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OLDEST CONCRETE VAULTED AND ARCH BRIDGES IN THE CZECH REPUBLIC – EVALUATION AND PRESERVATION OF THEIR HISTORICAL VALUE

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Abstract. The paper is related to a research project focused on tools for an evaluation and preservation of the historical value and function of arch and vaulted road bridges. It deals with the beginning of use of concrete vaulted and arch bridges in the area of the Czech Republic from the first structures built at the end of the 19th century up to the time just before the WWII. The paper includes examples of built structures as well as a general summary and development of the used technical solutions. Important part of the paper is a proposal of criterions for evaluation of their structural and historical value.

Keywords: Concrete bridge, arch bridge, vaulted bridge, existing structure, repair of bridges, strengthening of bridges, historical value of bridges, structural value of bridges.

1. Beginning of use of concrete for bridges in the area of the today's Czech Republic

The first structures using cement concrete were built here principally in the second half of the 19th century, when this area was a part of the Austria-Hungarian Empire (up to 1918) and it can be said a part quite highly economicly developed. Nevertheless, thanks to relatively cheap and easily accessible other construction materials, use of cement concrete for bridges and other load-bearing structures was not too needed from economical reasons and concrete was used more for such structures as water buildings, sewerage systems and foundations.

For the first time, cement concrete was applied for a bridge here probably in the town of Poděbrady – it was for watertight layers in anchoring chambers of main chains of a chain bridge, built over Labe river in 1840–1842. The chambers were several times flooded and damaged by high water and these watertight layers were found as really effective [1].

The first known concrete bridge in this area was a vaulted structure of a clear span of 8.000 m and a rise of 2.000 m, built in 1892 over Bobrava creek in Tetčice. The next proven concrete bridge was built here for the Ethnographic Exhibition held in Prague in 1895. This exhibition included besides others also quite a large number of timber-made maquettes of typical buildings from various cities and villages. One of such buildings was a maquette of the castle of Kokořín and on the access ramp to this castle, the concrete bridge was built. It was a vaulted structure of a clear span of 12.956 m and of a rise of the vault of 2.450 m. The bridge was designed by A. V. Velflík and built by company "Hrůza and Rosenberg". After the exhibition, it was removed (Figure 1).

The first concrete bridge built for transport reasons was the bridge over Rokytka river in Prague, built in 1896. It was built within only 35 days according to the design of Antonín Loss. It is a plain concrete vaulted structure of a clear span of 13.300 m and a rise of 2.750 m. The width of the bridge was during next years and decades enlarged by subsequently added structures – vaulted as well as made of girders – up to the form of a small "square". The bridge exists up to our days.

The first bridge made of reinforced concrete was built over a rocky gorge in the castle Veveří near Brno at the place of an older structure made of stone masonry. The bridge was built in 1898 according to a design of Josef Melan with reinforcement made of internal embedded steel I-shaped girders. Josef Melan elaborated and patented a whole system of concrete structures reinforced by this kind of reinforcement (so-called Melan system). Clear span of the bridge is 17.550 m and it has a three-cell box concrete superstructure fixed to abutments made of stone masonry (Figure 2).

In the next years, quite large number of concrete vaulted and arch bridges were built, so only a few of them can be mentioned here.

In 1900, a skew two-span vaulted bridge of span lengths of 2×16.260 m was built over Tichá Orlice river at Lanšperk near Ústí nad Orlicí, which was the largest concrete bridge in Bohemia after its completion. The bridge was built by company "Uhlíř – construction of concrete buildings at Velim" and after a repair in 1996 it is still in service.

