Widening the Paudèze Bridges with Precast and Cast-in-Place Ultra-High-Performance Concrete

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Built in the early 1970s, the concrete segmental box-girder bridges over the Paudèze River are a landmark of the Swiss federal highway network near Lausanne, carrying 55,000 vehicles daily. Photo: IngPhi SA, Lausanne.

In southwestern Switzerland, twin landmark bridges span the Paudèze River near the city of Lausanne and the Lavaux vineyard terraces—a UNESCO World Heritage site along the shoreline of Lake Geneva. When the federal highway bridges required retrofitting, the project team had to preserve their original form while minimizing traffic disruptions during construction.

Bridge Overview

The bridges were built between 1971 and 1973 as part of the Swiss federal highway network. Crossing the Paudèze River requires a long span: the bridges are 1325 and 1385 ft long with five spans between 150 and 340 ft. Each bridge was originally 39 ft wide and carried two traffic lanes plus an emergency lane. The concrete segmental box-girder design was erected using the balanced-cantilever method, which was the standard for 250- to 450-ft spans in Switzerland at the time. The box girders are approximately 7 ft tall at midspan and more than 18 ft tall over the piers. The box girders were designed with traditional post-tensioning in the longitudinal direction: draped tendons for every cantilever erection stage in the webs and continuous tendons in the deck (including the top flange) and the bottom flange. All tendons were grouted. There is no post-tensioning in the transverse direction.

The spans are supported by longitudinally oriented two-column piers that are up to 200 ft in height. The foundation uses drilled shafts and some anchorages to reduce horizontal movements from the sloping terrain.

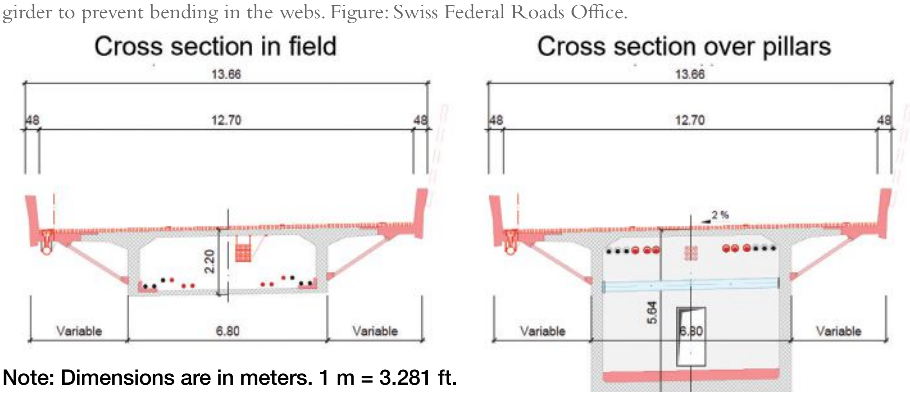
Bridge Condition

In 2002, some of the post-tensioning anchorages failed and were replaced. Deflection monitoring of the box girders began in 1988; in 2010, midspan deflections of up to 2 in. were measured on the longer spans. Tension force measurements on the continuous tendons showed losses of up to 30%, and cracks were evident in the bottom flange starting at the anchor heads. The cracking was similar to that found on the West Seattle Bridge in Washington state (see the Concrete Bridge Preservation article in the Summer 2022 issue of *ASPIRE*®). There were also a few localized shear cracks in the webs. A numerical analysis confirmed the crack pattern and that there was insufficient post-tensioning, a weak connection between the bottom flange and the webs, and insufficient flexural and shear reinforcement. An emergency repair was performed in 2010 with external post-tensioning tendons installed inside the box girders.

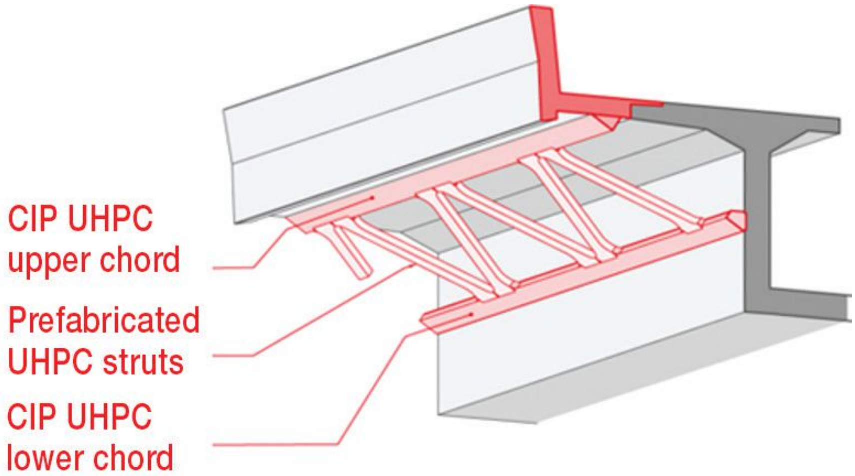
The resistance of the foundation against seismic actions and landslides was also found to be insufficient. Deicing salts combined with insufficient concrete cover and poor connections between the prefabricated concrete curbs and the slabs resulted in extensive corrosion of the reinforcing bars on the underside of the deck, as well as a lesser amount of corrosion on the top side. Joints, bearings, and abutments all needed to be replaced due to heavy chloride-induced corrosion.

