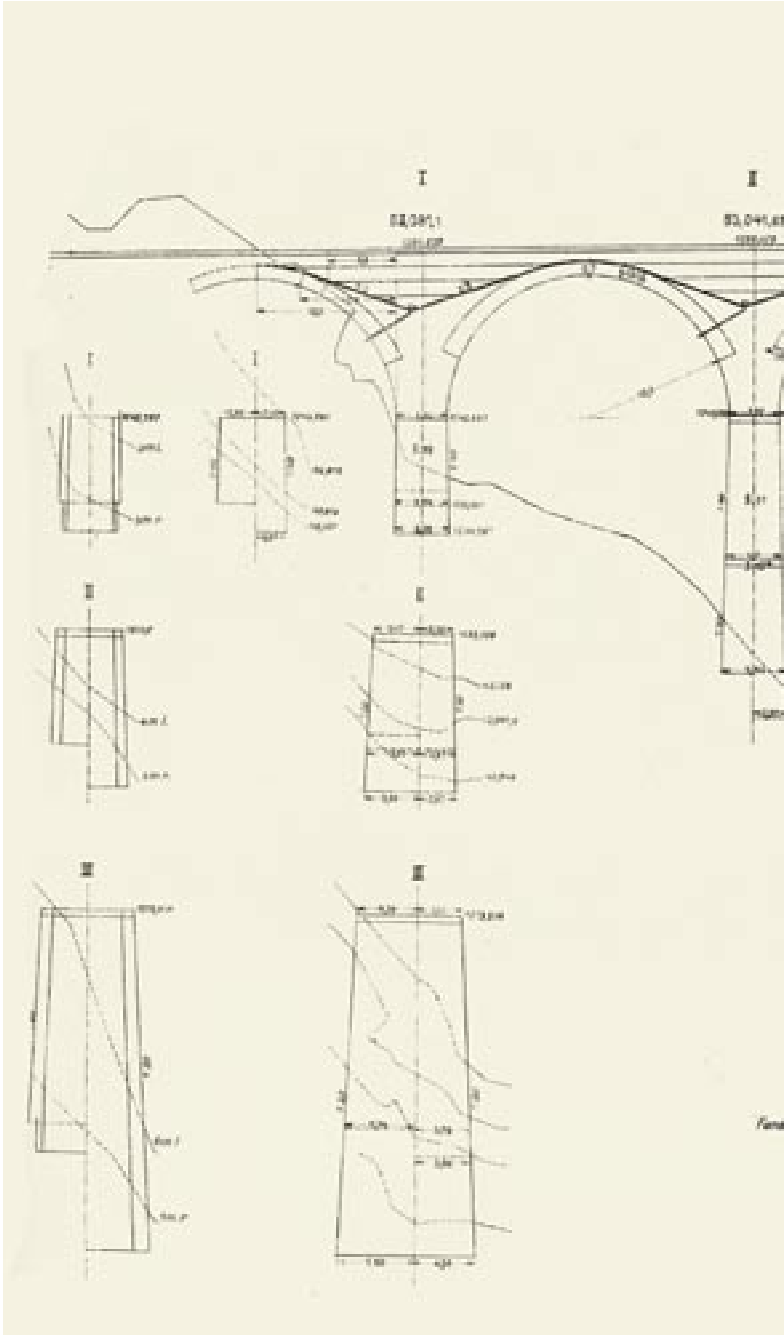
The great majority of the bridges along the Albula railway are stone viaducts. Only at a very few places, for instance when a stream or river had to be crossed at a low height, were iron structures used. Some of these were later replaced by concrete constructions. The most prominent example of this type is the bridge over the Upper Rhine immediately after Thusis railway station, where the railway originally crossed the river on a rhomboid iron trellis with an 80 m span. Untypical of the "stone" Albula railway, this was a last salute to the great Rhine river bridges. A concrete arched construction now stands in its place.
The Solis viaduct can certainly be regarded as the most important bridge on the Albula line. It is located in the Schin gorge and bridges the Albula River with an arch spanning 42 m. The viaduct thus has the longest span of any of the Albula rail bridges. With a height of 85 m, it is also the highest viaduct on the Rhaetian railway. Accordingly, its structure is rather more complex than that of the other bridges. The pillars above the arch abutments are widened and provided with masonry parapet attachments that form a type of bridgehead. The base and copings are trimmed on all sides.
The viaduct is built of siliceous limestone quarried from the Schin gorge itself. This is a solid stone that breaks into layers (with parallel surfaces) and thus supplies building material of outstanding quality – in terms of both durability and ease of working.
Construction of such a large arch for a railway bridge was an innovation in Switzerland at that time, and the latest available method was used to calculate its static parameters, namely the elasticity theory according to the graphical method of Wilhelm Ritter. In addition to engineer Hans Studer, who was later to become a specialist in stone arches in Switzerland, the young Robert Maillart also worked on these innovative studies. The Solis viaduct is among the first "elastically" dimensioned stone viaducts. In his standard reference work "Grandes Voutes", Paul Séjourné mentions only three arched bridges in Austria-Hungary (Jaremcze, Jamna and Worochta on the then Carpathian railway from Stanislau to Wronienka of 1893/94) that may be regarded as forerunners of the Solis viaduct.
The falsework was an early achievement by legendary constructor Richard Coray. He succeeded in designing it as a relatively lightweight structure, as the main arch was constructed in three successive concentric interleaved rings so that it had to be dimensioned only for the weight of the first ring.
The Landwasser Viaduct at Filisur has the largest masonry cubage of any bridge on the Albula line – namely 9,200 m^3, its mass is about three times greater than that of the Solis viaduct. This is due to the pillars with their unusual height of 65 m and that they also stand a short distance apart, as the spans of the arches are a mere 20 m. The highest pillars measure approximately 8 x 8 m at their base, i.e. with a spacing of 23.50 m between the pillar centre-points, a third of the valley's longitudinal profile is built up at the bottom. The spaces between the pillars are short because the railway on the bridge traverses an unusually narrow curve with a radius of only 100 m – otherwise minimum



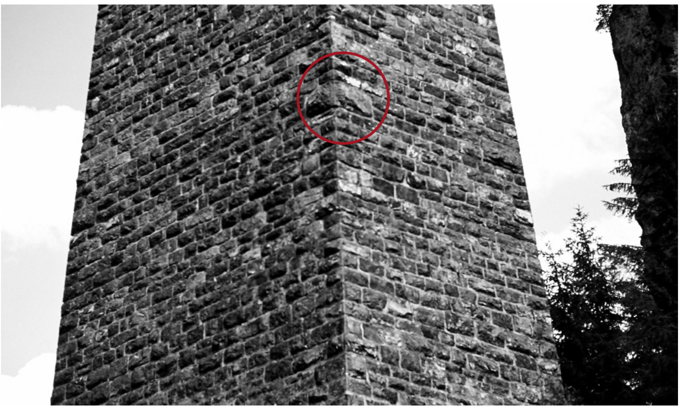
Albula line > Landwasser Viaduct near Filisur under construction, 1902.
Rhaetian Railway

Albula line > Historical photograph showing the Schmittentobel and the Landwasser Viaduct.
Rhaetian Railway