In 1901, a vaulted bridge of two spans of 2 × 20.0 m

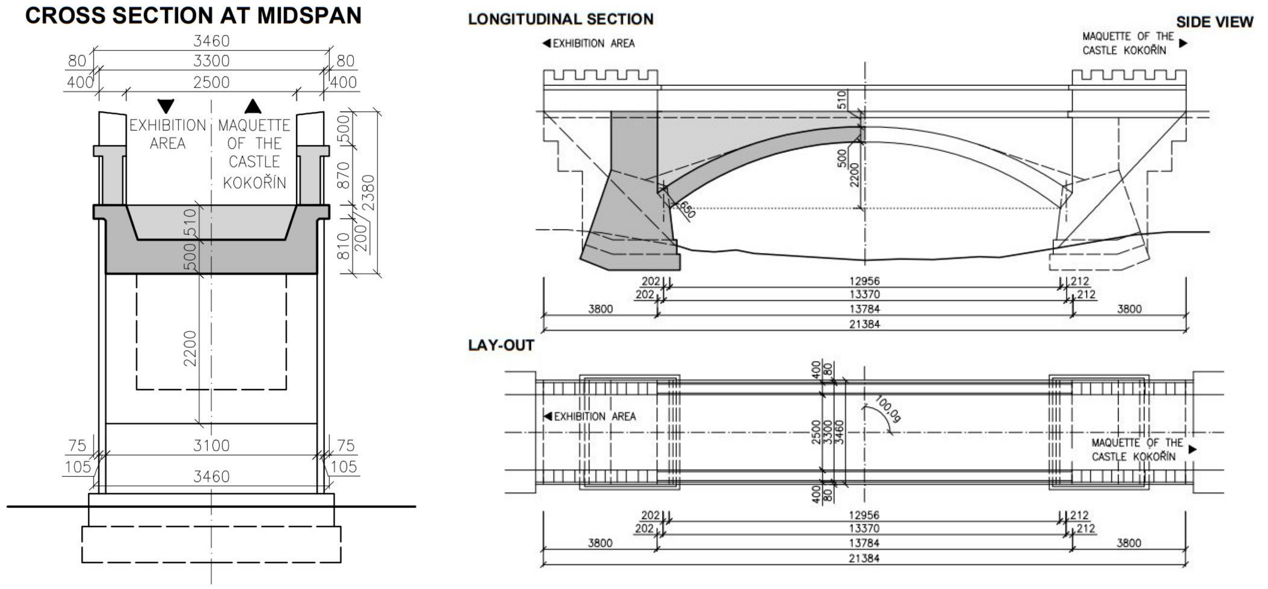

Figure 1. Concrete bridge at the Ethnographic Exhibition in Prague 1895.

Figure 2. Bridge over rocky gorge at the castle Veveří near Brno, 1898 (left – former masonry bridge [2], right – concrete bridge at present).

was built at Leština near Zábřeh. In 2010, after 109 years of service, the bridge was replaced by a new one with a single-span arch (“bow-string”) superstructure with a span length of approximately 40.0 m.

In 1902, a single-span vaulted bridge of a span of approximately 20 m was built in Olomouc over former Mlýnský potok (“Mill Creek”), removed in 1951. Another single-span vaulted bridge was built in 1902 at Srbská Kamenice near Děčín – its span length is 18.0 m [3]. The bridge was built at the place of an older structure, destroyed by floods in 1897. One more single-span vaulted bridge of a span length of 26.900 m was built in 1902 at Písečné – Modletice near Jindřichův Hradec. Both of these structures exist so far. In the same year, a vaulted footbridge over tracks in the railway station at Sokolov was built, with a span length of 16.5 m.

In 1903, a three-span vaulted bridge over Bečva river was built in Přerov on the place of a former timber structure. Span lengths were 3 × 22.400 m. This bridge was destroyed in May 1945 and then a temporary timber and then a steel footbridge were built there. Since 2012, a new reinforced concrete cast-in-situ girder bridge with a noticeable artistic decoration is at that place.

In near Hranice, a new bridge was built in 1905 on the place of an older structure (Figure 3). The final solution with two reinforced concrete arch spans of a length of 32.500 m was chosen of several steel as well as concrete proposals. This bridge was also destroyed in May 1945; then in 1960, a new two-span reinforced concrete arch bridge with a similar arrangement but not the same structure was built at this place. Span lengths of the new bridge are 34.150 + 34.020 m.