The good news was that no signs of alkali-silica reaction were found in the concrete of the bridges, and there was no evidence of physical damage to the post-tensioning systems.

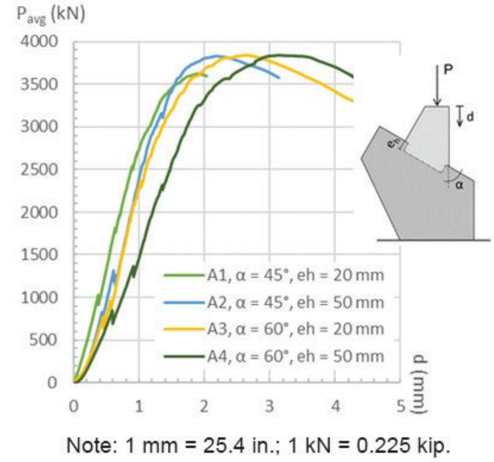
The cross section of each bridge showing the support for the widening. The location of the diagonally oriented Warren-truss style girder required reinforcement measures (shown in blue) inside the box girder to prevent bending in the webs. Figure: Swiss Federal Roads Office.



Note: Dimensions are in meters. 1 m = 3.281 ft.



The Warren girder deck support was constructed using ultra-high-performance concrete (UHPC). The struts were prefabricated, and the upper and lower chords were cast in place (CIP). Figure: Swiss Federal Roads Office.



Test results for connections between the lower chord and the box-girder web, and the upper support girder chord and the new deck extension. Figure: IngPhi SA, Lausanne.

Widening Concept

In addition to the noted deterioration, the original bridges were not wide enough according to the strategic guidelines of the Swiss Federal Roads Office, which require that each bridge be capable of carrying all traffic lanes (with reduced lane widths) during future rehabilitation measures. By approximately 2040, the Paudèze Bridges will also require additional width to enable the emergency lanes to become temporary third traffic lanes during rush hours. This change is needed because traffic volume is expected to increase beyond the current daily traffic volume of 55,000 vehicles.

The required widening for each bridge on each side was about 3 ft. The goal was to support the widened deck in a manner that would minimize the increase of bending moments in the deck. This support was achieved using a diagonally oriented girder modeled after a Warren truss. Additional longitudinal external post-tensioning tendons were installed to transfer the additional loads to the bearings.

Materials

The project team evaluated both steel and ultra-high-performance concrete (UHPC) for the Warren girder. UHPC was selected based on life-cycle cost analysis, appearance, and tolerances, and because it would eliminate the need for anchor bolts in the tendon-loaded webs.

Prefabricated UHPC struts were used to accelerate the construction schedule, achieve better quality, and produce a smooth, uniform appearance. The upper and lower chords were cast in place to allow for tolerances.

Struts are in their formwork at the precast concrete plant. Four types of forms were required. Photo: IngPhi SA, Lausanne.

The precast ultra-high-performance concrete (UHPC) struts in position before the upper and lower chords of the Warren girder are cast in place using UHPC. Photo: IngPhi SA, Lausanne.

The completed connection of the prefabricated strut to the cast-in-place upper chord shows the adjustability to the geometry that the innovative construction detail allowed. Photo: IngPhi SA, Lausanne.

The Swiss Federal Roads Office's temporary steel bridge (flyover) on the deck of the bridge resulted in a 12-ft-long work area across the entire width of the bridge that accommodated 40-mph traffic during construction activities. Photo: IngPhi SA, Lausanne.

Proof of Concept

The following full-scale laboratory tests were conducted to assess the performance of the new design concept:

- Testing of the connection between the lower chord and the web
- Testing of the connection between the top chord and new part of the deck
- Buckling tests on the struts

The test results for the connections showed large margins compared with the axial design load of around 170 kip.

Construction of the UHPC Warren Girder

The bridge required 816 struts, each weighing 500 lb and measuring 5 in. × 12 in. × 8 ft. The design of the struts was optimized for simple construction.

The 3 ft widening was constructed in 200-ft-long sections, except for one shorter section at one end. Each section was built in five stages as follows:

1. Scaffolding and installation of formwork for the lower and upper chords
2. Installation and adjustment of the prefabricated struts
3. Installation of reinforcement and placement of UHPC for the lower chord
4. Installation of reinforcement and placement of UHPC for the top chord
5. Finishing of deck formwork and reinforcement, placement of concrete for the deck

Each section required 2½ work weeks to complete.

Accelerated Bridge Construction under Traffic

All lanes had to stay open to traffic except for short closures between 10:00 p.m. and 5:00 a.m. As a result, construction proceeded in three main stages:

- First year: foundation, external post-tensioning, abutments
- Second year: widening of one side per bridge
- Third year: widening of the remaining side and remaining bridge deck rehabilitation measures

During replacement of the abutments and joints, temporary steel bridges (flyovers) were used for two lanes to allow work to continue under them without affecting traffic.

The unique widening and rehabilitation scheme retained the bridges' clean lines and provided a modern aesthetic that preserves the area's cultural heritage landscape. Photo: IngPhi SA, Lausanne.

Conclusion

Retrofitting an existing landmark bridge in a sensitive environment without interrupting traffic is a complex task. The Paudèze Bridges show that a motivated, skilled team of consultants, contractors, and owner can successfully complete such a project with the use of innovative materials and methods. This project successfully extends the service life of these bridges such that they are ready to use for the next two generations.

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