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Tomorrow's Megastructures

Rehabilitation of Flon Arch Bridge

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Abstract

The bridges over the Flon river were designed in 1964 by Sarrasin, a Swiss pioneer in reinforced concrete bridges. They are an illustrative example of the technique used to minimize the use of materials by, among other things, dividing the bridge deck in consecutive parts.

The mountain side bridge over the Flon river is in poor condition. The degradation of the half-joints is particularly concerning. This poses a risk for the structural integrity of the bridge. The aim of the rehabilitation project is to concrete every half-joint thus removing any risk associated with keeping them (brittle failure, fall of deck in case of seismic activity & progressive degradation). This solution will however modify the static system of the bridge.

The joints will be concreted using temporary steel structures placed under the deck, linking both sides of the joints. The joints are then demolished, thus removing all chloride contaminated concrete. The abutments are modified to allow horizontal movement. They are designed to include an access, with expansion joints and sliding bearings that are easily accessible for any maintenance work. The deck slab is reinforced by removing the cover concrete and adding a micro-concrete layer on the whole surface. The arches, piers and crossbeams are reinforced to maintain the integrity of the bridge. These reinforcements are made by wrapping the different concrete parts with carbon sheets or lamellas (FRC). The noise barriers laterally attached to the edge beam of the deck are replaced.

The construction project allows continuous traffic on the bridge during the works with only three work phases during which traffic lanes are modified.

Keywords: concrete arch bridge; highway bridge; half-joints concreting; rehabilitation; strengthening; FRC; post-tensioning; abutments

1 Bridge description

The two bridges over Flon river are parallel and each carry one direction of highway N9 in Lausanne, Switzerland. The bridges have a length of 430 m and cross the valley with a 120 m long concrete arch which has a 23 m sagitta. Both bridges are independent.

The Flon bridges, also called Chocolatière viaducts and illustrated in Figure 1, were designed by Alexandre and Philippe Sarrasin engineering firm. As described in [1], they were pioneers in the design of reinforced concrete bridges in Switzerland.

