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EXPERIMENTAL BREAKING OF A PRESTRESSED CONCRETE BRIDGE BEAM REINFORCED WITH BONDED FRP

ADRIEN HOUEL[1], CHRISTOPHE AUBAGNAC[2], DIDIER GERMAIN[1], and JEAN-PHILIPPE MAHERAULT [3]

[1]*Cerema, Central and Eastern Territorial Directorate, Bron, France*
[2]*Cerema, Central and Eastern Territorial Directorate, Autun, France*
[3]*Cerema, Mediterranean Territorial Directorate, Aix-en-Provence, France*

The Central and Eastern Territorial Directorate (DterCE) of Cerema in France has set up an experimental project about a prestressed concrete bridge beam recovered during the demolition of a bridge. Before testing, an accurate diagnosis of the beam has been achieved. Three series of tests were carried out in 2014: bending tests before reinforcement, after a first phase of reinforcement bonded composite materials, and finally after a second and final phase of reinforcement bonded composite materials. This final test was gradually led to a complete break of the beam. This experience on a PPCBB reinforced with FRP allows us to deliver some first lessons. The real break of the beam was held to a force of about 61 tons, corresponding to a bending at mid-span to about 20 cm. Thereafter, the effort has been decreasing. The complete shearing by delamination of the bonded composite reinforcements (which have thus accompanied the beam to maximum effort of loading), was held to a force of about 59 tons, corresponding to a bending to about 27 cm. The complete break in bending in a controlled section (cracking up in the upper table) was obtained for an imposed displacement of more than 40 cm.

Keywords: Monitoring, Bending, Strengthening plates, Composite.

1 CONTEXT OF THE TESTS

1.1 Specific Context of the Management of Precast, Prestressed Concrete Bridge Beam Viaducts

Precast, prestressed concrete bridge beam [PPCBB] viaducts were built in large numbers in France in particular before the 1970s. These « first generation » constructions were designed as fully prestressed and built to last, made from compressed, perfectly waterproof concrete.

In reality, a certain number of these older PPCBB viaducts suffer from the corrosion of the prestressed cables: the characteristics of the corrosion can vary from case to case. The structural disorder usually manifests itself once the cable corrosion is already at an advanced stage. Certain structures are, therefore, very vulnerable to corrosion of the prestressed elements due to the lack of passive steel, and the possibility of fragility fractures particularly due to shearing actions.

It is very difficult, therefore, for supervisors of such structures to manage this type of security problem, as presently there are no reliable means of carrying out diagnostics to evaluate the residual prestressed nature of the beam and its evolution over time.

1.2 Contexts for the use of Composite Materials in Civil Engineering

In France the last fifteen years have seen civil engineers develop the use of structural strengthening with external plate bonding using composite materials.

With regard to existing structures, these materials allow them to be repaired, strengthened and adapted to changing requirements and new uses and to conform to current norms, standards and regulations. For the construction industry, composite materials help make elements of the structure, or the complete structure, last longer. The main reasons behind the growth in the use of composite materials in construction projects are that they prolong the useful life of the structure, and they increase user security and economize on non-renewable natural resources.

Bonded composite materials complete the panoply of techniques used to reinforce PPCBB viaducts. The French Civil Engineering Association [AFGC, *Association Française de Génie Civil*] made some provisional recommendations concerning the use of composite materials to rectify problems with the passive steel elements in precast, prestressed concrete structures, particularly with vertical elements near to areas where improved resistance to shearing is required (AFGC 2011). Questions are still raised concerning the efficiency of using bonded composite materials to reinforce prestressed concrete structures that are in a "critical" state, as well as concerning their performance when bonded over existing cracks in structures.

2 THE PROJECT FOR TESTING A PPCBB OF THE VIADUCT FROM CLERVAL (Aubagnac *et al.* 2015)

2.1 Presentation of the Structure and the Particular Beam being Tested

The Viaduct over the River Doubs at Clerval using PPCBBs was built between 1952 and 1954 (see Figure 1). It suffered from waterproofing and concrete injection defects which caused corrosion of the prestressed cables. As this reduced the load bearing capacity of the structure, it was demolished and rebuilt on 2002.