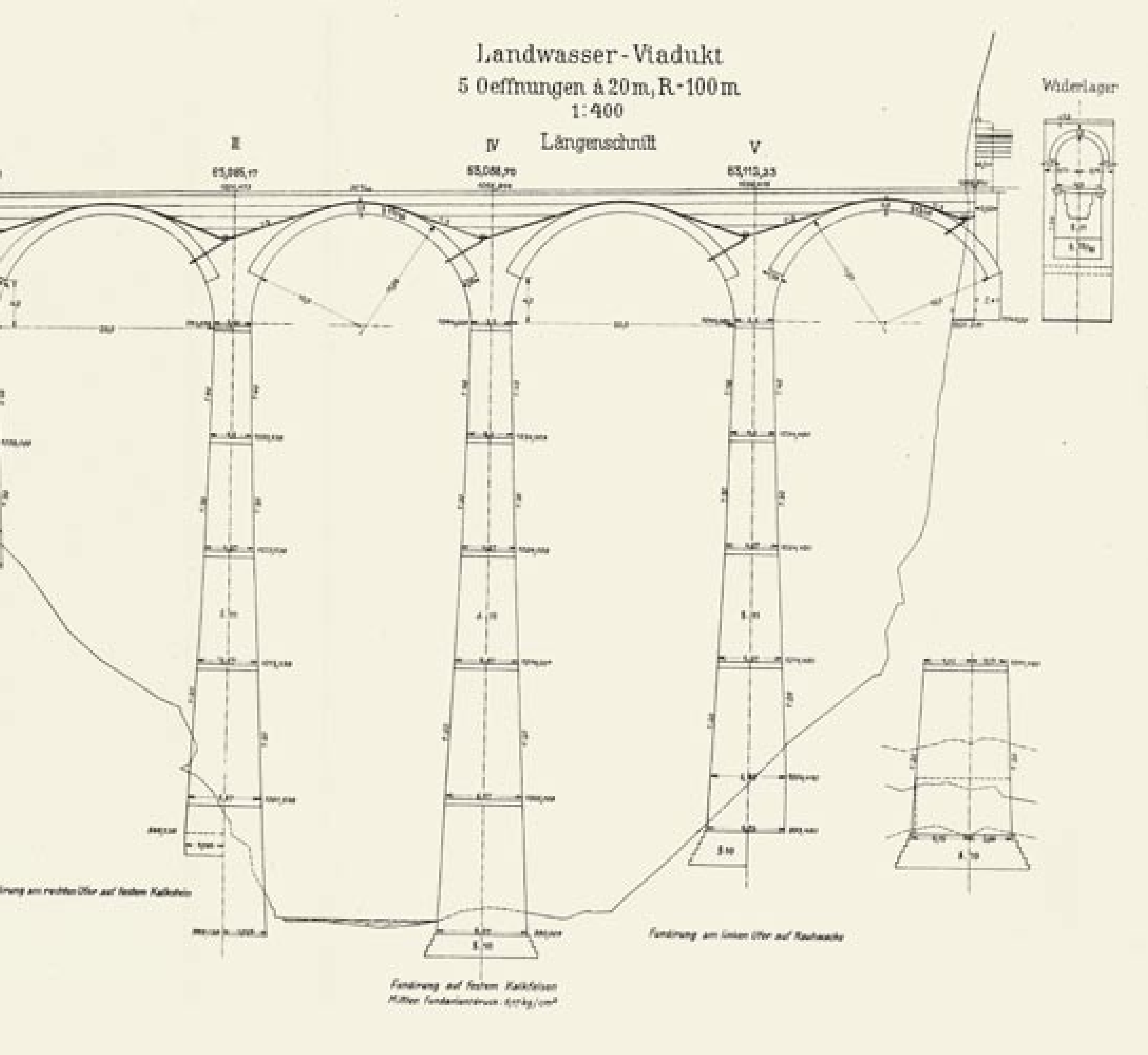
Filisur > The Landwasser Viaduct is still in the original state, over 100 years after it was built.
Canal, Engadin Press



Landwasser Viaduct > The iron towers supporting the bridge cranes were built into the piers. This made it possible to do without construction frameworks in an area liable to flooding.
Rhaetian Railway



Landwasser Viaduct > Detail of a pier. The circle pinpoints a cornerstone marking the position of the inner level course.
Rhaetian Railway



Landwasser Viaduct > Longitudinal section. Plan (reduced in size) taken from: FRIEDRICH HENNINGS: *Albulabahn. Denkschrift*, Chur 1908.

curve radii of 120 m were observed on the Albula route. In order to compensate for the resulting greater tractive resistance, the gradient here was reduced from 25 ‰ to 20 ‰. The individual arches have a polygonal ground plan, i.e. are slightly offset with respect to each other. As a result, the pressure forces in the pillars are directed slightly outwards, as the horizontal force components of the respective arch do not exactly compensate each other. The trains running over them generate centrifugal forces with a similar direction. In order to counter these effects, the pillars are constructed asymmetrically and transversally to the rail axis.

The narrow curve meant that the lengths of the Landwasser Viaduct and the directly adjoining Landwasser Tunnel could be kept comparatively short. This point of the railway installation shows in an impressive way how strongly the conditions of the track layout and the topography influence bridge-building technology and mutually affect each other.

The Landwasser Viaduct is built of dolomite limestone that was transported on a construction railway running from a nearby quarry to the building site. A problem arose with this bridge that is otherwise encountered only in flat river crossings, namely the restricted flow profile of the Landwasser between the two highest pillars. The contractor therefore decided not to place framework towers in areas of possible flooding and constructed the pillars without scaffolding with the aid of two gantry cranes whose steel towers stood in the middle of the pillars and were progressively encased by them. At the pillar head, the lowest part of the arch was extended in a kind of free projection so far outwards that the wooden constructions of the adjacent Schmittentobel Viaducts with somewhat shorter spans could be re-used as falsework, thus saving costs. Traces of this construction process may still be seen today on the iron fastenings placed above each other in two rows, and the arch stones seen from below in the free projection area are embossed identically to the pillar masonry, whereas they had to have a flat surface in the falsework section in order to lie smoothly on the boarding.

The design of the pillars and arches, at first sight completely unadorned, creates an effective contrast purely because of the consoles and copings of the upper bridge border, with their comparatively delicate appearance: it clearly reflects the architectural thinking of those years after 1900.

A closer look reveals a further design refinement that uses a constructional feature to create subtle structuring. In the pillars of the Landwasser Viaduct, each layer of the internal equalisation strata is marked by four larger cornerstones that extend over two height sections.

Other viaducts remarkable for their spans are the Muttnertobel Viaduct (30 m wide) before Solis and the Mistail Viaduct (27 m wide) before Tiefencastel. These arches were also constructed with wooden formwork and, similarly to the Solis viaduct, scaffolding costs were saved by constructing the arches with a ring structure, although in this case only two rings were used rather than three. The two arches over the Stulsertobel (25 m and 23 m) between Filisur and Bergün/Bravuogn are only slightly shorter than these viaducts.

Some viaducts were constructed in a typical way on the basis of several standardised spans so that their dimensions could be read directly from a table. This category of viaduct includes Albula Viaduct III (openings of 3 x 10 m, 3 x 20 m, 2 x 10 m) below Preda: with a masonry volume of 4,090 m^3, this bridge has the second largest cubature on the Albula route. The following viaducts also have 20 m spans: Albula Viaduct II

Albula line > Artificial elongation between Bergün/Bravuogn and Preda due to Viaducts and helical tunnel. The Albula Viaducts II (left) and III (right) can be seen clearly.
Foto Geiger

Albula line > The Albula Viaduct III, the bridge with the second largest cubature on the Albula line.
Foto Geiger

Albula line > Three arch design in the revetment wall at Fuegna ❶; the passengers can see it as the train emerges from the Rugnux tunnel.
J. Conzett

Albula line > Three arch overpass at Bergün.
J. Conzett

Albula line > Layout above Bergün/Bravuogn. Illustration taken from: FRIEDRICH HENNINGS: *Albulabahn. Denkschrift*, Chur 1908.

Captions:
1 = Revetment wall at Fuegna
2 = Albula Viaduct I
3 = Rugnux Spiral Tunnel
4 = Albula Viaduct II
5 = Tuoa Spiral Tunnel
6 = Albula Viaduct III
7 = Albula Viaduct IV
8 = Zuondra Spiral Tunnel

Albula line > The Albula Viaduct III 6, under construction, 1902.
Rhaetian Railway

