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Repair and Strengthening of Concrete Structures by Post-Tensioning

Réparation et renforcement de structures en béton au moyen de la précontrainte

Instandsetzung und Verstärkung bestehender Betonbauten mittels Vorspannung

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SUMMARY

Repair and strengthening often is a cost-effective alternative to demolition. One method which has significant advantages is the application of additional, or replacement of post-tensioning tendons. This paper presents a number of recent examples of bridges strengthened by application of external post-tensioning.

RÉSUMÉ

La réparation ou le renforcement de structures est souvent une alternative rentable par rapport à la démolition. L'application de précontrainte additionnelle ou le remplacement de précontrainte existante est une méthode qui présente des avantages certains. Cet article présente plusieurs exemples récents de renforcement de ponts par l'application de précontrainte extérieure.

ZUSAMMENFASSUNG

Instandsetzung oder Verstärkung sind oft kostengünstige Alternativen zum Abbruch und Neubau. Die Verstärkung oder das Ersetzen der bestehenden Vorspannung ist eine Methode, welche erhebliche Vorteile mit sich bringt. Dieser Artikel beschreibt einige neuere Beispiele von Brücken, welche mittels externer Vorspannung verstärkt wurden.

1. INTRODUCTION

A significant percentage of highway bridges anywhere in the world was constructed between 1940 and 1970. Traffic volumes, speeds and the average weight of heavy vehicles for which these bridges were designed have increased significantly since then. This, together with some design deficiencies, e.g. underestimating the effect of temperature gradients and of creep and shrinkage, and with the fact that many bridges were not maintained properly, has resulted in deficiencies of various degrees of a great number of bridges. Repair and/or strengthening often is a cost-effective alternative to demolition. One repair/strengthening method which has significant advantages is the application of additional, or the replacement of existing post-tensioning tendons.

2. PRINCIPLES, ADVANTAGES AND LIMITATIONS OF EXTERNAL POST-TENSIONING

The application of additional, or the replacement of existing post-tensioning tendons requires very little interference with the existing structure. The tendons, deviation saddles and anchorage blocks are placed inside the bridge girder so that the overall appearance is not changed, very little extra weight is added (especially when foundations are already fully utilised) and the work can often be carried out without significant restrictions in the normal use of the structure. Depending on the type of deficiencies which can be classified in two major categories (insufficient strength and excessive deflections and cracks) the post-tensioning can either follow a straight line or be draped. Obviously straight tendons do not markedly increase the shear capacity. The applied axial force and/or upward acting load-balancing forces from the post-tensioning tendons improve the performance of the structure in both serviceability and ultimate limit state. In the case of excessive deflection and cracks, one should however not expect that the opposing forces from the draped tendons would reverse the mid-span deflection by more than a fraction nor will wide cracks or open joints completely close after applying the additional prestress. This is because a cracked section is substantially stiffer for unloading, e.g. due to opposing moments, than for continued loading, and because the long-term creep induced part of the deflection cannot be reversed by a significant degree.

3. RECENT EXAMPLES

3.1 Oléron Viaduct, France

3.1.1 Background :

The Oléron Viaduct linking the Island of Oléron to the main land of France with a total length of 2862 m was built between 1964 and 1966. The bridge superstructure consists of a prestressed concrete single box girder constructed by the balanced cantilever method using precast segments 3.30 m long and 10.60 m wide. It rests on the abutments and 45 piers equipped with reinforced elastomeric bearings. The spans are 28.75 m / 7 x 39.50 m / 59.25 m / 26 x 79.00 m / 59.25 m / 9 x 39.50 m / 28.75 m. The viaduct is segmented by eight expansion joints into 9 sections of roughly 320m each. The girder has a constant height of 2.50 m in the spans up to 39.50 m and a variable height of 2.50 m to 4.50 m in the other spans.

