STRENGTHENING BY ORGANIC PRESTRESSING OF EXISTING LAUNCHING GANTRIES, IN THE CONSTRUCTION OF HIGH SPEED RAILWAY BRIDGE DECKS

Pedro PACHECO, António ADÃO DA FONSECA,
António ANDRÉ, António GUERRA
Civil Engineering Department, University of Porto
Porto, Portugal

Francisco FREITAS, Teresa OLIVEIRA, Carlos PINTO, Joaquim MENDES
Mechanical Engineering Department, University of Porto
Porto, Portugal

ABSTRACT

High speed railway bridge (HSRB) decks are significantly different from both ordinary railway bridge decks and highway bridge decks. The former ones are heavier because live load magnitudes are higher and deflection requirements are more severe. Most of the Portuguese cast *in situ* construction equipment (for medium span lengths, ranging from 30 to 50 m) requires strengthening if it is to be used in the construction of HSRB decks. The alternatives are either to be built new launching gantries or those existing launching gantries are strengthened with organic prestressing (OPS). In this paper, OPS technology is briefly described and an example is used to explain the advantages of OPS launching gantry strengthening in the construction of HSRB cast *in situ* decks.

1 - INTRODUCTION

New concepts on active structural control have been proposed in the last decade under the names of “effector systems” [1] and of “parastressing” [2]. Both involve control systems where actuators are also structural elements and not just external supplementary elements. An useful example of effector system is called organic prestressing system (OPS) and was first studied in several numerical applications [3,4,5,6,7,8,9].

OPS allows for an “optimised” prestressing, because permanent undesirable stresses are avoided and prestressing time-dependent losses are greatly reduced. Furthermore, OPS allows for the design of lighter and more slender structures with the same structural materials. An OPS is particularly recommended to situations of high “live-load/dead-load” ratio, which is the case of launching gantries.

In 2003, a reduced scale model of an organic prestressed launching gantry was constructed in the Structural Laboratory of the Faculty of Engineering of the Porto University [8,9], with the support of a bridge contractor. Experimental results confirmed all numerical studies. Several reliability tests followed in order to move into a full scale model to be used in the construction of a bridge, scheduled to take place in the last quarter of 2004.

One of the main objectives of this particular OPS application is to improve contractors' capability to face the great challenge that construction of high speed railways bridges (HSRB) will raise in Portugal over the next decade.

It is known that HSRB concrete decks are heavier than common railway bridges decks and much heavier than the correspondent highway decks. That is due to higher magnitude loads and to stricter deflection requirements [11, 12].

For the particular case of cast *in situ* post-tensioned decks, such as voided slabs, commonly used in HSRB medium/short span lengths – ranging from 20 m to 35 m, the volume of concrete per square metre may increase more than 30%, when compared with the same type of decks for highway bridge decks. Similarly, HSRB dead load per longitudinal metre of the deck is about 25% to 30 % higher than in highway bridges, and that taking into account that highway bridges are usually wider. Therefore, existing launching gantries cannot accommodate such an increase in the load prior to significant reinforcements, unless OPS is adopted.

In this paper, OPS technology main tools are synthetically described, and the performance of an OPS reinforced launching gantry is presented by means of one example.

2 - DESCRIPTION OF OPS

OPS is based on well-known technology. The main elements are the “organic anchorages”, the unbonded tendons, the sensors, the actuators and the automatic electronic controller. All of them have been used with reliable results. Obviously, the prestressing cables must be unbonded. The design and construction technologies are similar to the ones required in post-tensioned unbonded prestressing structures.

A very simple methodology was first developed for simply supported beams [1]. An effective control system was achieved, where the main objective was to ensure no tensions (or even low compressions) could be generated at predefined control cross sections.

