Nose-Deck Interaction in Launched Prestressed Concrete Bridges

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ABSTRACT: Incremental launching is a competitive construction method for medium-span prestressed concrete bridges. Compared with the other techniques for in situ casting, in short bridges it is an alternative to the use of falseworks and reduces the cost of labor with the same investment. In longer bridges it is an alternative to self-launching centering and reduces investment with the same cost of labor. Compared with segmental precasting, it may reduce both investment and the cost of prestressing. The design of a launched bridge is affected by temporary stresses arising from its movement over fixed bearings. These stresses tend to increase the cost of materials, reducing the competitiveness of the construction method. Of the various devices used to reduce temporary stresses, adopting a launching nose has virtually become standard, permitting an effective control at competitive costs. The techniques of optimizing the nose-deck interaction are illustrated here through several graphs, and the analysis of special cases may be carried out by means of an ordinary spreadsheet.

INTRODUCTION

Incremental launching is a construction technique for prestressed concrete bridges widely used in Europe. The deck is cast in situ in a fixed formwork placed behind an abutment, by alternating construction cycles with the front launch of the entire deck section progressively built.

Compared with segmental precasting, the only alternative construction technique involving highly industrialized procedures, this method eliminates all the weak points. The segment length is no longer restrained by shipping requirements and is therefore much greater—generally half a span (that is, from 20 to 30 m), compared with the few meters of precast segments. The number of joints, weak points of the structure, is drastically reduced, and the structural continuity in the matchcast joints is perfect even at ultimate owing to the presence of continuous reinforcement. Total prestressing is not necessary (joints do not open, but only crack at the tension edge) and this results in lower costs of prestressing, a better use of reinforcement, and a more ductile ultimate behavior. Partial prestressing improves the deck behavior and reduces the effects of time-dependent phenomena.

From a quality standpoint, therefore, the standards allowed by high repetitiveness and industrial environment, no longer shadowed by uncertainty on the monolithic behavior of the structure, are so high as to make this construction technique a point of reference. Also, the advantages over in situ casting are interesting: a substantial reduction in times and cost of labor with similar investment compared with falsework and lower investment at an equal or lower cost of labor compared with movable centering systems (Rosignoli 1997a). Achieving high quality levels at competitive economic conditions explains the increasing adoption of this construction method in a wide range of spans and deck lengths. The competitiveness of the project is promoted by the good adaptability of the equipment, which stimulates innovation and improvement.

A launched bridge turns out well designed and economically competitive if the savings permitted by technology are not made worthless by higher structural costs arising from launching stresses. These stresses are high, are different from the permanent ones, and are variable along the deck (Rosignoli 1997b).

During launch, each cross section of the deck passes cyclically in midspan and on the piers, and therefore is subject to both positive moments and negative moments and shear forces. Although under only dead load (but in the presence of thermal gradients and bearing settlement), the situation evolves cyclically between the two limit conditions shown in Fig. 1. The condition in Fig. 1(a) is similar to the final position, with the deck support diaphragms placed over the piers. The second position, that of Fig. 1(b), is with the deck advanced by half a span, and therefore supported on sections that on completed launch will become midspan ones.

In both positions the midspan sections will be unlikely to turn out critical: shear force is low, bending moment is much lower than the values reached under service loads, and the edge tensile stresses may be reduced or avoided with an adequate launch prestressing. In addition, box girders are morphologically better suited to resist positive moments, since the wide top slab provides a large compression area and draws centroid upward.

With regard to support sections, in the position given by Fig. 1(a) launching stresses are lower than the final ones, and the design of the cross section for service loads is generally adequate. However, an adequate launch prestressing and web reinforcement for the full absorption of the shear tensile stresses must be provided, since parabolic tendons will reduce the shear diagram only after their introduction at the completion of launch. On the contrary, in the position shown in Fig. 1(b) the cross sections that on finished launch will be in midspan to resist positive moments and low shear forces are subjected to the highest negative moments and shear forces. They often have to be designed for these temporary stresses and tend to be oversized compared with the service requirements. As

![Fig. 1. Limit Support Configurations Assumed During Launch](image-url)
each cross section passes over the piers during launch, these temporary stresses require a marked uniformity of the flexural stiffness and the web thickness along the deck, while with other construction techniques the midspan cross sections are frequently lightened, especially for long spans and constant depth decks. This results in oversizing of the entire deck, and in heavier structures.

