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SUMMARY

For more than 40 years, the construction of large bridges has been marked by the association of intensive pre-fabrication of box-girders in match-cast sections and assembly of these segments using powerful equipments, either movable launching gantries or temporary stay cables. Associated with modern, well designed prestressing systems combining both internal and external post-tensioned tendons, this technique has been continuously improved and is, nowadays, extremely successful thanks to the quality and reliability of the structures built that way.

Though several millions of square metres of bridge decks have been built using precast segments and as the demand for more and more performances in terms of erection speed and quality, it is not useless to remind the lecturers some historical steps as well as some fundamental principles which governs the design and the implementation of these wonderful technologies

KEYWORDS

Prefabrication; Casting Unit; Pre-Cast Segment; Match-Cast Joints; Shear Keys - Assembly; Epoxy Glue; Temporary Pre-Stressing - Placing Methods; Balanced Cantilever Construction; Progressive Construction; Span-By-Span Assembly - Equipment; Launching Gantries; Temporary Stay Cables.
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1. **Introduction**

Large civil engineering structures have always been designed taking into account a certain number of parameters of which the following are the most usual:

- geographical location;
- available materials;
- known and practical construction methods;
- and most probably, economic and aesthetic considerations.

During the last century, a number of new materials were created, steel and concrete replacing wood and stone, and structures and forms have been simultaneously adapted to the evolution of resistant materials while traditional construction methods have been improved thanks to the imagination of construction engineers.

Developed at the beginning of the previous century, the idea of pre-stressing, which can be considered as one of the most homogeneous and fruitful construction technique ever imagined is today undergoing a spectacular regeneration responsible for renewing our present knowledge and perhaps our way of thinking.

However, if reinforced and pre-stressed concrete box-girder of variable depth were rapidly adopted for balanced cantilever construction, which remains the most adapted construction method for medium and large spans (including cable-stayed spans), Prefabrication of Segments will be first mentioned because of the considerable advantages it brings to this construction method [4].

Whilst forms and structures were based on the engineer’s know how it has become apparent that the best construction method was also that which was the most suited to the structure to be built, to the chosen architecture and the best technological solutions.

It is quite obvious that this trend was justified by the search for quality and perfection in construction methods, which become easier, safer and quicker.

This lead to the development of new construction methods and segment by segment or span by span progressive construction were considerably improved since 1980 in France and many other countries.

As a result of this, the cost of construction equipment and labour per square metre of bridge deck is less and in any case lower than the corresponding cost of raw materials.

In spite of this, the quality and lightness of the structures thus built were also responsible for the huge success of all structures constructed in this way and numerous examples show clearly how interaction between construction technology and design is rather an advantage than a problem to be solved more or less elegantly by engineers.

Structural lightness and geometrical simplicity are the result of the on-going research for increased competitiveness and must be associated with the use of External Pre-stressing which has the great advantage of obeying clear and precise design rules.

External pre-stressing of concrete presents, for Civil Engineering structures, practical and theoretical advantages which have lead during the past twenty years to large construction in all fields where traditional pre-stressing allowed a fruitful development of structural methods and techniques. It has been opening up new horizons for some time now, with the appearance of 3-dimensional concrete frames, composite steel-concrete structures built with the aim of bringing together lightweight properties and efficiency.

Experience now acquired allows a rigorous explanation of the basic properties of simple and well balanced cable layouts in external pre-stressing, as well as the quality of structures built that way.

Research carried out in this field has allowed the optimisation of the design of incrementally launched bridges.
The past ten years will mark undoubtedly the history of Civil Engineering with an impressive series of prestigious projects. High Rise Buildings, Towers, Stadiums and Bridges, have broken successively a lot of world records, in terms of height, slenderness or span length but it has to be recognised that many of these new structures would not exist yet without the fantastic development of unusual and spectacular construction methods using the power of engines and all the latest refinements of a modern technology.

2. Prefabrication

The construction of bridges has, for 40 years, been marked by the association of two major concepts combining Prefabrication of single or multicellular box girders in short sections (segments) and the Cantilever Assembly of these prefabricated elements across the bridge supports using mobile launching gantries. This method of construction has been in constant evolution, since the Oleron viaduct was built between 1964 and 1966, and is often used for the construction of large bridges with fairly wide and variable spans. Balanced Cantilever Construction using a Launching Girder has now been technologically mastered, and is perfectly adapted to bridges located in unfavourable sites where work is difficult. It enables the quality and reliability of supporting structures to be improved under interesting economic conditions. It can be used to build bridges of varying widths, whatever their horizontal and vertical alignment.

