FEASIBILITY STUDY OF LONG SPAN ARCH BRIDGE

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ABSTRACT

The present paper presents the feasibility study for long span reinforced and prestressed concrete arch bridge. It contains two parts:The first adopts a suitable solution that satisfies specific constraints such as heavy loads, high velocities, construction methods. The second part introduces dynamic study of the bridge. In addition to classical methods, several finite elements programs have been utilized.

Keywords: Arch bridge, bridge, dynamic analysis.

INTRODUCTION

In general, arch bridges can be classified to the following types:

1. According to static structural system, we can distinguish:
   - . Fixed arches.
   - . Two hinged arches.
   - . Three hinged arches.
2. According to deck position, we distinguish:
   - . Arches with superior deck.
   - . Arches with intermediate deck.
   - . Arches with inferior deck.

For this study we have adopted a solution of two arches of span 265m with intermediate deck suitable for crossing rivers not deeply embanked (Figure 1). The two arches are hinged at their bases. They are formed of unicellular rectangular caissons(5mx3m) with sides of thickness 0. 5m. Their height is 45m (height=span/6). On the other hand, the two arches are inclined to the vertical. They are spaced 24m at bases and 6m at top. A bracing system links them to insure the transverse stability.

The deck has a total width of 17m, includes two railway lines. It is composed of two longitudinal prestressed rectangular girders, and transverse beams covered by a slab of 25 cm thickness.

The deck is suspended to arches by inclined cable system (prestressed cables), which provides a lightness and transparency to the bridge. On the other hand, this solution permits to avoid crack problems of reinforced concrete column suspensions noted on existing bridges. The inclination of suspension cables minimises arch distortions under unsymmetrical loads and in consequence the deck deflections, which are fundamental for railroad bridges. Each cable can be regulated or even replaced.

The arches supports are hinges, and must be based on bulky foundations, eventually on inclined piles according to the soil properties, in order to support the horizontal and vertical reactions transmitted by the arches. In weak soil case, the horizontal reactions can be taken by the prestressed cables which link the arches bases.

STATIC ANALYSIS

The static analysis is conducted in linear elasticity. The finite element analysis has been made on the program SYSTUS. The model chosen is the spacial bars, constituted of 701 nodes and 1214 elements (Figure 2).

Each of the two lateral girders have been modelled by a set of longitudinal bars. Each of the two arches have been modelled by an inclined bar of very short segments. The deck slab have been represented, longitudinally, by three sets of bars, having characteristics deduced from the correspondent slab.

Several cases of loading have been studied, for which we have made the different possible combinations(working and ultimate), and from which we have extracted the loads combination that gives the maximum internal forces for design. The comparison between theoretical design (4, 7, 11, 24) and computer design gives a deviation of 5. 7% (for reactions as an example), which proves the validaty of the model adopted for our study.

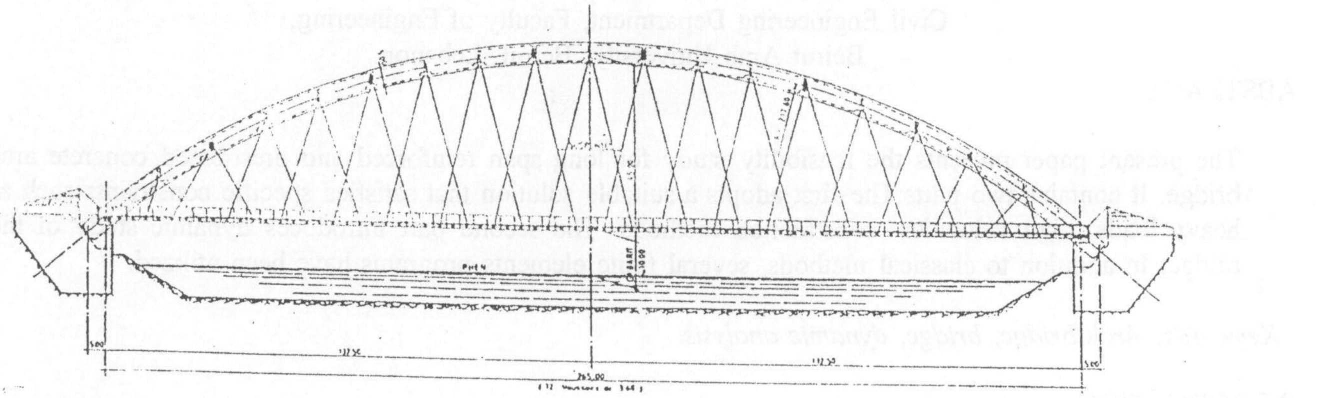

Figure 1. Problem layout.