Moreover, the cyclic change of sign of bending and shear does not allow the use of parabolic tendons, and the edge tensile stresses are controlled by a centroidal launch prestressing that results in uniform compression of all cross sections. At the completion of launch, this uniform compression is not only insufficient to absorb service load tensile stresses (and therefore needs to be integrated by more effective parabolic tendons), but also detrimental, since it increases the stresses in the deck edges already compressed by the bending moment final diagram. As a consequence, these temporary stresses require several checks and a specific type of prestressing that optimizes, among the various aspects, the deck performance during launch as well, reducing the requirement for material at those points where oversizing would be pointless or, worse, damaging in the service stage.

Even more significant problems arise in the first two spans of the deck. In a continuous beam composed of several bays of span \( l \) and constant dead load, far from the ends the support sections remain vertical and the static scheme of each span is the one of the perfectly fixed beam. On the other hand, at each approach to the next pier the front span of the deck overhangs beyond the first support with a cantilever of length \( l_c \); therefore the negative moment in the first support section is up to six times higher than the one at the rear supports, and the shear force is double (see Fig. 2).

Reasoning necessarily in terms of cylindrical geometry of the solid to be "extruded" (that is, of a constant depth deck), design based on the front span launch stresses would burden the entire structure, while design optimized for the rear zone would be inadequate in the front one. As this second alternative is more economical than the first (the rear zone is much longer than the front one), it is convenient to introduce devices able to control the front zone stresses beyond that critical cantilever, \( l_c \), for which the negative moment at the first support is equal to the perfectly fixed beam moment of the rear zone:

\[
\frac{qL^2}{2} = \frac{QL^2}{12} \tag{1}
\]

and which is \( L_c = 0.41l \).

There are two possible solutions: (1) reduce the launching stresses diffusely by increasing the number of supports or (2) limit the difference between the launching stresses in the front zone and in the rear one by supporting the cantilever or reducing its weight.

The first applications of incremental launching were carried out by dividing the spans with temporary piers distributed along the entire length of the deck (see Fig. 3). In fact, it was observed that using a single temporary pier located in each case under the cantilever span would have involved significant time and cost, acceptable only for spans long enough to make absorption of the launching stresses more expensive than their reduction, even in the rear zone of the deck. It was also observed that the adoption of several temporary piers in each span would not have actually produced the dramatic stress reduction predictable at first sight owing to the different elastic and thermal bearing movements, the construction tolerances, and the deck flexural stiffness. This resulted in the general use of a single temporary pier per span.

Nowadays, the cost of the temporary piers (even if prefabricated and reusable), their foundations, and the additional labor they require is justified only in the case of very long or variable spans, where savings in launch prestressing (unless made worthless by a higher parabolic prestressing) and reinforcement may turn out to be competitive. These limitations narrow the field of application of the principle of the launching stress generalized reduction. Instead, normally the stress differences along the deck are limited to make it possible to overcome the full span with a cantilever.

In the first of these techniques, the cantilever is supported by means of a stayed scheme comprising a tower integral with the deck and strand tendons anchored symmetrically to the tip of the cantilever and two spans behind, thereby creating a sort of external prestressing with great eccentricity. In relation to the position reached by the tower during launch, this scheme requires continuous adjustment of the force in the stays because of the concentrated action exerted by the tower on the deck. Just before the contact with the pier the tower passes on the front support and the maximum pull in the stays supports the cantilever and reduces its elastic deflection. However, once the bearing has been reached the pull must be relieved so as not to increase the positive moment in the deck front span with the concentrated action of the tower. Resort to this technique is discouraged not only by the longer time required for the continuous adjustments of the stay force and the deflection of the deck, but also by its intrinsic delicateness and complexity, presenting considerable stress concentrations and serious risks in the case of errors.

