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Comparative study of prestressing consumptions in 7 different constructive methods for 75 m multi-span box girders

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ABSTRACT: In the last few years new constructive methods have been developed and applied in multi-span prestressed concrete decks, with medium-large spans (70 to 80 m), where, typically, box girders cross sections are adopted. Each constructive method has its own field of application and frequently decisions are taken after a comparative analysis of different options, comprising main issues like Safety, Risk, Economy and Time. Present paper presents a comparative study of prestressing consumption on 7 constructive methods for 75 m multi-span concrete box-girder decks. Thus, being mainly useful for the cost evaluation of alternative methods (Economy). The methods considered in this study are: (1) span by span, cast in situ, with constructive joints over the piers; (2) span by span, cast in situ, with constructive joints at 0.2 of the span; (3) precast segments – span by span (simply supported); (4) precast full span segments (simply supported); (5) precast full span segments with post continuity; 6) in situ balanced cantilever and finally (7) precast segmental balanced cantilever. The study considers a unique width of a typical highway cross section and Eurocode design criteria and materials are adopted. All solutions are performed with the same volume of concrete per span and with the same height, but with different geometries (optimized for the conditions of each case) in order to obtain a uni-parametrical study on prestressing consumption. A typified intermedium representative span (in a multi span deck) is considered in all cases. Common prestressing layouts are adopted. The materials' time-dependent behavior, the influence of the construction stages and the internal forces redistributions are taken into account according to standard procedures. Stresses are analyzed during construction and service stages. All the design optimization procedures are performed by means of genetic algorithms. The prestressing consumptions for mentioned 7 cases are presented and results are very briefly discussed.

1 INTRODUCTION

It is known that main factors of decision, while selecting a Constructive Method are: Economy; Time and Safety, not necessarily by this order. Economy is normally evaluated by the sum of Materials consumption; Main Equipment; Man Power; Secondary Equipment; Site Preparation; Indirect Costs and Others.

In what regards to Material Consumption one of the main factors is the Prestressing Consumption. It is known that for the same deck cross section and for the same spans, the prestressing consumption may have relevant variation. In this paper a study of uni-parametric variation of prestressing consumptions is presented for 7 different constructive methods as per Figure 1.

Present approach is to be clearly understood us an exercise to give tendencies and never exact, relative or absolute, values. Indeed, it is known that the design always depend on multiples factors. For example, it is possible to achieve significantly different results if the optimization procedures

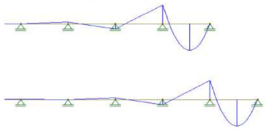
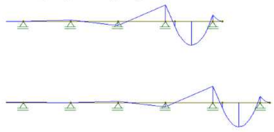
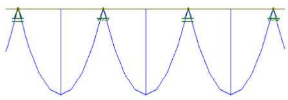
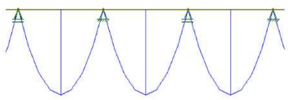
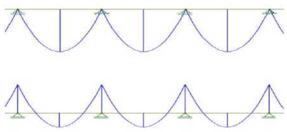
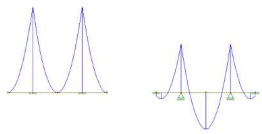
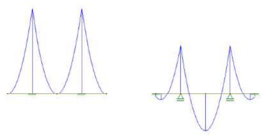
<table>
<tr><th>Method / Structural System Evolution – Lateral view</th><th>Main Equipment</th></tr>
<tr><td>(1) Cast in Situ; Span by span, Joints over the piers
</td><td rowspan="2">
Figure 1A. MSS (BERD, 2010)</td></tr>
<tr><td>(2) Cast in Situ, Span by span, Joints at 0.2 of the span
</td></tr>
<tr><td>(3) Precast segments, span by span (simp. supported)
</td><td>
Figure 1B. Launching Gantry (BERD, 2014)</td></tr>
<tr><td>(4) Precast full span segments (simply supported)
</td><td rowspan="2">
Figure 1C. Mega Crane - Central spans of Vasco da Gama Bridge, Lisbon, (Vinci, 1997)</td></tr>
<tr><td>5) Precast full span segments with post continuity
</td></tr>
<tr><td>(6) In Situ, Balanced cantilever
</td><td>
Figure 1D. Cantabria, Spain (Construgomes 2007)</td></tr>
<tr><td>(7) Precast Segments, Balanced cantilever
</td><td>
Figure 1E. Tenerife, Spain (Ferrovial, 2012)</td></tr>
</table>

