HAMMERSMITH FLYOVER: A COMPLETE INNOVATIVE RENOVATION

Boris Cousin (1), Vanessa Buchin-Roulie (1), Christophe Vandevoorde (1) and Nicolas Fabry (1)

(1) FREYSSINET INTERNATIONAL & Cie, France

Abstract

The Hammersmith Flyover is a 16 spans, 630 meters long concrete precast segmental bridge built in the 60's. In 1999, detailed inspections have highlighted corrosion of existing prestressing tendons that could compromise the structural integrity of the structure. In 2006, acoustic monitoring was installed to assess the deterioration of the tendons. In December 2011, 6 months before the 2012 Olympic Games, additional analysis revealed an immediate structural risk. The flyover was closed to all traffic on 23rd December, causing extremely severe traffic disruptions. This paper describes a formidable surgery operation in two phases, to fully replace the existing post-tensioning system.

Résumé

Le viaduc Hammersmith est un pont à voussoirs préfabriqués de 630 m de long, composé de 16 travées construit dans les années 60. En 1999, des inspections détaillées ont mis en évidence une corrosion des câbles de précontrainte pouvant compromettre son intégrité structurelle. En 2006, l'ouvrage a été mis sous surveillance acoustique afin d'évaluer la détérioration de ces câbles. En décembre 2011, 6 mois avant les Jeux Olympiques de 2012, des analyses complémentaires ont révélé un risque structurel imminent : le viaduc a été fermé à toute circulation le 23 décembre, créant un véritable chaos dans tout l'ouest de Londres. Cet article présente l'opération chirurgicale en 2 étapes subie par l'ouvrage pour le remplacement de la totalité des câbles de précontrainte.

1. INTRODUCTION

The Hammersmith Flyover is a key artery in London, carrying the A4, the main west gate for vehicles into and out of the city centre (Figure 1).

Bypassing the Hammersmith gyratory, it is critical to the flow of traffic, avoiding eight roads and four tube tracks. Emergency closures resulted in traffic chaos over a huge area.

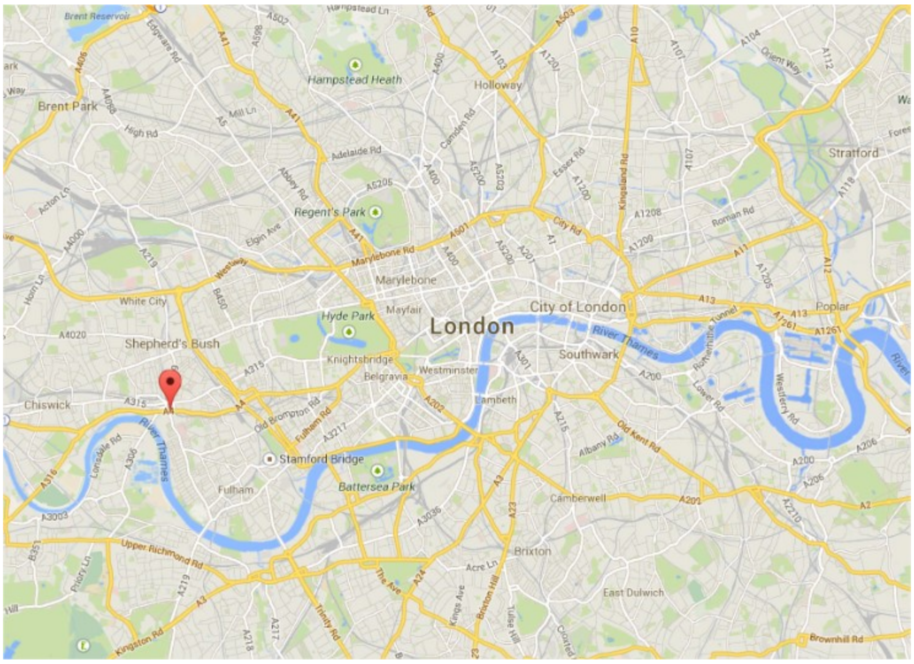

Figure 1: Location of Hammersmith flyover

Figure 2: The Hammersmith Flyover before remedial works

When opened in 1961, the Hammersmith Flyover – or “HFO” – was an innovative concrete structure. Made out of precast reinforced concrete, assembled by post tensioning (Figure 2, Figure 3 and [1], [2] and [3]), it used cutting edge technologies. Heating systems, integrated into the carriageway, were designed to avoid the use of road salt. Nevertheless a few technological details are questionable. The tendon anchors are immediately below the thin surfacing, and the tendons were simply cast into in-situ mortar boxes after stressing. The staggeringly high running cost of the heating system terminated its use as early as 1963, necessitating the use of road salt in winter.

