Tamina Canyon Crossing, Bad Ragaz, Switzerland

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ABSTRACT

In 2007 the City of St. Gallen, Switzerland, has announced a public competition for a new bridge across the Tamina Canyon. This paper presents the winning design, and gives an overview of the most important design and construction aspects.

KEYWORDS: integral structure, high aesthetic quality, slender arch, concrete hinges, inclined piers,

1. Introduction

The Tamina river valley forms the southern tip of the canton of St. Gallen. It is orientated approximately from south to north and ends at the spa town of Bad Ragaz around 500 m above sea level in the alpine Rhine valley. In its lower end the Tamina flows through a deep gorge that separates the higher valley plateaus and their communities from each other.

The Tamina valley belongs to the administrative district of Bad Ragaz with about 1,600 inhabitants. The main community of the valley Pfäfers is located on a plateau on the eastern slope about 300 m above the valley floor. On the western side an internationally renowned rehabilitation center was built in the Valens community. Both valley plateaus are accessible by roads high above the canyon, starting from the center of Bad Ragaz. They win first height with a series of bends in the forested steep slopes of the Rhine Valley and continue from there serving the communities in the higher Tamina valley. The bottom of the gorge can be reached from Ragaz by footpaths along the river reaching the spring close to Valens.

Due to the geological risks, the road in the west to Valens is no longer sufficient to the current and future requirements. For this reason, the communities of Bad Ragaz, Valens and Pfäfers decided in 2005 to work out a preliminary concept for the rehabilitation and maintenance of the Valens street and in comparison the crossing of the Tamina valley with a bridge between Pfäfers and Valens, with the result that a valley-crossing would be the most economical solution. The new road should bypass the village of Pfäfers northwest and lead into the district of Bofel. From Bofel to the district of Berg on the other side of the Tamina valley (Fig. 1) a 400 m long bridge would be spanned, crossing at about 200 meters height above the gorge.

Figure 1. Tamina Bridge, View North-West © Tiefbauamt St. Gallen

Bridging the Tamina gorge requires exceptionally high standards for a harmonious integration of the structure in the natural surroundings. For achieving this objective, sensitive handling of the boundary conditions and local conditions are essential. This is particularly the case for the technically demanding stages of construction of the bridge with the least possible disturbance of the nature reserve. Furthermore, an intensive study of the geological and geotechnical situation was essential for a successful approach.

It was decided to achieve this best solution by inviting for an international design competition. The grade of detailing of the submitted designs had to allow for a reliable assessment of the following criteria

- Technical Feasibility
- Appearance
- Cost and Efficiency.

The road geometry in plan and elevation, the bridge deck dimensions and the normal road profile were given as binding in the competition documentation. In addition, the geological conditions were summarized in a geotechnical report. The area of the Tamina gorge near Bofel is recognized as a habitat sanctuary according to the cantonal conservation plan. The area under the planned bridge for example is used by chamois and this has to be taken into consideration during construction. In habitat sanctuaries the objectives of protection of the landscape have to be in accordance with the conservation plan e.g. buildings changing the character of the landscape should be avoided.

2. Design Concept

2.1. General

The response to the invitation to this anonymous unrestricted design competition was overwhelming with 24 entries and within these 14 arches of different shape and configuration had been proposed. In a two stage tedious selection process the jury came in the first step to the conclusion to select 4 arches as finalists. For the final round all 4 proposals had been modeled by the authority in a landscape model in scale 1:250 for further detailed evaluation. The jury came at the end to the unanimous conclusion to select the presented scheme which had been developed by Leonhardt, Andrä und Partner (Fig. 2).