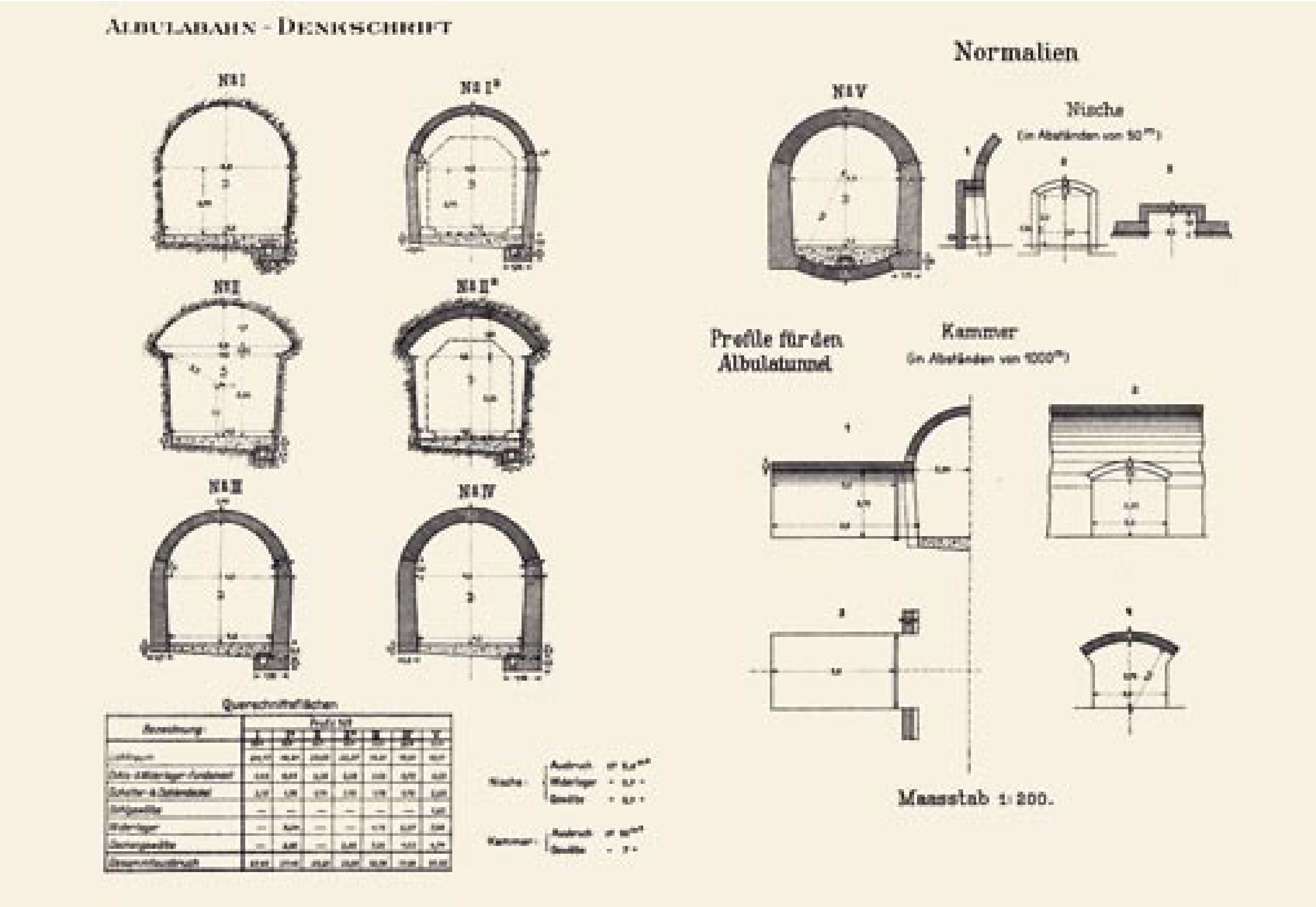
Albula line > The Albula Viaducts II 4 (foreground) and III 6 (behind) shortly after completion. Bottom right the Val Rots linesman's hut. Photographed in November 1902.
Rhaetian Railway

(three main openings of 20 m), Val Tisch (three main openings of 20 m) above Bergün/Bravuogn and Surmin (one opening of 20 m) above Filisur. The 16-m type is represented by the Bendertobel viaduct (three openings each 16 m wide) and the Lochtobel viaduct (5 x 16 m) in the Schin gorge, the Schmittentobel viaduct (7 x 16 m) between Alvaneu and Filisur shortly before the Landwasser viaduct and Albula Viaduct IV (2 x 16 m) below Preda.
The uppermost layers of the slope are liable to creeping movements, particularly in the Schin gorge. Dangerous cutting of such unstable slopes can be avoided by constructing leaning viaducts. The foundations that push through the slope at specific points required the construction of deep shafts, that – framed with wooden props – had to be sunk down to the stable rock surface. Thus the foundations of the Lochtobel viaduct extend up to 14 m below the terrain surface. Thanks to this structure, the Albula route has remained largely free of later repair work due to terrain sinking.
The small bridges are also of interest. Between Bergün/Bravuogn and Preda, the convoluted track route means that the railway installations are always visible to passengers looking forwards and backwards. This circumstance may explain why the railway builders frequently resorted to three-arched underpasses and overpasses here, a motif widely found in garden and park architecture. On one occasion, the "three arches" even appear in a supporting wall, near Fuegna, just at the point where the rail track runs parallel to itself on a short section before and after the Rugnux tunnel. This offers an unusual example of a "compositional" approach by the planning engineers with an eye to a clientele who can recognise the leitmotiv in a complete work of art.

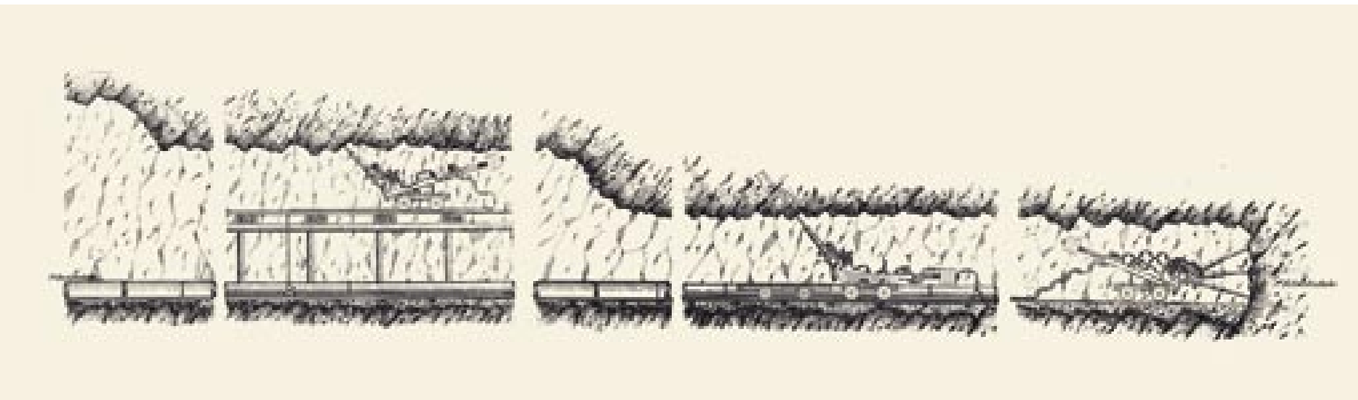
Tunnels

The most important tunnel of the Albula railway is the Albula tunnel. It is around 5,865 m long, extends from Preda in the Albula valley to Spinas in Val Bever, breaks through the watershed between Rhine and Inn and is the highest Alpine tunnel on any main-line railway, peaking at 1,823 m. It was constructed between 1898 and 1903. The rock in its middle zone consists of solid Albula granite, and formations that are more difficult to traverse are found on either side of it. On the north side, there is a 1,100 m layer of wet lime and clay shales, 110 m of cellular dolomite (the last 20 m of it in quicksand) and 50 m of solid Casanna schist: eleven months of work were needed to break through the cellular dolomite alone. On the south side, the tunnel penetrates a landslip area with large unstable blocks in the first 170 m; these had to be carefully braced during the construction. The granite was reached after a further 90 m in the moraine.
Brandt drilling machines driven by water under pressure were used to excavate the tunnel. These machines had been developed in the Gotthard railway Pfaffensprung helical tunnel and were later used in the Arlberg tunnel. The water pressure was 100 atü and the drilling implements were supplied by rigid pipes and corresponding fittings. The construction took place in the "Austrian" manner, with sole-gallery operation, so that the excavated material did not have to be reloaded on its way out. The sole gallery was then broadened with a "ridge groove" which was followed in the usual way by excavation of the roof section, bricking of the vault, excavation of the sidewalls and underpinning of the vault abutments. Extensive parts of the solid Albula granite could be left unfaced.
Other longer tunnels are found in the Schin gorge and in the loops between Filisur and Preda.

