

Post-strengthening of a motorway bridge with prestressed CFRP strips

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Post-strengthening of a motorway bridge with prestressed CFRP strips

During rehabilitation work to the bridge on the A3 over the Escher Canal, prestressed CFRP strips were used for the first time in Switzerland to post-strengthen a motorway bridge.

The condition of the structure and the results of the structural investigation necessitated transverse post-strengthening of the deck. Under restricted working conditions, the combination of pre-stressed CFRP strips on the bottom and externally-bonded CFRP strips on the top was the only practicable method of repair to the deck.

This bridge on the A3 Sargans-Zurich motorway was built in 1957 and crosses the Escher Canal near Weesen in three spans of 21.40 m, 55.40 m and 21.40 m (Fig. 1). The superstructure is a fully prestressed box girder 2.00 to 2.45 m tall (Fig. 2) with joints in the side spans. Two Zurich-bound A3 lanes now use the 11.10m wide deck. Structural repairs had not previously been carried out on the bridge.

Six years after completion of the bridge, it had to be raised to compensate for the 10-15 cm of settlement that had occurred. During an inspection in 1964, a continuous crack running the whole length of the

bridge was discovered in the centre of the deck soffit. In a further inspection in 1985, the durability of the bridge was found to be at serious risk due to the inadequate reinforcement cover and lack of a seal in the deck.

A structural reanalysis to current standards showed that the longitudinal bending resistance of the bridge was satisfactory. The loading ratio of the deck over the web was in order. The bending resistance was clearly inadequate in the span, which explained the longitudinal crack in the deck. The top reinforcement present in the span did not meet the minimum reinforcement requirements. The repairs had the following objectives:

- Correction of damage and defects
- Elimination of cause of damage
- Protection of the structure

The target residual life of the main load-bearing elements was 50 years. Components to be post-strengthened had to be designed to current SIA structural standards:

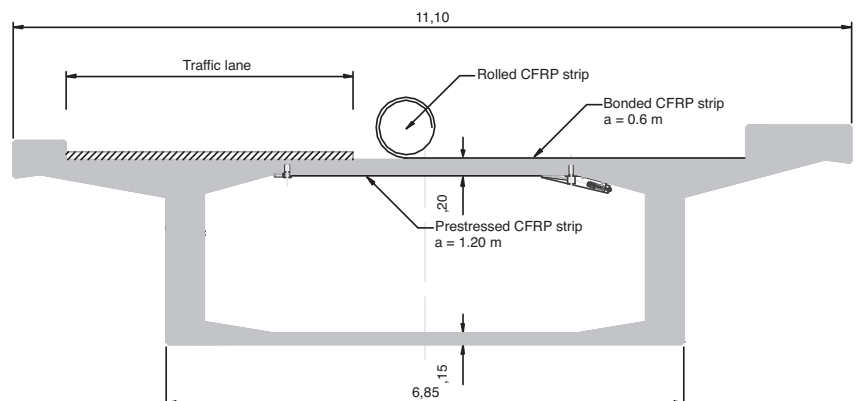
- The deck had to be transversely strengthened in the span for positive and negative moments (see next page).
- Further opening of the crack on the deck soffit had to be prevented.

At least one lane had to remain open to traffic throughout the construction period. The inside of the box girder was only accessible through a small opening in the soffit.



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General view of Escher Canal bridge. Bridge cross-section and transverse post-strengthening measures, scale 1:100 (Photos: Thierry Berset and Luc Trausch)





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Stress head for CFRP strips



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Fixed anchorage

CFRP strip	CarboDur S624
Cross-section	60 mm x 2.4 mm
Characteristic tensile strength f_{tk}	2800 N/mm ₂
Elastic modulus	170 kN/mm ²
Dimensions of stress head	60/80 mm x 110 mm
Initial prestressing force P_0	220 kN
Stress in strip at P_0	1540 N/mm ₂ (0.55 f_{tk})
Strain of strip at P_0	0.95%
Minimum deflection radius (without special measures)	1.0 m

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Sika Stress Head system technical data

PROJECT PARTNERS:

OWNER

Canton of Glarus

CLIENT

Canton of Glarus Building Directorate,
Civil Engineering Department

CONSTRUCTION SUPERVISION

Canton of Glarus Building Directorate,
Civil Engineering Department

PROJECT ENGINEER AND SITE SUPERVISION

Locher AG, Zurich, Consulting Engineers

CONTRACTORS

Spaltenstein AG, Zurich

Sika Bau AG, Zurich

CFRP STRESS SYSTEM

Stress Head AG, Lucerne

Comparison of various post-strengthening options

Increasing the structural level by concreting over

New reinforced concrete bonded to the old concrete by means of shear connectors would increase the bending resistance to positive and negative moments. Transverse installation in two stages would be possible. The longitudinal structural safety of the bridge would not be guaranteed due to the additional superimposed load and flexural and shear strengthening of the deck girder would be necessary. The additional stress on the foundations might lead to further settlement.

