Experimental Study of a Launching Gantry Reduced Scale Model strengthened with Organic Prestressing

Antonio Carlos Guerreiro Morgado Andre, Eng., BERD, Jr Lecturer, Univ. of Algarve, Portugal; **Pedro Alvares Ribeiro Pacheco,** Eng., BERD, Portugal, Assist. Prof., Univ. of Porto, Portugal; **Antonio Adao da Fonseca,** Eng., AFAConsult, Portugal, Prof., Univ. of Porto, Portugal

Summary

An experimental study of a launching gantry reduced scale model strengthened with organic prestressing (OPS) is briefly described. Results prove that this control system provides a significant increase in the load capacity of gantries, reducing at the same time their service deflection. Technical feasibility of the system is also confirmed. Full scale critical issues are identified and measures to minimize their importance are presented.

Introduction

Organic prestressing is a concept inspired by the behaviour of an organic structure found in nature: the muscle [1]. It is no more than an auto-adjustable prestressing system, that is, with adaptive behaviour.

Since 1994, several OPS applications in civil engineering structures have been studied. Results [1, 2, 3] reveal that OPS can be a very advantageous solution in structures where "live-load/ dead-load" ratios are high. Launching gantries are one example of those structures. Results reveal also that this technology can reduce prestressing losses substantially and ensures a high reduction of the non favourable effects in conventional prestressing [3, 4].

According to previous numerical studies, OPS application in launching gantries provides 25 to 35% saving in the gantry structural material, percentage that increases with span [5, 6].

Conception of a launching gantry scale model started in 2002 in the laboratory of the Faculty of Civil Engineering of the University of Porto. The main goals were to evaluate the feasibility of OPS technology and to prove accuracy of previous numerical analysis results. More recently, a 1:1 prototype has been built and is currently under use. That will be object of a separate publication.

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The OPS main components are the "organic anchorages", the unbonded tendons, the sensors, the actuators and the automatic electronic controller.

The design and construction technologies are similar to those in post-tensioned unbonded prestressing structures.

An effective control system is developed for mid-span deflections. In mathematical terms, the control strategy is stated by expressions (1):

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

where,

$\Delta(t_i)$ is the mid-span deflection at instant t_i;
Δc is the limited mid-span deflection;
$nc(t_i)$ is the number of elementary courses covered by the actuator at instant t_i;
D_t 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 to the next span. The active control application involves a simpler algorithm than those for other active control applications [7, 8].

Scale Model Description

The scale model is a strutted webs steel box-girder and it is supported by steel end pinned supports which are fixed on the laboratory slab (*Fig. 1*). The total length (L) of the model is 14 m, making up a simple supported span 4L/5 long and a cantilever span L/5 long. The cross section is square shaped (0,40 × 0,40 m^2) and has different flanges (the upper level flange has a larger cross-section area) except in the vicinity of the continuous support, where the flange cross section areas are equal.

The conception criteria of the scale model were aimed at testing the OPS system primarily with respect to functional problems, with no concern on scale model classical rules. Launching gantries cinematic issues were also not contemplated.

Two exterior unbonded tendons are passive anchored in the cantilever end and active anchored in the other end (*Fig. 2*), with two deviation saddles located in the simply supported span at the distance of L/3 from the supports.

A high precision hydraulic actuator motor-pump controlled automatically by a programmable logical controller (PLC) moves the active anchor away from the launching gantry end, thus applying the prestressing to the structure.

The pouring of the bridge deck concrete is simulated by the slow water filling of "boxes" positioned along the model. The slow rate of the loading allows OPS to be a static control system.

As previously stated, the system controls the mid-span deflection. That is achieved continuously by measuring the difference between the static pressure given by the fluid level inside a fluid reservoir located at a fixed position (over one support) and the pressure in a pressure transducer located at mid-span of the scale model (*Fig. 3*), with a flexible fluid line as interconnection [9]. The mid-span deflection is then measured as a pressure variation on the pressure sensor. This value is only affected by vertical movements, since it is insensitive to lateral movements or compression phenomena on the structure [10].

A programmable logical controller (PLC) reads the continuous measurements of the mid-span deflection and reacts accordingly by controlling the hydraulic actuator movement.

