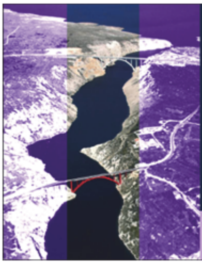

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AESTHETICS AND HISTORY

SPACE ARCH STRUCTURES

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Keywords: Pedestrian bridge, arch, curved deck, funicular shape, inclined arch, composite deck, static and dynamic analysis, model tests.

Abstract: *Comprehensive studies of several plan curved arch structures have been performed. At first, bridges with curved decks suspended or supported by arches situated in the bridge axis are discussed. Then optimum arrangements of curved arch bridges are presented. Finally a model test that is being prepared is described.*

1 INTRODUCTION

Comprehensive studies of several types of plan curved arch structures has been performed at the Faculty of Civil Engineering of the Brno University of Technology, Czech Republic. The first structure that is formed by a flat curved arch of span of 45 m (see Figure 1) was presented at the 6th Conference on Arch Bridges [1].

Figure 1: Model test of the curved stress ribbon & flat arch structure

The butterfly structures with a concrete deck suspended on two inclined arches are being designed for crossing of the Willamette River in Salem, OR [2] and the Berounka River, in Civice, Czech Republic (see Figure 2). At present, the curved bridges supported or suspended on one arch are being studied.

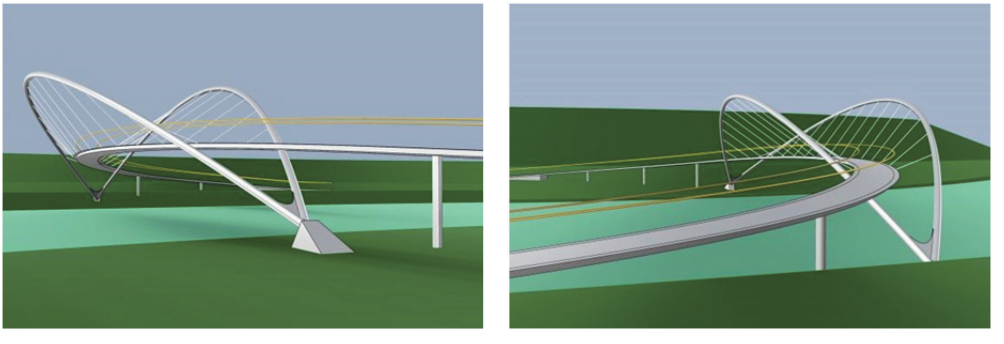

Figure 2: Pedestrian bridge across the Berounka River

2 ARCHES SITUATED IN THE BRIDGE AXIS

To static behavior of curved arch bridges suspended on or supported by a plan curved arch situated in the bridge axis (see Figure 3) was studied for the radii ∞, 500, 250, 100 and 50 m.