The second technique provides, instead of a support for the deck end, a limitation of its cantilever weight by means of a lighter extension—the launching nose—which anticipates the contact of the deck with the pier (see Fig. 4). The launching nose is a "passive" solution, perhaps less elegant than the
stayed scheme but much simpler; it is safe, fast, and economical, so that its adoption has become virtually standard in full-span incremental launching.

Even with the use of temporary piers the reduction of the cantilever weight is advantageous (Fig. 3), and it is essential in the longest spans. What is more, the stayed scheme takes advantage of it (Fig. 5). The launching nose thus characterizes practically all the applications of incremental launching.

In the 30 years during which this construction method has been used, launching noses of all types have been used. They have been more or less rigid trusses or plate girders made of steel or concrete with front realignment sledge or hydraulic systems to recover the elastic deflection. These launching noses have sometimes been designed according to customs and experience, but often they were already available and therefore ready to be reused. The most common type of launching nose consists of two steel plate girders connected to the deck front end with their bottom flanges aligned with the lower edge of the deck. Acting as an extension of the deck perfectly integral at the joint, the launching nose affects the stresses in the deck (or, more exactly, in the continuous beam comprising the deck and the nose itself) and permits their homogenizing.

The behavior of the nose-deck elastic system is governed by three dimensionless parameters that describe its geometrical and mechanical characteristics:

1. The nose length compared with the span to be overcome, \( l_n/l \)
2. The unit weight of the launching nose compared with the unit weight of the deck front zone, \( q_n/q \)
3. The flexural stiffness of the nose compared with the one of the deck front zone, \( E_n l_n/EI \)

The model developed below makes it possible to illustrate the influence of these three parameters and to optimize rapidly the nose-deck interaction, avoiding the trial and error use of sophisticated calculation methods.

**NOSE-DECK INTERACTION**

In order to develop a theoretical model of the nose-deck interaction, the following assumptions are made:

1. The nose and the deck are of constant stiffness and weight. Since they generally vary both in the launching nose and in the deck front zone, it is correct to consider their weighted average.
2. The number of spans behind support C (see Fig. 6) is assumed to be so large as to assimilate the deck to a continuous beam composed of infinite bays of constant span \( l \).
3. Launch prestressing is centroidal also in the deck front zone, so as not to introduce additional redundant unknowns.

**Theoretical Model**

Defining the progression of launch with the distance \( x \) of the nose-deck joint section from support B (Fig. 6), the cantilever configurations assumed before the nose reaches support A vary from the starting position, \( x = 0 \), to the contact one, \( x = l - l_n \), and the dimensionless launching progress

\[
\alpha = \frac{x}{l} \tag{2}
\]

varies in the range \( 0 \leq \alpha < 1 - l_n/l \).

At the start of launch, for \( \alpha = 0 \), the bending moment in the support section B is that of the cantilever nose, which in a dimensionless form (hereinafter the moments due to cantilever masses will be marked with an asterisk) is

\[
\frac{M_B^*}{q^*} = -\frac{q_n}{2q} \left( \frac{l_n}{l} \right)^2 \tag{3}
\]

Once launch starts, this increases (in absolute value) with the dimensionless law

\[
\frac{M_B^*}{q^*} = -\frac{\alpha^2}{2} - \frac{q_n l_n}{q} \left( \alpha + \frac{1}{2} \frac{l_n}{l} \right) \tag{4}
\]

and set

\[
C_1 = \frac{l}{3EI} \tag{5}
\]

\[
C_2 = \frac{l}{6EI} \tag{6}
\]

\[
C_3 = \frac{l}{2\sqrt{3}EI} \tag{7}
\]

\[
C_4 = \frac{ql^2}{24EI} \tag{8}
\]
Negative Moment at the First Support

To be effective, a launching nose must at the same time reduce the cantilever moment \( M_\theta \) and ensure high values of \( R_\alpha \) (16). Therefore it must satisfy two a priori contradictory requirements.