2.1 Principle of manufacturing bridge segments

Although the traditional prefabrication of precast pre-stressed concrete girders has never really been a practical problem, due to the fact that the prefabricated components could be concreted and then installed at their final location individually, the same cannot be said for box girders cut up into segments. In the first bridges constructed with short elements, (bridges over the Marne near Paris), the major problem (final assembly) was partially solved by Freyssinet, who joined the segments with mortar during the construction process. These mortar joints, and the resulting constraints, remained an obstacle which prevented the method from developing for a certain time. It was necessary to produce extremely thin joints. The idea was simple, but putting it into practice was another matter:

- the joints between segments were liable to become the weak points of the construction, the stresses could be unevenly shared and water may sweep through and attack the cables, all this had to be avoided.
- The continuity of the material had to be restored in the most perfect manner, after prestressing the deck.

2.1.1 Segment matching

Segments cast in series against each other in the same order as they will be assembled, after coating of the mating faces with epoxy glue, was to be the only satisfactory solution and this
was implemented for the first time by Campenon Bernard (now a division of Vinci) for the
construction of the Choisy-le-Roi bridge over the Seine river near Paris.
During prefabrication (Figure 1), the segments are conjugated such as the joints are perfectly
matched, the face of a completed segment being used as a formwork for the new segment to
be cast.

Correct positioning of the segments with respect to each other (centring) was originally
obtained by means of a three single key system.

2.1.2 Equipment used

The prefabrication installations used can be organised very differently, depending on the
available area in the site or the type of segments to be produced.
These installations usually consist of fixed concrete casting units (Figure 2), used to
prefabricate standard segments only, plus one concrete casting unit used to produce pier or
abutment segments.

Each casting unit consists of 4 major components:
- the blank end (at a fixed location);
- the external forms (at a fixed location but adjustable);
- the bottom soffit (movable, transportable and interchangeable);
- the internal form core (movable and adjustable).
When possible, the prefabrication installations consist of a long casting bed, having the appropriate geometry (length and profile), and each standard segment is cast at a fixed location while a casting machine, including external forms, internal forms and a blank end, is moved from one location to the next one (Figure 3).

2.1.3 Prefabrication Process

Whatever the method, short line or long line, segments are cast in between a blank end and the segment previously achieved.

In the short line method, each cycle of the prefabrication process can be summarised as follows (Figure 4):
- as soon as tensile strength of the concrete of a new prefabricated segment has reached what is required before forms are moved, the previously completed segment (used as a form at one end) is translated and moved to the storage area;
- the corresponding soffit form is recycled and placed in the casting unit;
- the new completed segment is translated and adjusted according to the bridge profile and alignment;
- the reinforcement and all requested PT devices are placed in the casting unit;
- the forms of the casting unit are adjusted against the blank end and the translated new segment;
- and concrete of the next segment is poured.
All these operations can be achieved in a very short time so that the prefabrication pace is governed by the concrete hardening time and, usually, one segment per day and per casting unit is produced.
In the long line method, segments are cast as if they were at their final location and the geometry control is therefore much easier. In addition, completed segments do not need to be moved as soon as forms are removed and the production cycle can be adequately optimised.

### 2.2 Segment Storage and Delivery

It has to be pointed out that, when the segments are moved for the first time, they are commonly no more than 2 days old. That means that the lifting points, as well as the lifting equipment, have to be designed accordingly. Lifting points are then to be preferably located in the most massive and stiff parts of the prefabricated component; i.e. in the gussets, as close as possible to the webs.

![Figure 5: Delhi Metro Line 3 – Arrangement of the Storage Area (Photo Systra)](image)

That also means that the segment storage area (Figure 5) should be thoroughly designed and prepared in such a way that the segments rest on stable supports which prevent them from any unexpected distortion and destruction of the match-cast properties. That care is even more important when the available storage area is not so large and segments have to be stored in 2 or 3 superposed layers, but the necessary works to consolidate the soil as necessary and produce such a perfect storage zone would be unrealistic and too much expensive.
This is the reason why the segments have to be stored on 3 soft bearings devices, preferably made of wood, arranged in such a way that the deformations, if any, will be minimised (to reduce creep effects), the same for all segments and therefore permanently kept under control.