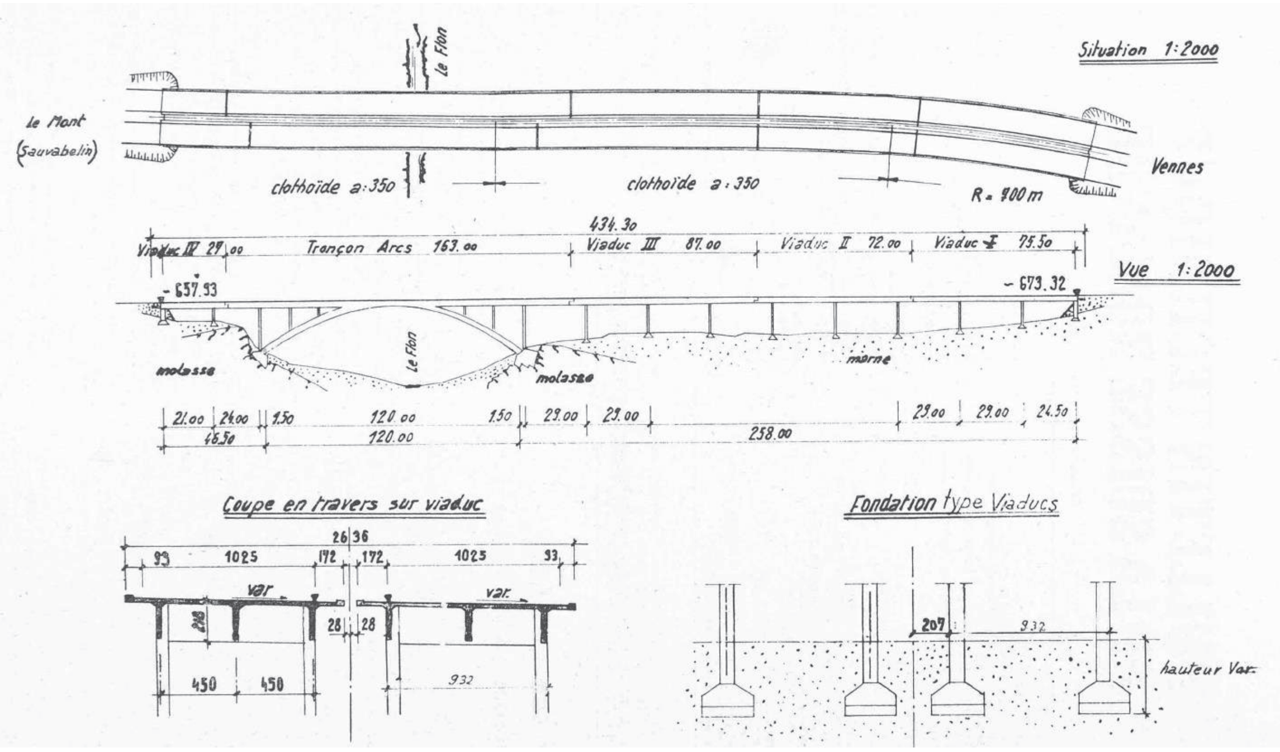

Figure 1. Flon bridges, taken from [1]

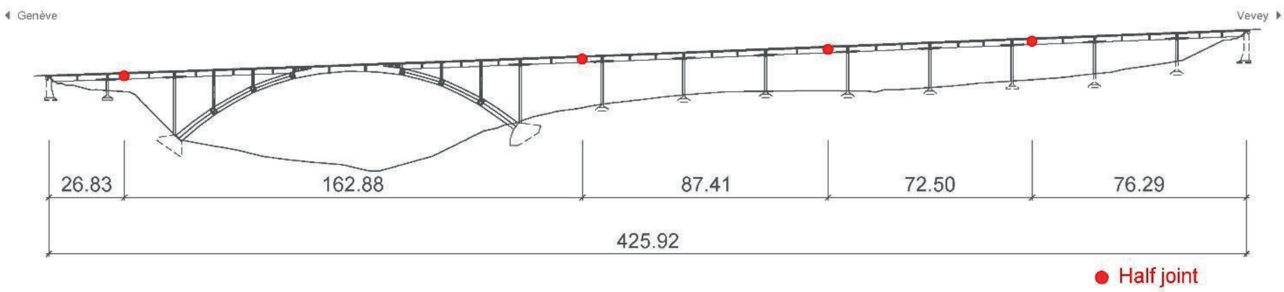

Figure 2. Bridge elevation and localization of the 4 half-joints.

Each arch is made of two curved girders connected by crossbeams. Coulumns link the arch girders to the edge beams of the deck, as shown in Figure 3. A third longitudinal beam is placed in the center and is connected to the columns by crossbeams. Therefore, the 12.90-meter wide bridge deck is composed of three longitudinal beams, crossbeams and a slab.

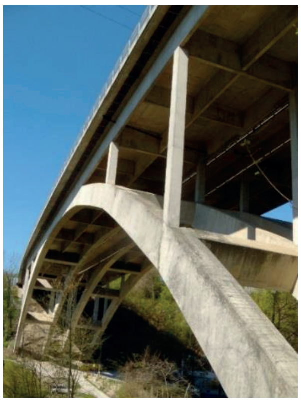

Figure 3. Arches and deck

The Flon bridges are an illustrative example of the technique used to minimize the use of materials.

At the apex of the arch, the two curved beams connect into and become one with the edge beams. Therefore, the bridge deck slab, the columns over the arch and the main girders give the impression of a monolithic structure as described in [2]. However, the structure is not monolithic in longitudinal direction as the bridge deck is cut in 5 parts linked by half-joints, as shown in Figure 2.