- On the one hand it must be light, to reduce \( M_\theta \), and sufficiently long that at the contact with the pier the portion of cantilever concrete deck, which is much heavier, is as short as possible.
- On the other hand it must be stiff, so that recovery of the elastic deflection at support A produces an initially high reaction \( R_\alpha \) that immediately increases, as launch proceeds, to balance the increase of \( M_\theta \) caused by the progressive lengthening of the concrete segment affecting the first span.

For a long launching nose, \( l_\alpha/l = 0.80 \), of relative weight \( q_\alpha/l_\alpha = 0.10 \), the progression of \( M_\theta \) with launch in relation to the flexural stiffness is described in Fig. 8. (Note there that with a long launching nose the maximum cantilever moment is lower than the end-of-launch one.) Until contact with support A, for \( \alpha < 0.20 \), \( M_\theta \) grows with (4). Upon reaching the support, the positive moment generated by recovering the elastic deflection reduces \( M_\theta \), and as launch continues \( M_\theta \) depends on the flexural stiffness and tends to an end-of-launch (EOL) value that, setting \( \alpha = 1 \) in (15), is

\[
M_\theta^{\text{EOL}} = 0.134q_\alpha l_\alpha^2 - 0.106 q l^2
\]

As in the cantilever configuration, for \( \alpha < 0.20 \), in this final stage of launch, with \( \alpha > 0.90 \), \( M_\theta \) does not depend on \( E_\alpha l_\alpha/EI \). Therefore the flexural stiffness of the nose can be used only to prevent the launching moments after contact with support A and until the stabilization of the EOL value (for 0.20 < \( \alpha < 0.90 \)) from exceeding the moments at contact and at EOL, since deck oversizing is generally more expensive than stiffening the launching nose.

Optimum stiffness, in this case, turns out to be around \( E_\alpha l_\alpha/EI = 0.2 \) (thicker line). Greater stiffness is pointless, since it cannot prevent reaching the EOL moment, and less stiffness increases the negative design moment of the deck. Moreover, the maximum cantilever moment is much lower than the EOL one: contact with the pier is uselessly anticipated; that is, the launching nose is excessively long, and it is convenient to shorten it.

On the other hand, in the case of a short nose (equal relative weight but \( l_\alpha/l = 0.50 \)) the progression of \( M_\theta \) is as given in Fig. 9. (Note there that, with a short nose, the maximum cantilever moment is higher than the EOL one.) Until the contact with support A it is favorably affected by the lower weight of the nose but unfavorably by the greater length of the cantilever concrete segment. Upon reaching \( A \), \( M_\theta \) is reduced more ef-
fectively, and at the EOL it stabilizes on the value given by (18).

The effects of the flexural stiffness are comparable as well, and also in this case optimum stiffness should be around $E_J/J/EI = 0.2$ (thicker line). However, keeping $M_b$ below the EOL value during the intermediate launch stages loses significance since this threshold is substantially exceeded in the previous cantilever configuration.

In contrast to what occurs for the long nose, in the case of a short nose the maximum cantilever moment is greater than the EOL one, and it is therefore the first phase of launch to affect the design of the deck. Contact with the pier occurs too late; that is, the nose is too short and should be extended.

Proceeding by trial and error, the optimum nose length is obtained in Fig. 10: with $E_J/J/EI = 0.2$ the cantilever moment at contact is equal to the EOL one, and in the intermediate stages it is lower.

The diagrams examined so far analyze the behavior of the nose-deck elastic system for a given relative weight; Fig. 11 compares the diagrams of $M_b$ calculated for the optimum parameters obtained for $q_o/q = 0.10$ as a function of this ratio.

$M_b$ depends significantly on the relative weight of the nose only during the first phase of launch. In the second phase it is limited to a family of curves contained in $15-20\%$ of the EOL value, which twist because of $M_b^*$ (18). The different relationship between $M_b$ and $q_o/q$ in the two phases of launch means that, once the system has been optimized for a given relative weight, an increase in $q_o/q$ modifies the diagram of $M_b$ toward the type of Fig. 9 ("short" nose), and vice versa its reduction modifies the diagram toward the type of Fig. 8 ("long" nose). To force the value of $M_b^*$ on contact toward EOL moment it is then necessary to modify the length of the nose, shortening the cantilever concrete segment, that is, lengthening the nose, as the relative weight of the latter increases.