In 1910, the first “bow-string” (with a deck carried by ties below the arch) reinforced concrete bridge was built within the area of a paper-producing factory at Hostinné near Hradec Králové (with so called Melan

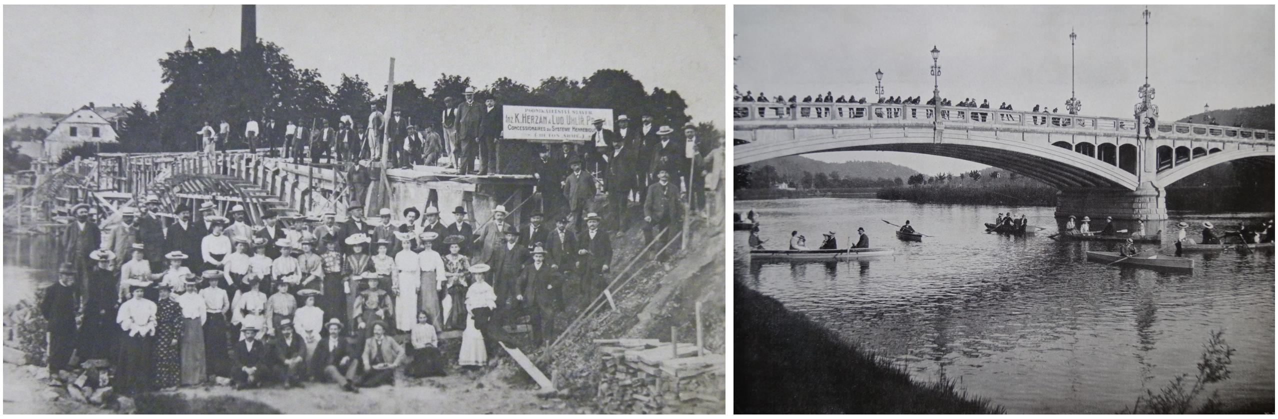

Figure 3. Arch bridge at Hranice, 1905 (left – during construction, right – after completion) [4].

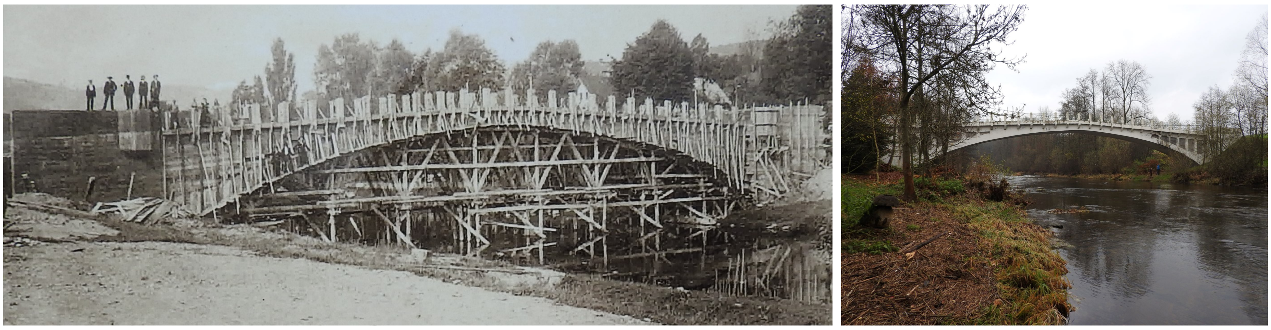

Figure 4. Vaulted bridge at Peřimov – Dolní Sytová, 1912 (left – during construction [5], right – at present).

system), of a clear span of 24.000 m. The arch of the bridge is rigidly fixed to the abutments, while its deck is separated from the abutments by expansion joints. The bridge was strengthened by external steel elements end exists so far.

In 1912, a single span vaulted bridge of the span length of 45.0 m was built at Peřimov – Dolní Sytová near Liberec (Figure 4). Its vaulted superstructure had three hinges – two at springers and one at the top of the vault. The structure was repaired and strengthened (the hinges were canceled during that repair) and exists so far.