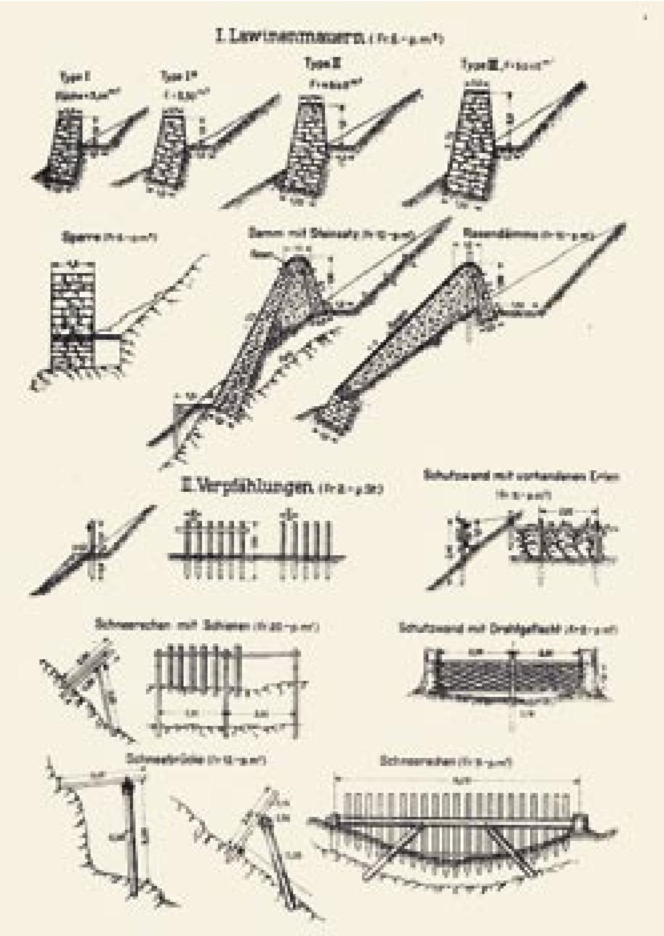
Albula line > Rugnux inclined Viaduct. A "Crocodile" engine hauling the Pullman Classic Express carriages.
P. Donatsch



Albula line > Profile for the Albula tunnel (reduced in size).



Albula tunnel > The sole tunnel and ridge groove excavation with the Brandt hydraulic drive drilling machines.



Albula line > Standards for avalanche walls and baffles to protect the railway line.

Albula line > When it was built, the largest avalanche baffle in Switzerland: Muot. Bottom right the Chanaletta gallery, 1907.
Rhaetian Railway

Albula line > Walls with snow catchers, Muot avalanche protection baffle.
Rhaetian Railway

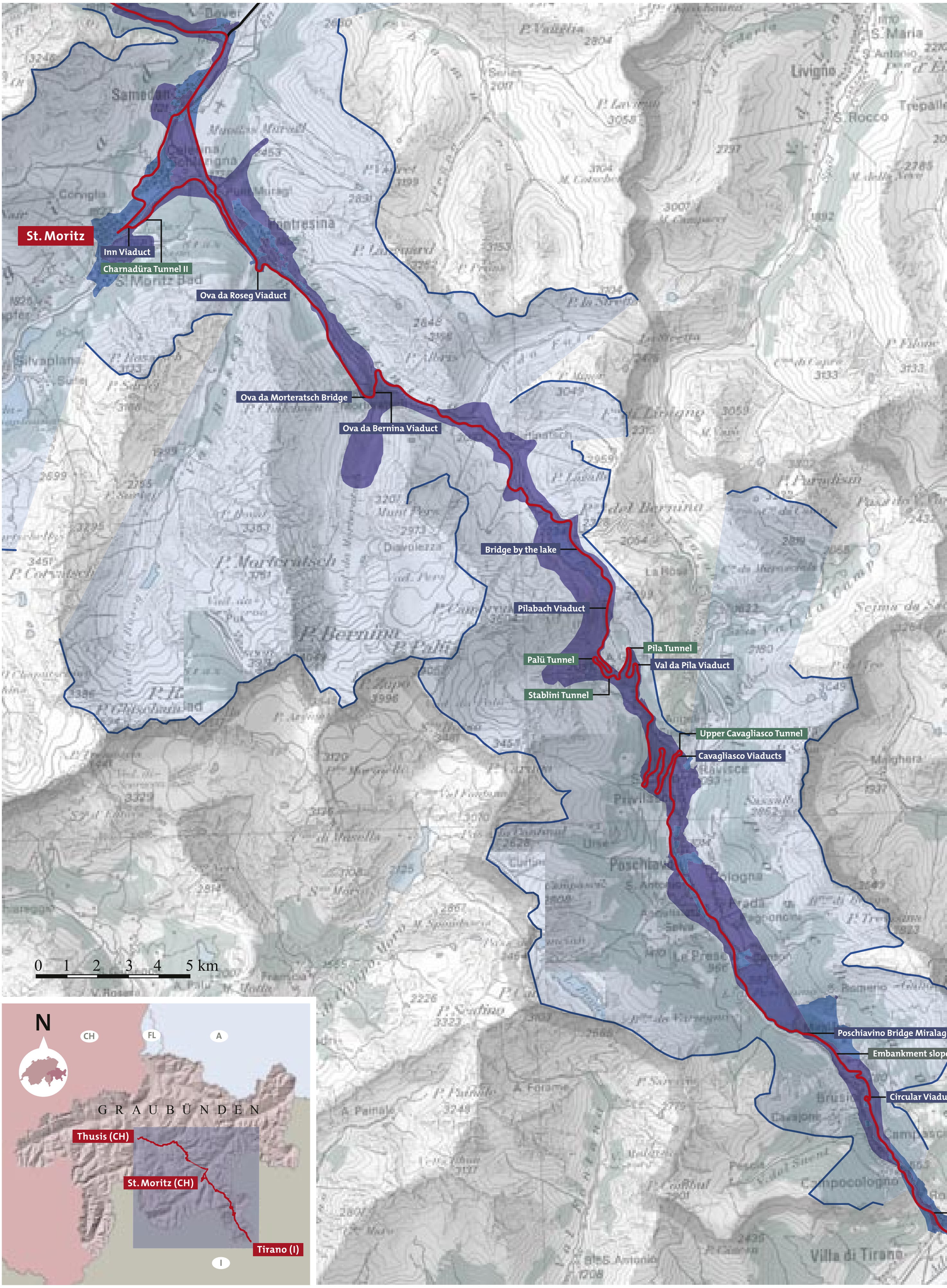
All the plans on this double page are taken from: FRIEDRICH HENNINGS: *Albulabahn. Denkschrift*, Chur 1908.

The Schin gorge contains the following tunnels: Runplanas (502 m), Versasca (694 m), Passmal (420 m), Solis (986 m) and Alvaschein (609 m). The unstable layer of the uppermost slope of the Schin already mentioned also created problems for some of the tunnels. Thus at the upper end of the Versasca tunnel, where it traverses this unstable layer, the tunnel facing had to be reinforced and a sole vault built. In contrast, the Solis tunnel traverses such hard limestone layers that two-thirds of its length could be left unfaced.
Between Bergün/Bravuogn and Preda, the construction of the Rugnux helical tunnel (662 m), the first of three spiral tunnels of this route section, ran into special difficulties when it cut into cold-water springs that greatly hindered the progress of construction. And even when the tunnel was completed, ice formation within it was a constant nuisance. The problem was finally solved by the installation of a tunnel gate.
The engineering structures along the Muot-Preda route testify to an intensive struggle with the geological and climatic conditions of the region. The double terminal loop in Val Rots, originally planned for the left bank, was abandoned in favour of the right-bank Toua tunnel (677 m) because the track with its tunnel would otherwise have had to traverse the extensive wet debris area of a massive rockfall.
With the exception of the Albula tunnel, all the tunnels were constructed using the "Belgian technique" with ridge galleries. The excavation was carried out by means of manual drilling and dynamite blasting. All the portals are built in natural stone. In important tunnels, the stonework is graduated towards the terrain in a classicistic style (tunnel portals Solis [south], Versasca [north], Nisellas [south], also the portals of the Albula tunnel): as a rule, however, their outlines follow the adjoining terrain in a polygonal pattern.

