Istanbul Bridge Conference
August 11-13, 2014
Istanbul, Turkey

CONVENTIONAL AND ALTERNATE DESIGN OF HIGHWAY BRIDGE IN ENGATIA MOTORWAY ACCORDING TO EUROCODES WITH INNOVATIONS IN AESTHETICS, ECONOMY, CONSTRUCTION, DURABILITY, SERVICEABILITY AND SEISMIC SAFETY

D. A. Anastasopoulos[1], Z. N. Kopelia[1], V. Pilitsis[2], I. A. Tegos[3]

ABSTRACT

Undoubtedly, one of the most interesting topics is to devise innovative solutions to problems dealt by conventional means. Regarding bridges, there are several innovations that can be applied. Some of the innovative terms are associated with the construction process, economics, aesthetics, durability, seismic safety and serviceability. This paper tried to deal with these particular terms and improve them. For this purpose it has been used as reference bridge, one of the Egnatia Highway bridges. The bridge designed and constructed as cast-in-situ with many innovative features. The most important feature is its monolithic structural method, which is interrupted only at the end parts of the deck. The bridge consists of six spans while the cross section of the deck is a prestressed box-girder. The cross section of the five piers is wall-type, while the abutments have relatively small height. In the current paper the following subjects are studied:

(a) the design of the existing structure according to the current valid Eurocodes, while the constructed bridge was designed according to the German DIN standards.

(b) a new idea of gradual construction method. This new idea introduces the use of straight tendons only at the supporting areas of the deck.

(c) a variable cross section for the deck has to be selected for aesthetical and economical purposes. As a result of that selection, conventional reinforcement was used in the middle sections of the spans. This is considered to be another innovation in design of the deck.

(d) in order to manage a uniform aesthetical result, the deck is fully fixed at its edges, instead of simple seating. For that reason, a new type of abutment has been created in order to receive significant amounts of moment.

The results of the two different analyses have been compared and the conclusion leaded to significant notifications.

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Introduction

The aesthetic improvement when driven by economical aspects could contribute to a very essential stimulus, in order to seek all the necessary adaptations in a load bearing structure that it could respond to certain principles harmonized with the surrounding environment and the tradition. In the field of bridges, the load bearing structure consists almost 100 percent of the ultimate structure and for that reason it is the exclusive subject of a Civil Engineer, who has to perform the role of an architect as well. The last consideration would benefit the final result because the structure should always be designed according to symmetric and safety principles. Of course, there is a set of criteria that has conformed to the given data of the problem and lead to the selection of the proper solution. For instance, if the position of the main structure relative to the ground is low enough, it might indicate a cast-in-situ option towards to a precasted one in higher-position cases. Furthermore, in cases such as hard terrain, large partial spans or difficulties in foundation, there is always the option of a non-conventional constructing method ("luxurious" methods), such as the balanced cantilever bridge construction and the progressive span by span incrementally launched bridge construction.

The main problem in the construction of a bridge is the construction of its deck. There are five different construction methods introduced bellow:

1) The precast prestressed I-beam deck
2) The conventional cast in situ bridge construction with stable scaffoldings
3) Cast in situ utilizing movable scaffoldings normally supported to piers.
4) Balanced cantilever bridge construction, which either utilizes scaffolding or precast deck segments
5) The progressive span by span incrementally launched bridge construction

The conventional cast in situ bridge construction with stable scaffoldings:

- Is a traditional method of bridge construction for bridges of small height H and length L
- It is preferable in cases that the formworks are supported directly to the ground or to a well compacted temporary embankment
- Does not face any problems from theoretical view under the condition that the work joints are placed in less critical places (low sheer/high moment) and the joints are well constructed (vertical joints/rough and clean surface)
- The stress is considered to be restored in a natural way after the removal of the formworks. All the formworks must be removed simultaneously and uniformly in length of the deck. In special cases the synchronization of the removal of the formworks can be ensured by a system of hydraulic jacks.