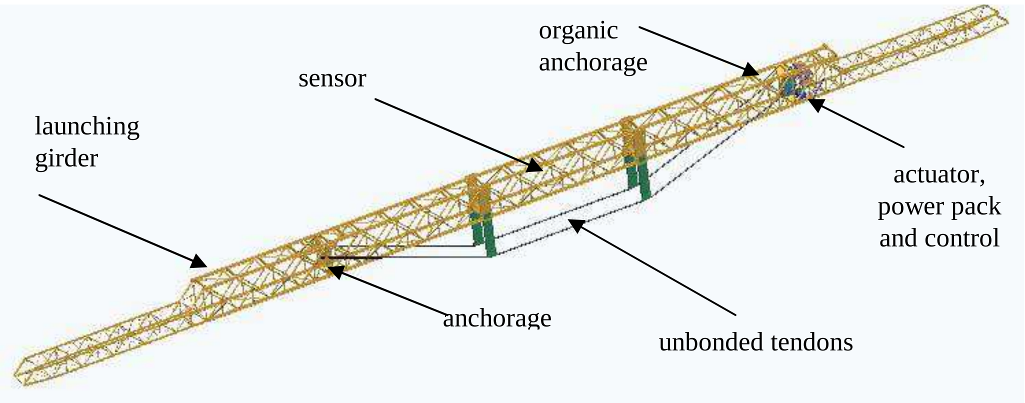


Figure 1: 3D scheme of a launching gantry reinforced with OPS

In mathematical terms, this is stated by expressions (1):

$$\begin{cases} \Delta(t_i) > \Delta c & \Rightarrow \quad nc(t_i + Dt) = nc(t_i) + 1 \\ \Delta(t_i) \le \Delta c & \Rightarrow \quad nc(t_i + dt) = nc(t_i) \end{cases} \tag{1}$$

where,

$\Delta(t_i)$	is the mid-span deflection at instant t_i;
Δc	is the limit mid-span deflection;
$nc(t_i)$	is the number of elementary courses covered by the actuator at instant t_i;
Dt	is the response delay of the control system;
dt	is the time step considered in the control algorithm.

This algorithm controls the “concrete filling phase”. The inverse algorithm controls the “deck prestressing phase” before the gantry moves ahead.

The mid-span deformation is monitored continuously. This measurement is crucial for the application of the organic prestressing principle and has to be accurate, reliable, stable, mechanically robust and easy to be installed and used. Furthermore, the measurement principle has to be compatible with the working conditions existing in a construction site.

The automatic control of the system is located in a cabinet where a programmable logical controller (PLC), a human-machine interface (HMI) and other monitoring and alarm devices (related both to the measurement of the mid-span deformation and to the condition of the hydraulic actuation circuit) are installed. It also includes an urgent power supply (UPS) unit to secure normal functioning of the system in the event of power failure. The PLC is a robust industrial component that is currently applied on several other Civil Engineering activities like synchronized lifting of bridge decks. It reads the continuous measurements of the mid-span deformation and reacts accordingly by controlling the hydraulic actuator(s) movement.

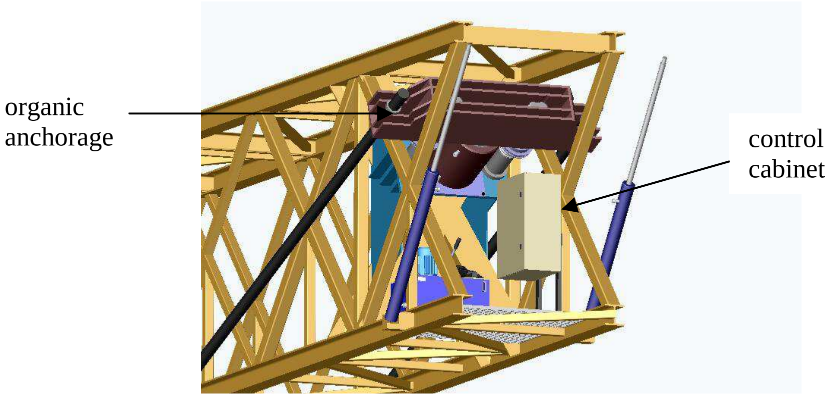


Figure 2: 3D scheme of the organic anchorage and of the control cabinet

2.1 - Sensors

The main constraints for the selection of a measurement method are:

- In most cases, it is not possible to fix an external position as reference. Therefore, only relative measurements are taken.
- Exemption from environmental factors (temperature, wind, rain, fog, dust, electromagnetic fields, etc.) must be high.