2.3 Advantages of Prefabrication

The advantages of prefabrication are noticeable in all fields where reinforced and pre-stressed concrete play an important part. To begin with, concrete which is produced on solid ground, on a site that can be set up as efficiently as necessary, is normally of better quality than concrete which is cast directly at the final location. It is more homogeneous, stronger, of a better colour, and its edges are sharper. Secondly, prefabrication means that segments can be produced well before being fitted to the bridge structure, i.e., well before being pre-stressed. The concrete will therefore be older than concrete which is cast directly on-site, when PT tendons anchored in the segments are tensioned. This means that there will be less creep and less residual shrinkage: the various distortions will be reduced. Finally, the construction time of the bridge deck is greatly reduced, since it no longer depends on concrete hardening times. Provided that production starts as early as possible and there is enough room to store the segments, the construction time will only depend on the transport, installation, adjustment and pre-stressing of the segments. All these advantages are definitely at the origin of the success of any construction method based on the assembly of prefabricated components.

3. Assembly

The description of the principle used to produce the segments would be incomplete if no mention were made of the way in which the continuity of the deck is restored and forces are transmitted through the joints, when the different segments are assembled together at their final location.

3.1 Application of epoxy glue

Match-cast joints allow obtaining an excellent degree of geometrical precision, but the result is even more satisfactory if a film of glue is introduced in the joints when the segments are assembled. Used in this way, the epoxy glue has indeed four functions:

- During construction, before hardening:
  - it lubricates the contact surfaces during the assembly operations, whilst the web keys temporarily absorb the shear forces;
  - it compensates minor imperfections in the combined surfaces.
- After hardening and when the bridge is finished:
  - it constitutes a waterproof seal in the joints, particularly under the road surfaces;
  - it plays a part in the strength of the structure, by transmitting the compression and shear stresses through the joints.
3.2 Force Transfer through match cast joints

Initially, key system located in a match cast joint consisted of reinforced single keys attached to the top slab (for centring) and the webs (for resisting shear as long as the glue had not hardened). Shear keys in the webs were typically, 10 cm deep and 30 cm high and the angle of the inclined faces was of the order of 30° to 35° (Figure 6). As bridges made of pre-cast segments were basically built using the balanced cantilever erection method, a temporary pre-stressing (generally consisting of PT bars) was installed during placement of each segment in order to make the assembly operation as short as possible and place two symmetrical segments prior to tensioning operation of the permanent PT tendons anchored in these two segments.

3.2.1 The Epoxy Glue Effect

It is clear that, immediately after application, the epoxy glue does not provide any friction resistance with regards to tangential forces to be temporarily resisted in an assembly joint. As a result, distribution of forces generated by the weight ($W$) of the new assembled segment and the pre-stressing forces ($P$, whatever they are as long as applied to the fresh joint), in the assembly joint (Figure 8), is completely different of what it would be if the fresh joint could be ignored (Figure 7).

- Figure 6: Typical Single Shear Key
- Figure 7: Forces generated by the assembly of a new segment in a fresh joint if glue effect is ignored
As it can be seen from Figure 8, actual resulting forces in the fresh joint are distributed along two major directions:
- the longitudinal axis of the assembly;
- and the perpendicular to the upper face of the web shear keys.

As a result, the shear force being necessarily withstood by the web shear keys, a part of the normal forces generated in the joint by the pre-stressing is concentrated in the keys and no longer squeeze the glue located in the joint; in addition, the eccentricity of the resulting normal force is globally more unfavourable.

Forces $F$ generated in the shear keys and normal force $N'$ generated in the joint only depends on two important parameters:
- the location of the web shear keys;
- the angle of the inclined faces of the keys.

As shown in Figure 7, forces in the joint if glue effect is ignored are as follows:

$$\begin{align*}
N &= P \\
T &= W \\
M &= -0.5Wl + P.x = N.e_a
\end{align*}$$

The apparent eccentricity of the normal force is then $e_a = \frac{M}{N} = e - 0.5 \frac{T}{N} l$

\[\text{Figure 8: Distribution of Forces in a fresh joint taking into account the glue effect}\]