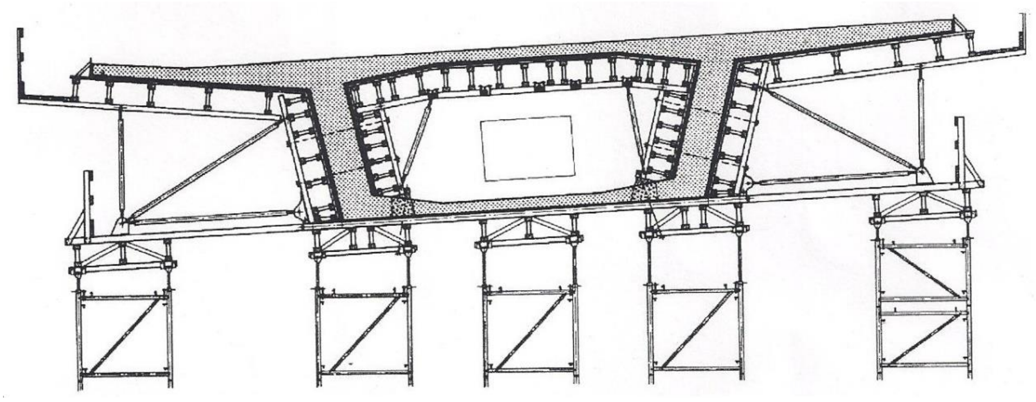


Figure 1. Typical formworks of a box-girder section

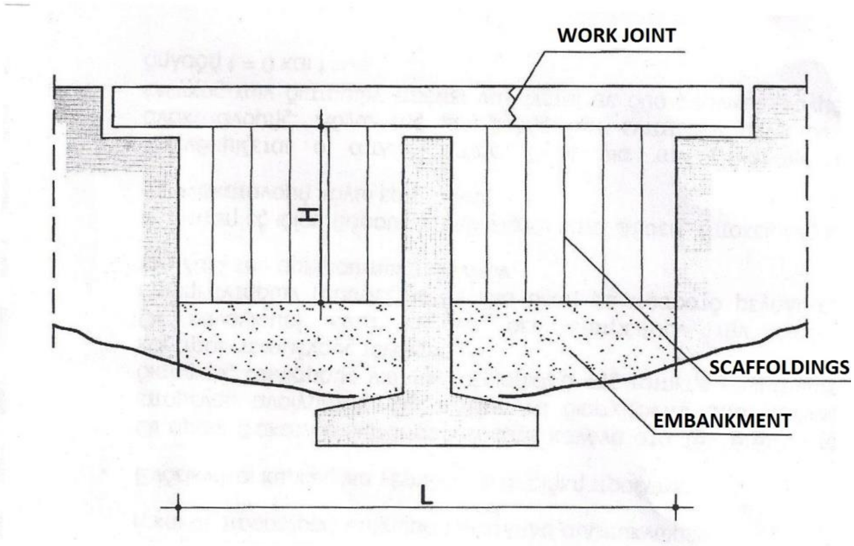


Figure 2. View of a cast in situ small bridge with the scaffolding

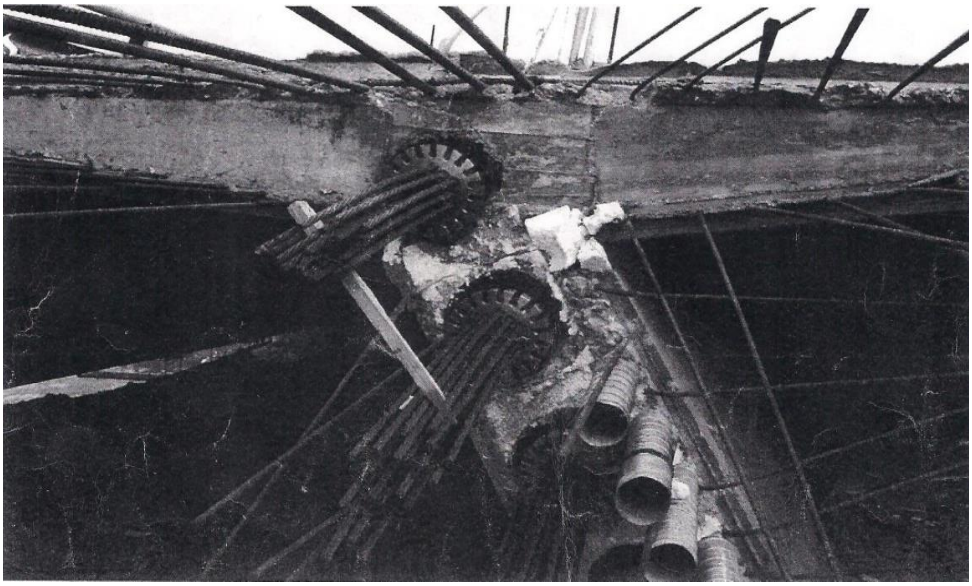
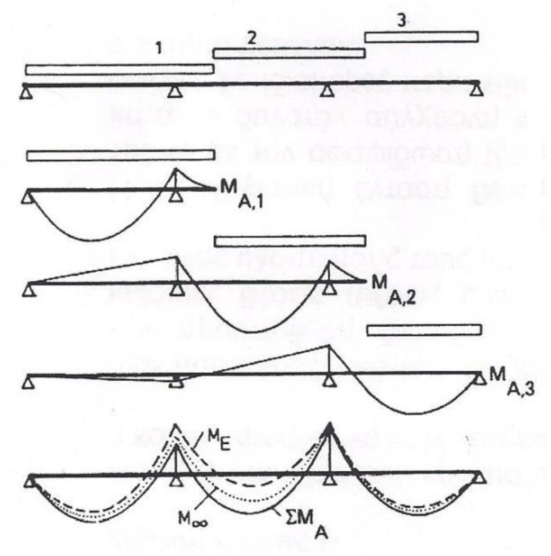


Figure 3. Work Joint

The segmental construction method:

- Consists a modern construction method for bridges of large length L and low height H
- It is performed on formworks supported directly to the ground or to a well compacted temporary embankment
- It is preferable for bridges with longitudinal prestress
- In most cases the work joints should be placed at the 15%-20% of the next span. They must be crossed by thick longitudinal reinforcement bars in order to limit the local cracking and by prestressed cables.
- The stress because of the weight of the construction is restored because of the redistribution due to creep.

The simple Trost & Wolff equation was used for the calculation of the redistribution of stress due to creep. The checking of the sections must be done in two times, t=0 και t =∞, because of the modification of internal forces.



$$M_\infty = \Sigma M_A + (M_E - \Sigma M_A) \cdot \frac{\varphi_\infty}{1 + \chi \cdot \varphi_\infty}$$

where

M_∞ : final moment

ΣM_A : sum of the elastic moments

M_E : moment of ideal structure

φ_∞ : creep coefficient

χ : aging coefficient

Figure 4. Segmental construction of conventional bridge

Description of the innovative interventions

General description

Undoubtedly the curve of the bottom flange accompanied with the progressive decrease of sections’ height from the piers to the middle of the span consist an improvement for the aesthetics of the bridge. However, there are three problems that have to be solved in order for this solution to be feasible:
a) The invention of a new construction method. This is required for cast in situ bridges bigger than two spans because these bridges are segmentally constructed and the immediate losses due to friction are extremely high. These losses are high when the distance between the ends of the bridge exceeds the distance of two spans.
b) Abutments are required to receive moments apart from gravity loads [1], [2]. This is important in order to ensure that the arc view of the bridge will not be affected.

c) The curvature of the bottom flange has negative sign which is attributed to the unfavorable geometry and it is responsible for diversion actions which have the direction of gravity loads. As a result of that, the bottom flange needs to be reinforced with longitudinal bars in order to limit the unfavorable diversion actions.