Laser technology and ultrasounds were considered, but the need to guarantee accuracy, sensitivity, interference immunity and low cost lead to “static column head fluid pressure measurement” to be selected.

This is a very simple measurement strategy based on the static pressure difference between the fluid level in a fluid reservoir located at a fixed position (over one column) and an adequate pressure transducer located at mid-span of the launching girder, with a flexible fluid line as interconnection. Any deformation of the deck is measured as a pressure variation on the pressure sensor. This value is only affected by vertical movements and is insensitive to lateral movements or compression phenomena on the structure.

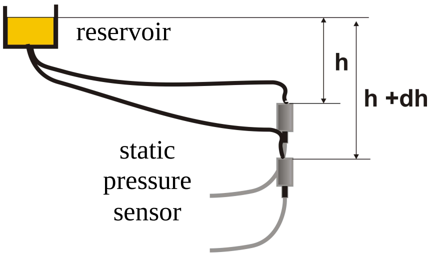


Figure 3: Static column head fluid pressure measurement

Although water could be used, for this type of application a low-viscosity mineral oil is more adequate due to the low temperatures that may occur in construction sites. Also, due to the lower density of mineral oils, a larger (at least 10%) measurement span is achieved with the use of these fluids in relation to water.

The correct selection of the pressure transducer is extremely important in this application. It must be mechanically robust and insensitive to environmental interferences like thermal variations and electromagnetic fields. It’s not unusual to have *in situ* temperatures than may range from -10 to +50ºC and also the operation of large electric motors in auxiliary construction equipments. Therefore, the option for a current output signal (4-20mA) transducer is justified, because it provides a higher degree of immunity to those interferences, especially in cases where the transducer is located several tenths of meters away from the control cabinet.

Nevertheless, this solution is still affected by environmental interferences. The transducers are mounted on polyester cabinets and all the tubing is coated with a polyethylene foam sleeve and placed inside PVC rigid tubing. This helps protecting the transducers and the fluid tubing from thermal variations, solar rays and accidental mechanical shocks.

To ensure maximum reliability of the measurement, two pressure transducers are placed next to each other, connected to the same fluid tubing and thus reading the same mid-span deformation. If any problem occurs with one of them, the second will guarantee the continuous normal functioning of the system. This solution provides adequate measurement accuracy (less than 1% of the full scale measurement) for this type of application. It is possible to obtain total maximum errors of ± 1 mm for a 500 mm measurement span.

2.2 – Actuators and power control

Prestressing of tendons requires a high pulling force that can reach several hundred tons and must be easily controlled. The most practical way to achieve this is to use an hydraulic actuator controlled by a PLC deciding in each cycle whether the linear actuator should advance or retract a predefined stroke, according to the variation of the mid-span deformation (see equation 1).

The hydraulic actuation system comprises the control cabinet, the linear hydraulic actuator(s) and the hydraulic power pack.

The hydraulic actuators are similar to those applied in other civil engineering applications like conventional prestressing or lifting of heavy concrete structures. They operate with hydraulic pressures up to 700 bar and must have an appropriate stroke to fit each specific OPS requirement.

To improve the safety and reliability of the solution, the power pack must have two identical sets of motor-pump assemblies and control valves. It must also include other hydraulic pressure generating solutions, independent from electric power supply, like a pneumo-hydraulic converter or a manual pump. Therefore, a pressure source is permanently available to drive the hydraulic actuator(s).

Figure 4: Hydraulic actuator

This type of application requires reduced electric power (maximum 3kW). Loads are high but actuator speeds are very low (less than 8 mm/min). The advance and retract movement of the linear hydraulic actuator in automatic mode is done by pre-established minimum strokes. This process ensures very good repeatability and has been tested on laboratory, where the maximum deviations were under 0.1mm.

As an additional safety feature, a pair of automatically driven power screws backs up the whole hydraulic actuation solution. Each power screw has a motorized nut that follows the position of the hydraulic actuator at a minimum distance, through a distance sensor. In the unlikely event of a hydraulic actuator failure, the power screw nuts will support the beam that retains the tendons, preventing them from loosening up and endangering people or structures.