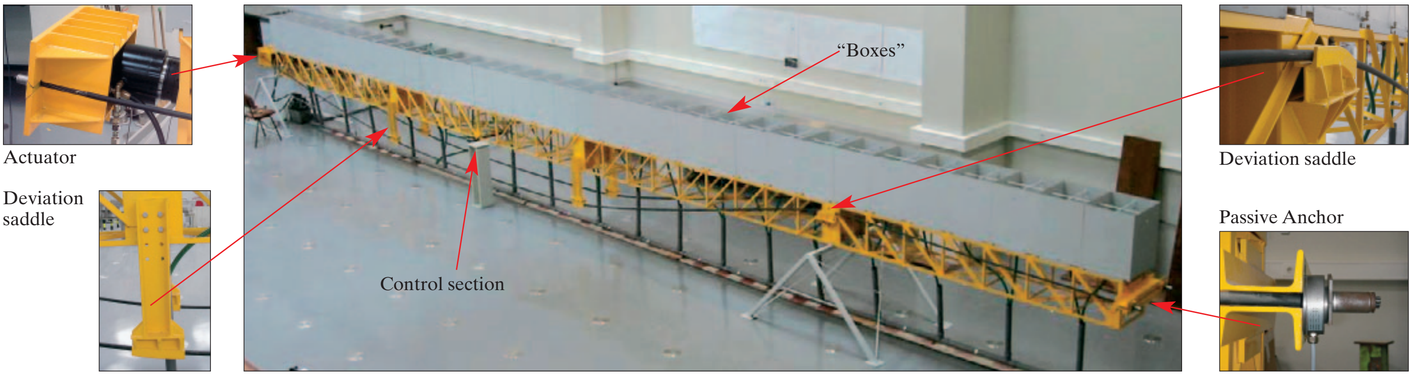

Fig. 1: Model with loading simulator ("boxes" to be filled with water)

In this laboratory model, no specific safety measures were implemented. In "real" scale applications, several active and passive measures are to be taken. That includes alarms and warnings, hydraulic valves and software complementary codes, etc. Preventing the actuator system fail, a mechanical retention system was conceived for the 1:1 prototype application. It comprises two screws and respective nuts, which physically retain the anchorage beam, preventing a decrease in strength of the prestressing cables.

Experimental Results

Several experimental tests were carried out simultaneously with a very detailed similarity analysis between experimental and numerical models (*Figs. 4* and *5*). A stiffer response from the scale model was identified and explained by the larger than expected cross sections of the steel profiles, due to manufacturing tolerance.

Material physical characteristics and scale model geometrical characteristics were determined with utmost precision (*Table 1*), because they are all essential to scale model validation.

where,

E_c is the modulus of elasticity;
A_c is the scale model cross section area;
I_c is the scale model cross section inertia moment;
b_v,b_a are the cross section widths at mid-span and above the support (cantilever section);
h_v, h_a are the cross section heights at mid-span and above the support (cantilever section);
L is the structure total length;
$E_p x A_p$ is the axial stiffness of a 1 m long monostrand;
L_p is the unbonded tendons length;

The first mode natural frequency was experimentally identified (5,19 Hz) and matches the value from the numerical model (5,25 Hz).

Deck Concreting Simulation

Experimental tests were performed to simulate the two more common concreting procedures (type X and type Y). Only one procedure (type X) will be thoroughly illustrated here. Concreting was simulated by pouring water in the "boxes". Moderate load levels were previously defined.

Type X Concreting Procedure

This procedure is characterized by symmetrical concreting from the front support (reducing the rotation on the support section) (*Fig. 6*). Experimental tests with OPS (test 1) and without OPS (test 2) were made.

	Parameter	Theoretical values	Measured values	Units
Gantry	Ec	210,0	203,8 +/–1,64	GPa
	Ac	5,72	6,729 +/–0,213	cm^2
	Ic	2029,9	2323,352 +/–72,776	cm^4
	bv	0,4	0,398 +/–0,003	m
	hv	0,4	0,401 +/–0,001	m
	ba	0,4	0,399 +/–0,001	m
	ha	0,4	0,401 +/–0,002	m
	L	14,0	13,997 +/–0,001	m
Unbonded tendons	Ep × Ap	27300	27765	kN
	Lp	14,69	14,700 +/–0,005	m