Other engineering structures

Other engineering structures that mark the landscape include retaining walls and avalanche baffle works. The numerous retaining walls were constructed exclusively in natural stone (as mortared or drystone walls) and form a unity with the viaducts and tunnel portals by virtue of their material and surface treatment.
The traversal of the Muot valley slope above Bergün is particularly striking as regards the interaction between engineering structures and the track layout, because the open line route here incurred extraordinary costs. The first part of the slope traversal required the largest avalanche baffle works ever seen in Switzerland at that time. The train runs through a masonry-built gallery under the avalanche ridge known as "Blais Chanaletta" adjacent to this baffle-lined slope. The question arises as to why this open railway route was not simply run through a tunnel. Hennings remarked on this problem in general: "Where it was possible to build baffle works in an avalanche area, this approach was taken, partly because of lower costs and partly to save tourists a doubly undesired tunnel in such beautiful surroundings." However, a rough cost comparison (using price data from Hennings) gives the following picture in this case: the stretch exposed to avalanches is 700 m long. It is adjoined by the 117 m long Chanaletta Gallery.
The open route cost CHF 62,000 and the gallery CHF 115,000, making a total of CHF 177,000. To this must be added the costs of the baffle works of CHF 300,000. The cost of constructing this 817 m long route thus totalled CHF 477,000. A correspondingly long, regularly faced tunnel would have cost CHF 347,000, significantly less than the open route. Even if the Swiss Federal subsidy of CHF 137,000 for the avalanche baffle works is included, the open route was not

Bernina line > Circular Viaduct at Brusio.
P. Donatsch


St. Moritz
Inn Viaduct
Charnadüra Tunnel II
Ova da Roseg Viaduct
Ova da Morteratsch Bridge
Ova da Bernina Viaduct
Bridge by the lake
Pilabach Viaduct
Pila Tunnel
Palü Tunnel
Val da Pila Viaduct
Stablini Tunnel
Upper Cavagliasco Tunnel
Cavagliasco Viaducts
Poschiavino Bridge Miralago
Embankment slope
Circular Viaduct
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Thusis (CH)
St. Moritz (CH)
Tirano (I)
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Selected engineering structures on the Bernina line

- Viaducts and bridges
- Tunnels
- Galleries
- Dam embankments

Core zone

- Core zone with railway and cultural landscape

Buffer zone

- Buffer zone in the near area
- Buffer zone in the distant area (backdrop)
- Horizon line

Other contents

- Other stretches of the Rhaetian Railway

Sources:
Basic map: PK 200'000 swisstopo, Wabern
Geo-data: Amt für Raumentwicklung Graubünden
Thematic data: Jürg Conzett
Design: Süsskind, SGD, Chur
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cheaper than a tunnel, especially if the expensive maintenance of the baffle works is included in the cost comparison. So the argument of attractiveness to tourists was a determining factor in favour of the open rail option. This is particularly remarkable because Muot represents the only point along the Albula railway where a conflict between a line's tourist appeal on the one hand and the search for cost effectiveness was decided in favour of tourism. At all the other points on the route of particular importance for tourism – one may mention the impressive interplay of the old road bridge and the more recent railway bridge at Solis, the Landwasser viaduct with its dramatic views from the train, the loops between Bergün and Preda offering broad views and surprising perspectives – tourist and technical-economic criteria largely coincide.

Engineering structures on the Bernina line

Bridges

The bridges on the Bernina line were built largely on the basis of the standards applied to the Albula railway. Some of the dimensions were merely reduced slightly in view of the differing operating requirements. As on the Albula route, stone viaducts were preferred. The bridges with the longest spans were the two Cavagliasco viaducts above Poschiavo, of identical design – each with an arch of 26 m – for which the same scaffolding was used to carry out the masonry work. Unfortunately both viaducts have suffered major distortions in the course of time due to slope movements. The upper Cavagliasco viaduct was replaced by a parallel steel-concrete composite bridge in 1989, and the lower Cavagliasco viaduct by a steel truss girder in 2002. Other longer spans are found on the north acclivity: they are the 20 m arch spanning the river Ova da Roseg and the 17 m wide Ova da Bernina viaduct on the ascent between Morteratsch and Montebello. Another one is the Inn viaduct at St. Moritz whose main opening has an 18 m span. Among the larger stone viaducts on the south side are the Pilabach bridge (10 m wide) between Ospizio and Alp Grüm, and the striking Val da Pila viaduct (3 x 10 m) above Cavaglia station. It was possible to preserve this viaduct despite strong slope movements by rebuilding the lower abutment in 2004 and placing it on friction bearings. The high point of bridge engineering on the Bernina route is the masonry-built circular viaduct of Brusio that bridges a height discontinuity analogously to a helical tunnel. It consists of nine openings each of 10 m that lie in a curve with a radius of 70 m. One opening spans the railway line running under it. The solution adopted for this viaduct was both cost-effective and attractive from a tourist standpoint, so this remarkable construction can really be seen as the embodiment of the objectives that guided the construction of the Bernina railway. In addition to the viaducts mentioned above, the Bernina line also has a large number of masonry passages and other leaning bridges. The stone bridges were built with granite at least on their outer parts, this material being available at various locations along the railway line, for instance in Montebello above Morteratsch station as well as in Ospizio Bernina, Cavaglia and Brusio.

Stone viaducts would have been unsuitable in certain cases because the construction height was too low or technical difficulties precluded them. The Ova da Morteratsch was originally traversed by a steel parable arch truss of 22 m span that was rebuilt in 1934, also as a steel dual-arch truss. The Poschiavino river is crossed at Miralago and La Rásica by truss bridges each

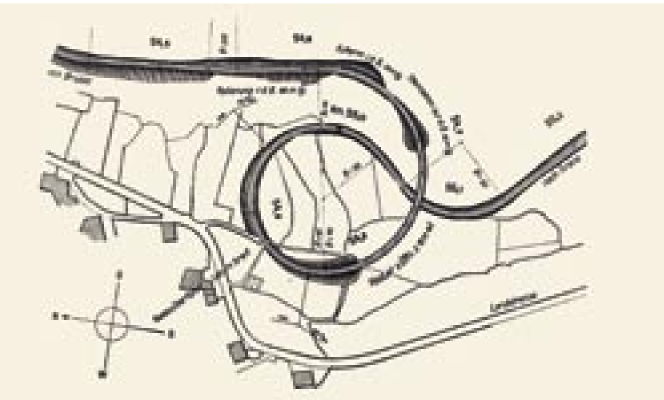
Bernina line > The lower bridge over the Bernina stream was built in 1934 in connection with a realignment above Bondo alp.
Rhaetian Railway

Bernina line > Upper bridge across the Bernina stream.
Rhaetian Railway

Bernina line > Alignment at Alp Grüm. Plan taken from: E. Bosshard: *Die Berninabahn*, Zurich 1912 (*Schweizerische Bauzeitung*, offprint).

Bernina line > Galleries protect the three traverses across theAlp Grüm slope against avalanches. The photograph was taken later than 1951.
Rhaetian Railway

Bernina line > The Bernina Express on the Brusio circular viaduct which climbs on the same principle as a helical tunnel.
P. Donatsch



Circular Viaduct at Brusio > Plan of the position and longitudinal section taken from: E. Bosshard: *Die Berninabahn*, Zurich 1912 (*Schweizerische Bauzeitung*, offprint).

Circular Viaduct at Brusio > Arch masonry 1907. Photograph taken from: E. Bosshard: *Die Berninabahn*, Zurich 1912 (*Schweizerische Bauzeitung*, offprint).

22 m wide that are preserved in their original form. The iron bridges of the route section between Bernina Lagalb and the lake Lei Nair were not built until later, namely in 1934, when a new line section with stronger avalanche protection was selected above Alp Bondo. In sharp contrast to the original design principles, these airy bridges with direct track placement and often with railings on only one side give an almost provisional impression and present a powerful image of the difficulties of building railways and maintaining them in the high mountains. The iron "bridge by the lake" that was only extended beyond Ospizio Bernina station in 1949 belongs to the same category.