Fig. 12 compares the diagrams of $M_b$ that restores this condition: starting from $q_o/q = 0.10$, as the relative weight increases equalization is obtained with longer noses and for progressively lower values of $M_b$, which tends to the perfectly fixed beam moment of the rear zone of the deck.

Proceeding by trial and error, the curve of Fig. 13 is obtained, which defines, as $q_o/q$ varies and for the optimum flexural stiffness, the values of $l_o/I$ that equalize the negative moment on contact with the EOL one. The diagram makes it possible to determine easily the optimum length of the launching nose in relation to its relative weight.

In conclusion, a correct design of the nose-deck system can be arrived at starting from a length $l_o$ equivalent to about two-thirds of the typical span and from a first attempt unit dead load $q_o$ obtained by such statistical formulas as

$$q_o = K l_o^2$$  \hspace{1cm} (19)

in which, in kilonewtons and meters, is $0.012 \leq K \leq 0.020$.

![Fig. 9. Progression of $M_b$ with Launch for $l_o/l = 0.50$ and $q_o/q = 0.10$ in Relation to $E_J/EI$](image9)

![Fig. 10. Obtaining the Optimum Nose Length for $q_o/q = 0.10$ by Trial and Error (with the Maximum Cantilever Moment Equaling the EOL One at $l_o/l = 0.65$)](image10)

![Fig. 11. Progression of $M_b$ for $l_o/l = 0.65$ and $E_J/EI = 0.2$ in Relation to the Relative Weight $q_o/q$ (with the Thicker Line Representing the Optimum Diagram of Fig. 10 for $q_o/q = 0.10$)](image11)

![Fig. 12. Obtaining Equalization of Bending Moment on Contact and at the EOL by Adjusting the Nose Length as $q_o/q$ Varies](image12)

![Fig. 13. Evolution of the Relative Length $l_o/l$ That Equalizes the Negative Moment as $q_o/q$ Changes (for the Optimum Value of $E_J/EI$)](image13)
for highway bridges and $0.018 \leq K \leq 0.030$ for railway ones, with progressively higher values in the case of wide or heavy superstructures. The values of $l_a$ and $q_a$ so defined will be refined until the equalization of the contact moment with the EOL one is obtained. Then, the minimum flexural stiffness necessary to contain the moment in the intermediate launch stages under this common threshold may be defined.

**Negative Moment at the Second Support**

In Fig. 14, the progression of $M_c$ (10) shows that, independent of the nose length, the recovery of elastic deflection forces $M_c$ toward a single curve that stabilizes for $\alpha = 0.60$ on a slightly lower value than the perfectly fixed beam one. From this point onward, except for relevant additional fluctuations upon the contact with the following piers, the support moment is no longer affected by the front elastic system, and the deck rear zone begins.

In short, with regards to the negative moment, it may be concluded that by adopting launching noses of sufficient flexural stiffness and adequate length for the relative weight, the deck zone affected by the nose-deck interaction can be limited to a length of about $1.5l$, increasing to $2l$ in the case of very deformable noses.

**Positive Moment in the First Span**

The maximum positive moment in the front span is

$$M_{\text{max}}^{l/2} = \frac{R_A}{ql} \left( 1 - \alpha - \frac{q_a}{q} \frac{l_a}{l} \right) + \frac{1}{2} \left( \frac{R_A}{ql} \right)^2 + \frac{1}{2} \frac{q_a}{q} \left( \frac{l_a}{l} \right)^2 \left( \frac{q_a}{q} - 1 \right)$$

(20)

and Fig. 15 illustrates its evolution in the case of a long nose. In contrast to what happens to $M_B$, the flexural stiffness of the launching nose affects only the progression of $M_{\text{max}}^{l/2}$ toward the maximum value, which is in any event reached for $\alpha = 0.90$. It then starts to decrease because of the effect of $M_A$. By shortening the nose, the progression of $M_{\text{max}}^{l/2}$ is substantially similar (Fig. 16). The maximum value is obtained a little further on in the launch, for $\alpha = 0.95$, and is slightly higher because of the smaller contribution of $M_A$. Therefore, the flexural stiffness of the launching nose does not govern the positive moment behavior of the system, which depends essentially on the continuous beam static scheme of the concrete deck and can be modified only by means of $M_A$.