The mountain side bridge was built and opened to traffic in 1964 for the Swiss National Exhibition 64. The arch centering of the mountain side bridge was used to build the arch of the lake side bridge after a transversal shifting. The deck of the lake side bridge was built a few years later and was opened to traffic in 1974.

In 1992, the surface course and the curbs were redone, and a noise-barrier was installed on the mountain side bridge.

The lake side bridge was rehabilitated in 2017 and the two center half-joints were concreted and blocked while the two end half-joints were preserved and restored. For the mountain side bridge, described in this paper, the four half-joints of the bridge were concreted and blocked.

2 Bridge condition

2.1 Investigations and observed degradations

The bridge was inspected and analyzed, and the following critical points were identified:

- Half-joints heavily degraded and showing a risk of failure
- Road joints not waterproof and not accessible for control
- Deterioration of the concrete of the arches
- Many defects in the deck
- Defects of the waterproofing layer
- Curbs in a bad state
- Chloride contamination of the concrete
- Non-compliant restraint system

The bridge is in a bad state (level 4, according to the scale used by the Swiss Federal Road Office [7]) and it should be rehabilitated.

2.2 Half-joint

A 3D representation of the half-joints is shown in Figure 4.

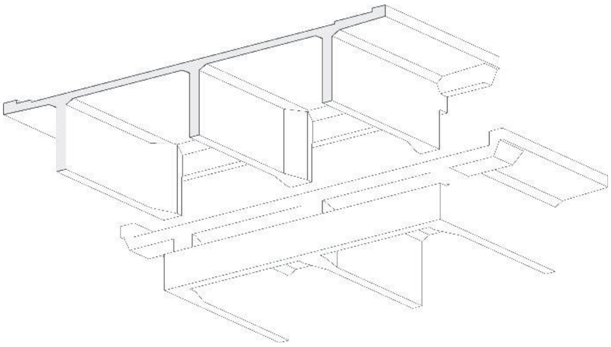

Figure 4. 3D model of a half-joint

The observed degradations of the half-joints cause a risk to the structural integrity of the bridge. The concrete is spalling in various location, showing corroded steel rebars with a significant loss of the cross-section. These damages are mainly due to important amounts of road water streaming from the road joints which have lost their waterproofing, as seen in Figure 5.

Figure 5. Important water streaming on a half-joint

The 32-cm width of the support zone at the half-joints is too small, according to the codes, to prevent the deck from falling under seismic load [3]. Moreover, the bar placement in the joint is not ideal as some of the most important bars are not correctly anchored, according to the codes [4].

The half-joints were first verified using stress fields and the results are given in Figure 6. According to this method, the failure load of the half-joint is 1'560 kN.

