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POST-TENSIONED SEGMENTAL BRIDGES

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INTRODUCTION

The idea of maximizing mechanical efficiency of concrete members, by placing them in full compression has gone to the beginning of the last century. But, the development of prestressed concrete as a construction material had to await to the end of the last world war. The first samples of this new and challenging technique may be taken as few prestressed bridge decks in Germany during the thirties. The list of contributors to the development of the prestressing technique, should include the scientist-engineers as Freyssinet from France, Magnel from Belgium, Dischinger from Germany, and Maillart from Switzerland. The second half of the century, witnessed the bright development of the applications of prestressing. Among others, Guyon, Lacroix, Muller, Leonhardt, Walter, Menn, Figg, ,and Linn should be remembered.

The first applications of prestressing is seen to be the span-to-span prestressed bridge decks. More elaborated and innovative applications were developed after sixties. Two exiting and widely applied samples of this new technique, are launching deck construction, and balanced cantilever segmental construction of bridges. A recent implementation of the latter, in Turkey, had been the Imrahor Valley Viaduct construction in Ankara (Ceylan Construction Company being the general contractor, .and Freyssinet-Freysas Group assuming the responsibilities regarding the prestressing operations). More recently, Turkish Highways Directorate gave some priority to construction of segmental bridges and few of them are in design process. This paper has been prepared with objective of segmental post-tensioned concrete bridge decks. As a successfully completed case, the Imrahor Valley Bridge will also be briefly referred.

DESCRIPTION OF SEGMENTAL BRIDGES

General Concepts

The post-tensioned prestressed bridge deck constructions constituted widely applied samples of prestressing techniques. A span length of 45 to 50 meters could be reached by precast post-tensioned girdered bridges while economical spans of pretensioned precast beams was about 30 m. Still, topographic conditions and intercity necessities can require much longer span lengths. This goal, can be achieved economically up to span lengths about 100 m, by launching. The

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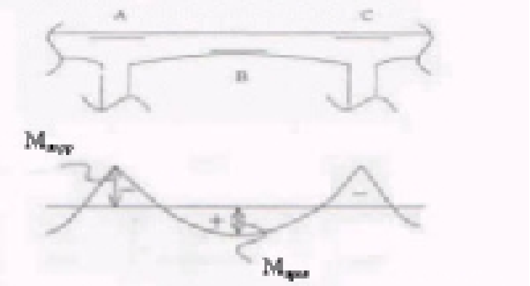
preprepared box sectioned decks are pushed from abutments towards the middle. This method will necessitate the piers to be cast beforehand.

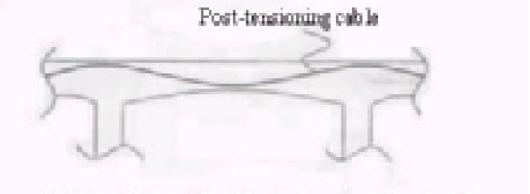
For larger span lengths, up to several hundreds of meters, the balanced segmental bridge construction can be adopted. This method is consisted of constructing the bridge decks as segments which are put together longitudinally, one on the previously erected other, progressing cantileverly from piers to mid-spans. This method will facilitate the construction considerably, especially when passing rivers navigated densely, or passing deep valleys, or constructing overpasses through dense urban settlements.

Construction Steps and Stages

Two cantilever decks will begin to be constructed from one pier towards the mid-spans, keeping the weight balanced (Figure 1). Segments could be either of precast components lifted and erected or of in-situ concreted deck portions cast in self advancing sophisticated shuttering systems. In both cases, scaffolding is eliminated, which corresponds to a huge technical and economical advantage. When the decks of two consequent piers meet, a cast in situ key segment will ensure the continuity of the bridge. The balancing of the weight will be provided by constructing the segments at both ends of the cantilever, simultaneously. Each segment will be fixed to the existing part of the bridge by post-tensioned prestressing cables. At this stage, prestressing only from top of the deck will suffice. This prestressing combined with the self weight of the segment will keep the segment in place through shear friction, that is the friction caused by the axial compression along the bridge. In mid-span, prestressing at the bottom is needed to keep continuity by meeting the positive flexural moments that will develop.



Classical Structural Systems in Continuous Effects
(a)



Cabling Principle in Continuous Post-tensioned System

Figure 1

External prestressing is then required to maintain the geometry of the structure after long term deformations. These cables are not embedded into the bridge construction, but are placed in hanging sheaths between pier heads. Though, they are set inside the box section, to protect them from atmospheric effects. Provision is also required for constructing future external prestressing cables, if they ever needed.

DESIGN FUNDAMENTALS

Design Loads

Construction of a cantilevered segmental bridge proceeds from piers towards the mid-span, thus the load on a bridge section increasing as construction develops. This procedure causes the piers to stand as cantilevers fixed to foundations, thus being sensitive to any unbalanced load during construction. Such a situation will require a careful analysis of loading and deformation throughout the construction.