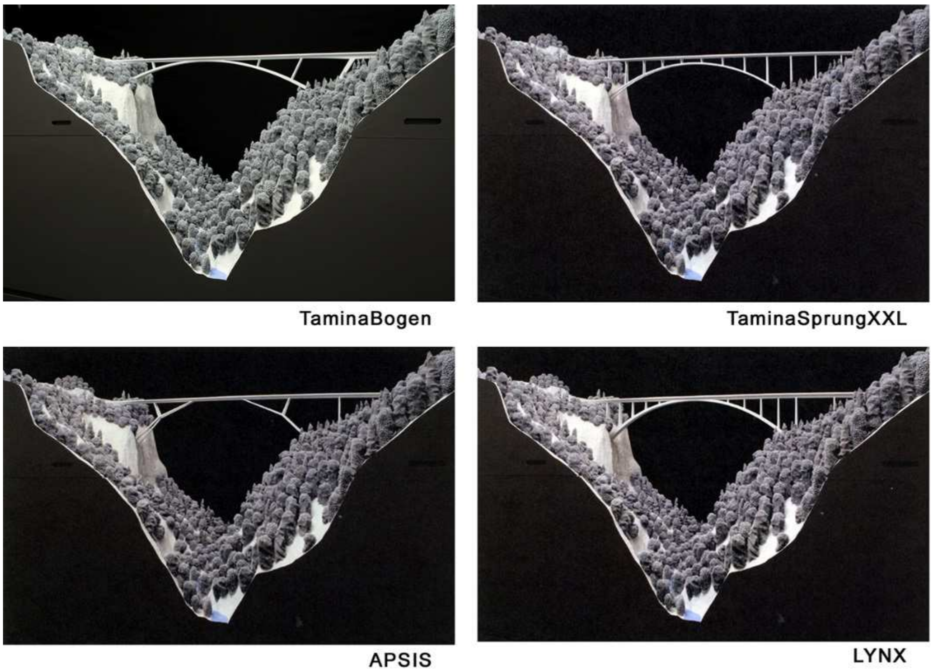

Figure 2. Short-listed Projects

2.2. Geological situation

According to a geological summary "no unusual problems" were to be expected with the integration of the bridge foundations in the rock. The rock compressive strengths had been estimated between 30 and 60 MPa and are thus in the top range of higher strength concrete. However from the left side of the valley falling layers were noted in connection with certain clefts and because of the potential mobilization of larger rock packages in the steep terrain due to construction activities which had to be kept in mind.

2.3. Environment

The Tamina Gorge is reported as habitat sanctuary where the aims of landscape protection apply in particular. Below the bridge, considerations for the chamois areas along the valley sides resulted as much compelling as respecting all concerns of the sensible sanctuary of the Tamina river gorge itself. Any activity in the steep valley sides or from the valley floor during the construction period had to be avoided. In the upper, shallower widening of the valley towards the Bofel side (municipality Pfäfers) and Berg side (municipality Valens) construction activities were to be reduced to a minimum.

For the final state it was to pay attention to a particularly harmonious incorporation of the bridge in the landscape and the rural surroundings. Under any circumstances the landscape character should not be changed.

2.4. The concept

From the boundary conditions described above, the following conclusions were obtained for the design concept:

- main structure has to be located below the roadway

- Tamina gorge to be crossed column-free (arch with 265 m span)
- end region of the hillside areas had to be also column-free (rigid frame with 89 m span Bofel side - and 48.5 m span - Berg side)
- construction of the main opening (arch area) had to be by balanced cantilever method with a temporary stay system.

The basic design idea was to cross the Tamina gorge with an arch and also bridge column-free the hillside area towards the abutments with rigid frame structures (Fig. 3).

Figure 3. Tamina Arch-Bridge, View from West, © Bastian Kratzke

The interventions in nature could thus be reduced to four foundations, the two abutment foundations at the ends and the two arches next to the gorges. Both proved technically and from a geological point of view as completely unproblematic. The thrust application point of the left arch side was pulled as high as possible and therefore kept outside of the extremely steep valley walls but still in the area of the bedrock.

The selected structural system translates the geological boundary conditions consistently into practice. The rock formations above the steep valley walls are ideal to carry the thrust from the arch effect. The difference in altitude between both arch foundations reflects the overall asymmetrical valley geometry. On the Berg side the end frame with the two endspans results in smaller spans than at the Bofel side which reflects exactly the valley profile.