Table 1: Theoretical and measured values of scale model main parameters

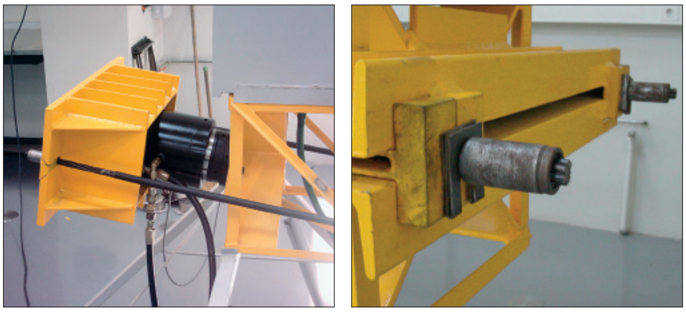

Fig. 2: Active (organic anchor) and passive ends

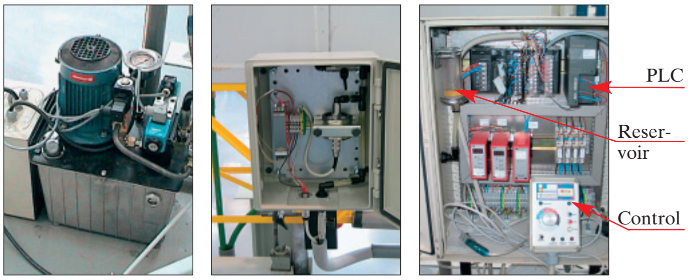

Fig. 3: From left to right: hydraulic actuator motor-pump, pressure transducer and power pack

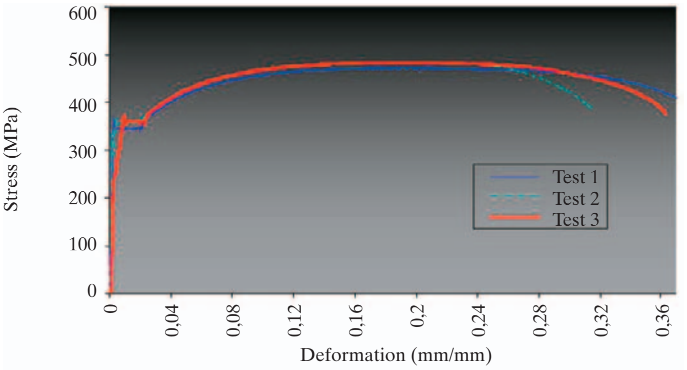

Fig. 4: Stress/deformation profile steel tests

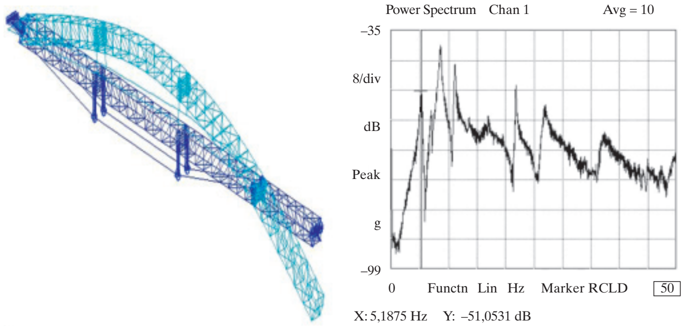

Fig. 5: First mode deformation and average spectral estimative of vertical accelerations measured in one of the scale model ends [7]

The following notation is used:

u – mid-span deflection; **Lc** – actuator course; **σ_f** – flange stress f (**lo** – lower or **up** – upper) ***w/OPS*** – model with OPS; ***wo/OPS*** – model without OPS; abbreviations ***num***. e ***exp.*** refer to numerical and experimental model values, respectively.

These graphics (*Fig. 7* to *10*) display the similarity between numerical and experimental deflections. The symmetric loading with OPS produces approximately zero mid-span deflections. Oscillation in the high precision pressure transducer is explained by the water impact due to pouring and by other ambient vibrations.

Type Y Concreting Procedure

This procedure is characterized by concreting from the cantilever end (*Fig. 11*). Results are detailed in [6], where tests 3 (with OPS) and 4 (without OPS) are shown. Initially, stress and deflection values exhibit "inverted" signs (the mid-span section "goes up"). After that first phase, behaviour becomes very similar to the behaviour in the Type X concreting procedure.