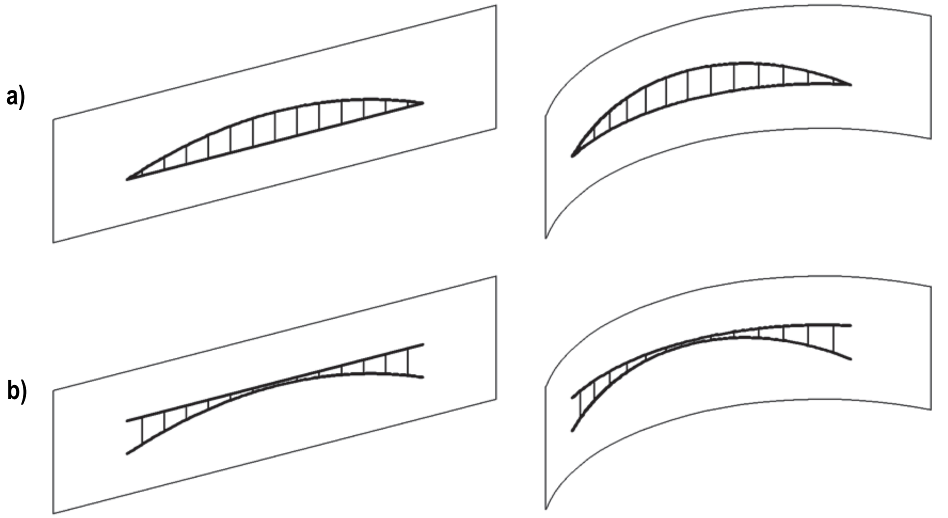

Figure 3: Plan curved bridge suspended (a) or supported (b) by a curved arch

The bridges of a span length of 60.0 m have composite decks of width of 4.5 m – see Figures 4a and 5a. The decks are formed by a steel pipe and a concrete deck slab stiffened by steel cross beams. The arches formed by steel pipes have a shape of the second degree parabola in developed elevations.

The bridge suspended on the arch has deck's pipe of a diameter of 508 mm. The arch of a diameter of 610 mm and rise of 8.0 m is fixed into the end diaphragms. The suspenders are formed by steel bars. The bridge supported by the arch has deck's pipe of a diameter of 700 mm. The arch of a diameter of 700 mm and rise of 6.0 m is fixed into the footings. The deck is supported by pin connected columns.

The static and dynamic non-linear analyses were performed by program systems ANSYS and MIDAS – see Figs. 4b and 5b. At first, the initial stage was determined, and then the structures were analyzed for different positions of the live load. From results is evident that the structures can be easily designed for the radii ∞, 500, 250 m. For smaller radius the bridges requires significant stiffening. Structure with the radius of 50 m is not able to resist the design load.

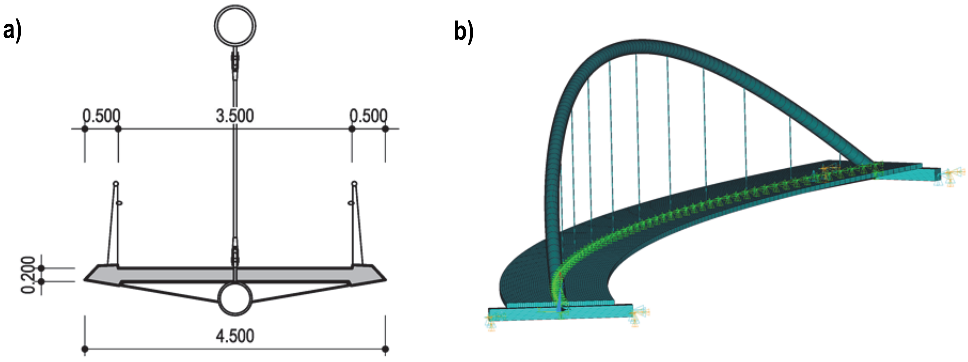

Figure 4: Bridge suspended on the curved arch – a) cross section, b) calculation model

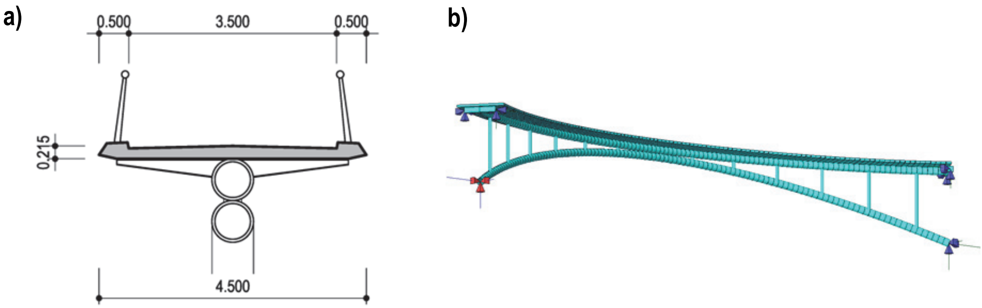

Figure 5: Bridge supported by the curved arch – a) cross section, b) calculation model

The function of studied bridges was also verified by dynamic analyses. At first, the natural modes and frequencies were determined. Since the first bending frequencies are close to 2 Hz, the forced vibration according to [3] was also performed. Table 1 presents first natural frequencies of the studied structures.