In order to optimize the spans of the end frames, the frame stems which are the high piers were inclined and reach the springing foundation perpendicular to the arch axis. The resulting inclinations are similar to the slopes of the steep valley walls, which has a favorable effect to the natural appearance of the bridge in the valley. The remaining piers were arranged as well radial to the arch curve, so that the overall system received an organic, orderly and harmonic expression.

This structural system allowed the arrangement of all members below the road and a cautious insertion in the landscape was guaranteed. The overall character of the landscape remained unchanged. Only during construction temporary towers and stays will be arranged above the roadway for the cantilever erection process. This erection method allows a maximum degree of protection of all areas below the bridge during construction.

2.5. Detailed description of the structural elements

The arch is designed as a reinforced concrete structure with a span of 265 m, which is fixed in the foundation springings and has therefore in the impost area with 4 m the largest height which decreases towards the center to 2.05 m (Fig 4). The width of the arch varies as well and changes between the foundations with 6.95 m (Berg side) or 9 m (Bofel side) and 5 m in the crown area. Over a great extension the arch can be developed from a hollow box; between the last two piers and the center it becomes a monolithic section.

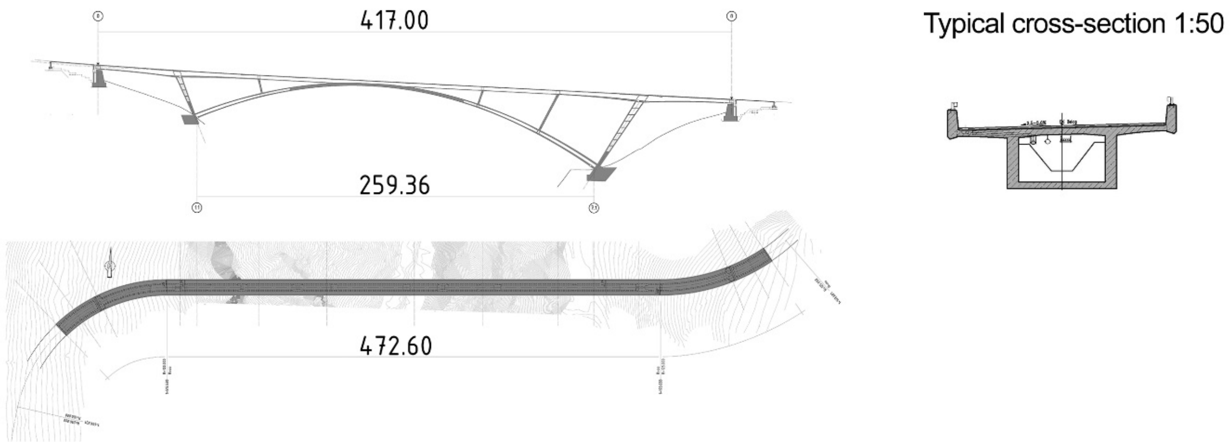

Figure 4. Layout and Cross-Sections

The three small piers are as well from a solid section. In view of the arch these appear very slender being executed with hinged supports of the superstructure and from the arch (Fig. 5). With variable sections they match both the arch and deck dimensions.