Figure 1. The upstream edge prestressed concrete bridge beam of the viaduct from Clerval.

2.2 Test Program and Benefits expected from the Project Results

The project included third point load bending tests conducted on the beam, alternating the strengthening stages of bonded composite materials with load bearing test stages. In 2014, the load bearing tests were carried out up to the final rupture of the beam.

The main benefits of the results of the tests are:

- Helping contractors manage viaduct PPCBB risks: improving surveillance, auscultation and structural evaluation methods for viaduct PPCBBs;
- Results validated on the efficiency of the bonded composite strengthening material used, particularly for "critical" structures that urgently need to be strengthened while waiting for the results of a more in-depth analysis.
- Justifying regulations particularly adapted to controlling cracking.

2.3 Preparatory Investigations on the Beam

Two objectives of these investigations were as follows:

- Listing the beam's initial visible defects,
- Characterizing the concrete used in the beam.

Removal tests using tractive force showed that the concrete had substantial surface cohesion (> 5MPa), which confirmed the possibility of using a bonded reinforcement.

2.4 Strengthening Work on the Beam

The analyses made by the engineering office recommended bending stress strengthening work on the beam using pultruded carbon fiber plates bonded to the underside of the heel, in two stages:

- Stage 1: two packets of three maximum 24m long plates fixed to the sides of the heel,
- Stage 2: two packets of three maximum 24m long plates fixed to the central part of the heel.

Please Note: During the "cracking" tests made after the first strengthening stage, the six plates were intentionally cut level with pre-cracked section S2.

The work was carried out by the company Freyssinet, following the strengthening procedure using CFP (carbon fiber plates 50 x 1.4 mm^2, module 165 GPa and bonding adhesive Epx SC 980). Certain areas of the heel needed to be re-profiled. The surface was prepared and sanded down prior to the plates being bonded.

3 IMPLEMENTATION TOOLS/INSTRUMENTS

During the shear load tests on 30 October 2014, 187 measuring points were monitored by twenty-five PEGASE WiFi connected sensors (wireless platforms developed by

Ifsttar and marketed by the company A3IP). The supervising software SYSADYP, developed by the Cerema's Mediterranean France Territorial Directorate [DTer Med] using Labview, allows instrument data acquisition at a frequency of 10Hz.

The major physical characteristics being measured were:

- Beam rotation: An inclinometer with 10^{-5} radian precision was installed in line with each of the beams supports.
- Temperature: In order to calculate and take into consideration the average temperature of the beam and vertical and transverse thermal gradients, a section of the beam was equipped with sixteen PT 100 sensors.
- Deformation of concrete: Five sections of the beam were fitted with 12 deformation gauges with temperature compensation systems. During the load bearing tests, five Navier diagrams were monitored in real-time.
- Deformation of the prestressed structures: In line with each of the seven windows made in the beam's concrete and the substantially damaged area on the heel, deformation gauges were attached to three prestressed wires.
- Deformation of composite strengthening elements: In line with each already cracked section of the beam, S2 and S4, twenty two deformation gauges were fitted at the level of each bonding interface, as well as on the underside of the packet of three superimposed strengthening composite plates. Eleven extra gauges were bonded along the beam on the underside of a packet of reinforcing composite plates.
- Crack movements: The cracks on sections with measuring instruments were equipped with LVDT movement sensors. In association with the deformation gauges, these sensors helped monitor the decompression of the concrete and the expansion of the cracks during the load bearing tests.

4 BENDING STRESS TESTS – INITIAL FINDINGS

Bending shearing was observed on the beam in three successive stages:

- First shearing of the side bonded composite strengthening plates of the first strengthening stage: flaking of the concrete surrounding the prestressed cables between sections S2 and S4 (flaking initially at section S2, due to partial sectioning during the strengthening process): maximum force = 614KN, maximum bending = 20.4 cm ; subsequently, the effort mobilized for the load continued to reduce;
- Second shearing of the bonded composite strengthening plates notably in the centre of the second strengthening stage: flaking of the concrete surrounding the prestressed cables between sections S2 and S4 and a long section of the central strengthening plates coming loose at the back of section S2, and further than section S4: force = 588KN, maximum bending = 26.3 cm;
- Definitive break of the beam in section S2 with maximum bending of around 40 cm: vertical fracture from the bottom towards the top only a few centimeters from the top face.