As we have mentioned before the proposed innovative construction method dominates over the conventional one. The proposed construction method aims to upgrade the aesthetic aspect of the bridges and furthermore to produce a more cost effective, easier in construction and seismic safer result. Furthermore, the serviceability is improved because the joints are abolished. In addition the monolithic result of the load bearing structure improves the durability of the bridge. Therefore, the adaption of this proposal by the engineers is expected to contribute in the improvement of the monolithic bridges and the final constructed product.

Proposed construction method

At first, the piers are constructed in their full height and then the formworks used for the construction of the two cantilevers are placed in both sides of the pier. The length of the cantilevers is equal to the half span and their height is variable.

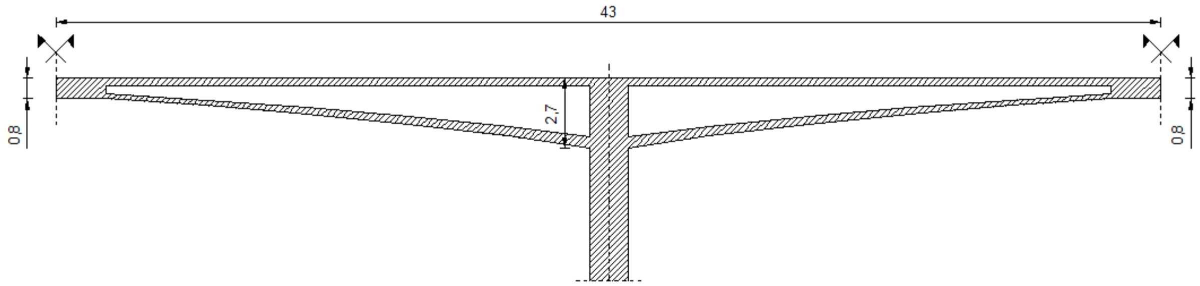


Figure 5. Longitudinal section of the pier and the two cantilevers

The prestressing tendons are straight and continuous and they are placed in constant height in the top flange of the deck. The minimum height of the deck is considered 80cm. The cantilevers are statically determinate and the variation of their centroidal axis is favorable. As a result of that, the high presstresing bending moments overbalance the negative ones that are imposed by the self-weight of the deck. Furthermore, a slight pre-cambering of the cantilevers can be imposed. This pre-cambering is deemed necessary in order to compensate the long-term prestress losses due to the creep and shrinkage of the deck. The cambering that is necessary for these losses determines the exact prestressing force. The adequacy of the prestressing force is finally checked with the long-term combination of loads combined with the long term losses. At the ends of the cantilevers reinforcement bars must exist in order to ensure the connection at the middle of each span. It is obvious that the proposed construction method is superior to the conventional one in many features such as: the significant decrease of the immediate losses due to friction, the avoiding of non anchored tendons at the work joints, the use of less formworks and the increase in construction speed because of the relatively faster removal of the formworks.

Innovative reinforcement of the bottom flange

As it has been mentioned before, the reinforcement of the bottom flange of the deck has to be done with longitudinal, ordinary steel bars. In order to deal with this disadvantage, the lengths of the bars are chosen to be overlapped. The geometry of the bottom flange is chosen to be the inscribed in the span polygon, with an approximate length of sides of 4-4.5m.