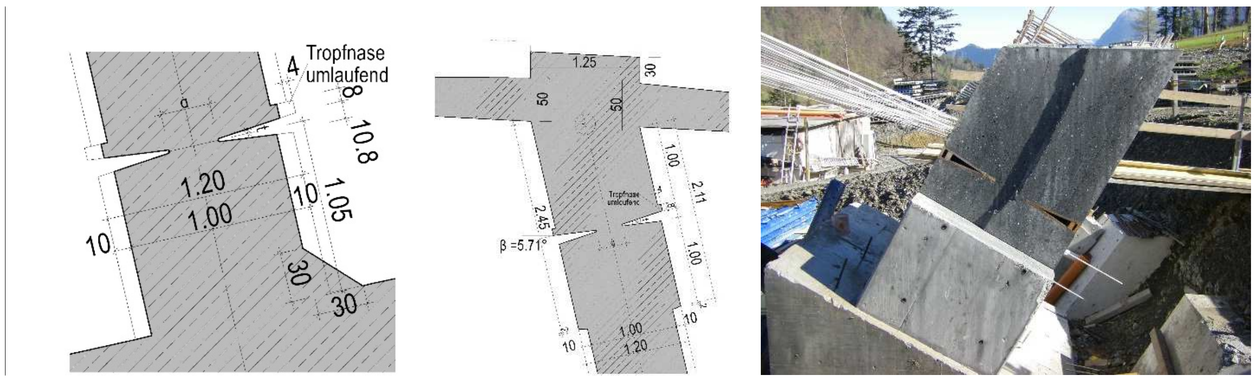

Figure 5. Concrete hinges

The inclined higher piers which arise from the arch foundation are fundamentally different from typical pendulum columns which are normally placed.

Those inclined ones fulfill in addition to primarily support the superstructure the function of a frame as part of the end spans. By this rigid frame structure (superstructure as a frame member, pier as the framework stem) the column-free bridging of the hillside area (89 m Bofel side; 48.5 m Berg side) is realized economically and aesthetically appealing. These piers, designed as variable hollow box sections with a significant increase towards the top where being connected to the superstructure reflect in the side view the frame effect perceptively. Their function within the framework structure becomes clearly noticeable, especially in the distinction to typical pendulum-like arch piers.

The design of the superstructure consists of a continuous pre-stressed concrete girder. The spans result between the monolithic connection with the arch and the abutments as a result of the arrangement of piers between 38.45 m and 62.7 m. Due to the inclination of the piers the spans the end spans could be reduced significantly (Bofel side from 89 m to 62.70 m – Berg side from 48.50 to 38.45 m). The hollow box section is determined over a wide range with a constant height of 2.75 m. In the area of the end spans it receives according to its function as a frame member a haunch to 4.75 m and 5.00 m (Bofel side) and 4.3 m and 4.5 m (Berg side). With the width of the hollow box of 5.00 m, the length of cantilevers, including parapets, reach 2.73 m. It is thus a well-balanced cross-section and a transverse prestressing was not required. With the monolithic connection of the piers with the arch and superstructure no bearings are required except for the location at the abutments, where also expansion joints are arranged to compensate for changes in length. For the superstructure, this results in an overall length between the abutments of 48.5 m + 265 m + 89 m = 402.5 m. In the end regions in front of the abutments, the superstructure is curved in plan according to the alignment. The resulting additional torsional moments are carried easily by the hollow box.

All structural elements are from reinforced concrete or prestressed concrete. With this choice of material a consistent implementation of the overall concept is above all economically and coherently feasible.

Superstructure	**Arch**	**Abutments and foundations**
Concrete: C 45/55	Concrete: C 45/55	Concrete: C 30/37
Reinforcing steel: B 500 B	Reinforcing steel: B 500 B	Reinforcing steel: B 500 B
Prestressing steel: Y1860S7-15, 7		

2.6. Summary of principal design aspects

Some aspects should be pointed out to explain why in the view of the authors of the proposed generous and delicate arch solution is the appropriate response to the given task at this location

- Integral structure by monolithic connections of all main components (bearings only at the abutments) and thus a high degree of durability, robustness and redundancy
- Choice of concrete as a logical implementation of this concept
- Implementation of a hybrid structural system composed of a global arch effect combined with frames supporting the end regions. Further typical bending effects in superstructure and arch leading to reasonable and economical component dimensions
- The conclusive static concept being easy to read from the appearance of the bridge
- Emphasis on the rhythm of the spans of the superstructure by reducing the length towards the arch crown
- Extension of the typical appearance of arch structures by radial arrangement of the piers which brings distinct static advantages due to shorter end spans and in general (compared to vertical piers) showing a very favorable loading for the arch

- Patterning of the arch soffit by a 10 cm deep recess at a distance of 1.50 m from the edges
- Patterning of the piers in the same sense; the recessed areas are executed with a rough surface, the remaining surfaces smooth producing an additional accentuation by differently colored areas