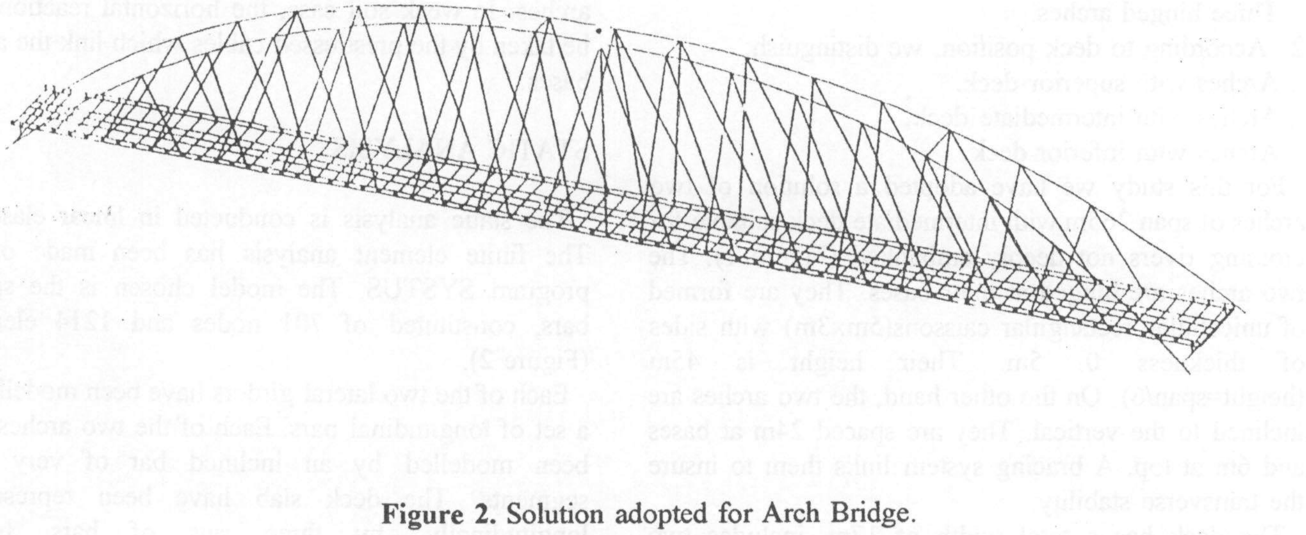

Figure 2. Solution adopted for Arch Bridge.

Afterwards, we have done the design of sections, for example, concerning the arches, we note that they are entirely under compression under all cases of loading. It is logical then to design the arches as reinforced concrete without putting any prestressed cables in definitive phase and provide the minimum percentage of reinforcing steel.

The lateral two girders have been designed in class 1 of working limit state. Six prestressed cables of 19T15s at top and bottom, have been provided to simplify the prestressing reinforcements. The undulation is feeble and uniform:its amplitude is 15cm. The cables pass at top and bottom in span, between each two point of anchoring. The anchorage must be of screw type, permitting a recapture of tension or a regulation of suspensions or eventually possibility of replacement. The sections of suspension cables are different and proportional to correspondent internal forces. The biggest section is 62T15s for he first two suspension cables from each side of arches.

On the other hand, the effect of variation of the suspension cables dispositions have been examined, in order to reduce the efforts. We have made the analysis for the three following dispositions:

1. One disposition in which the suspension cables are lightly inclined and cross each other only at the level of the arch.
2. A second disposition in which the suspension cables are more inclined and cross each other at deck and arches levels.
3. A third disposition in which the suspension cables are highly inclined and less in number.

METHOD OF CONSTRUCTION

Among different methods of construction of arch bridges, the following methods are cited:

1. The method utilising the prestressing to construct the arches without scaffolding, by cable stays. In this method, the arch is composed of precast units, cast in-situ in movable equipage moving on the arch detained progressively during their advancement with cable stays. We distinguish:
   . The construction arches with superior deck by temporary triangulation in which the temporary cable stays have been utilised as stretched diagonals before end of arch construction.
      . The construction by direct cable stays.
      . The method utilising a temporary column in the river on each bank, beside the first suspension column. This solution is permitted in cases of low depth of the river beside each base.
2. The method of scaffolding constructed on the ground and transported to its position by floating.
3. The method of construction on wood bends supported on soil. This method leads to a complicated execution, an expensive price of the bridge and long construction delays.
4. Construction of arches by lowering method (27). In this method, the two halves of the arch are constructed in vertical position and then lowered with the help of cables to their final positions. The principal characteristics of this method are:
   . The reduction of execution time.
   . The means utilised are more reduced for the construction.
   . The quantity of temporary cable stays is relatively low.

   The application of this method is limited to bridges of little to medium span.

In this study, the first method is chosen for demonstration. The arch is realised in two halfs, each one include several phases of successive cantilevering. After execution of a pair of precast units, the cables which end at its extremity are put in tension permitting to pursue the construction.