If the glue effect is taken into account and if $y$ is the distance of intersection of the key upper face axis with the vertical line of the joint, then forces in the joint and the keys are the following:

$$\begin{align*}
N' &= N - T.tg \theta \\
F &= \frac{T}{Cos \theta}
\end{align*}$$

$$\begin{align*}
M &= -T(e'_a - y)tg \theta + N.e'_a = N'e'_a + T.ytg \theta = N.e_a = (N - T.tg \theta)e_a + T.e_a tg \theta = N'e_a + T.e_a tg \theta
\end{align*}$$

with $e'_a = e_a + \frac{T}{N'}(e_a - y)tg \theta$ (i.e. $e_a > y \Rightarrow e'_a > e_a$)
3.2.2 Major Points of Concern

From the above, it is clear that, when the glue effect is taken into account, normal force $N'$ and eccentricity $e'_a$ are the very characteristics of the resulting forces which have to be used for the calculations of the theoretical compressive stresses generated in the film of epoxy glue, while $F$ is the force to be resisted by the web shear keys. For a given $N$ and a given $T$, forces $N'$ and $F$ only depends on angle $\theta$ when $e'_a$ is a function of both parameters $y$ and $\theta$ with $e'_a = e_a$ if $y = e_a$.

It has to be pointed out that $N'$ is necessarily less than $N$ and that the force $F$ is sufficiently large to make engineers aware that the web shear keys played a fundamental role. In addition, several key failures, which had happened when match cast segments were separated, had revealed that the reinforcement of the single keys was not necessarily at the right place; i.e. that the single shear keys were not reliable.

At the beginning of the seventies, the construction of the 80,000 m² of the B3 motorway viaducts (suburb of Paris) in a very short time, by using prefabrication and a powerful launching gantry, lead Campenon Bernard to investigate the capacity of the single shear keys. Actually, to deliver the viaducts on time according to the contract, it was necessary to place up to five successive segments per day on each side of each cantilever.

Several test, simulating forces generated in a joint and mainly in the keys, were made on web panel assemblies with different shear key types and sizes, with and without reinforcement, while the glue (without hardener) was maintained fresh. All these tests showed that it was not reasonable to rely on single shear keys for the following reasons:
- either reinforced or not, capacity of single shear keys was just enough to safely withstand shear forces generated by the weight of one segment;
- increasing the high of the single shear keys had no substantial benefits.

Figure 9: Force concentration evidenced by tests performed in 1970

Due to the stress concentration on small areas of the shear keys when the glue was squeezed under vertical loads, the results were even worse if the keys were shaped with curved surfaces (Figure 9) so that segment separation be easier and assembly be of better quality.

3.2.3 Multiple Shear Key System

The only acceptable solution was finally proved to be the multiple key system (Figure 10) where keys, located in the webs and typically 3 cm deep and 7 to 10 cm high, are small and as many as possible in order to distribute the force $F$ along the webs¹ [3]. Test performed at that time confirmed that the shear strength of joints provided with many such small size keys was close to the strength of the webs without any joint.

¹ The original idea developed by Pierre Thivans from Campenon Bernard was to create artificially and without destroying the match cast properties, something similar to what is got when surfaces are sand blasted in traditional construction.
This solution, implemented for the first time thirty years ago during the construction of the Saint-Andre-de-Cubzac bridge over the Dordogne river, has been since widely used everywhere in the world, as long as prefabricated segments are used.

The multiple shear key system allows to be confident that the keys will resist the shear forces generated by the dead weight during construction even if several segments are placed in a row. Meanwhile the designer has still to be aware that, despite the use of a multiple shear key system, the reduction of the resulting normal forces in the joints will remain proportional to the resulting shear force in the joint and the upper face angle of the keys as long as the shear force will be applied before the glue of the joint has not fully hardened (i.e. this reduction will be equal to n.W if n segments weighing W are placed whilst the glue of the joint is not hard enough).

4. Placing methods

The construction of bridges by successive cantilever progression from the supports is a very ancient technique that has been put into practice with all materials used and developed throughout the history of mankind.

The original idea of this method was furthermore simple and natural, since it consisted in taking advantage of the decreasing gap as the bridge construction progressed. The method has been taken up again, and developed, since the invention of reinforced and pre-stressed concrete. The traditional method consists in casting bridge decks in successive symmetrical sections on either side of the piers, the formworks being supported by the parts of the bridge that are already built and resistant. This method was used to build a great number of bridges, but it only started to be widely used between 1950 and 1960; nowadays, it is used to construct very long span bridges, including cable-stayed structures.