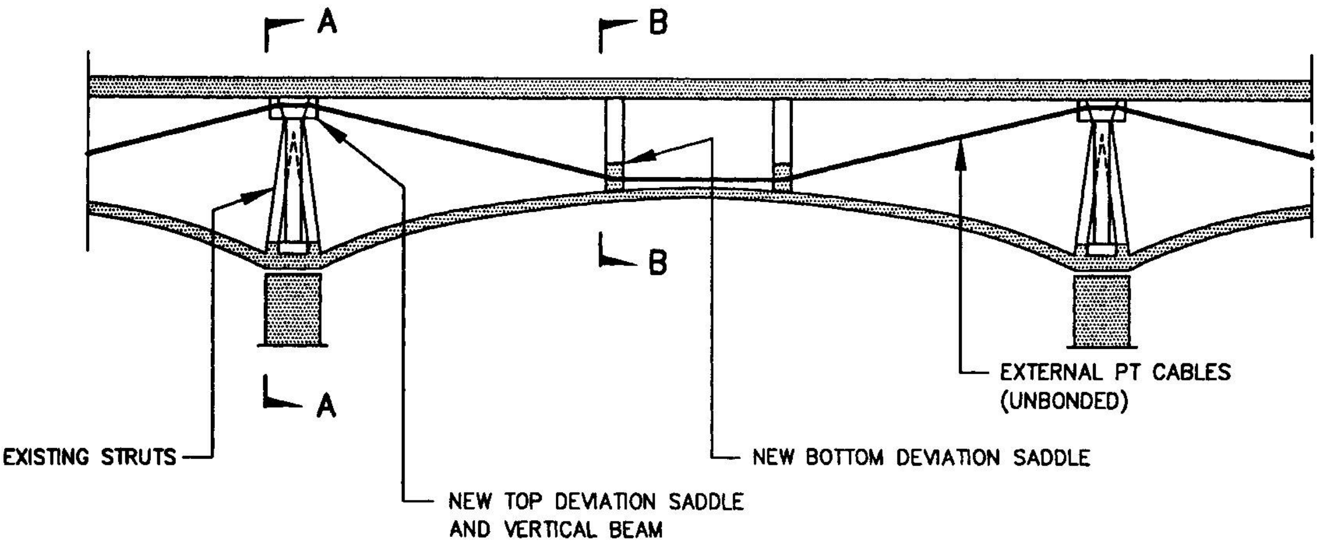


FIG 1 : OLERON BRIDGE : CABLE LAYOUT OF ADDED EXTERNAL POST TENSIONING

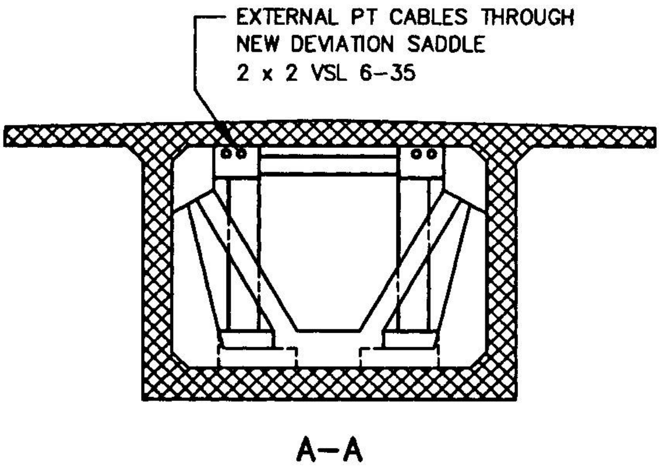


FIG 2 : OLERON BRIDGE :
DEVIATION SADDLE AT PIER

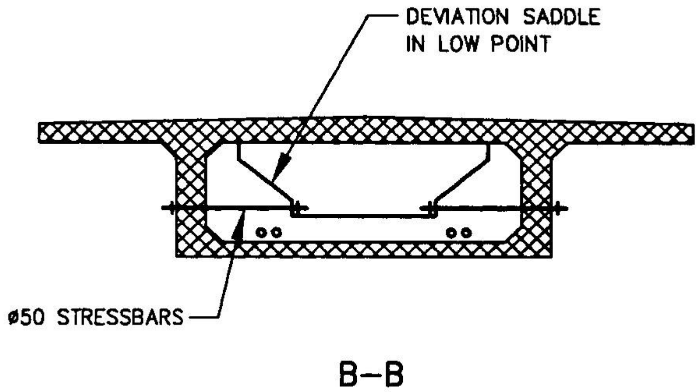


FIG 3 : OLERON BRIDGE :
DEVIATION SADDLE AT MID SPAN

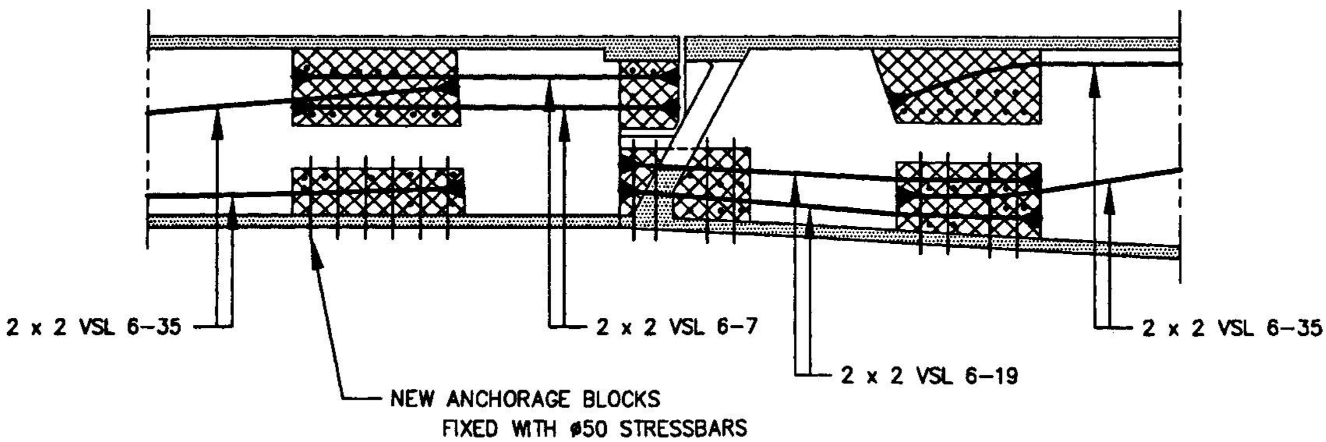


FIG 4 : OLERON BRIDGE : CABLE LAYOUT AT EXPANSION JOINT

3.1.2 Rehabilitation Concept

It was decided to use draped external post-tensioning tendons to strengthen the superstructure. Based on the official solution of the DDE of Charente Maritime, VSL, assisted by BOUYGUES TP consultant office, suggested some modifications in order to optimise the strengthening works.
The main modifications concern :

- Reduction of the number of anchoring blocks by using continuous tendons over 320 m instead of tendons over one span.
- Modification of the geometry and the nailing of the anchorage blocks. This is achieved by replacing stressbars spanning from one web to the other by shorter stressbars nailing directly each anchorage block so that the transmission of the friction force to the existing structure is improved and the local stresses are minimised. The prestress force losses in the stressbars due to the stiffness of the box girder are therefore eliminated.
- Modification of the pier deviator geometry in order to obleviate all nailing (autostable structures). This is achieved by replacing the top anchorage blocks nailed to the box girder by an autostable frame. The thickness is slightly increased in order to wrap the new frame around the existing diaphragm at the top of the box girder creating a longitudinal restraint (to cater for the differential in post-tensioning force).
- At last, the modification of the tendon geometry in order to avoid overstressing the hinges in the end spans which support the non-strengthened parts of the structure (spans 1 and 9)

Using continuous tendons over 320 m length calls for a few modifications in the choice of the post-tensioning : a total of 2 x 2 tendons of 35 strands 0.6" each (instead of 2 x 37 + 2 x 27)were placed in order to allow for the increase of friction losses and the steel grade had to be chosen slightly higher than originally planned (1860 MPa resp. 1770 MPa). The anchorage blocks near the expansion joints were adapted in order to allow stressing at both ends. The costs of these two measures were largely compensated by the saving of 40 anchorage blocks as well as a large number of anchor heads and stressing operations.
The feasibility of external tendons of such considerable length had been demonstrated, in principle by the successful placing of 400 m long straight external tendons to strengthen the Höll viaduct in Switzerland.