3. Design and Construction

3.1. General

In spring 2011 the so-called "construction project" could be completed by the engineering firm Leonhardt, Andrä and Partners. This corresponds to approximately 30% to 40% design level. In addition to that rather high degree of pre tender detailing in Switzerland, the independent checking engineer is already involved in these early design phases of the project. The design continued between June and December 2011 to complete all tender documents and in 2012 it was publicized for tender and early in 2013 a contract could be awarded to the JV of Strabag AG Glattbrugg, J. Erni AG Flims Dorf, Meisterbau AG Balzers. Actual construction on site takes place since March 2013. In fall 2014 the auxiliary towers should be erected to commence with first free cantilevering steps of the arch.

3.2. Actual design progress

The implementation of the contractors chosen erection process had to be done after award of the contract. It can be summarized in these 5 stages (Fig. 6):

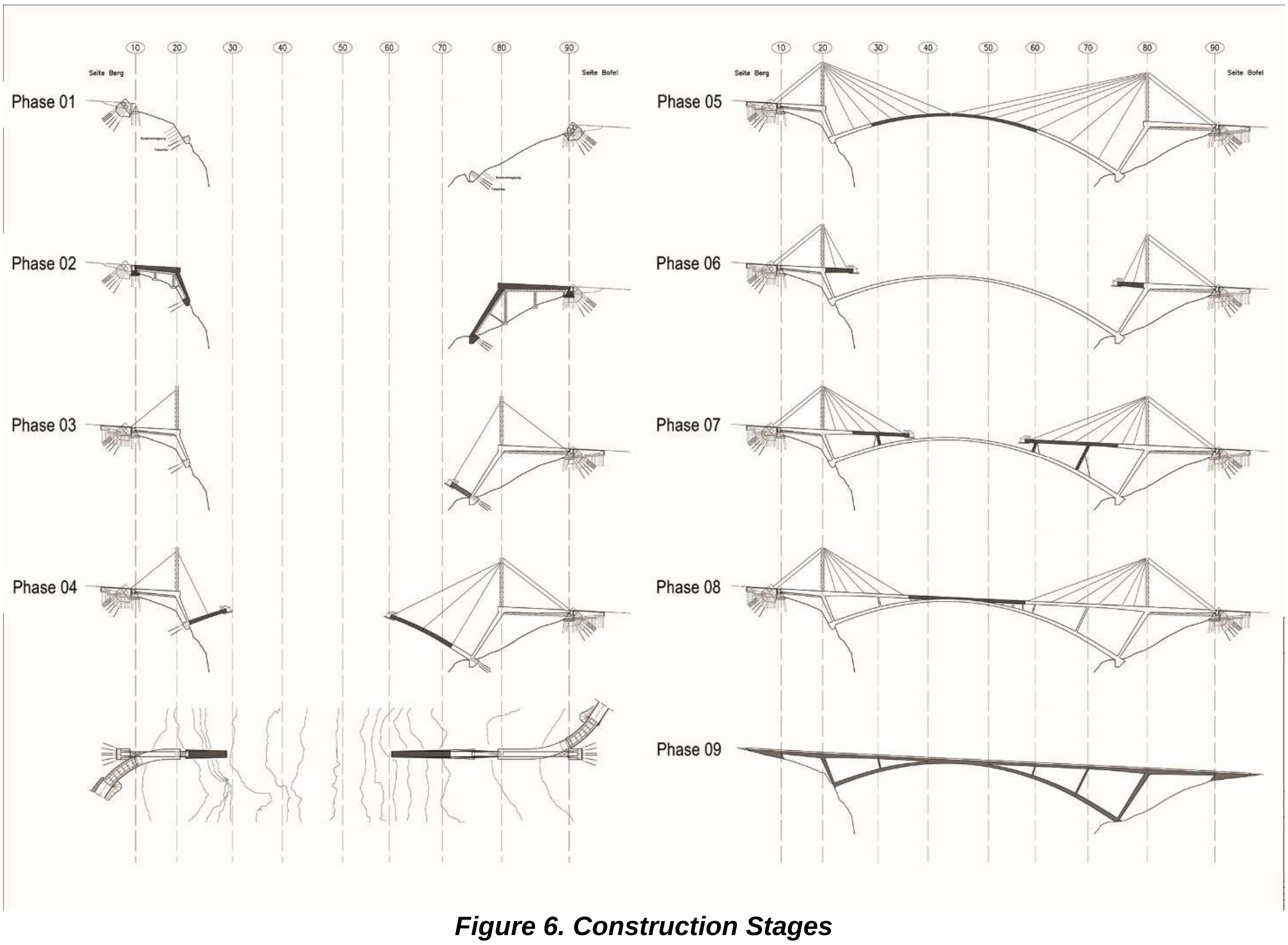

Figure 6. Construction Stages

1. foundations and abutments
2. half frames on both ends (inclined pier + superstructure towards the abutment)
3. free cantilevering segmental construction of arch with auxiliary towers and stay system, movable scaffolding
4. superstructure portion at the crown point
5. superstructure and piers construction in four steps from center towards end span.

Figure 7. Erection of arch as free cantilever