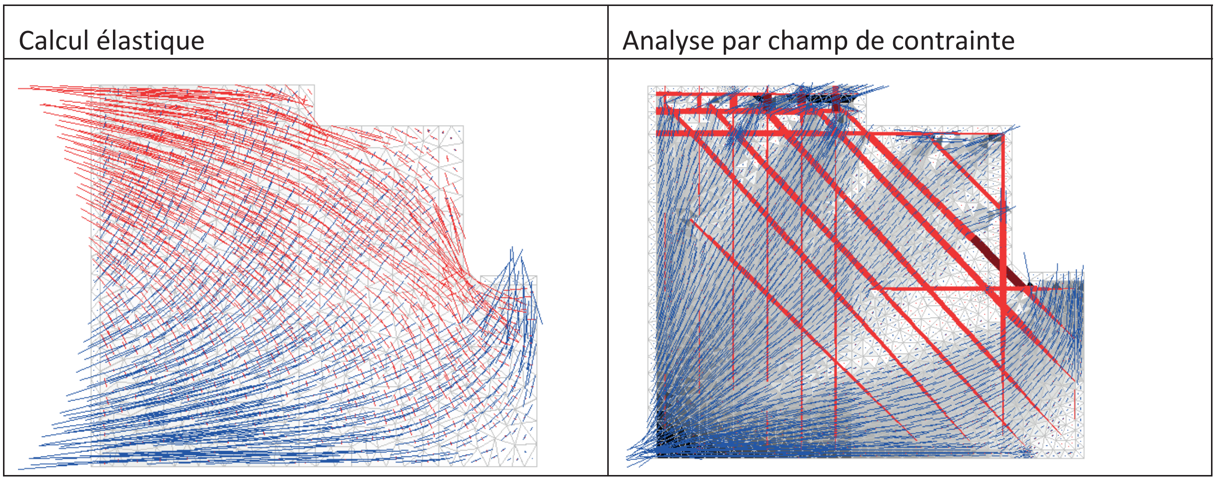

Figure 6. Stress fields model (Vd = 1'560 kN)

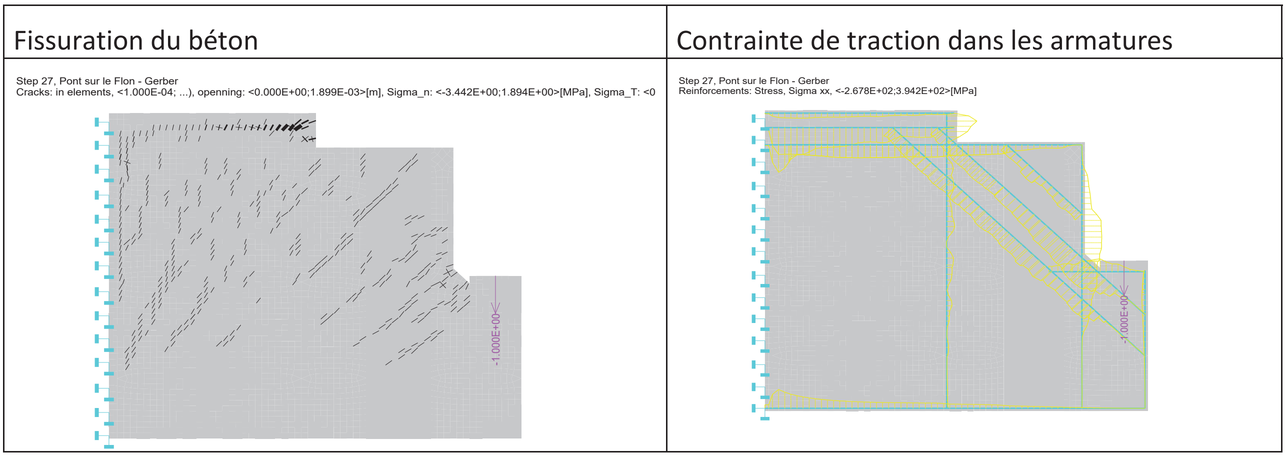

Figure 7. Non-linear finite element model (Vd = 1'450 kN) with Atena

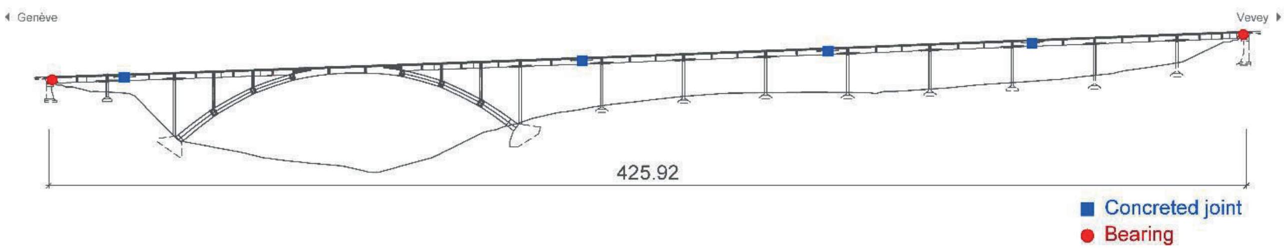

Figure 8. Modified bridge static system.