Figure 1. Constructive Methods and Structural Systems Characterization.

also comprise concrete volume optimization or reinforcing steel optimization. And, in fact, common design procedures always consider simultaneously multiple factors. Thus, the propose of this approach is no more than sharing "what would be the tendency variation of prestressing consumption, for different constructive methods considering the same concrete consumption and the same deck height for all (Lopes 2015)

1.1 *Main Assumptions*

In order to perform a uni-parametrical evaluation of different prestressing consumptions following assumptions were adopted:

- All assessments performed according to Eurocode (EC 0a 0b, 1 2, 2003, to 2007),;
- Equal concrete volume and height of the deck for all 7 evaluated solutions, comprising different geometries, optimized for each case;

– Equal height and width of the cross section in all cases;
– The deck's geometry definition and the prestressing layout/dimensioning performed simultaneously by means of a genetic algorithm (Ferreira & Lima (2015)). In order to perform this optimization, the relation used between costs for concrete, prestressing and reinforcing steels is 100:2:1.

Other secondary assumptions were adopted. Some of them may influence the absolute results, but as they are the same in all cases, there influence on the relative values is to be reduced:

– Infinite number of spans;
– Service stages analyzed at the end of the construction and 10,000 days after it;
– The stresses redistribution due to creep and shrinkage determined based on the simplified formula of Trost & Wolff (1969);
– Prestress strands of 0,6" (1,5 cm^2 of cross section area), with $f_{puk} = 1860$ MPa, and stressed at $0.75 f_{puk}$;
– 10% prestress immediate losses, constant throughout the cable length;
– Prestress time dependent losses considered between the end of the construction and 10,000 days after it;
– Prestress stress at the age of 10,000 days assumed equal to 1000 MPa;
– C40/50 concrete class at 28 days, and equivalent concrete class of C30/37 at stressing;
– No stresses considered due to pier/foundations-constraints to imposed deformations.

2 LOADS AND COMBINATIONS

2.1 *Loads*

In all cases the loads are evaluated according to Eurocode and comprise:

– Concrete self-weight;
– Prestress;
– Dead loads, due to the presence of new-jerseys and bituminous layer, of 36.35 kN/m (longitudinally);
– Road bridge traffic loads - Load Model 1;
– Temperature gradients of +10°C and −5°C;
– Movable scaffolding system rear reaction (valid for span by span construction) considered equal to 1.60 the rear reaction for the weight of the wet concrete, to take into account the scaffolding system self-weight; at a distance of 2 m of the construction joint section;
– Form traveler's (valid for balanced cantilever construction) self-weight considered equal to half the weight of the heaviest segment (SETRA (2007)); resultant force located at the middle of the segment in construction;

2.2 *Load Combinations and Design Assessments*

Following combinations of actions were adopted:

Table 1. Load combinations.

Combination	Expression
Construction Stages	$\sum G_{k,j}$ "+" P
Characteristic	$\sum G_{k,j}$ "+" P "+" Q_{k1} "+" $\sum \psi_{0,i} Q_{k,i}$
Frequent	$\sum G_{k,j}$ "+" P "+" $\psi_{1,1} Q_{k1}$ "+" $\sum \psi_{2,i} Q_{k,i}$
Quasi-Permanent	$\sum G_{k,j}$ "+" P "+" $\sum \psi_{2,i} Q_{k,i}$

Following concrete stress verifications were considered in table 2:

At joints of precast elements a more demanding stress verification is required, as shown by the table 3:

3 DECK CHARACTERIZATION / PRESSTRESING LAYOUTS

3.1 *Cross Sections*

The Cross section follows a typical prestressed concrete box girder design, where the indicated variables are defined together with the prestressing amount, by means of mentioned Genetic Algorithm.