However, the construction of bridges by successive cantilever progression, and casting the segments directly in position, does have its disadvantages which clearly limit its area of use:

- the concrete has to be stressed before it has had time to reach certain age;
- the method involves many delicate operations when the piers are difficult to reach.

The concept of prefabrication, applied to box girders, has solved all these problems through design of fast and practical techniques for installing the prefabricated segments.

4.1 Balanced cantilever assembly

The first bridge to be built by successive cantilever progression using prefabricated segments (Choisy-le-Roi Bridge), was constructed using a large capacity floating crane which carried and installed the segments symmetrically on either side of the piers (according to the standard principle).
The most effective method however, is to install the prefabricated segments using a steel girder launched over the deck part to be built. This process, which was used for the first time in the construction of the Oleron viaduct, now makes it possible to take advantage of the high production rate of the segments, since the rate of installation of the prefabricated segments can be as high as their production rate.

4.1.1 Principle used to install segments

The method basically consists in installing a steel girder with two legs (one in the centre and one at the back end), the length of which is somewhat greater than the maximum bridge span, on the first segment of the new symmetrical deck cantilever to be constructed, and on the end of the deck that has already been built (Figure 11). The girder is equipped with a trolley, which runs on the lower chords of the girder, enabling the successive segments to be installed. Due to the static configuration of this type of girder, the segments necessary for the construction of the deck can be supplied over the bridge itself, which explains the power and success of the process, a very large number of bridges having been built in this way, both in France and abroad.

![Figure 11 : Oleron Viaduct (France) – The first launching gantry](image)

Movable launching gantries used are normally designed specifically for the bridges they are intended to build. They can be designed to install segments of 130 t with spans of 120 m. They consist of a steel truss girder, built-in two tunnel legs which provide the opening for the segments to pass through. For large spans, the main girder is reinforced by a cable suspension system spread out over the upper chords.

The central leg and rear leg are supported on steel beams, which enable the necessary adjustments to be made according to the curve and inclination, of the deck; a temporary front leg enables the first segments of each double cantilever to be installed.

4.1.2 Operational stages of the construction

The part of the end span, which usually completes the first symmetrical cantilever, in order to correctly balance the bending moments in the final bridge, is placed on a system of temporary supports (multiple bents/props – scaffolding).
The installation gantry is then placed on the access ramp behind the abutment, and the pre-cast segments are successively installed outwards from the abutment. They are assembled together, after gluing the joints, and secured by a temporary pre-stressing system.

When this initial phase has been completed (Figure 12), the launching gantry is moved onto the part of the deck that has been constructed, so that the trolley can install the segments on the first pier, which will be used as a support for an auxiliary tower for the first launch of the gantry (Figure 12).

![Figure 12: Typical launching sequences](image)

When the launch has been completed, and the central leg is supported on the centre-line of the first pier, the construction proceeds with the installation of the segments which constitute the first symmetrical cantilever.

At the end of this second phase, the two parts of the deck, constructed entirely independently, are connected together by casting an in-situ concrete joint between them and, the next day, by tensioning the PT tendons passing through the deck.

The launching gantry can then be moved again to the end of the cantilever that has just been completed, in a position which enables the installation of the segments on the following pier; it is then launched for the construction of the corresponding balanced deck cantilever, which is subsequently joined to the part of the deck that has already been constructed.

These steps are then repeated until the gantry has completely crossed the gap to be bridged.

4.1.3 Advantages of construction using a launching girder

Construction by successive cantilever assembly, using a movable launching gantry, enables the deck to be built without the need for any intermediate support. Furthermore, the bridge under construction is itself used to supply the facilities needed for its own construction: personnel, segments, tensioning jacks and tendons.

This process therefore makes it possible to span rivers, railway lines and roads without affecting their normal operation. It enables congested areas to be spanned without any difficulty. It makes it possible to build bridges of varying widths with a great degree of flexibility.

The major disadvantages of construction by successive cantilever assembly of pre-stressed reinforced concrete bridges, i.e. the creep effect, cannot be totally eliminated, but the fact that there is no overloading of the box sections at the ends of the consoles during assembly of the cantilevers, the speedy execution, plus the undeniable advantages of prefabrication previously mentioned, all widely contribute to reducing the effects of creep.
With the use of high performance steel and the concept of stay-cables, the equipment used as reached a stage of perfection (Figure 13) which tends to limit future progress. For very large bridges, the performance of the method can nevertheless still be improved by producing girders of a length which is longer than two consecutives spans; this would mean that the girder would, after a single displacement, be able to install, at the same time, the standard segments of the double cantilever being built and the pier segments of the next one to be constructed.