A non-linear analysis of the half-joints was also carried out with the finite element program Atena [8] using the Menétrey – Willam [9] material model. The results of this analysis are shown in Figure 7. The failure load is 1'450 kN.

These two analysis methods gave a security factor close to 1, considering a perfect bond of the rebars and the full cross-section of the rebars. In further analysis, a 10% loss of the rebar cross-section due to corrosion is considered. Moreover, the real anchorage based on the indications of the as-built drawings is also considered. The security factor then reduces to 0.6 which is not acceptable.

3 Rehabilitation concept by modifying the static system

Because of the risk linked to the half-joints and the difficulty to repair them in a durable way, it was decided to concrete all of them. With this solution, all risks linked to keeping and repairing them are removed (brittle failure, fall of deck in case of seismic activity & progressive degradation).

However, concreting all the half-joints to create a continuous structure can only be done if the bridge movements due to temperature change is allowed at the abutments. It is thus a change in the static system of the bridge as illustrated in Figure 8.

The concreting of the half-joints to create a continuous structure leads to an increase of the bending moment in the end piers of the bridge. A reduction of the bending stiffness of the piers and of the foundation soil stiffness was considered to verify the piers. Therefore, the action effects could be reduced, and it could be shown that almost all the piers satisfy the code requirements. Only the shortest pile located on the Geneva-side was strengthened for bending and shear.

4 Rehabilitation project

4.1 Overview

The rehabilitation project plans the following works:

- Concreting all the half-joints.
- Rebuilding the abutments to allow movement at the ends of the bridge.
- Replacement of the noise barriers.
- Strengthening of the deck slab.
- Strengthening of the arches, piers, longitudinal beams and crossbeams.
- Concrete repairs.
- Replacement of the bridge equipment.

To limit the inconvenience of the works for the users, two traffic lanes are maintained on the bridge during the whole duration of the works. This requires performing the works by phases, each phase on 1/3 of the highway surface. This work by phases added technical constrains for the concreting of the half-joints, as it had to be done in three times. The three distinct phases also complicated the work logistics as the small working width forces the site traffic to cross the half-joints.

4.2 Half-joints concreting

To concrete the half-joints and insure the continuity of the bridge, the following interventions were necessary: erection of a temporary steel structure, complete demolition of the half-joints, reconstruction of the now continuous longitudinal beams and placement of local external prestressing on each side of the concreted half-joint.

During the concreting of the half-joints, the temporary steel structure under the longitudinal beams of the bridge deck allows the transmission of the action effects from one side of the half-joints to the other, as shown in Figure 9.