The auxiliary erection equipment for all the above stages, except for the stays is summarized in a drawing (Fig. 7).

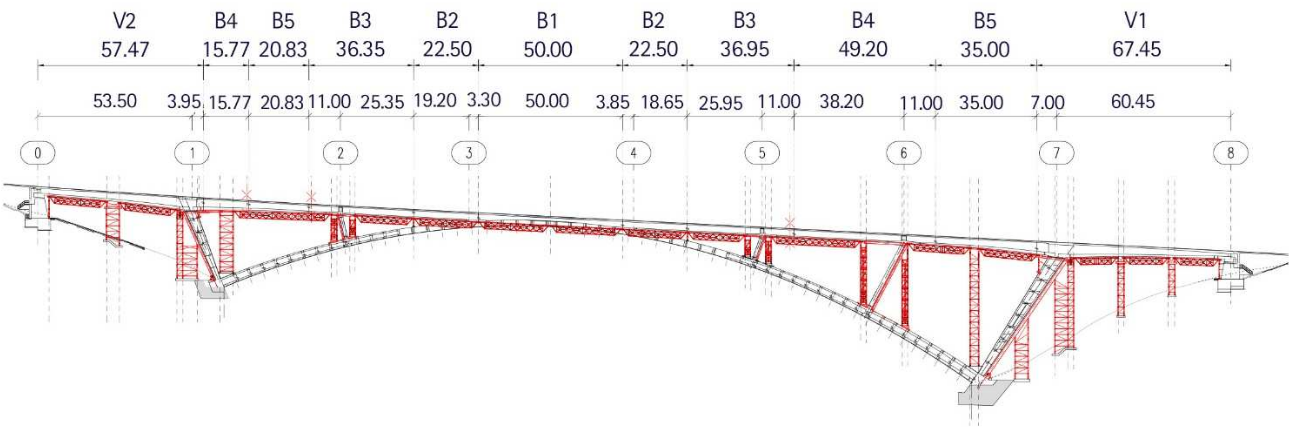

Figure 8. Construction of superstructure on standard falswork


Figure 9. Falswork construction

A few special issues of the design analysis may be mentioned. The evaluation of numerous erection stages took a wide range. Potential failure of certain cables was considered and even seismic events during construction were revised. Stability and second order effects were examined both for the final state as well as for several construction stages, taking into account the stiffness drop due to crack formation.

Ground investigations have been carried out on the basis of the engineer's exploration concept. Those revealed that both the arch and the abutment foundations could be raft foundations.

4. Conclusion

By bridging the Tamina gorge with a generous arch solution in combination with column-free approaches, a valley crossing is enabled, with a minimum of support points and the best possible consideration for the surrounding terrain. The arrangement of the entire bridge structure below the road level leads to a crossing which recedes in its appearance significantly and the overall landscape character remains essentially unchanged. At the same time the concept developed its own distinctive design language by combining an unsymmetrical arch with framework elements.

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Geotechnical Expert:	Dr. von Moos AG, Zurich, Switzerland

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