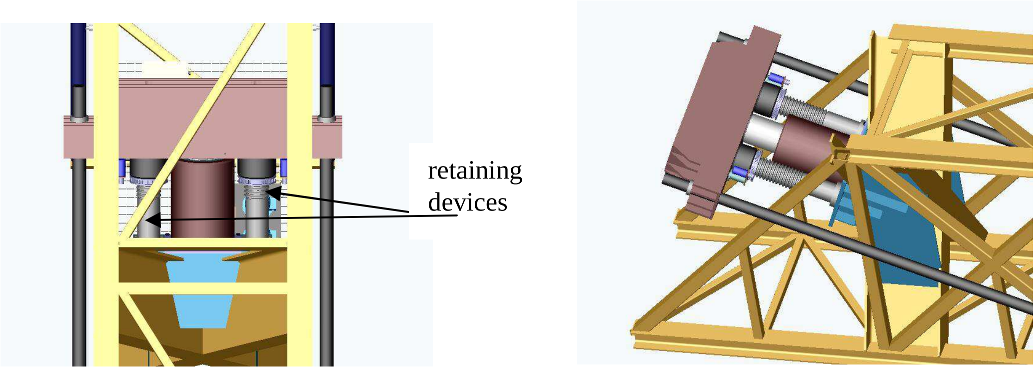


Figure 5: Mechanical retention safety system

2.3 – Prestressing devices

The prestressing devices are similar to those which are used in external unbonded prestressed structures.

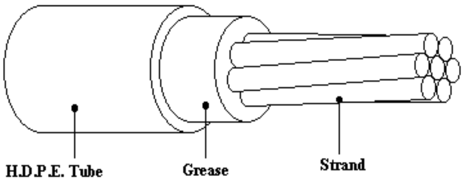


Figure 6: Unbonded tendon

The most significant difference lies on the fact that the organic anchorages are anchorages with hydraulic systems incorporated. That means that the jacks are permanently accommodated in the structure.

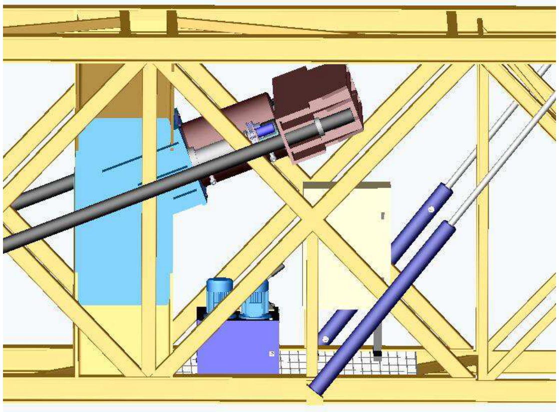


Figure 7: Lateral view of organic anchorage

Struts for the deviation saddles of the prestressing cables may have to be retractable in order to allow the move ahead of the launching gantry.

3 - EXAMPLE

The strengthening by organic prestressing of existing launching gantries for the construction of high speed railway bridge decks is applied to the example that follows.

The K launching gantry presented in figure 7 is an overhead movable scaffolding system which is property of a Portuguese contractor. It has been used several times in the construction of highway bridge decks, with great success.

Figure 8: K launching gantry

In what concerns to its capacity, main functional limits are as follows:

● Maximum bridge deck length = 39.5 m (maximum distance between supports = 33.0 m)

● Main design load (deck weight) = 260 kN/m

For 20 m to 35 m span HSRB decks (voided slabs), the concrete volume per square metre is about 0.83 ± 0.10 m^3/m^2 [11], leading to a load of up to 325 kN/m along the deck. For that K launching gantry, it represents a 30% main load increase.