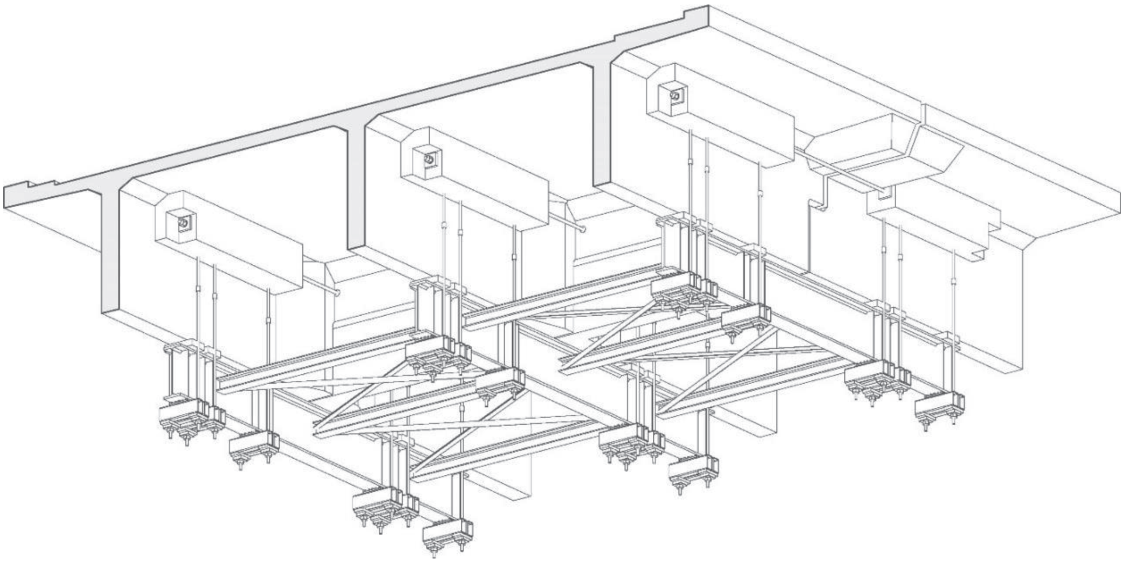

Figure 9. 3D view of the half-joint with the steel structure used for concreting.

To limit the differential displacement between both sides of the half-joint, the steel structure is sandwiched to the longitudinal beams using flat-jacks. The service load effects are introduced into the steel structure and the bearings are partly unloaded. The steel structure is shown in Figure 10.

Figure 10. Steel structure supporting the half-joints

The half-joint is demolished, as shown in Figure 11. During this work, high chloride contamination was measured in the concrete of the half-joints.

Figure 11 . View of the half-joint zone on 1/3 of the highway surface.

The reconstructed longitudinal beams are concreted to create a rigid and continuous system in place of the half-joints. The link between both sides is done by insuring continuity of the longitudinal steel reinforcement and completed by prestressing bars anchored in concrete protrusions on each side of the beam.

4.3 Releasing the abutments

The new abutments will include road joints and bridge bearings to allow the expansion of the bridge. To create these new structures, the beam-column connection in the existing abutment most be demolished at both ends of the bridge.

This demolition and construction of the new abutments, with an access for inspection as shown in Figure 12, is done during the different work phases planned on the highway surface. In its final state, the abutments can be accessed, and the joints and bearings can be inspected.

The abutments are equipped with road joints and sliding bearings easily accessible for any maintenance work.

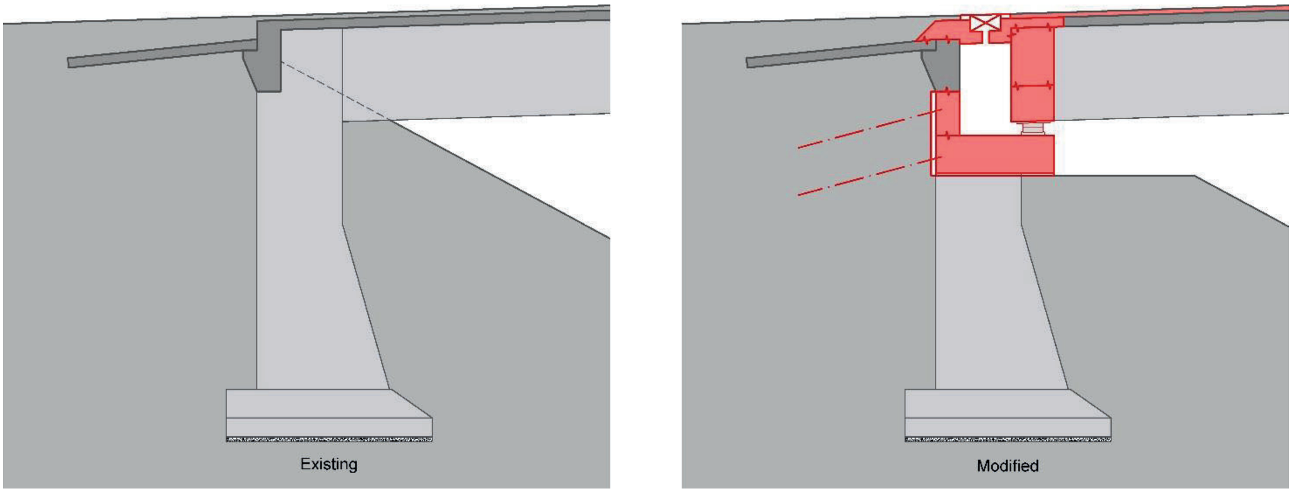

Figure 12. Releasing the abutments and creation of an access

The new abutment was built underneath the bridge deck and the loads were transferred using jacks, as shown in Figure 13.