The narrow box girder forms the spine of the deck. With 16 spans, in average 40 m long, the deck adds up to 630 m. Two straight sections, fixed at the abutments, are connected by a single expansion joint. The pier segments are fully restrained on the piers, consequently sliding bearings at the bottom of the piers allow thermal expansion.

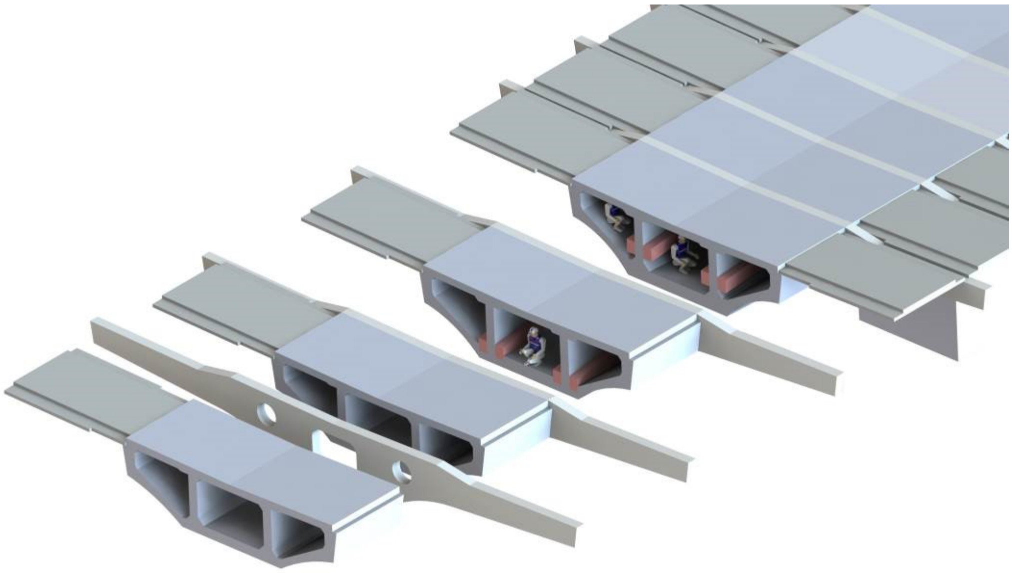

Figure 3: Simplified exploded view of original construction

Water ingress into the tendons caused substantial corrosion to the post tensioning system. The loss of a significant part of the original prestressing force would lead to a partial or complete collapse of the structure. From 2006, an acoustic monitoring system enabled the quantification of the wire failures, leading to better evaluations of the deterioration rate.

In December 2011, six months before the London Olympic Games, additional analysis revealed an immediate structural risk. TfL (Transport for London), owner of the flyover since 2000, decided to close to all traffic on the 23rd December, causing extremely severe traffic disruptions. After three weeks, partial opening for light vehicles was possible. The race had begun to make this “red route” between Heathrow and the Olympic village up to the task.

2. 2012: PHASE 1, PARTIAL EMERGENCY REPAIR

Emergency repair, in the form of new external prestressing located in the central cell, focused on the most critical sections (five out of the sixteen piers sections) and aimed at restoring integrity of theses sections under two lines traffic in both direction without weight restriction.

Using conventional methods, 40 no. in-situ concrete blisters were constructed, in order to anchor new tendons. These supplemented the top fibre prestressing on the five most critical piers (Figure 4 and Figure 5) bringing around 4,000 t of compression at each of them. 500 no. post-tensioning bars and 30 t of post tensioning strand were delivered, installed and stressed in less than four months. Access and time issues were essential to the safety of the site operations. The bridge was fully re-opened to all traffic, just in time for the Olympic Games.