Bonded CFRP strips

Externally-bonded carbon-fibre reinforced polymer (CFRP) strips on the top and bottom of the deck would increase the bending resistance to positive and negative moments. The strips for the top surface would first be bonded on only half the deck, the remainder being rolled up. After the contraflow switch, the CFRP strips would be bonded on the second half. The durability of the CFRP strips under the waterproofing and surfacing would be secured for the 50-year residual service life. The bending resistance of the deck to positive span moments would be exceeded shortly after the end of the haunches, with a considerable moment gradient. Insufficient anchorage length was available for bonded CFRP strips.

Prestressed CFRP strips

Tensioned CFRP strips on the deck soffit would function as external prestressing. The introduction of the force into the concrete would be entirely at the strip end and could be located where required to obtain the optimum post-strengthening effect. The transfer of the force between strip and concrete would not depend on the quality of the concrete surface or the type of stress. The tendon would help to transfer the loads immediately after tensioning; no additional deformation would be necessary. Being light and flexible, the material would be easy to move through the opening into the box girder.

Other options

Externally-bonded steel strips on the top and bottom of the deck would function like bonded CFRP strips but at lower material costs and with ductile material properties. On the top of the deck they would be at risk from corrosion and could not be inspected. The transverse phasing would require a bonded joint, so that the maximum steel tension permitted in the strip would have to be considerably reduced. The anchorage length at the haunches would be insufficient for steel strips and an additional end anchorage would be necessary. Additional reinforcement bars installed in chases which would then be filled would supplement the existing reinforcement. Due to the transverse phasing and restricted accessibility in the girder, joints would be necessary, leading to a very tight reinforcement configuration and anchorage problems. The new reinforcement would have the same partially inadequate cover as the existing. For the level of strengthening

required, this method would have significant project risks.

With a conventional external prestressing system on the deck soffit, the tendons under the haunches would be run through the web and anchored on the outside, so that damage to prestressing cables could not be ruled out. To transfer the prestressing force from the webs to the deck, the corners of the frame would have to be strengthened.

The inadequate anchorage length for bonded CFRP strips on the deck soffit could be improved by using end anchorages as for the prestressed CFRP strips, but the deformation necessary to activate the end anchorage would far exceed the deformability of the bond. Interaction between bond and end anchorage interaction would not be possible.

The CFRP strip prestressing system

The Sika Stress Head system comprises a tendon consisting of a CFRP strip with a stress head (Fig. 3) at each end and a fixed or movable anchorage. This part of the system is adapted to each project. The fixed anchorage used for post-strengthening of the Escher Canal bridge is shown in Fig. 4. Fig. 5 lists the system technical data. The prestressing force is introduced into the concrete entirely through the anchorages. A bond is not necessary to achieve the strengthening effect. The strip is protected from mechanical damage by a post-tensioning conduit or a bond without quality requirements. In this project the force was transferred to the concrete at each anchorage by a 100 mm diameter plug. The anchorage was aligned in the direction of the tensile force, preventing bending stress on the strip.

Testing the CFRP strip tensioning system

In Switzerland, only prestressing systems listed in the Register of Standard Prestressing Systems of the Federal Highways Agency (Astra) and the Federal railway's register (SBB) can be used on motorway and railway bridges. The requirements in the standards are formulated for conventional prestressing systems and cannot be applied directly to a system with composite fibre tension members. The following principles were applied to the prestressing system testing:

- Adequate security against failure of the tension member
- Failure in the tension member, not in the prestressing tendon anchorage

In short-term tests on tendons consisting of a CFRP strip 1.60 m long and a stress head, the ultimate load had to be not less than 75% of the tensile strength of the CFRP strip. The increase in strain in a tendon without a bond was very small in the failure mode of the strengthened system. Adequate protection against failure of the strip was guaranteed at a prestressing level of 55% of the tensile strength of the strip.

The CFRP strips used in the post-tensioning system showed negligible relaxation when the prestressing was applied. The anchoring of the strip in the stress head by a wedge system was less susceptible to creep deformation than bonding or grouting. Initial results from

long-term tests at increased prestressing forces showed that some slip occurred between strip and stress head immediately after tensioning but after a short time the increase was negligible.

The manufacture and cutting of the CFRP strip tendons were covered by an overall quality control plan. The cross-sectional area, fibre content, tensile strength and elastic modulus of the CFRP strips were continuously monitored by the manufacturer. Critically, every tendon was tested in the outgoing inspection at a stress of 100% of the prestressing force P_0 .

Installation

A $D=110$ mm core had to be drilled for each anchorage, taking care that no structural reinforcement bars were cut. The fixed anchorage was then bonded in the hole. The movable anchorage was moved dry and fixed by two plugs.

The concrete substrate preparation was similar to that for slack bonded strips. The tendon was coated with adhesive, placed in the anchorages and tensioned with a hydraulic press to a controlled force and path. The threaded rods were then fixed at the movable anchorage.

Prospects

Prestressed CFRP strips offer interesting new opportunities for post-strengthening of structures. Other potential applications are vertical prestressing of masonry walls to increase earthquake resistance, strengthening of beams and joists in industrial buildings and use as prestressed external shear reinforcement for beams.

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