Several vaulted and arch bridges of the span length of approximately 30 m to 50 m and even more were built during next years – e.g. Hlávka Bridge in Prague (39.0 m; 1912), Hradec Králové – Plácky (34.0 m; 1913), Nymburk – Velké Valy (40.0 m; 1913), Mánes Bridge in Prague (41.800 m; 1914), Masaryk Bridge in Plzeň (55.600 m; 1918), Libeň Bridge in Prague (42.8 m; 1928), the bridge at Hradec near Stod (63.860 m; 1928), the bridge at Kolín (30.400 m; 1928), Masaryk Bridge at Kralupy nad Vltavou (85.0 m; 1928), Mohelnice nad Jizerou (40.0 m; 1930) and Ostrov Bridge at Karlovy Vary (77.500 m; 1931) – the both with a three-hinge arches, Švehla Bridge at Tábor (81.600 m; 1935), the bridge at Loket (62.0 m; 1936) etc., as well as reinforced concrete bow-string bridges and bridges with a lower deck or an intermediate deck – for example the bridge at Hořepník (26.6 m; 1912), the bridge at Besednice – Pořešín near Český Krumlov with the superstructure fixed to the abutments (30.0 m; 1913), Sokolov (34.0 m; 1920), skew bridge at Dřevohostice (19.70 m; 1922) and at Horky nad Jizerou (29.40 m; 1923), Česká Třebová (41.0 m; 1924), Mladá Boleslav – Debř (46.50 m; 1924), Svijany – Podolí (48.10 m; 1924), Tuřice (51.50 m; 1924), Karviná – Darkov (56.0 m; 1925), Hradec Králové – Malšovický (43.20 m; 1925), the bridge at Brno – Husovice with a three-hinge arch, Uherský Ostroh (52.80 m; 1928) etc.

In 1928, an arch bridge over Lužnice river was built at Bechyně in southern Bohemia (Figure 5). The bridge with a length of the main span of 90,0 m is used both for road traffic as well as for a single-track railway line. The bridge was repaired in 2004 and is still in use.

At Štěchovice near Prague, an arch bridge with an intermediate deck and with a pair of box arch ribs for a span length of 113.80 m was built in 1939. At the end of construction, the bridge was flooded by high water reaching up to the handrail. The bridge sustained that situation without a serious damage and after another repair in 1995 it is still in service (Figure 9).

Between Podolsko and Temešvár near Písek in southern Bohemia, an arch bridge of a total length of 510.0 m and a length of the main span of 150.0 m was built from 1939 to 1942 (Figure 6). The bridge was built in the place of an older chain bridge constructed in 1848 because of the rise of the water level due to