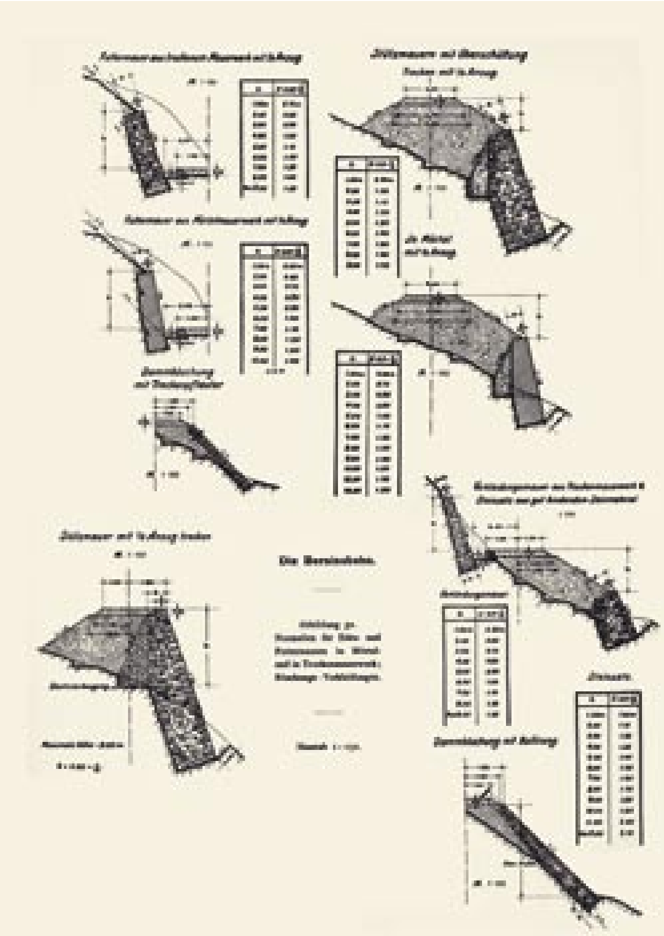
Tunnels

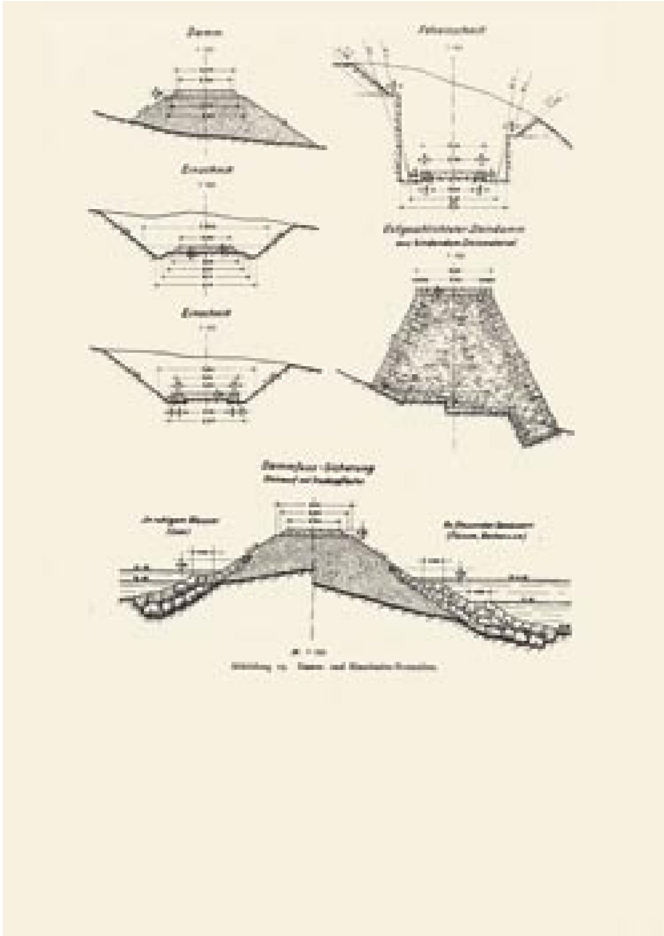
The longest tunnel on the Bernina railway is the 689 m Charnadüra tunnel II immediately after St. Moritz (opposite Charnadüra tunnel I of the Albula railway), the only tunnel on the north acclivity. This tunnel, that was not originally planned, had become necessary because adjacent communities and local preservation groups had objected to a direct connection between St. Moritz and Pontresina, as this would have intruded on the unspoilt moorland of the Stazerwald. The fight against this rail route was one of the reasons for the founding of the Bündnerische Vereinigung für Heimatschutz (Graubünden Heritage Society), which initially had a tense attitude to the idea of railway buildings. Several years passed before the Society finally declared the installations of the Rhaetian Railway and the Graubünden private railways to be both unique and exemplary.

The various tunnels on the south acclivity tend to be short but were difficult to construct. They were built in the "Belgian" manner with manual drilling. The most important ones are located in the section between Alp Grüm and Cavaglia, such as the Palü helical tunnel (254 m long), the Stablini tunnel (289 m) and the Pila helical tunnel (227 m). Difficulties due to geological conditions were encountered on the Upper Cavagliasco tunnel (32 m) that was built with walls up to 2 m thick from the outset so that it could withstand the slope movements. However, it had to be slit open in 1968 and replaced by an anchored retaining wall. In all the tunnels, the first 30 m from the portals are lined with masonry, this length corresponding to the frost limit. The mountain section above Cavaglia presented particular problems for tunnelling: the working season was of only brief duration, as the tunnels were not long enough to offer the workers sufficient protection from the winter cold. When the steep tunnels were being excavated, a process largely executed from below, the natural ventilation was deficient. For this reason, only blasting gelatine and dynamite were used in this phase of the construction. The dynamite called for great care, as it froze quickly and then exploded easily upon mechanical impact. But the safer explosive known as Cheddite could not be used until the ventilation conditions had improved with the cut-through of the driftway.

Other engineering structures

Retaining and lining walls are characteristic elements of the Bernina railway. Wherever possible, use was made of drystone walls with a slope of 1:3. Steeper walls were mortared, normally with a 1:5 slope, and in some cases were even vertical. Extensive walls were built for the joint rail-road foundations along Lago di Poschiavo. The "embankment slopes with dry paving" with a slope of 1:1 between Miralago and Brusio, where the track had to be built along an unstable landslip region, are also of interest.





Bernina line > Standards for revetment and supporting walls. Plan (reduced in size) taken from: E. Bosshard: *Die Berninabahn*, Zurich 1912 (*Schweizerische Bauzeitung*, offprint).

Bernina line > Below Miralago there is extensive dry stone masonry work supporting the embankments between the railway and the road; the size and type is unique in Graubünden.
J. Conzett

Background to the engineering structures

Typology

The engineering structures along these two rail routes illustrate pronounced conceptual thinking. The most varied initial factors might merge in a basically straightforward measure, such as the choice of semicircular masonry arches for bridges. These factors can then no longer be distinguished from each other in the completed product – precisely because a kind of irreversible, almost "chemical" process had occurred. It is particularly difficult to determine in retrospect which aspect had been weighted to what degree where the measures have a strong conceptual character and cover many aspects. At the same time there is a risk of decision-making processes seeming trivial by reducing them to simple motivations.

Almost without exception, all the bridges on the Albula route were built as viaducts in natural stone. The topographic and geological peculiarities of the Albula valley offered ideal conditions for this uniformity in bridge design; the lateral valleys to be traversed are usually deeply cut and permit the construction of high-arched viaducts. Their dimensions correspond to standards laid down in tables. The bridges on the Bernina route were originally built on the basis of similar principles. The different character of the railway as of the landscape it runs through and the later additions and rebuilding work explain the greater diversity of bridge buildings along this route.

However, the typology was more than merely an arbitrary instrument of rational planning and execution, it formed a design principle that extended beyond the viaducts to cover overpasses and underpasses, stream and path traverses as well as tunnel portals and retaining walls. Differentiations may also be noted within this typology: almost all the viaducts on both rail routes have standardised railings with an upper angular steel bar and a centre tube, the Solis viaduct, however, has posts of flat steel and tubular spars. This refinement underscores the importance of this large arched bridge. It also shows that not only the perspective of the railway user but also the views seen by tourists (or specialists) not travelling by train were taken into account: looking from the old road bridge, they saw the viaduct from the front. The fine points of the design indicated here remained hidden from train travellers because of the speed of the train.

Further differences are due to the construction materials used. To avoid longer transport distances, the material for the engineering structures was usually taken from the immediate surroundings. It thus reflects the particular features of the local geology. In the buildings of the Albula valley, the nature of the masonry changes with increasing altitude towards more irregular stone forms: the changeover from the smooth strata-like siliceous limestone of the Schin gorge to the embossed dolomite blocks at Preda corresponds to the ascent from the cultivated plain to the wild, high mountain region.