3.2 *Longitudinal Section / Prestressing Layout*

The longitudinal sections, with a 75 m span length, are as follows:

Table 2. Stresses verifications.

Combination	Maximum compressive stress	Maximum tensile stress
Construction Stages	0.60 $f_{ck}(t)$	$f_{ctm}(t)$
Frequent	–	$f_{ctk,0,05}$
Quasi-Permanent	0.45 f_{ck}	0 (zero)

Table 3. Stresses verifications at joints.

Combination	Maximum compressive stress	Maximum tensile stress
All combinations	-	0 (zero)
Characteristic	0.60 f_{ck}	-
Quasi-Permanent	0.45 f_{ck}	-

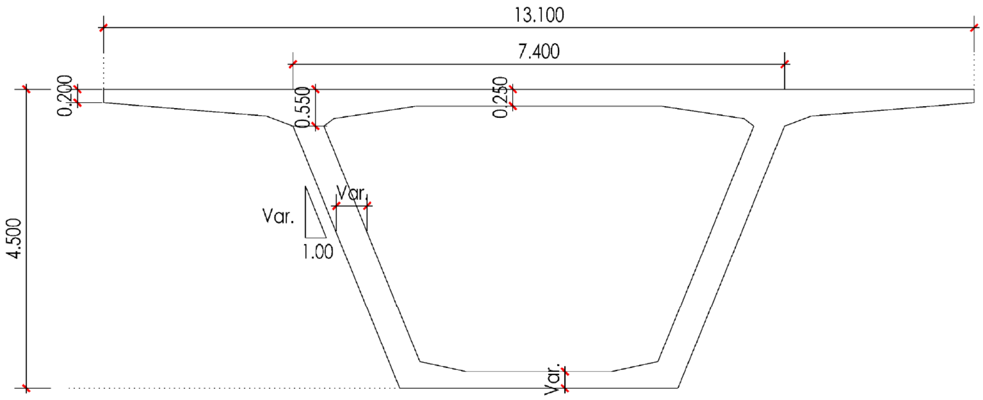


Figure 2. Mid Span Cross Section.

4 PRESTRESSING CONSUMPTIONS

Following prestressing consumptions were achieved table 5:

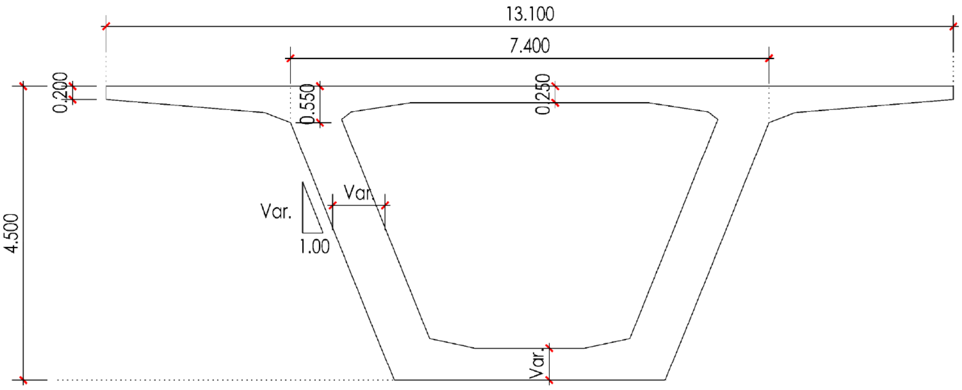


Figure 3. Support Cross Section.

Table 4. Longitudinal section.