f [Hz]	Bridge suspended on the arch			Bridge supported by the arch		
	bending		torsion	Bending		torsion
R ∞	1.311	2.825	2.948	3.029	5.706	3.277
R 500	1.310	2.858	2.953	3.016	5.666	3.164
R 250	1.309	2.915	2.971	2.981	5.585	3.947
R 100	1.301	3.007	3.087	2.855	5.350	5.668
R 50	1.249	2.845	3.475	2.706	5.261	8.875

Table 1: First natural frequencies

3 OPTIMUM ARRANGEMENTS OF CURVED ARCH BRIDGES

From the above it is evident that for the smaller radii of the plan curvature it is necessary to find an optimum arrangement. To allow free, un-disturbed walking the curved deck suspended on one side inclined arch (see Figure 6a) seems to represent an optimum solution. However, it is necessary to find an optimum arch geometry - the arch has to have a funicular shape. The same is true for the structures supported by the arch; however, the arch can be connected with the deck at the bridge axis (see Figure 9a).

3.1 Bridge suspended on the arch

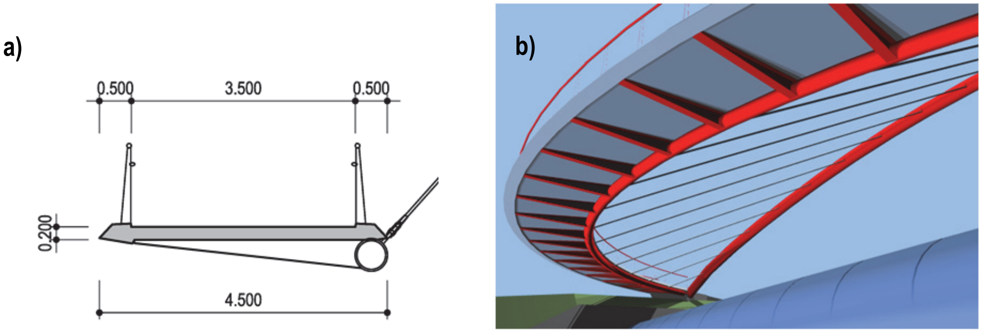

Figure 6: Bridge deck – a) cross section, b) visualization

The study has been performed for the circular deck of the radius of 37.5 m and rise of 15 m – see Figure 7. The developed length of the deck is 69.55 m. The arch has a vertical rise of 9.36 m. The deck's pipe has a diameter 508 mm, the arch's pipe 914 mm. The suspenders are formed by bars. The torsion of the deck is balanced by radial cables situated at handrails.

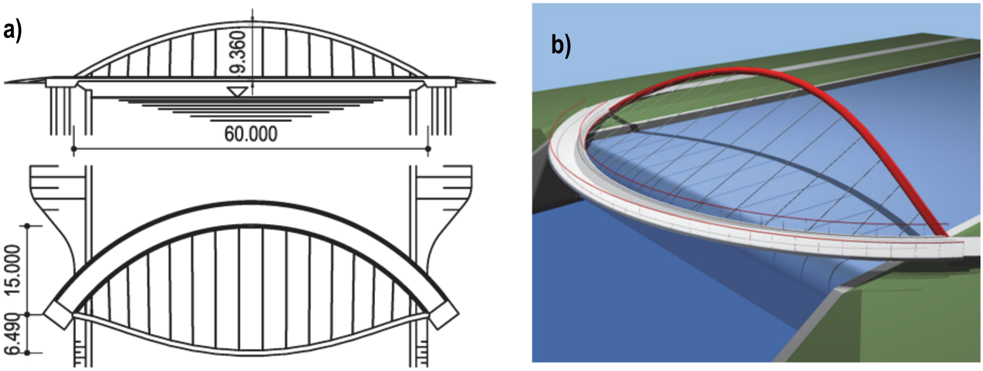

Figure 7: Bridge suspended on the arch – a) elevation and plan, b) visualization

The optimum shape of the arch has been obtained by the analysis of the curved suspension structure in which the suspension cable situated under the curved deck had zero stiffness – see Figure 8. The forces in the cable were determined by iteration. The funicular shape of the arch was obtained by inverting the suspension structure. The static and dynamic non-linear analyses were performed by the program system ANSYS. At first, the initial stage was determined, and then the structures were analyzed for different positions of the live load. The detailed analysis has proved that the structure is able to resist all loads given in Eurocode. The Table 2 presents the first natural frequencies.