"Giving stone its due"

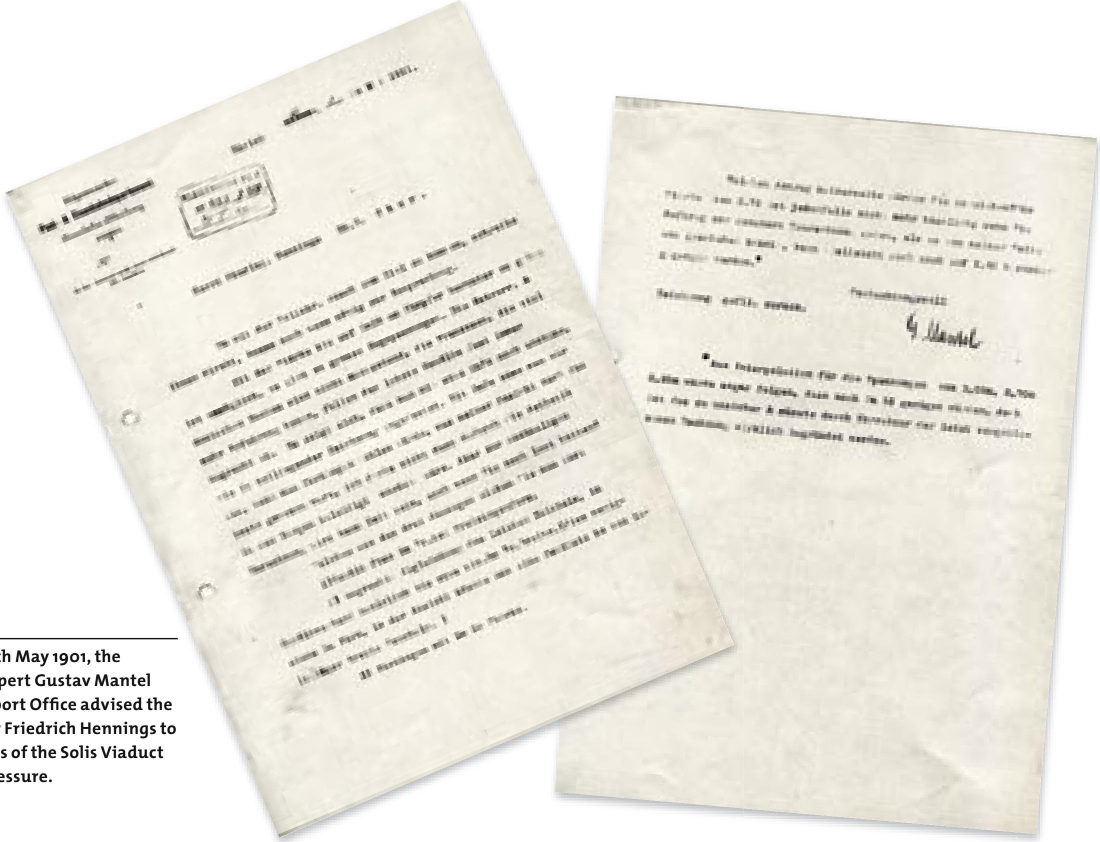
The bridges of the Albula railway indicated the beginning of a renaissance of stone bridge-building in Switzerland after a preceding period of fifty years during which railway bridges had been dominated by iron constructions, at least in the sector of longer spans. A tendency to stone building can also be noted in southern Germany and Austria-Hungary during the same period. In the second half of the 19th century, the theory of trusses had developed quickly: iron bridges were lightweight, could be quickly assembled and were correspondingly inexpensive. In larger

Albula line > A non-standard parapet was used for the Solis Viaduct that looks particularly delicate when viewed from the side.
J. Conzett

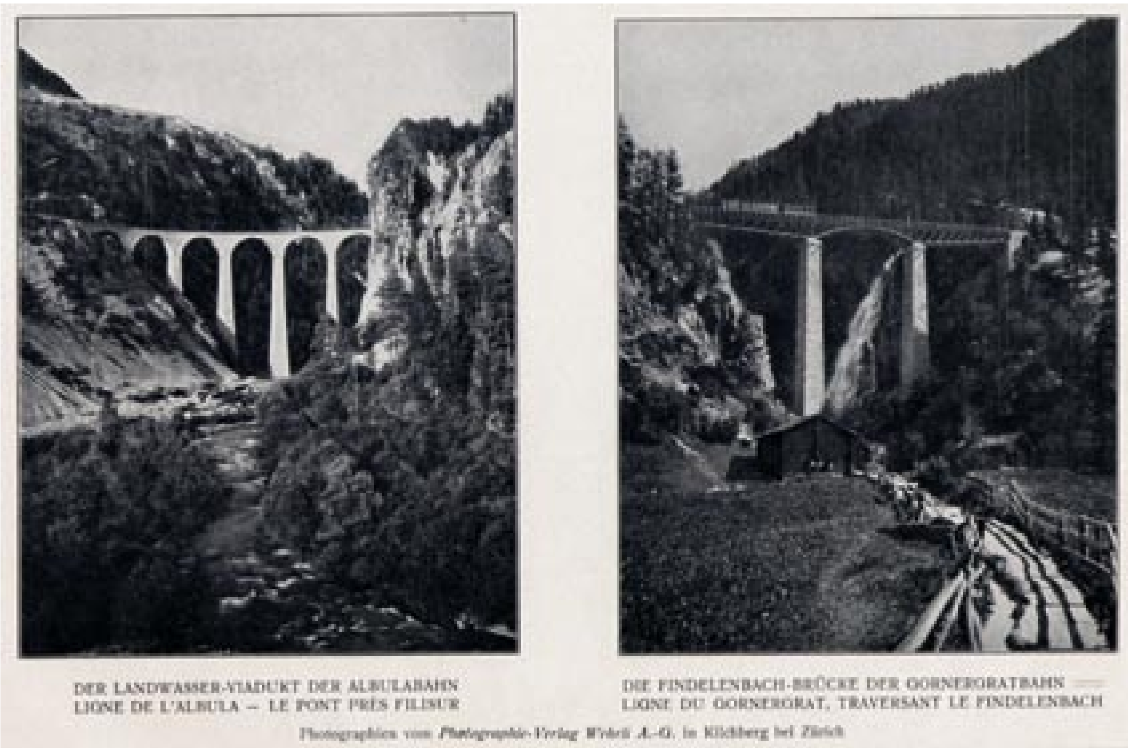
Solis Viaduct > Detail of the crown of the wall and the parapet.
J. Conzett

bridges, the iron trusses were usually supported by stone pillars and abutments, such as those of the Gotthard railway (1882) or the Landquart-Davos railway (1889). Not until the 1890s did the drawbacks of iron bridges become apparent. Locomotives had become increasingly heavy and powerful, the trains ran more frequently, and questions of iron fatigue became significant. It became evident in 1891 that by no means all iron bridges could cope with these growing stresses when the Birsbrücke in Münchenstein collapsed under a heavy express train. Traumatised by the accident, the Swiss Railway Department issued a new bridge-construction directive in 1892 that required all existing iron bridges in Switzerland to be redimensioned for updated loads. This led to extensive reinforcements to existing bridges. New iron bridges were now built to heavy and strong specifications. Where previous practice had been to screw the tracks directly onto the bridge with timber sleepers, they were now laid into a ballast bed on bridges too in order to cushion the impacts of the trains. However, this greatly increased the loading of the bridges, which was in turn associated with higher costs. Under these conditions, Robert Moser (1838 – 1918), then chief engineer of the North-East Railway, began to campaign in favour of stone bridges. Moser, together with Gustav Mantel, won the competition for the Lorraine road bridge in Bern in 1897. Their concept bore the motto "Give stone its due". Moser sent photographs of a plaster model of the project to all Swiss building contractors. He pointed out in an accompanying letter that stone bridges had hitherto been far too neglected in Switzerland and the choice often fell in favour of iron bridges even if these were associated with higher costs than a stone construction. He set himself the aim of gaining new friends for the "national and solid" manner of building. Three years later, Moser published detailed and systematic specifications "on the construction and costs of railway viaducts" in the Swiss construction magazine that confirmed his thesis of the cost-effectiveness of stone bridges. At the Rhaetian Railway, its director Achilles Schucan and chief engineer Friedrich Hennings as well as section engineer Hans Studer were also proponents of Moser's ideas. In his 1926 article on "Stone Bridges of the Rhaetian Railways", the latter criticised the "incorporation of relatively delicate iron trusses into a mighty granite environment shaken by avalanches" on the Gotthard railway as "something completely inorganic". In contrast, he praised the Albula railway, "whose construction had been determined by lofty ideas … by avoiding the use of materials alien to nature wherever possible and choosing a bridge-building material that was in the truest sense of the word solidly grounded in order to blur the distinction between human activity and nature as far as possible, to fit this human product as imperceptibly and modestly as possible into the beauty and majesty of the sublime mountain environment, and to minimise or completely avoid disturbing its harmony!"