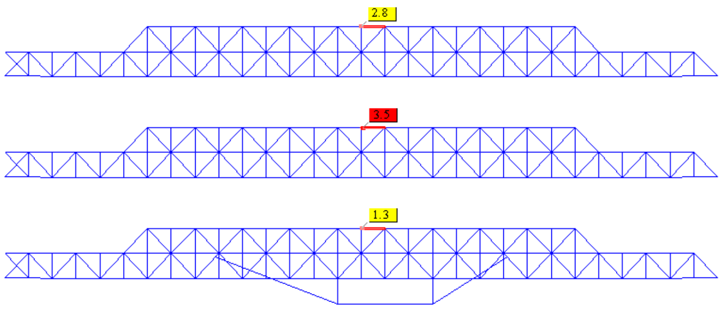
If that K launching gantry is to be used in a HSRB deck with the same span as before, “new” loads have to be considered. In order to evaluate them, three numerical models were studied and compared:

1 – Launching gantry K under highway bridge deck loads.

2 – Launching gantry K under HSRB deck loads.

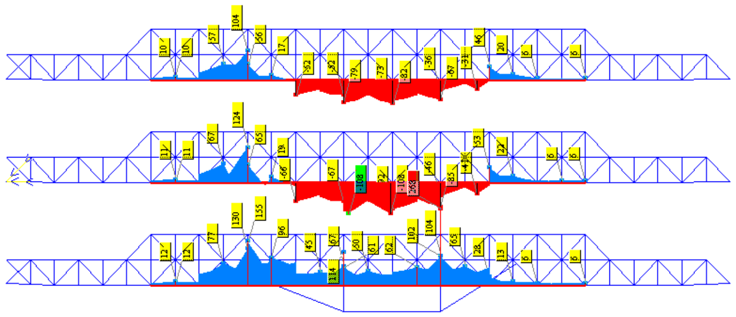
3 – Launching gantry K_{OPS} under HSRB deck loads (launching gantry reinforced with OPS)

The following results were obtained:



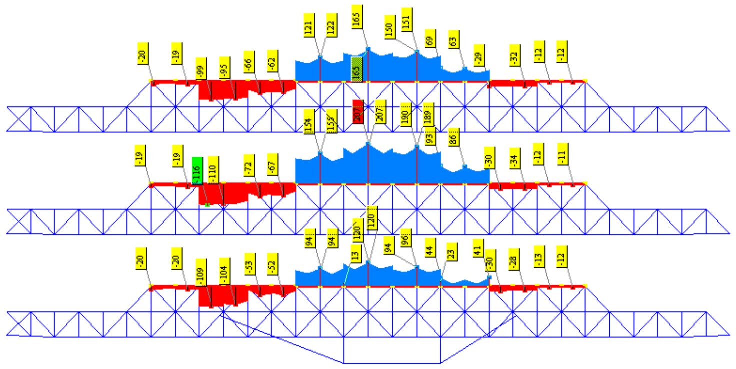
	Maximum deflection (cm)
K (HB)	2.8
K (HSRB)	3.5
Kops (HSRB)	1.3

Figure 9: Deflections



	Maximum stress (kPa)
K (HB)	104
K (HSRB)	208
Kops (HSRB)	114 (local 155)

Figure 10: Stress in the lower profiles



	Maximum stress (kPa)
K (HB)	165
K (HSRB)	207
Kops (HSRB)	120

Figure 11: Stress in the upper profiles

The main technical data of the OPS application is as follows:

- Number of prestressing cables: 2 (with 24 monostrands)
- Maximum force per cable: 2570 kN
- Actuators stroke: 330 mm (Δ_c = 13 mm)

A very simplified analysis of the numerical results shows that an increase of 25% to 30% in steel weight would be required to reinforce that K launching gantry for the construction of the HSRB deck with the same span.

With OPS, only local reinforcements are required and the cost of the OPS system represents no more than 10% of the cost of the original launching gantry.

Finally, most of the OPS equipment can be re-used in other existing launching gantries.

4 - CONCLUSIONS

The research on organic prestressing is at an early stage and various applications are being studied, some with strongly motivating results (when “live-load/dead-load” ratios are high).

The OPS technological solution is simple and feasible.

Experimental tests confirm numerical analysis.

Strengthening by organic prestressing of existing launching gantries for the construction of high speed railway bridge decks is splendid alternative to conventional reinforcement of launching gantries or to construction of new ones.

5 - ACKNOWLEDGEMENTS

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