The erection loads to be taken into account during the construction period are as follows:

- Dead load of the structure: Load due to the weight of the structure under construction, including weight of diaphragms, anchor blocks, etc. .
- Differential load from one cantilever: For only balanced cantilever constructions, 2% of the dead load is to be applied to one cantilever as a differential action.
- Superimposed dead load: Any permanent weight that will exist during construction, which is not included in dead load of the structure.
- Distributed construction live load: Allowance for miscellaneous items of plant or machinery apart from the major erection equipment. A distributed live load of 50 kg/m^2 that may exist during construction. In balanced cantilever construction, an unbalanced value of taking 50 kg/m^2 on one cantilever and 25 kg/m^2 on the other is appropriate.
- Weight of specialized construction equipment. The load from any special equipment, such as a launching gantry, beam and winch, truss or similar major item .
- Impact load from equipment: Dynamic effect that may occur during the lifting of segments, moulds, etc. .
- Segment unbalance: In balanced cantilever construction, the load due to any out of balance segment weight, or due to any unusual lifting sequence.
- Longitudinal force exerted by the construction equipment.
- Lateral wind load.
- Wind uplift: In balanced cantilever construction, 25 kg/m^2 uplift, applied to one side, only.
- Accidental impact: An accidental drop of a precast segment or form traveler or application the impact effect of an otherwise static load (A), creating an impact force (2A)
- Creep. Creep effects are to be considered as part of rib shortening
- Shrinkage.
- Thermal effect. The effects of thermal rise and fall or of differential temperatures.

- Seismic effect that may occur during construction period if construction lasts long or interrupts causing a partial risk of seismic event. (Full seismic effect should be considered on the finished construction during the service stage).

As for the short term and long term effects on the completed bridge, in addition to dead load, live load, wind load, thermal effect (including seasonal variation and differential temperature effects), and full earthquake action as referred above, the effect of high stresses in both concrete and prestressing steel must be taken into consideration. The effects of high stresses, include initial and final post tensioning actions, the prestress losses and deflections due to creep and shrinkage. The final structural system is to be analyzed for redistribution of erection stage moments resulting from creep, shrinkage and from any other change in the structural system.

Design Process

Codes and standards provide only a general guide for design. Any effect arising from the particular construction method applied, including the sequence of construction, any delays or interruptions, deviations from the computed values during erection, must be taken into account. Codes recommend consideration of several load combinations to check stresses in superstructure and substructure under service load conditions, and load combinations to check bearing capacity for load factor design. For the segmental bridge design, also, the joints of segments are to be analyzed subjected to several load combinations. Since the post tensioning provided is a mixture of fully loaded tendons and unbonded or partially bonded tendons, strength computations at any section must be based upon the existing state of prestressing, following the lifetime of the construction.

Sectional Analysis and Design

The essential philosophy of the prestressed concrete consists, as was already mentioned, to maintain the concrete medium in compression, in order to eliminate cracks due to tensile stresses in the concrete. But, post-tensioning forces, applied to eliminate tensile stresses in all possible sections, would generate, on the other extremity, too high compressive stresses. Therefore, shape and geometrical features of the section and the eccentricity of the post tensioning force and the level of its magnitude should be analyzed in a correlated way. Such an analysis will require a very high number of repetitions in sectional computations. A computer aided process has been developed by Coskun ERKAY, co-author of this report, to analyze the behavior of cross-sections when subjected to service loads or at ultimate state. The process evaluates a measure through a functional defined on the cross-section, which uses the geometry of the section, the material properties, and the deformation. This measure which will be referred to as "bending stability measure" is a real number that can be positive or negative. If the bending stability measure evaluates to a positive number then the deformation is stable and the corresponding load on the section, which is the resultant of the stresses on the cross-section, can be resisted. If the bending stability measure happens to be less than zero, the deformation is unstable and the corresponding load cannot be carried by the section. The zero value of this measure determines the ultimate state of deformation of the section. This procedure is used through a program named "BEX".

Program BEX uses an initially parabolic and then bilinear stress-strain diagram for concrete. Essentially, Thompson and Park model is adopted for this relationship and Hognestad's parameters are used as default [6]. Steel stresses are assumed linear until yield point and then constant. Design value of concrete stress, the yield stress and the modulus of elasticity of steel must be provided by the user. These values could be obtained from codes and standards, while special values based on reliable publications and research results might also be used in particular analyses.

In computational process of the program, the concrete boundary must be introduced, first, in a format reduced to a polygonal shape. Steel section should be given as concentrated at locations where the bars are set. Strains of sectional fibers are automatically correlated to direction and intensity of bending action and to normal force. Resultant values of stresses corresponding to computed deformation could be defined with any specified reference point if one is specified. If a reference point is not specified, the resultant is computed at the origin.