With the exception of some low bridges and passages, all the viaducts of the Albula railway have semicircular arches. Even for the widely spanned arches of the Solis viaduct, Hennings insisted on the statically slightly sub-optimal semicircular shape. It would have been better to adapt the arch to the line-of-thrust, wrote inspection engineer Gustav Mantel from the Transport Office in an instructive exchange of correspondence, he "does not think that this would detract from the aesthetic appeal of the mountains." What was to become self-evident a few years later in other large stone viaducts, namely the adaptation to the ideal static form, was still questioned around



In a letter of 30th May 1901, the engineering expert Gustav Mantel from the Transport Office advised the senior engineer Friedrich Hennings to adapt the arches of the Solis Viaduct to the line of pressure.



DER LANDWASSER-VIADUKT DER ALBULABAHN
LIGNE DE L'ALBULA — LE PONT PRÈS FILISUR

DIE FINDELENBACH-BRÜCKE DER GORNERGRATBAHN —
LIGNE DU GORNERGRAT, TRAVERSANT LE FINDELENBACH

Photographien vom Photographie-Verlag Wehrli A.-G. in Kilchberg bei Zürich

Cross comparison in the zero edition of the "Heimatschutz" (1905/1906). The Landwasser Viaduct on the Albula line as "good" example and the Findelenbach bridge on the Gornergrat Railway as "bad" example.

1900 for aesthetic reasons. In parallel to the use of the modern theory of elasticity, a last "artistic intent in a struggle with utilitarian purposes" (Alois Riegl) can be traced here on the part of the engineer.

National Heritage and National Romanticism

The Bündnerische Vereinigung für Heimatschutz (Graubünden Heritage Society) was founded in 1905. The organisation was not limited only to preserving popular culture and natural beauty, but also called vehemently for "education for the appreciation of beauty" and in this context for the renewal of Graubünden's architecture. The canton's leading architects Nicolaus Hartmann junior, Emil Sulser, Martin Schäfer and Otto Risch, as well as engineers Achilles Schucan and Gustav Bener were members of the Association. The magazine "Heimatschutz" (Heritage Conservation) published by the Swiss Heritage Society, the umbrella organisation of all local preservation groups active in Switzerland, on several occasions contrasted the bridges of the Albula railway as "good" examples compared with the "bad" iron bridges. In the issue of January 1913, Jules Coulin pondered with reference to the Rhaetian Railway on the "magnificent local preservation work of a railway company": "The secret of the great impact that ultimately brings honour not only to the company but to its narrower and broader homeland, lies in the individualised treatment of the various technical and architectural challenges. Dedication to the finest ways of treating materials, the rhythm of form and characteristic building methods has led to the viaducts and bridges of the Rhaetian Railway representing not only marvels of technology but also of good taste for all time […]".

The heritage conservation movement was a part of a general cultural mood known as national Romanticism (cf. 2.a.5). The "national art in a good modern spirit", that Richard Kuder called for in 1900 with reference to the Scandinavian countries, was expressed simultaneously in painting, literature, architecture and now also in bridge construction. Typical features of national Romantic architecture were a preference for regional materials and artisan traditions, compact proportions and restrained mass impacts, but also "the spirit of objective design". In the bridge construction for the Albula and Bernina railways, not only does the preference for stone point to the Romantic movement, the elaboration of the details also shows affinities with it. Sentences such as "they seek to bring out the effect of piled-up masses and undisguised material […]. Bare walls rather than façades in a scenic style, rich and delicate details only where necessary on significant points as a contrast to large areas", that J.J. Tikkanen expressed in the Swiss construction magazine of 1906 with reference to Helsinki's main railway station, read like a program for designing the stone viaducts of the railway lines described here. Here lies the key to the unusually strong formal reference of the bridge construction practice of the time to the contemporary architecture of Graubünden, but it also underscores the importance of finishing the upper parts of the viaducts with cover panels and corbels that can also be read as "rich and delicate detail" with an ornamental effect.

Impact

In the years between the construction of the Albula railway and the First World War, the bridges along newly laid railway lines ever more frequently took the form of stone viaducts: there are stone bridges on the Engadin line of the Rhaetian Railway, the Chur – Arosa railway, the

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DIE RHÄTISCHE BAHN.

DER achte Jahrgang unserer Zeitschrift wird heute mit einer Veröffentlichung begonnen, die ganz der grossartigen Heimatschutzarbeit einer Bahngesellschaft gewidmet ist. Noch vor wenigen Jahrzehnten wäre es kaum denkbar gewesen, dass ein verkehrstechnisches Unternehmen die Eigenart der Landschaft, den Charakter ihres Baustiles in ganz eingehender Weise berücksichtigte. Ebensowenig hätte man daran gedacht, dass Heimatfreunde, denen die Schönheit des Vaterlandes und die Erhaltung seiner Natur- und Kunstdenkmäler eine Herzenssache ist, das Walten modernster Technik in ihren mannigfachen Erscheinungen freudig begrüssten. Es ist gar noch nicht so lange Zeit her, dass die englischen Reformatoren des Kunstgewerbes und des volkstümlichen Kunstgeschmackes — ein Ruskin und W. Morris — nicht nur alle maschinelle Arbeit verpönten, sondern auch der Eisenbahn grundsätzlich den Krieg erklärten; Morris hätte die Waren, die aus seinen Werkstätten kamen, nicht einmal einer Bahn anvertraut; er liess sie zu Wagen in die Stadt befördern. Das war zu jener Zeit, wo Technik und

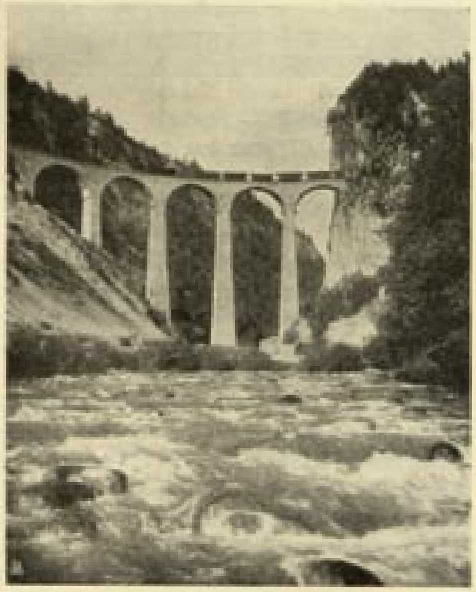

Abb. 1. Viadukt der Albulabahn bei Filisur. Eines der elegantesten und zugleich grossartigsten technischen Werke aller Zeiten. Aufnahme von *Wehrli A.-G.*, Kilchberg-Zürich. — *Fig. 1.* Le viaduc du chemin de fer de l'Albula, près de Filisur. Une des plus élégantes et en même temps des plus grandioses constructions industrielles de tous les temps.

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The Swiss Heritage Society "eulogy" on the Rhaetian Railway buildings and installations.

Lake Constance – Toggenburg railway and on the Centovallina line. A large number of stone bridges were also built on international transit routes such as the Lötschberg and Tauern railway. These bridges usually corresponded down to their details to the types on the Albula railway. However, the experience gained in the construction of larger stone arches could also be transferred to concrete as a building material. The concept of elevated concrete arch bridges was taken over from stone construction. One line of development leads from the Solis viaduct (semicircular arch) via the Wiesen viaduct (line-of-thrust arch with concrete blocks) to the Langwies viaduct (line-of-thrust arch with two edgewise concrete ribs).

After the First World War, stone increasingly gave way to the less expensive concrete. However, it continued to be used for bridges with a claim to national importance. The bridge-rebuilding work on the Gotthard railway used stone (or at least stone facing) from 1920. The same applies to the bridges of the Susten pass road (opened in 1946) and the new Devil's Bridge in the Schöllenen gorge (1956).

These stone viaducts have remained well preserved for a century where the terrain has not moved too strongly. Today, the sealing of their arches is in most cases no longer intact and there are signs of frost damage. Repair of the stone viaducts while retaining their architectural character represents a major challenge for the years to come (cf. 4.a.1).