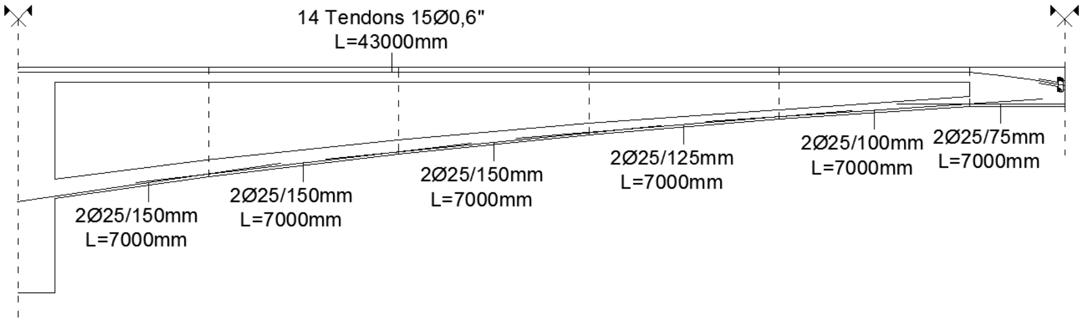


Figure 6. Longitudinal section of the cantilever - innovative reinforcement of the bottom flange

The length of the 4.5m is not a random choice. It is related to the length of the 7m which is the half of the length of 14m that is the ordinary length of the manufactured steel bars. The difference (7m -4.5m) / 2 = 1,25m reflects the required overlapping length for reinforcement bars of Ø25 diameter in favorable anchorage conditions. For common spans, 35m – 45m, the number of the sides of the inscribed polygon, are determined from 7 to 11. The number of the sides has to be odd so that the central section is horizontal. This particular central section has to be solid, voidless and its height must be at least 80cm. Its role is to ensure the proper and safer anchorage of the tendons. Their eccentricity must not exceed a maximum value that would cause cracking effects at the opposite flange.

Description of the innovative abutment

The innovation of the abutment consists of its ability to deliver bending moments apart from gravity loads, permanent and live [3]. In figure 7 is presented the longitudinal section of the proposed abutment with its embedded cantilever. The bending moments are delivered by a system which consists of the following parts: the wall of the abutment, two bearings which are placed on the wall and a second structural tie [4]. This structural tie transfers the second force of the system which balances the moment of the embedding [5]. A special retaining wall is necessary for the embankment.

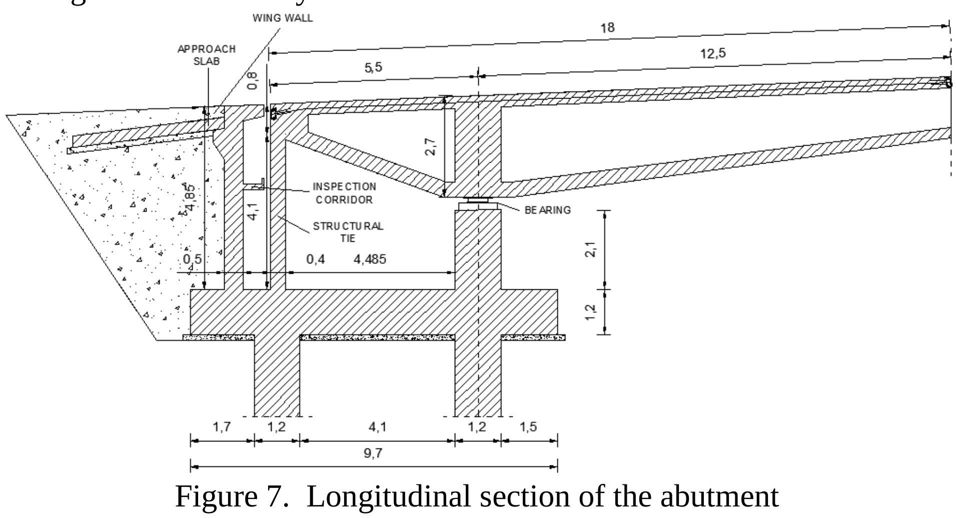


Figure 7. Longitudinal section of the abutment

Comparison of results

This paper examined the existing bridge positioned between Arahthos – Peristeri locations at Egnatia Motorway. This bridge consists of two separate branches (one in each direction), and serves the transition between towns of Ioannina - Metsovo. However, in this paper, only the left branch of the bridge has been examined. The structural system of the bridge is a 3D frame, which consists of the deck of the bridge, the abutments, the piers and foundation. The existing bridge is a continuous frame with six spans and a total theoretical length of 240,0m ($2 \cdot 34 + 4 \cdot 43 = 240$m). The length of the bridge is referred as theoretical because the deck in plan is not straight in all sectors but has a variable steering angle. The body has a longitudinal slope of 4.4% while the slope of the cross sections ranges from 2.5% to 7%. The cross section of the body is a box-girder with a fixed height of 2.70m.