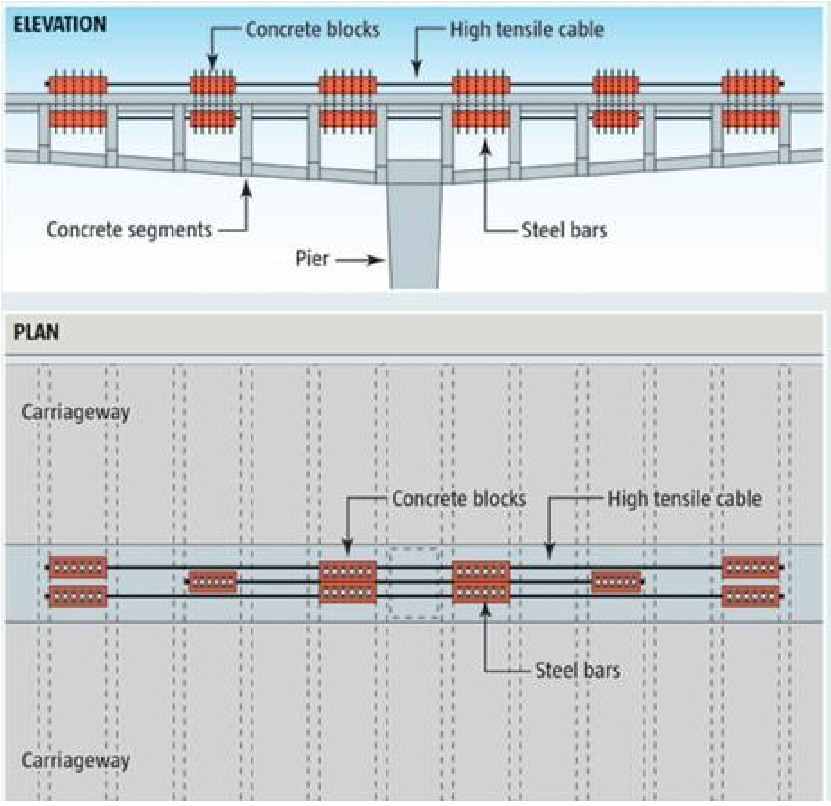

Figure 4: Details of new external cable for Phase 1

Figure 5: Phase 1 works

However, existing prestressing was still deteriorating and would potentially become ineffective. As it was not possible to rely on existing prestressing anymore, some additional strengthening works were required, known as phase 2.

3. 2013-2015: PHASE 2, COMPLETE REPLACEMENT OF THE PT SYSTEM

3.1 Design drivers: safety and space

The objective defined by TfL sounds simple: make the existing post tensioning system redundant, maintain existing headroom and maintain traffic on the deck at all times. Bringing the structure as much as possible in line with Eurocode design rules, with the constraint of having the best locations for tendons already occupied by the existing cables, necessitated a cutting edge solution.

The final design, carried out by Ramboll and Parsons Brinckerhoff partnership, was developed thanks to a contractual system involving the Main Contractor Costain, and its specialist sub-contractor Freyssinet early in the design process, in order to fully utilize the available technologies and to ensure all practical aspects were taken into account. The resulting new post tensioning system is made of two families of tendons: "short" cables, exterior and anchored on UHPFRC blisters and "long" cables using large units and placed inside central cells (Figure 6, Figure 7 and Figure 8).