Figure 13: High Speed Railway Bridge near Avignon – France

4.1.4 Tendon layout

The principle of the longitudinal pre-stressing in a bridge erected by successive balanced cantilever construction is therefore particularly simple, since it necessary comprises two types of tendons:
- the cantilever tendons, which ensure the final assembly of all the segments as they are installed;
- the continuity tendons, which rigidly integrate the successive double deck cantilevers in order to produce the final bridge.

This principle makes it possible to modulate the pre-stressing and adapt it remarkably well to the stresses generated in the bridge during construction, to the cutting up into short sections (segments) and to the final stresses involved. Furthermore, it is this technique that has contributed to the success of the process in the field of pre-stressed concrete bridges. Although very economical, these standard dispositions do have certain disadvantages, which affect the quality of the pres-stressing:
- the PT tendons are too much deviated;
- the anchorages located in the webs are impractical;
- the anchor concrete blocks inside the box girders cause considerable local deviations.

From this point of view, external post tensioned tendons opened up new horizons at the beginning of the eighties and presents many advantages [2]:
- better concreting conditions;
- threading and tensioning problems elimination;
- suppression of discontinuities in the pre-stressing layout;
- suppression of injection pipes in many locations;
- ease of visual and mechanical checking of the pre-stressing forces;
- possibility of cable replacement or addition;
- large independence between the structure and its pre-stressing tendons.

4.2 Progressive segmental construction

It was towards the latter part of the seventies that the first spectacular applications of external pre-stressing were to be seen, combined with innovative construction methods. In the meantime, the need for repairing and reinforcing existing structures provided the necessary experience and a better understanding of its possibilities.

4.2.1 Progressive construction with temporary stay cables

The progressive construction method [1] with temporary stay cables is based on a very simple idea (Figure 14). It consists of placing the prefabricated segments of a deck continuously, from the first abutment to the other one, the stability of the deck being maintained with a set of stay cables.

Equipment used therefore consists of:
- a steel mast;
- a lifting and placing device;
- a set of temporary stay cables arranged in two planes.

The first span is generally built on temporary scaffolding but it can also be built according to the general construction procedure by using a temporary span at the rear of the first abutment.

Figure 14 : Basic principle of the segment-by-segment progressive construction

As soon as a new span has been completed (i.e. has reached a new pier), the installation of the final pre-stressing takes progressively place as the construction of a new span starts with the placement of some segments by the free cantilever method. During that short phase, the stay cables are removed and the mast is positioned over the newly reached pier. At this stage, each step of the deck erection can be described as follows:
- transported over the completed portion of the deck to the end of the cantilever span under construction, each new segment is placed in its final position with the lifting device;
- the new segment is held by temporary tie bars;
- the lifting device is moved to the end of the deck;
- the corresponding pair of stay cables is added and tensioned to equilibrate the weight of the new segment.

When the pier segment has been placed over the next pier, an adjustment of the deck level, if necessary, is carried out with the help of hydraulic jacks while the bearings are installed.

As the final pre-stressing of the new span has started, the structure gets ready for the erection of the following spans.

It has to be emphasised that the pre-stressing scheme of spans built that way is more economical than those used in cantilever construction.

In fact, the stability of the deck during construction, provision and progressive placing of the segments is essentially provided by the temporary stay cable arrangement, so that the pre-stressing of a completed span can be done after its completion.

This means that the tendons just have to run from pier segment to pier segment and, as a consequence, can be easily anchored in the diaphragms ensuring the force transfer to the bearings at deck supports (Figure 15).

Moreover, the pre-stressing tendons encased in a grouted polyethylene duct, can be located outside the concrete, within the void of the box girder, and simply deflected in deviation saddles.

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**Figure 15**: The modern external set of PT tendons of the Vallon des Fleurs viaduct (Nice – France)

Though limited to span length of the order of 55 m, the method allows the construction of bridge decks (whatever their alignment and profile) spanning any kind of urban area and many types of obstacles with a light equipment.

All the construction materials, components and personnel are provided with a high degree of safety at the end of the progressing deck.

With regards to the quality and reliability of structures built that way, it must be pointed out that the permanent bending moments in the deck are exactly the same as those of the entire bridge cast-in-place since match cast segments are used over the total length of the deck.