The deck of the bridge is based on five intermediate points on the piers with monolithic connection, while on the edges, on the abutments by elastomeric bearings. The cross section of the piers is solid with dimensions 5.00 x1.50m.

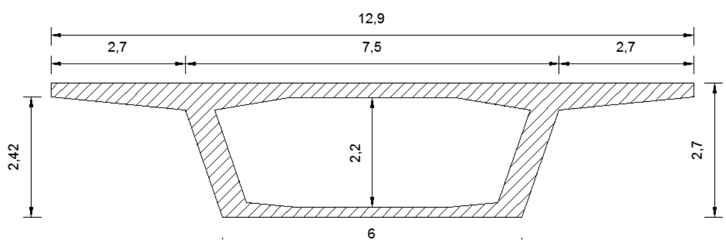


Figure 8. Cross section of the conventional deck

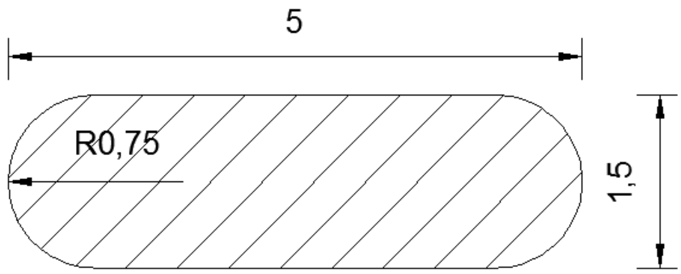


Figure 9. Cross section of the piers

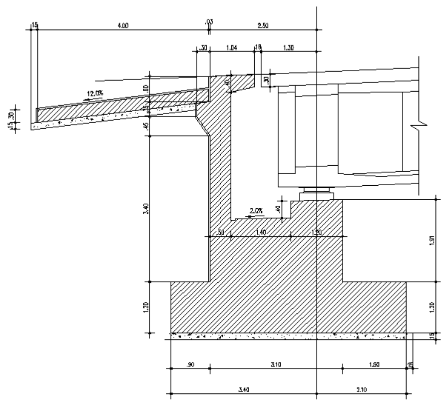


Figure 10. Longitudinal section of the abutment of the conventional bridge

For aesthetical and economical reasons, at the proposed innovative bridge a variable-height section has been selected for the deck. As a result of that, longitudinal, ordinary steel bars are used for the reinforcement of the bottom flange, at the middle of the spans. This is considered to be accepted by the applied codes (Eurocodes) and also constitutes another innovation.

The requirements of the aesthetics led in the embedding of the ends of the bridge on the abutments. Because of that, a new type of abutment has been introduced. This abutment is able to deliver significant bending moments. The cross section of the deck is a box girder with a height which varies from 2.7m above the piers to 0.8m in the middle of the spans. The bottom flange of the deck is discretized in eleven parts.

In both cases, the new European Codes (Eurcodes) have been applied. [6], [7], [8], [9], [10]. Two types of analyses were performed, for static and dynamic loads [11], [12]. The results from the two analyses are very interesting.