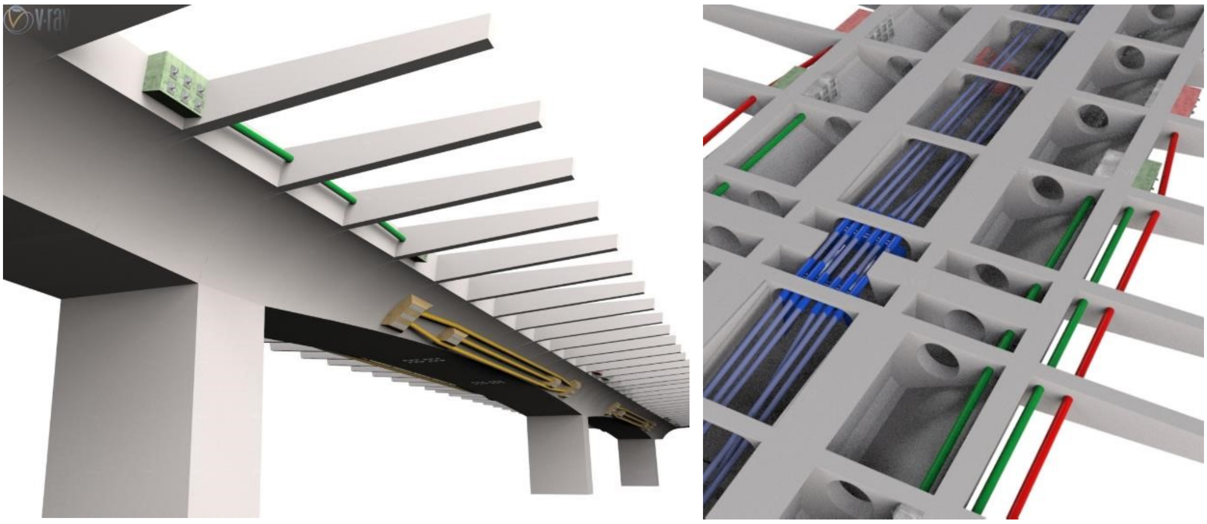

Figure 6: Additional Prestressing : long tendons in blue (37C15), short tendons in green (13C15), red (13C15)and yellow (22C15)

The short tendons provide post-tensioning forces localised to a span (bottom fibre) or a pier (top fibre). They are anchored in new built Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) blisters fixed to existing structure with Freyssibars+HTSR. The choice of UHPFRC combined with Freyssibars+HTSR has allowed the design to be compact enough to preserve the headroom under the deck (reduction of 50 % of concrete quantities and 30 % of Freyssibars compared to traditional anchors blocks fixed with traditional Freyssibars) and to optimize the tendons' eccentricity. The friction coefficient between UHPFRC blister and existing concrete, as well as the design of the blisters were validated by tests. The majority of the blisters were prefabricated, achieving unrivalled quality and aesthetics. Each segment receiving a blister was locally reinforced by an in-situ UHPFRC slab, inside the box girder (Figure7). These short tendons provided approximately 30 % of the post-tensioning force, but required around 70 % of the works.

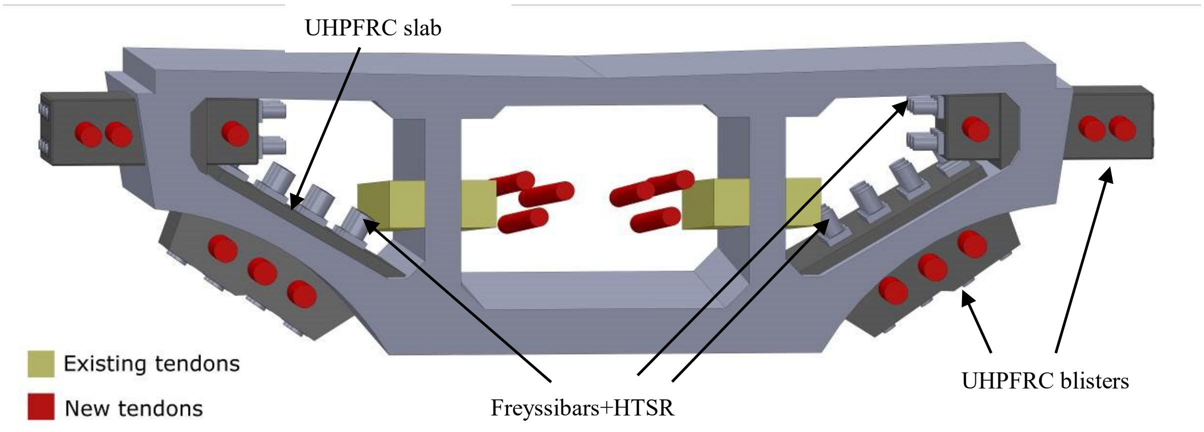

Figure 7: Summary view of complete solution "phase2"

Figure 8: Outside short tendons

The indispensable continuity post-tensioning is provided by traditional tendons installed in the middle cell of the box girder. In each section, 6 no. large tendons (37C15) are required. The transfer of almost 4,500 t of localised force to the existing structure is particularly complex. Consequently it was decided to avoid any intermediate anchors and opt for tendons in one piece. The length of the tendons reached 385 m to cover the East section of the bridge. Circulation corridors in the deck, for maintenance purposes, were maintained. The ability to install and stress tendons of such a length was crucial to maintain the program of the works and achieving the tight schedule.