There is therefore no redistribution of bending moments and stresses in the box girder due to creep effects.
4.2.2 Span-by span construction

When implemented for the first time, segment by segment progressive construction of the deck did not allow a high speed of erection. From this point of view, assembling the segments of a span on a truss seemed to be more efficient. This is probably the reason why this way of construction was successfully developed by Jean Muller for the very large bridges to be reconstructed in the Florida Keys.

Long Key Bridge was the first erected using the span-by-span construction method. The deck area could have justified heavy equipment but a rational use of the water surrounding the Florida islands allowed an impressive optimisation of the necessary equipment which consisted of three essential components:

- a big floating crane which lifted the segments, moved the erection truss and placed the pre-cast elements in their final position;
- a shuttle barge which transported the segments from the pre-casting yard to the job site;
- an adjustable temporary steel truss attached to a C shaped lifting hook which supported a full span during assembly.

The main steps of the construction of a span, typically 36 m long, were taking place as follows:

- after completion of a span, the assembly truss was moved to the following span and made resting on the corresponding bridge piers;
- the segments of the new span were placed on individual three point sliding supports and simultaneously adjusted into the right position (Figure 16);
- the joint between the previously completed span and the new one was poured;
- the PT tendons were tensioned when the closure had reached the required strength and the temporary truss was free for a new cycle.

Although the speed of erection was routinely two spans a week, it was necessary to increase this pace for the construction of Seven Mile Bridge.

To achieve it, the contractor revised the Long Key method and chose to preassemble the seven typical segments before setting a span. Barges delivered the superstructure elements to the site where they were placed atop a steel lifting frame aboard a shuttle barge. There, the segments were aligned and connected with four temporary strands. Then the assembly barge moved beneath the bridge for placing the span. the pier segment also accompanied the preassembled span. After completion of a span typically 41.15 m long, the self launching truss first lifted the pier segment to the top of the next pier (Figure 17). Resting on this new support, the gantry was launched and finally raised.

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2 The modern equipment designed and used by Campon Bernard now allows the placement of 10 segments within full working day duration.

3 Long Key Bridge and Seven Mile Bridge have been designed by Figg and Muller Engineers, Inc.
the lifting frame supporting the segmental span assembly from the barge below. After having placed that portion of span against the pier segment, the closure joints were concreted and the longitudinal tendons fully tensioned.

![Figure 17: Seven Mile bridge – major construction sequences](image)

Of course, the marine environment of these examples was a key factor but they show, more than any other, how interaction between design and construction methods can lead to simplicity and unusual performances.

As a consequence of the demand for more and more long road and light railway bridges in urban and congested areas, the span-by-span construction method, associated with an intensive prefabrication, has been widely developed and used over the world by using launching gantries used for the assembly of span typically 30 to 40 m long (Figure 18).

![Figure 18: The way Span-by-Span construction has progressed](image)  
Left: The Bangkok expressway (photo JMI) – Right: The Delhi Metro Line 3 (photo Systra)

### 5. Conclusions

Without a doubt, prefabrication is an attractive technique, especially under difficult building conditions and when time is of the essence. However, the quality of structures composed of pre-cast segments depends on a sound understanding of the process, not to mention a solid technique.
The quality of a prefabricated segment will be determined by the quality of its match-cast properties. Match-casting was invented out of a desire for optimal precision in assembled surfaces. Upon their removal from a casting unit, joints should be considered ready to use, regardless of any visible “imperfections.”

Any attempt to modify segments or an assembly of segments will result only in a faulty structure. Modifying the surface of a joint, for example by sandblasting as many contractual documents suggest, is impermissible and counter to the very nature of match-casting. Hasty “corrections” to the joint using large amounts of epoxy glue will result in abnormal thickness, whereas a good joint is fine, typically no more than 0.5 mm once the glue has hardened. An excess of glue is detrimental to the structural quality of the deck assembly.

Though the field of prefabrication has significantly evolved in recent years, further research is necessary to optimize the process. As demonstrated in the above theoretical studies, the concentration of forces in the keys of the joints must be taken into account when evaluating the normal force generated in a joint. This is especially important when a large amount of shear has to be transferred through fresh glue, as is the case when segments are quickly placed in a row. It is therefore necessary to evaluate stress distribution in the segments, as well as influence of time, on these stresses.

REFERENCES