f [Hz]	arch	Deck - bending		torsion
				
R 37.5	0.536	1.078	2.061	4.879

Table 2: First natural frequencies

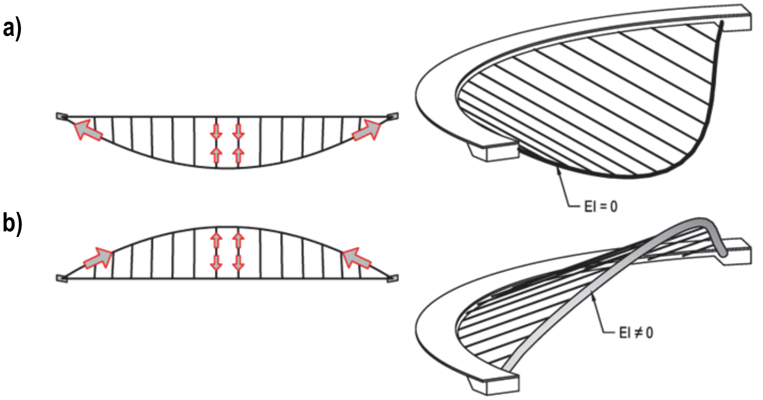

Figure 8: Form finding – a) suspension structure, b) arch structure

3.2 Bridge supported by the arch

The study was performed for the circular deck of the radius of 37.5 m and rise of 15 m - see Figure 10. The developed length of the deck is 69.55 m. The arch has a vertical rise of 6.0 m. The deck's pipe has a diameter 700 mm, the arch's pipe 700 mm. The deck is supported by inclined struts pin connected both to the arch and the deck.

The optimum shape of the arch was obtained by the analysis of the curved suspension structure in which the deck was suspended on the suspension cable of zero stiffness - see Figure 11. The forces in the cable were determined by iteration. The funicular shape of the arch was obtained by inverting the suspension structure. The static and dynamic non-linear analyses were performed by program systems MIDAS. At first, the initial stage was determined, and then the structures were analyzed for different positions of the live load. The detailed analysis has proved that the structure is able to resist all loads given in Eurocode.

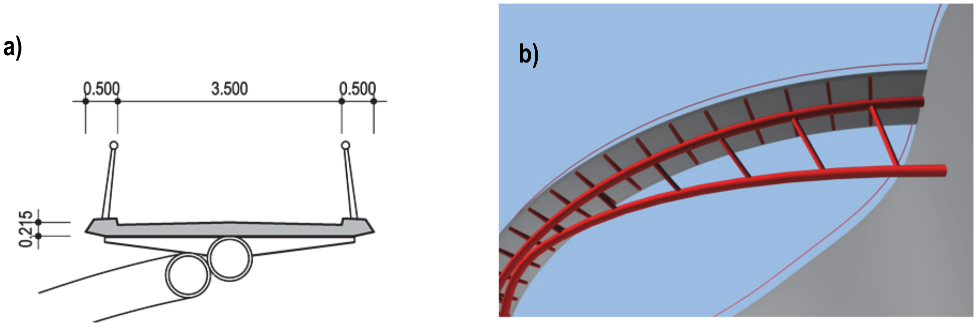

Figure 9: Bridge deck – a) cross section, b) visualization

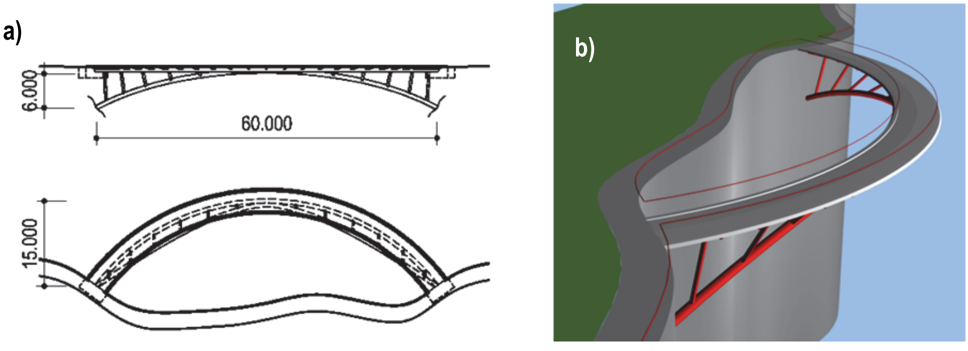

Figure 10: Bridge supported by the arch – a) elevation and plan, b) visualization