The construction is accomplished by concreting the precast units in place in moving equipage serving as formwork which are put forward progressively. The stability of the constructed part of the arch, is insured by cable stays composed of prestressed cables. These cable stays are fastened to the auxiliary steel tower which is placed adjacent to the arch (Figure 3). From the other side of the tower, the cables are weights anchored deeply in soil.

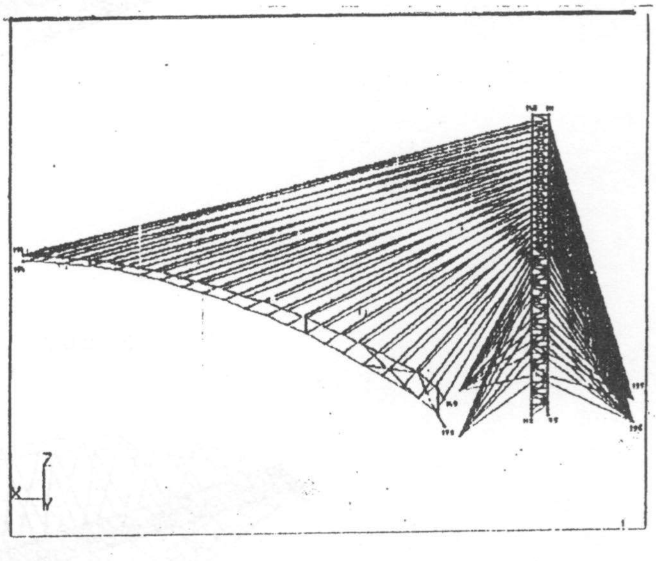

Figure 3. Temporary suspension system.

The realisation of the deck is accomplished by cantilevering with precast units of 3. 625m long. We have analysed the temporary structures (Figure 3) using the program ROBOT and the option spacial frame.

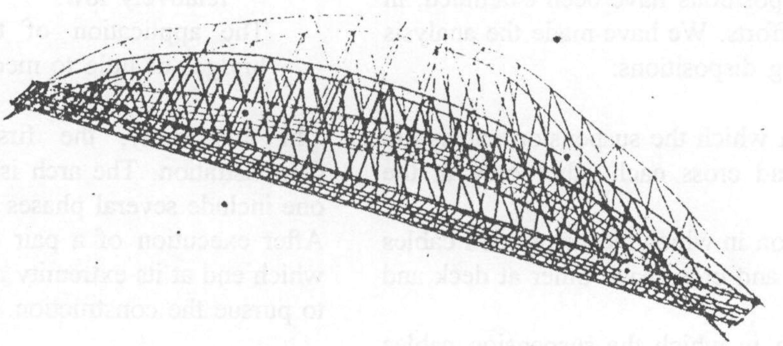

Figure 4. Vibration Mode No.1
Frequency=0.46734

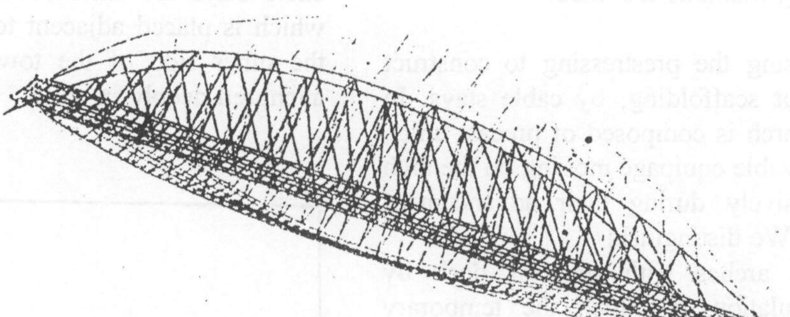

Figure 5. Vibration Mode No.2
Frequency=0.50016

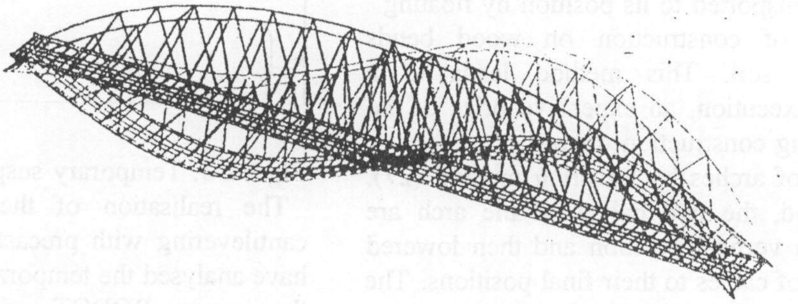

Figure 6. Vibration Mode No.3
Frequency=0.54456

The model comprise 198 nodes and 535 elements, representing the tower constituted of steel profiles of 5x5m horizontal dimension situated at 30m from the arch. The other supports are considered fixed. This analysis gives the internal forces and the displacements for the different elements of the model, which permits to design and verify sections.