In general terms, OPS advantages are similar in both type X and type Y concreting procedures.

Analysis of Experimental Results

Results show that scale and numerical model behaviours are consistent. Also, the control algorithm function is verified. Small differences between numerical and experimental values are due to experimental model vibrations and distinct loading velocities. These facts are irrelevant for a static control system. For example, final mid-span deflection in the numerical and experimental models in tests 1 and 3 differ 3,6% and 6,3%, respectively. Tests 2 and 4 also present small differences. *Table 2* presents deflection (u) and stress (σ) values on the mid-span section (control section) and the hydraulic actuator course movement (Lc) measured in tests 1 to 4.

	Concreting process – Type X				Concreting process – Type Y			
Parameter	Test 1		Test 2		Test 3		Test 4	
	Num.	Exp.	Num.	Exp.	Num.	Exp.	Num.	Exp.
$u_{max.}$ posit. (mm)	000	0,25	0	1,40	1,16	1,18	2,33	2,65
$u_{max.}$ negat. (mm)	–1,15	–1,63	–13,50	14,10	–1,16	–1,86	–13,64	–13,10
u_{final} (mm)	–0,84	–0,81	–13,50	–13,72	–1,04	–1,11	–13,64	–13,10
σ_{fup} max. (MPa)	–15,96	–12,91	–37,46	–38,54	–17,22	–14,55	–37,78	–39,59
σ_{flo} max. (MPa)	–12,17	–5,29	52,32	50,94	–8,43	–10,51	51,05	52,19
L_c total (mm)	3,05	3,11	–	–	3,05	3,15	–	–

Table 2: Numerical and experimental tests results

Process	Deflection reduction	Lower flange stress reduction		Upper flange stress reduction	
Type X	94,1 %	45,7 MPa	89,6 %	25,6 MPa	66,5 %
Type Y	91,5 %	41,7 MPa	79,9%	25,0 MPa	63,2 %

Table 3: Evaluation of experimental results with and without OPS

The evaluation of the performance of the OPS system in these experimental tests should be considered as qualitative. Nevertheless, results are objective and interpretation is evident. Experimental results for the described loading types, with and without OPS, are presented in *Table 3*.

Therefore, OPS in this structure meant 12,6% saving in the gantry structural material (following the "stress dimensioning criteria"). If the "deflection dimensioning criteria" were considered, that value would be much higher.

Quantitative savings in the experimental model can not be applied directly to 1:1 scale structures, but results in the laboratory model show that OPS is feasible and prove that its structural effect is as predicted in numerical mod-

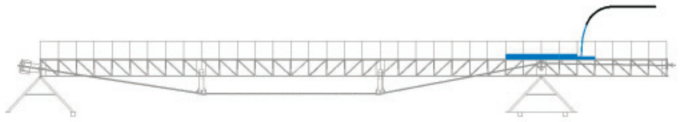

Fig. 6: Type X concreting procedure – symmetrical loading starting form the front support [6]

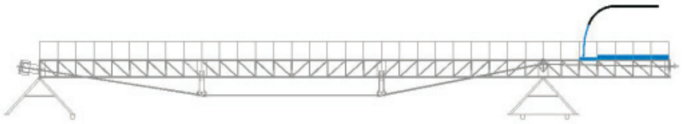

Fig. 11: Type Y concreting process – sequential loading starting from the cantilever's end [6]

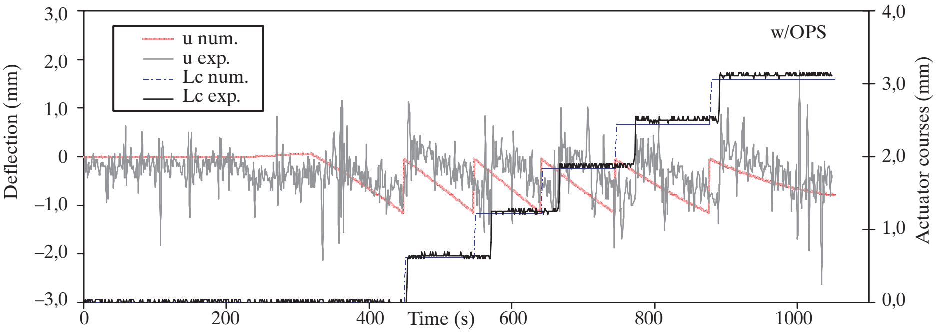

Fig. 7: Mid-span numerical and experimental deflection (u) values in Test 1 (with OPS) [6]