Two different technologies were used for short and long tendons. For long tendons, for compactness reasons, it was decided to use bare strand placed in an HDPE duct injected with wax. For short tendons, a “Plug and play” system using semi-bonded individually galvanized and sheathed strand, inspired by Freyssinet stay cable technology, has been proposed in order to avoid wax injections and enable quick, safe installation.

3.2 Construction

Construction of the new post tensioning system started with the short tendons. A complex survey algorithm was developed to ensure adequate alignment of the blisters. The inside UHPFRC reinforcing slabs were then cast-in, using a bespoke mobile mixing facility: mixing of UHPFRC concrete requires very stringent controls. After coring, the blisters were lifted by a specially designed lifting machine, which enabled the operator to manoeuvre the 2.5t blisters with six degrees of freedom, 7 m in the air, within a few millimetres accuracy. The short tendons could then be threaded and stressed, strand by strand. Strain gauges provided real time monitoring of the structure.

Figure 9: Long tendons deviator installation

The installation of the long tendons was more traditional, nevertheless the installation of the steel deviators inside the box was a delicate challenge. 130 t of steel were brought in via doors opened in five of the piers (Figure 9).

After stressing one third of the long tendons, it was necessary to deactivate some of the existing post tensioning tendons in order to avoid excessive compression. This deactivation was performed using precise diamond coring. Once the energy release could be checked and confirmed, the balance of the tendons was stressed. The tendons were fully injected with petroleum wax. Around 40,000 L of hot, liquid wax were required, leading to serious logistical challenges in this crowded area of the city.

3.3 Constraints and innovation

The dense urban environment dictated most of the methods of work. This time no closure of the flyover was permitted. Any disruption to traffic using the surrounding roads was restricted to the hours between 10:30 p.m. and 6 a.m., seriously limiting the access to the structure. Working inside the box girder was difficult: the central cell was only 1.4 to 1.8 m high, and the outer cells, triangular in shape, were even more cramped.

The space available outside the structure was limited by the requirement to maintain all pedestrian footpaths during the works. Sharing this restricted space between the different contractors was only possible through exemplary coordination

The solution relied on several fundamental innovations which made possible a positive response to the Client expectations. TfL were very supportive of the new technologies implemented on the project in spite of the inherent risks of innovations. These risks were carefully managed by, among other things, the construction of a full scale mock-up of half a span. This mock-up was a great asset to demonstrate the suitability of the solutions, to test the machines, and to train the teams.

The blisters were unique: not only were they made of UHPFRC but also they were precast. The transfer of loads from a PT system to a UHPFRC block was extensively tested for each tendon size. The interface between the new blisters and the existing concrete was also tested on samples (scale 2:3) in order to demonstrate the chosen friction factor, allowing daring, yet safe design optimisation. The clamping of the blisters relied on "Freyssibar+ 1200" post-tensioning bars. For a given diameter, they provide 20% more force than traditional PT bars. They pair extremely well with UHPFRC to build aesthetic, compact blisters. The decision to precast the blisters was a cornerstone of the safety of the works.

In order to construct the in-situ UHPFRC reinforcing slabs, the team developed a bespoke concrete pump. This was the only way to obtain slow yet powerful placement of the concrete. Using a 150 L hydraulic syringe, 60 m^3 of UHPFRC was poured with minimum waste and excellent control.

The lifting machine for the blisters was key to the installation operations (Figure 10).

Designed and manufactured in France, certified in France and in the UK, this machine is compact and very versatile. The scissor lifting mechanism minimizes the footprint, and the adjustment "hand" has six degrees of freedom to align the blister within millimetres. Where access was impaired for the scissor lifter, the "hand" was used on a fork machine, in particular above the London Underground tracks near the East abutment. The combination of these strengths permitted fast and accurate lifts in spite of the very short available time each night.