Conclusion

This paper proposes a new bridge construction method implied in an existing highway bridge in Egnatia Motorway. This bridge has been examined utilizing two different methods. The first one uses conventional construction practices while the second one uses alternative and innovative construction practices. The reason for the proposed innovative construction method is to introduce pioneering solutions related mainly to the construction and aesthetics. The most important conclusions of this paper can be inferred:

(1) The proposed innovative construction practices can be applied in cast in situ bridges.
(2) The deck has a variable cross section height along its longitudinal direction. This variable cross section contributes to a more aesthetic view of the bridge according to the rules of the traditional bridge construction of the area.
(3) The choice of variable cross section allowed the implementation of straight prestressing tendons at the top flange. The straight prestressed tendons contribute in the new construction method and ensured that cracking conditions will not appear on the deck.
(4) The reinforcement of the arc-type bottom flange consists of longitudinal steel bars and no prestressed tendons, whose action is unfavorable in the bottom flange of the arc-type deck. This form of reinforcement is able to be implemented, by means of rebar congestion, even in this case of spans with length over 40m. Any objections to differentiation in the type of reinforcement of the upper and bottom flange of the deck are not valid as the code requirements in any case can be satisfied.
(5) A new type of abutment has been introduced. This abutment contributes in the aesthetics of the bridge. The innovation of the abutment consists of its ability to deliver bending moments apart from gravity loads, permanent and live.
(6) Comparing the results of the two methods, it is obvious that the new innovative method is significantly more cost-effective than the conventional [13].
(7) The serviceability of the new method is also improved because of the relocation of the joints at the ends of the bridge. In addition the bridge is slightly seismic safer because of the slight reduce of the total mass of the deck [14].
(8) The proposed innovative construction method aims to solve the problems dealt by conventional means. This method can be easily used not only by the designer engineers but also by the constructors. The potential market is also open in new and pioneering proposals that can improve the safety and serviceability of the bridge construction by a more economical way.

Acknowledgment

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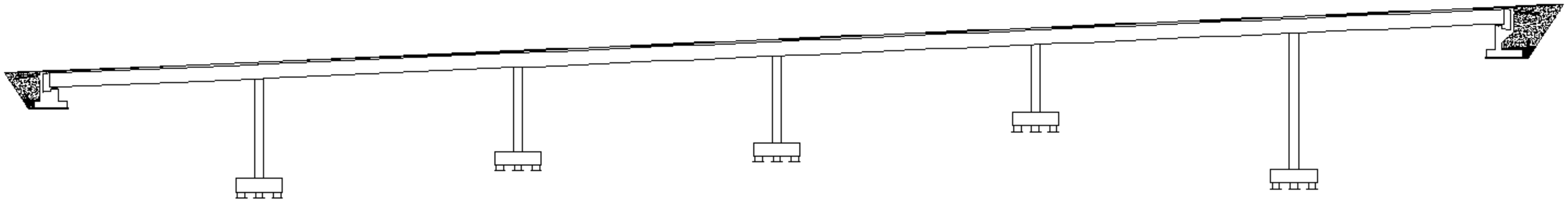

Figure 11. Longitudinal section of the conventional bridge

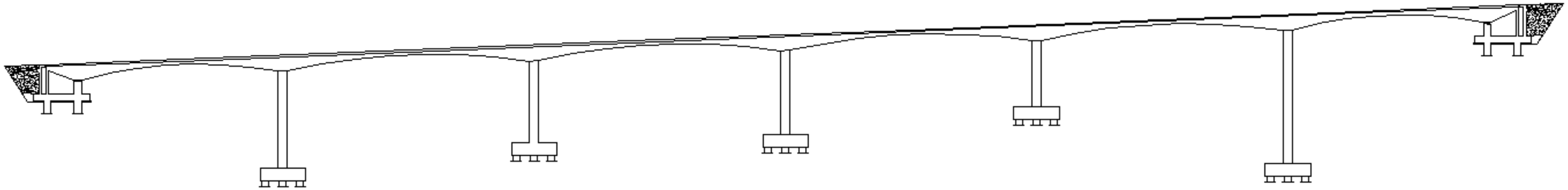

Figure 12. Longitudinal section of the innovative bridge