Figure 2. Definitive break of the beam.

The carbon fiber plates have a positive local effect preventing cracks from widening. Without strengthening plates, the size of the cracks measured in section S4 on the underside of the beam's heel were practically identical, if not greater, than those measured on the side of the heel. After strengthening, once the load was greater than 200KN the cracks measured on the underside of the beam's heel were smaller (up to -68%) than the cracks on the side.

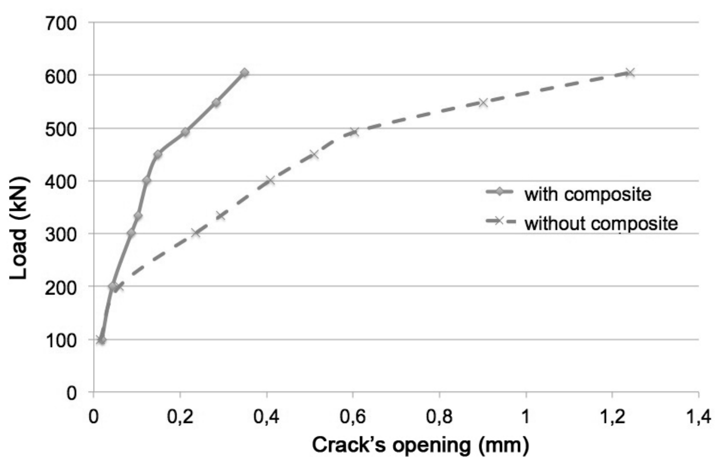

Figure 3. Positive local effect preventing cracks from widening thanks to composite.

The carbon plates improve the distribution of the load and subsequent cracking in the areas where the load is greatest. During the tests the longitudinal distribution of the tractive force between the composite strengthening plates adapted to the load, with the maximum tractive force being between sections S2 and S4. From 334KN to 492KN, the widening of the crack in section S2 accelerated, whereas the crack in section S4 remained stable, but new cracks appeared in the zone of section S4. From 492KN to 615KN, causing the first shearing of strengthening composite plates, the width of the cracks near S2 accelerated, whereas the crack in S4 closed slightly.

5 CONCLUSIONS

The bending load tests of the Clerval concrete beam confirmed the difficulty of correctly evaluating the structural security of a PPCBB of a viaduct which has been seriously damaged by the corrosion of the prestressed cables.

The monitoring instruments used on the beam (sections with deformation gauges, fibre optic cables, bending measuring instruments, movement sensors in line with cracks, acoustic emission and monitoring...) are complementary, cross-check one another and indicate the changes in performance of the different sections of the beam during the load bearing force test and the “key” stress values. This is reassuring in terms of the pertinence of using such instruments to check and monitor a damaged structure, with the caveat that the sensors are installed “in the right places”.

The beam's maximum load capacity was reached when the first stage of bonded composite strengthening sheared:

- The composite strengthening plates increased the damaged prestressed concrete beam's bending shearing resistance;
- They could have been even more effective if the strengthening plates had not been voluntarily partially sectioned in line with section S2 or if an optimal design for the strengthening had been applied.

The benefits of bonded composite plate strengthening have, however, been fully illustrated and justified: controlling crack width and a more controlled distribution of cracks. It is important to note the very good quality of concrete used to make the beam: this is very important for the efficient use of bonded composite strengthening plates.

References

AFGC *Réparation et renforcement des structures en béton au moyen des matériaux composites – Recommandations provisoires*, France, 2011.

Aubagnac, C., Houel, A., Germain, D., Sadone, R., Maherault, J.-P., Brioist, J.-J., Marcotte, C., Khadour, A., Chataignier, S., and Quiertant, M., Présentation des premiers résultats de l'expérimentation de la poutre VIPP de Clerval in *GC 2015*, Paris, France, 2015.