Figure 13. Bridge deck resting on the new concrete supporting bloc during the jacking

4.4 Strengthening

Besides the concreting of the half-joints and the work on the abutments, rehabilitation and strengthening on various part of the bridge was also carried out.

The bridge deck was rehabilitated and strengthen as shown in Figure 14. The curbs were replaced by parapets, the deck slab was strengthened with micro-concrete placed on the surface after removing the cover concrete by high pressure water jets. The waterproofing and the bituminous overlay were also redone.

The arches, the piers, the longitudinal beams and the crossbeams were rehabilitated and strengthened with fiber reinforced carbon (FRC) lamellas or fabrics wrapped around the different concrete parts.

The noise barriers are laterally attached on the edge beam, as in the original fixation system.

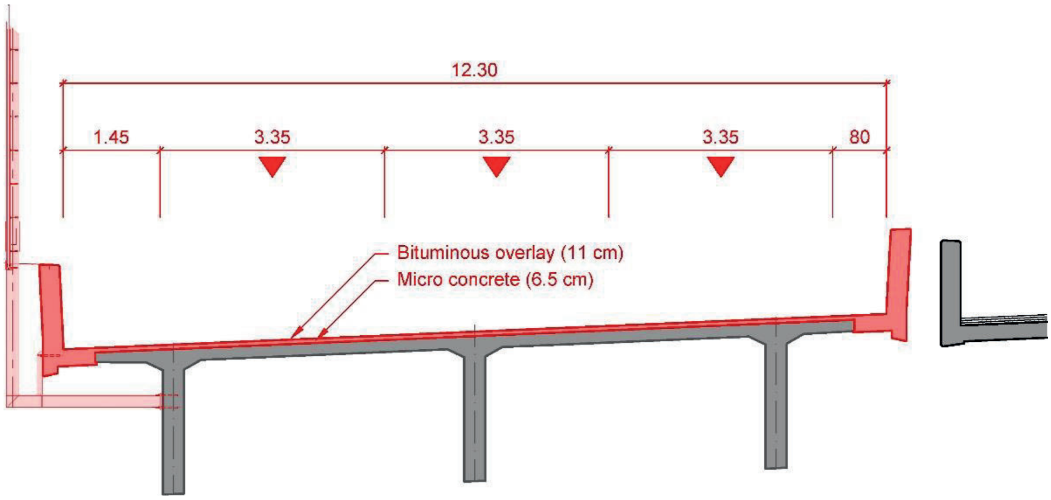

Figure 14. Coupe type du tablier renforcé

5 Conclusions

The Flon bridges were designed by Sarrasin engineering firm, pioneers in the design of reinforced concrete bridges in Switzerland. These bridges have a deck separated in 5 distinct parts by half-joints. Inspections of the structure highlighted the important level of degradation and analysis revealed the risk of failure of the structure.

The aim of the rehabilitation project is to concrete every half-joint thus removing any risk associated with keeping them (brittle failure, fall of deck in case of seismic activity & progressive degradation).

The whole structure was rehabilitated and reinforced. Moreover, the noise barrier was changed as well as all the bridge equipment.

Concreting all the half-joints was the only solution to insure a durable rehabilitation of these details, as they were a weak point of the structure. The concrete, contaminated by chlorides, was completely removed and the half-joints were replaced by a stiff and monolithic element. Even if this solution implied an important modification of the bridge structural behavior, it was the only solution to insure a durable bridge.

Even if the consequences are important, removing the contaminated and weak points of a structure should always be preferred. The rehabilitation project of the Flon arch bridge is a good illustration of this principle.

6 References

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