DYNAMIC ANALYSIS

For the dynamic analysis of the arch bridge subject to effects due to crossing of trains with high velocity, we have utilised the classical methods and the program SYSTUS.

The analysis is conducted using elastic theory. The modulus of concrete is taken equal to the instantaneous modulus corresponding to dynamic loading (E=39000MPa).

SYSTUS utilises either a direct method (step by step integration) or modal superposition, to integrate over time domain:

The second method is used in the study and which can be resumed in the following manner:

- Calculation of frequencies and proper vectors,
- Calculation of modal responses by the numerical resolution of the DUHAMEL equation,
- Calculation of total responses (displacements, accelerations, etc. . .)by superposition of modal responses.

We have chosen this method principally because of its linear elastic behaviour (and in consequence the principle of superposition can be applied), of its efficiency and of its economy from the point of view of analysis time.

To obtain the maximum responses of the structure subjected to dynamic loading of high velocity trains, the first 50 modes (Figures 4, 5, 6) have been considered. To each proper frequency, there exists a critical velocity of the excitatory railway lines, which can engender a resonance phenomenon. After analysis of different graphs, it sounds that the frequency associated to a longitudinal flexure mode, and that of 4. 26Hz is the critical frequency.

Determination of critical velocity

Using SYSTUS, we have simulated the crossing of the high velocity trains on the bridge at different velocities from 100 to 455 km/h. This demonstrates that the node the most frequently affected is the node number 532 situated at 187. 87m from left support of the bridge.

The maximum displacement of this bridge is 2. 67cm, for a velocity of 328km/h. At the moment of going out of the train from the bridge (last axle at 185m). This velocity of 328km/h result in a frequency of 4. 86Hz, which is equivalent to the frequency of the proper mode 40. This, permits to deduce the critical velocity=328km/h and the resonance frequency=4. 86Hz.

In the other hand, an empirical formula, presented hereunder, gives reasonable values for the critical period of the arch equal to 0. 235s(f=4. 25Hz) in place of 0. 205s (f=4. 86Hz) given by computer calculations:

$$T. 085h/ D \qquad (1)$$

where

h is the height of the bridge in m.

D is the length of the bridge in m.

Coefficient of dynamic increase

This dynamic study of the bridge has permitted to analyse the phenomenon of dynamic increase of efforts due to a vibratory behaviour of the structure. At the moment of crossing of the train, circulating at the critical velocity of 328km/h, the maximum deflection taken by the bridge is 2. 67cm, even though the static deflection in the same configuration (position of train on the 79. 95 last meters) is of 1. 08cm.

Thus, we have found a coefficient of dynamic increase equal to 2. 47=(2. 67/1. 08).

Limitations of the deflection

The limit of the deflection forseen for this type of bridges is of:

$$f<pan/3000 \qquad (2)$$

By finding a maximum dynamic deflection of 2. 67cm(=span/1000), we have a deflection 3 times less than the limit authorised:

Dynamic vertical acceleration

For a velocity of 328. 4km/h and at time t=6. 3s, we obtain a dynamic acceleration:

0. 25m/s2=0. 025g

This value is well lower than the limit value fixed for a ballasted deck (<0. 35g).

The maximum value for this reinforced concrete bridge, is 0. 033g, so we can conclude that there is no risk of appearance of disorders at level of the structure of railway lines.

Maximum rotation of deck

We have obtained by the critical velocity of 328km/h a maximum rotation (along the transversal axis y) of 7. 45x10-4 rad. This high value of rotation is due to the introduction in the analysis of fictitious inertias for the loading. The addition of two suspension cables at the two extremities of arches will have an effect of reducing the rotation at the extremities to a limit value (3. 5x10-4 rad). The approximated calculation, using values of dynamic deflections, give an acceptable value of 1. 988x10-4 rad which is lower than the maximum value specified by the codes.

CONCLUSIONS

By comparison among the results of different cases studied, we have deduced that the normal effort is approximately the same for the disposition 1 and 2 and the case of fixed arches. Even though it becomes bigger for vertical arches and much more bigger for the disposition 3. The shear force Ty is approximately the same for all studied cases. The shear force Tz is approximately the same for all the studied cases, except the disposition 3 which shows a great fluctuation. The distorsional moment Cx is approximately the same for all the cases studied, unless the disposition 3, where we have noted a great difference between the first and the last quarter of the span.

The results obtained demonstrate that the case of the adopted solution (which is the initial disposition, figure 1 and 2) gives the least values of moment My.

The results of this study permit to confirm the feasibility of this type of structure from the static and dynamic points of view in the construction phase as well as in definitive phase, especially for the crossing of trains at high velocity.

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