A synergistic action of increasing the length and the weight of the nose carried out with the optimum values of Fig. 13 can reduce at the same time the negative equalized moment (Fig. 12) and the maximum positive moment (Fig. 17). Remaining within reasonable limits the correction is effective, more for $M_{\text{max}}^{l/2}$ than for $M_A$, and the values reached with $l/l = 0.65$ and $q_a/q = 0.10$ decrease respectively by 15% and 4% with $l/l = 0.80$ and $q_a/q = 0.16$. Consequently, the choice among available noses can be made by also taking these savings into account.

Finally, it should be noted that the consideration that the first bay of the continuous beam is in any event subject to higher positive moments is deceiving, since correct design of the bridge involves shorter end spans just to compensate these increases, while during launch the front section of the deck has to overcome all the longer intermediate spans.

**Positive Moment in the Second Span**

For the B–C span one obtains

$$M_{\text{max}}^{l/2} = \frac{1}{2} \left( \frac{M_C}{q_l^2} - \frac{M_B}{q_l^2} \right) + \frac{1}{2} \frac{M_B}{q_l^2}$$

(21)

and the relative diagram, compared with the progression of $M_c$, confirms that the rear zone of the deck, unaffected by the nose-deck interaction, begins with reasonable approximation at a distance of $1.5l$ from the front end.
CONCLUSIONS

The design of a prestressed concrete bridge built by incremental launch depends on the technique adopted to control launching stresses, a technique that in all cases involves the use of a launching nose. The optimization of the nose-deck interaction produces savings in structural materials. It may be easily carried out by means of the described model (modified to take bearing settlement or the cable-stayed front scheme into account) and an ordinary spreadsheet.

Adopting the most common scheme, which provides for using just a launching nose, the evolution of the negative moment in the deck may be adjusted by acting on the parameters governing the nose-deck interaction. Among several combinations equally suited to the negative moment, some of them improve the behavior at the positive moment as well, with a higher cost of the nose balanced by lower costs of structural materials.

APPENDIX I. REFERENCES


APPENDIX II. NOTATION

The following symbols are used in this paper:

- \( C_i \) = generic constant;
- \( C_s \) = variable term;
- \( E \) = elastic modulus of the concrete deck;
- \( E_n \) = elastic modulus of the launching nose;
- \( E_{fl} \) = flexural stiffness of the concrete deck;
- \( E_{fln} \) = flexural stiffness of the launching nose;
- \( l \) = centroidal moment of inertia of the deck cross section;
- \( l_n \) = centroidal moment of inertia of the launching nose;
- \( k \) = preliminary design constant for the launching nose;
- \( l_s \) = length of the span (constant);
- \( l_w \) = critical length of the front cantilever;
- \( M \) = bending moment;
- \( M_{\text{max}}^{+} \) = maximum positive moment in the first span;
- \( M_s \) = negative moment at support B;
- \( M_{\text{max}}^{-} \) = negative moment at support B caused by cantilever masses;
- \( M_{\text{EOL}} \) = negative moment at support B at the end-of-launch (EOL);
- \( M_{\text{max}}^{+} \) = maximum positive moment in the second span;
- \( M_c \) = negative moment at support C;
- \( q \) = uniformly distributed dead load of the deck;
- \( x \) = distance of the nose-deck joint section from support B;
- \( \alpha = x/l \) = dimensionless progression of launch; and
- \( \alpha_{cr} \) = critical dimensionless progression of launch.