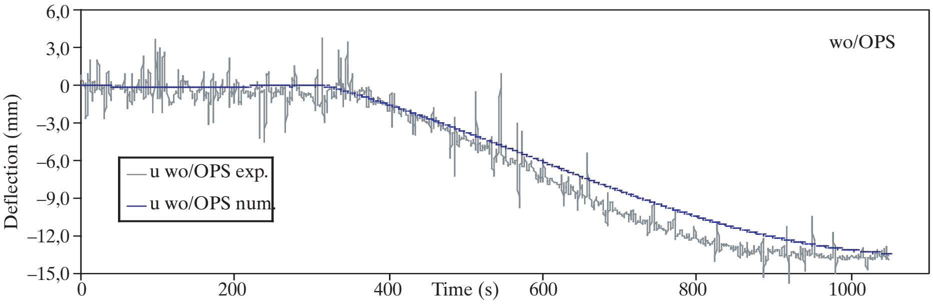

Fig. 8: Mid-span numerical and experimental deflection (u) values in Test 2 (without OPS) [6]

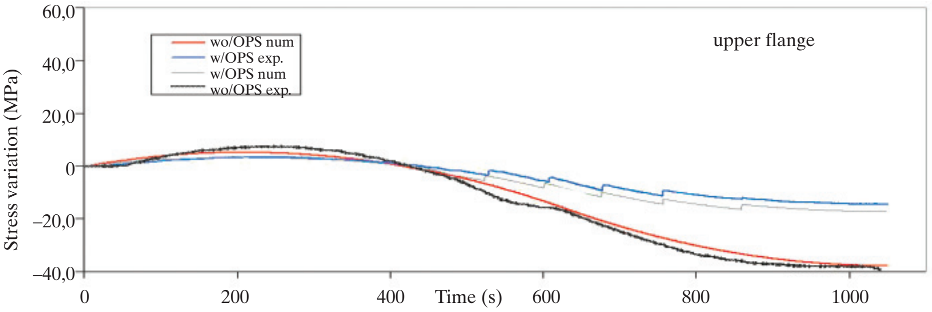

Fig. 9: Mid-span numerical and experimental upper flange stress (σ) values in Tests 1 and 2 [6]

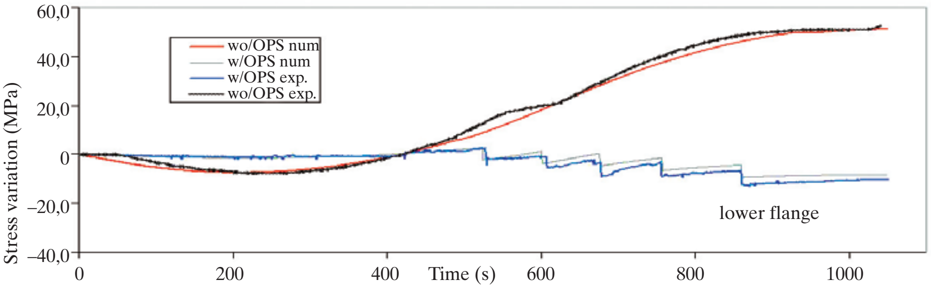

Fig. 10: Mid-span numerical and experimental lower flange stress (σ) values in Tests 1 and 2 [6]

els. Also, the correctness of different scale numerical models studied before is confirmed [5, 6].

Other tests were carried out, specifically in view of the reliability of the system. Two main conclusions for further application are emphasized:

- The deflection measuring system is very sensitive to thermal variations.
- Human (semi-automatic) operation of the system has to be carefully restricted. When the automatic OPS mode was turned off, a small accident occurred due to human error.

Conclusions

This experimental study confirmed that Organic Prestressing (OPS) is simple and feasible. Nevertheless, before a full scale model is set up:

- The deflection measuring system has to be tested under real environmental conditions.
- Restrictive rules have to be implemented to avoid human or semi-automatic "free" operations.

Experimental results confirm numerical results obtained previously and provide the following two conclusions about OPS in launching gantries:

- OPS system ensures a considerable increase of launching gantries load capacity.
- OPS system guarantees a drastic deflection reduction.

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