3.1.3 Execution of Work

The Oléron Viaduct is the only link to the main land for the traffic as well as for the services (telephone, water and electricity). It was therefore vital to maintain the traffic and the services at all time during construction. One traffic lane in each direction (7.0 m wide) was maintained and particular care was taken in the box girder when moving the equipment to avoid any damage to the 600 mm water supply and the 90'000 and 20'000 V electrical supply. Access for personnel and small equipment is provided through the existing man holes, whereas for the large equipment (jacks, pumps, etc.) the access is provided through an additional hole cut in the bottom slab near the abutment.
Once the position of the existing tendons was determined by gammagraphy, the stressbars were positioned and the anchorage blocks cast using a mobile pump placed on the deck. The HDPE sheath was then installed and supported temporarily approximately every 3 m. The coils of tendons were placed outside the box girder first at the abutment, then on the deck. The strands were then pushed individually through the sheath over the whole length (320 m). Openings in the sheath were provided 60 m from the end to enable a second pushing machine to be installed if need be. The tendons were stressed one by one from both ends using a multi-strand jack. Finally the tendons were injected with non-shrink grout.

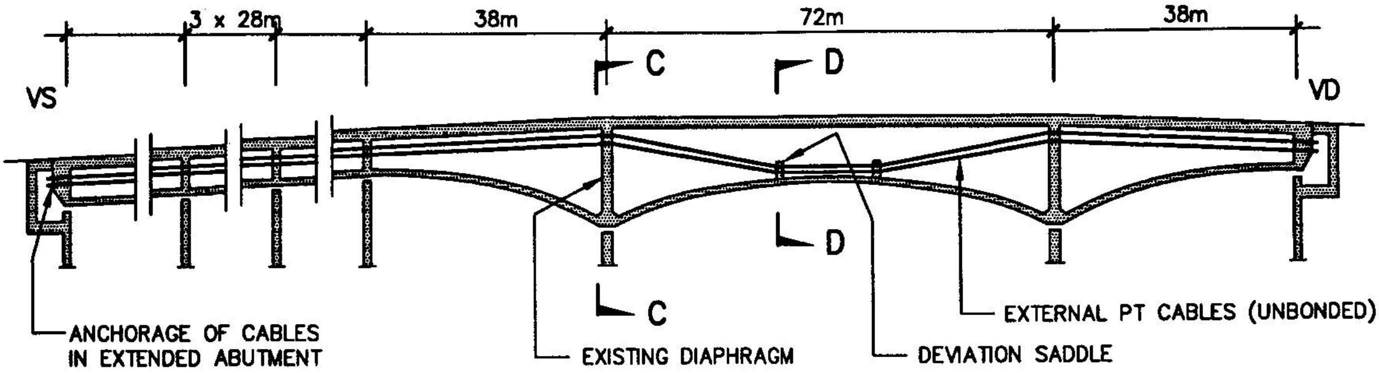
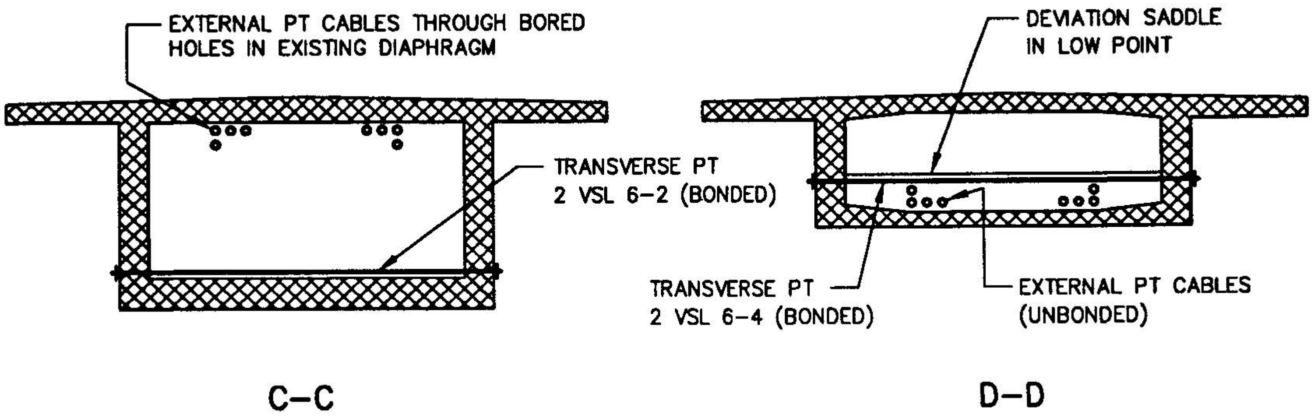