As for the introduction of data concerning prestressing steel in the section; prestressing force is applied to the section as an external normal force. The remaining potential of the steel stress to reach the yield point must be given as the yield stress of the steel to the program.

Evaluation of Long Term Effects

It is known by experience that the time dependent effects may severely damage the serviceability of prestressed segmental concrete bridges. Therefore, measures must be taken against long-term effects, such as use of low relaxation prestressing steel and to provide low creep in concrete. Moreover, provisions for future external prestressing are required to compansate the effects of any additional future dead load, or to adjust for cracking or deflection of bridges.

The design counterpart of long-term effects is to compute the displacement of each segmental joint and to adjust the geometry during construction so that the required grade line of the bridge will be developed at 4000 days after the completion of the bridge. Since each segment will be cast at different times, the time dependent displacement of each segment must be computed following the schedule of the construction and considering the change of the sectional effects on the joint. This computation is carried out by considering time intervals on which the load can be assumed constant. For construction period of cantilever units, these intervals will be the scheduled construction times of the segments. Then, the intervals between joining times of the cantilever units must be assumed. After the completion of the bridge, the load does not change. The total displacement of the joint under consideration will be subtracted from the project grade level at that location, to obtain the grade level of the construction time.

The levels of grade lines of segments during the construction time is closely related to the construction sequence and timing followed. Also, to differences between assumed material parameters from the actual ones, curing of concrete, environmental effect, etc. Therefore, the level of each joint is needed to be monitored throughout the construction to determine any deviation from the computed values and to make corrections, accordingly. That is, the grade line of the segments which are not yet casted, are subject to vary throughout the construction.

Recalling the Case of Imrahor Valley Viaduct

The Imrahor Valley Viaduct take place on one of new density circulated arteries around Ankara, relating Çankaya area to Mamak district. A total of 605.0 m. long overpass has been constructed by segmental technique. Four main spans were all 115.0 m. and two shorter external spans completed them to a total span of 604 m..

Height of five piers varied from 45.0 m. to 65.0 m., each having box sections externally sized by 3.0 m.*12.0 m.. Three interior longest piers had foundations resting on series of reinfoerced concrete piles having diameter of 165 cm. and being constructed by slurry wall technique. (Figure 2)

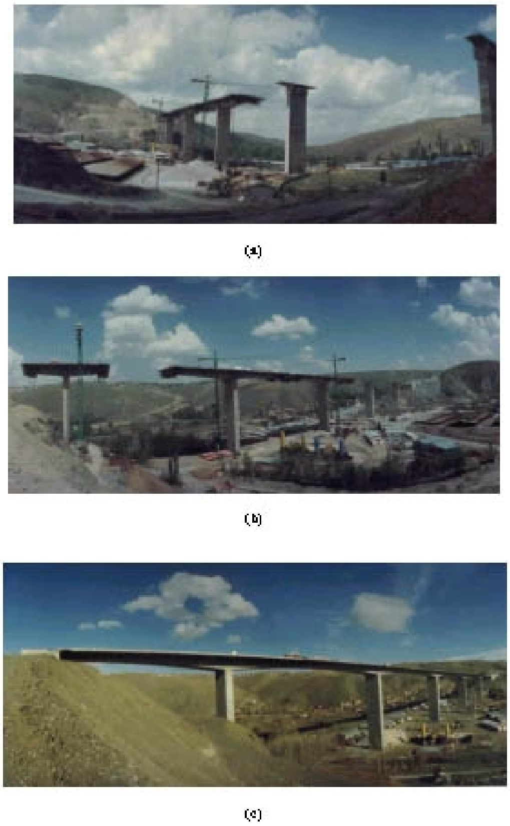


Figure 2. Operational Steps of the Deck Construction at the Imrahor Valley Viaduct

The authors has been involved in this constructional operation quiet actively at the capacity of advisor to Engineer's team. Photographic pictures showing various construction steps are given in Figures.

The supports at two ends of the bridge are set on sliding support elements. Thus, thermal deformations, and the long term effects of creep and shrinkage would be prevented to generate large stresses within the bulk of the construction. Elastomeric pads, installed between the bridge sides and the stoppers at these end supports, are aimed to soften the effect of a strike during an earthquake, if any. Provisions are taken in the abutment constructions to replace the support elements in case they are damaged or fail to operate properly.

CONCLUDING REMARKS

Construction of bridge decks by box-sectioned segments of post-tensioned concrete is an attractive work and became a world widely well known operation in our days. But, an unfortunate lack of attention and interest is witnessed in Turkish construction sector toward the post-tensioning technology. Consequently, segmental deck construction which is based on rather advanced concepts is completely ignored. The authors planned to make only a brief but concise account on this constructio-n technique mentioning also a stimulatively – and successful – example existing in Turkey. They would hopefully expect use of post-tensioning concrete would soon spread in Turkey and segmental decked bridges would be constructed much more frequently.

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