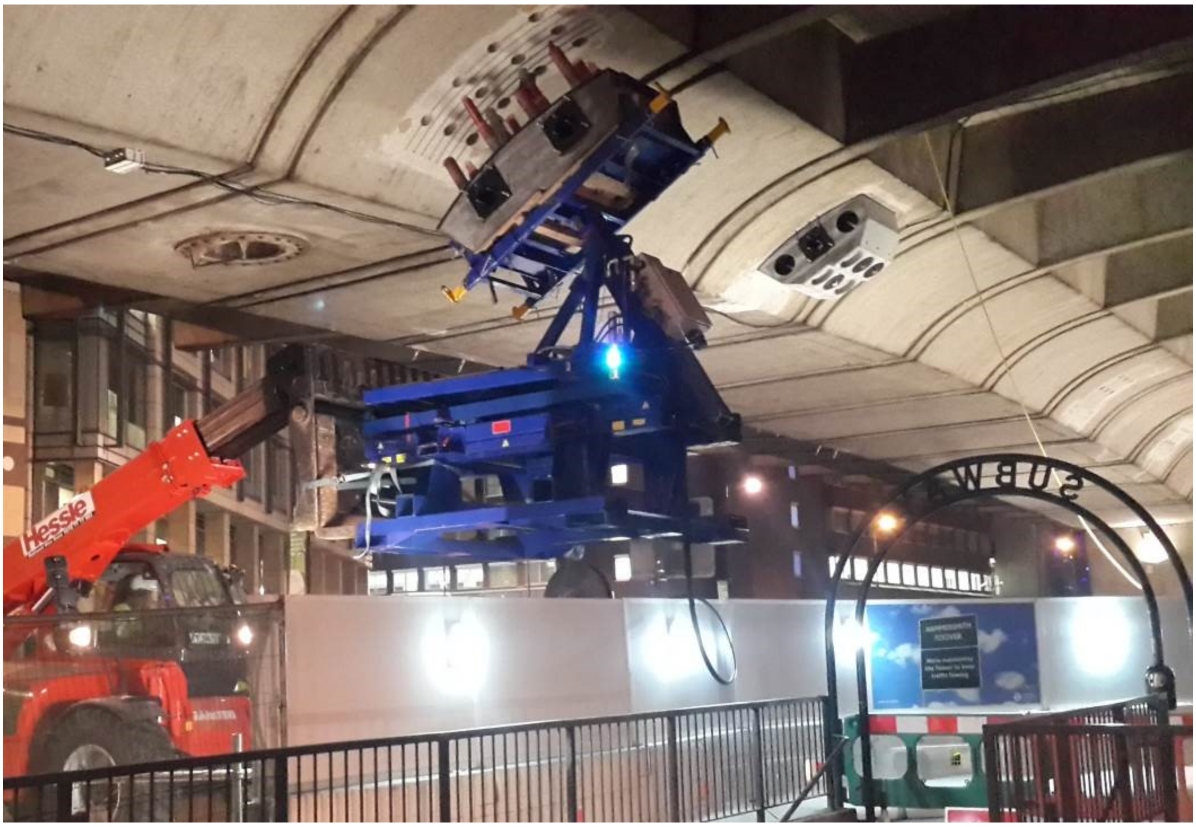

Figure 10: “lifting hand” used on forks

The post tensioning was the structural key point, but the works also covered many other elements of the structure, in particular the replacement of all pier bearings and of the expansion joint.

4. CONCLUSION

The Hammersmith Flyover was an extremely complex project for both design and operations. This complexity led to strong mutual dependence between the Client, the Main Contractor, the Designer and the expert Subcontractor. The project management structure put in place created early, strong links between these key players resulting in the implementation of a unique solution, loaded with innovation and cutting-edge technologies. This minimally-invasive surgery is seen as an archetypal successful repair project, at the service of the Client, to the benefit of the users and ensuring everybody’s safety.

ACKNOWLEDGEMENTS

All photos are from Boris COUSIN, Project Manager, Freyssinet.

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