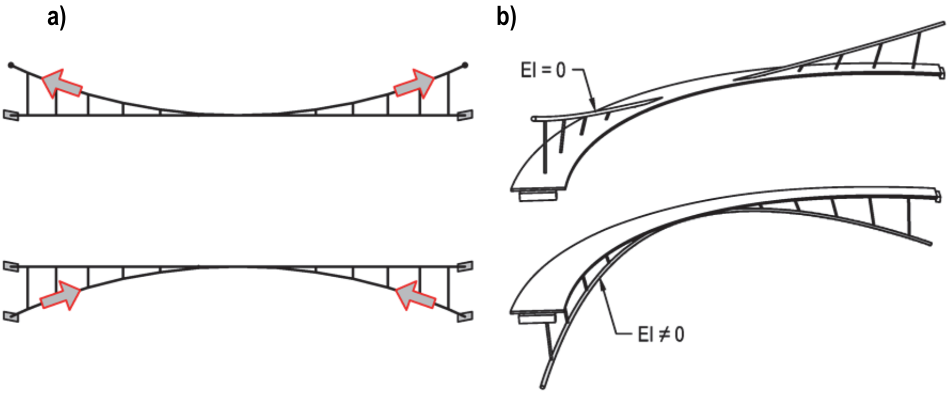

Figure 11: Form finding – a) suspension structure, b) arch structure

4 PHYSICAL MODEL

The function of the studied structure will be verified on a static model built in the scale 1:10. – see Figure 12. It will be built similarly as the model of the curved structures formed

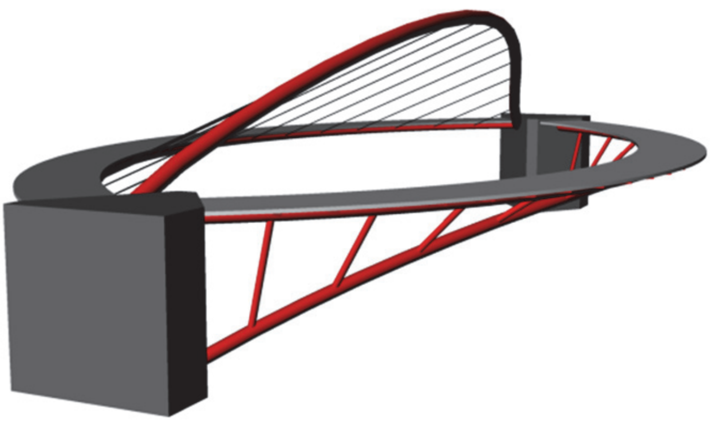

Figure 12: Physical model of the tested structure

by a curved stress ribbon & flat arch structure (see Figure 1), [1]. The decks and arches will be fixed into the end anchor blocks. These anchor blocks will be supported by concrete pedestals that will be mutually connected by steel members and PT bars.
To guarantee a model similarity, the structure will be loaded by concrete block and steel rods representing the self weight of the structure. The live load will be represented by additional concrete block and cylinders placed on the composite deck slab. The structure will be tested for several positions of the live load. At the end the structure the ultimate capacity will be determined.

5 CONCLUSIONS

It is evident that the aesthetically pleasing curved structures suspended or supported by arches are light, transparent and they are assembled from structural members that have a human scale. Therefore we believe that should be carefully studied and further developed.
The development of the described structures is being done by the engineering firm Strasky, Husty and Partners, Brno with a collaboration of the Faculty of Civil Engineering of the Brno University of Technology. The research work is being performed with the financial support of the Technological Agency of the Czech Republic; project TA02011322 - Space structures supported by arches and/or cables.

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