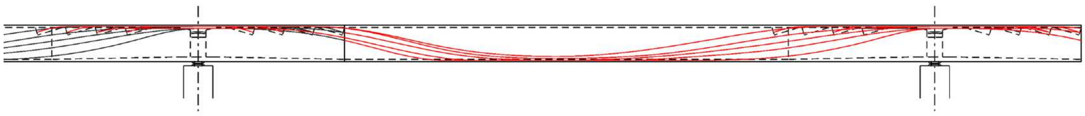
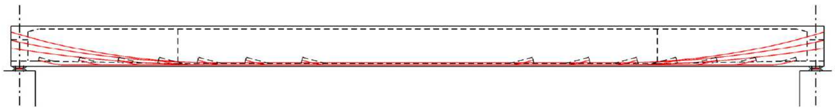
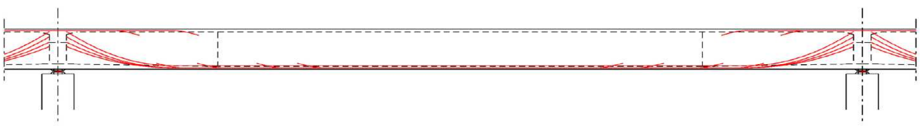
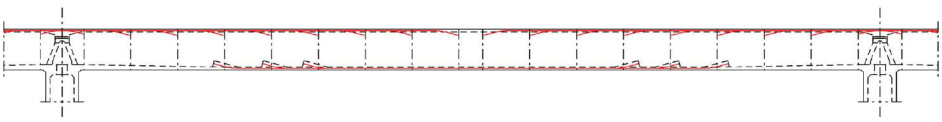
Longitudinal Section / Prestressing Layout
 Figure T5A. Prestressing Layout at method (2) Span by Span, in Situ, Joint at 0.2 L
 Figure T5B. Prestressing Layout at methods (3) and (4) Simply Supported
 Figure T5C. Prestressing Layout at method (5) Precast full span segments with post continu-
 Figure T5D. Prestressing Layout at methods (6) and (7) Balanced cantilever

Table 5. Prestress consumptions.

Construction Method	Prestress consumption kg/m^2
(1) Cast in Situ; Span by span, Joints over the piers	20.4
(2) Cast in Situ, Span by span, Joints at 0.2 of the span	15.1
(3) Precast segments, span by span (simply supported)	29.7
(4) Precast full span segments (simply supported)	23.4
(5) Precast full span segments, with post continuity	19.2
(6) *In Situ*, Balanced cantilever	18.0
(7) *Precast Segments,* Balanced cantilever	32.0

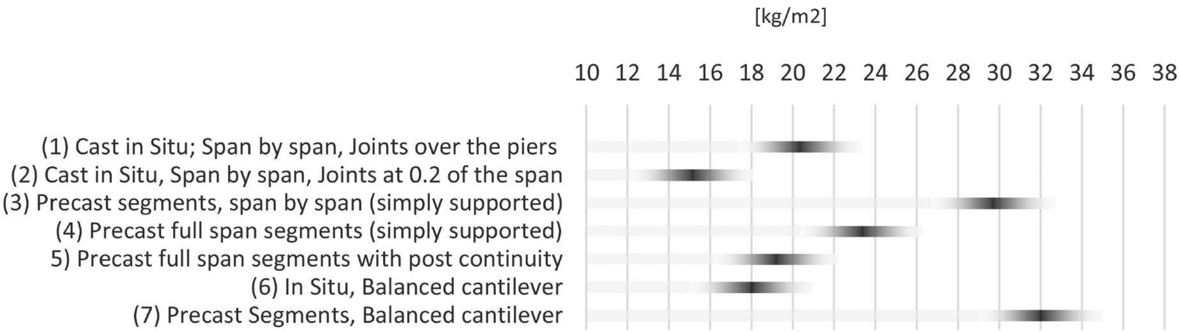


Figure 4. Prestressing consumptions tendency.

5 CONCLUSIONS

The performed study allows to establish the tendency variation of prestressing consumptions, for the different constructive methods presented in figure 4.

Cast in situ, span by span with joints at (0.2x L), reveals to be the method with less prestressing consumption. The segmental methods have the higher consumptions.

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