FIG 5 : MASSONGEX BRIDGE : CABLE LAYOUT OF ADDED EXTERNAL POST TENSIONING



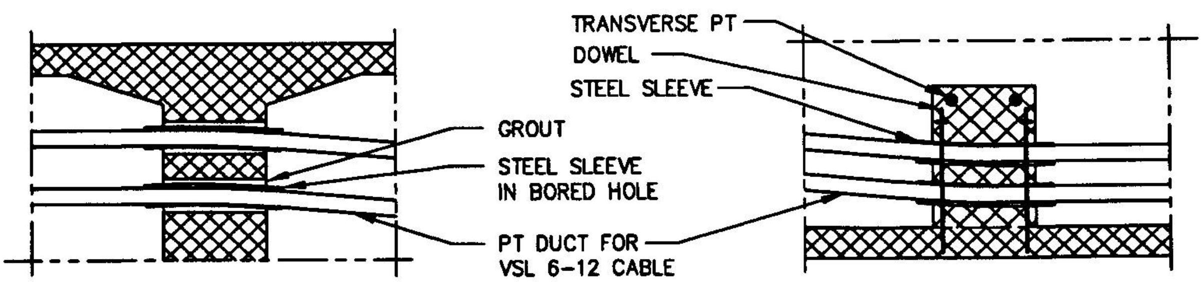


FIG 6 : MASSONGEX BRIDGE : SECTION AT PIER WITH DEVIATION SADDLE

FIG 7 : MASSONGEX BRIDGE : LOW POINT SADDLE

3.2 Motorway Bridge across the Rhône at Massongex, Switzerland

3.2.1 Background:

This 232 m long box girder bridge with spans 3 x 27 - 38 - 72 - 38 m was built between 1978 - 1979. Since 1980 (8 months after final stressing) the superstructure has been surveyed regularly and in 1991 exhibited 113 mm mid-span deflection in the 72 m haunched main span, accompanied by a number of cracks up to 0.5 mm wide. The deflection had increased linearly with time and it was feared that this trend may continue unless strengthening was implemented. A substantial gradient of temperature due to the proximity of the very cold water of the Rhône, combined with strong sun radiation was thought to be the reason for large tensile stresses (2.5 N/mm2). Furthermore it was suspected that the amount of precompression provided by the existing tendons was appreciably lower than assumed in the design.

3.2.2 Rehabilitation concept :

It was decided to strengthen the structure using external post-tensioning. A total of 8 tendons VSL 12 x 0.6" composed of 12 monostrands individually greased and sheathed, then placed in a HDPE duct were installed over the full length. This type of tendons allows their re-stressing, de-tensioning and replacement if required. Hydraulic load cells were installed to continuously monitor the cable force. The tendons are draped with deviator tubes placed in the existing pier diaphragms Which were strengthened with additional transverse bonded tendons, and two low-point deviators consisting of prestressed concrete cross beams in the main span. The anchorages are located in prestressed buttresses added to the abutment diaphragms in order to allow the introduction of the additional forces and to avoid further damage to the already cracked end sections. New access chambers were constructed with sufficient clearances for the stressing jacks and strand overlength.

3.2.3 Execution of work :

The HDPE sheath was installed beforehand and attached to a single prestressed strand strung along the profile, thus avoiding any further intermediate supports. The monostrand bundle was assembled near the site and pulled in from behind one abutment. After taking the slack out of the strands by slightly stressing them grout was injected into the HDPE sheath under vacuum. The full prestress was applied after hardening of the grout. After stressing, an upward deflection of 20 mm was measured at mid-span, i.e. roughly 18% of the deflection was reversed. The surfacing was partially adapted and the remaining cracks were epoxy injected. More importantly, further deflection and crack growth was stopped by the added prestress. The repair work was carried out maintaining the traffic in both directions on one half of the bridge.

ACKNOWLEDGEMENTS

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