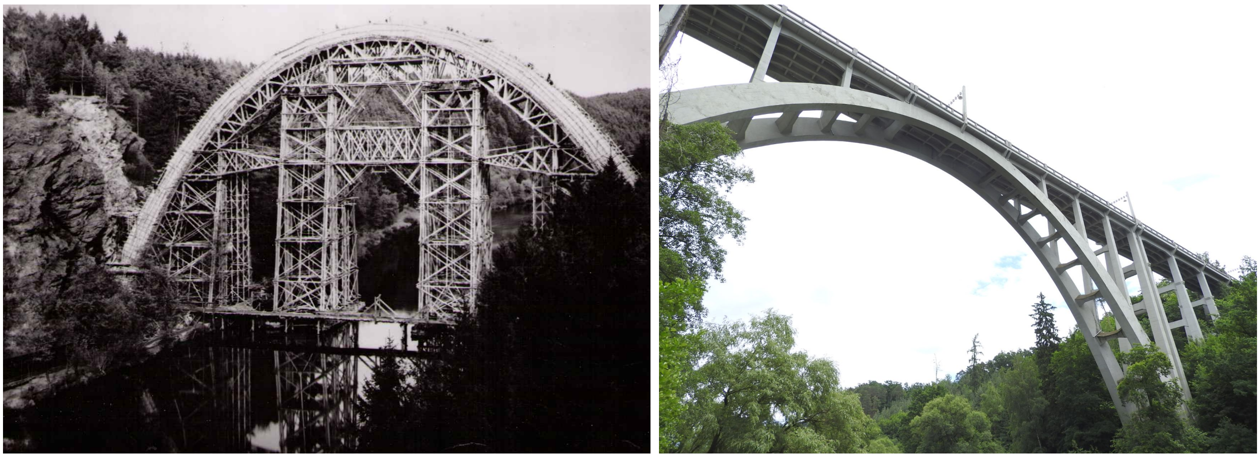

FIGURE 5. Arch road – railway bridge at Bechyně, 1928 (left – construction [6], right – at present).

FIGURE 6. Arch bridge at Podolsko, 1939–1942 (left – during construction still with the former chain bridge [7], right – at present).

construction of the Orlík dam reservoir. The chain bridge was disassembled, moved to Stádlec and built again over Lužnice river, where it still exists. The arch in the main span of the new arch bridge is fixed at the both ends, while the other arches (in the other spans and above the main arch) have two hinges at springers. The design of the bridge was in 1930's awarded at the architectural exhibition in Paris by the Gold Medal and was called "Le beau pont de l'Europe". Another award the bridge gained in 1939 at an exhibition in Liège.

Although this paper and the related project are focused primarily on road bridges and footbridges, we would like to mention here also at least two railway bridges – the bridge at Jizerní Vtelno with three arch spans of the length of approximately 3×50 m, built in 1924 and the arch bridge at Loučky with a main span of 110.0 m, built with some interruptions in 1940–1953.

2. Principles of structural arrangement

The structures considered in this paper were built as vaulted structures, i.e. covered by soil embankment or masonry filling, which carries the running surface for traffic, or arch bridges with a deck, which can be supported by struts above the arch (an "upper deck"), carried by ties below the arch (so called bow-string structures or bridges with a "lower deck") or arches with a deck in an intermediate position passing through the arch and supported partly by struts and partly by ties.

The vaults and arches with the upper deck and intermediate deck are in the most cases fixed to supports, but also structures with three hinges (two at springers and one at midspan) were built in relatively higher number of cases (Figure 7). Also existing, but rather exceptional (in concrete) are structures with just two hinges at springers. The hinges are made as concrete hinges, or steel hinges can also be used, similar to fixed bearings. Special arrangements of supports and bearings can be found at some multiple-span structures.

Bow-string bridges are usually supported by a manner, which enables displacements of the structure due to thermal changes and volume changes of concrete. For that, steel bearings are used in most cases at such older structures, which are sometimes replaced by new types of bearings during repairs of these bridges. In

Figure 7. Three-hinge arch bridge at Brno – Husovice, 1928 (left – overall view, right – steel hinges).

Figure 8. Pendulum supports (left – bow-string bridge at Bačkovice, 1929; right – end of the deck of the arch bridge at Přibyslav, 1940).

some cases, also concrete hinges and pendulum supports were used; pendulum supports have hinges at the both ends – concrete hinges or steel hinges can be used for that (Figure 8). In some cases, special arrangement of supports was used, for example supporting the structures just by thin elastomeric layers.

Not very often, but in some cases the superstructures of arch bridges with a lower deck are fixed into abutments and then it can be said by now-days terminology, that these bridges perform as integral structures. Exceptionally the deck is fixed at one end and supported by a movable manner at the other end. Also an arch bridge with a lower deck and with hinges at springers of the arch itself exists (at Brantice).

Vaults and arch structures are usually perpendicular, but also skew structures have been built. In the case of bow-string bridges, special arrangement of cross beams is then adopted in the support area of the deck. Also structures with horizontally curved carriageway can be found – then, the vault or the arch are usually straight and the curvature is obtained by a varying width of lateral cantilevers and/or by a change of position of struts in the transvers direction, exceptionally also arches are curved.

Struts of arch structures with the upper deck may be fixed at the both ends, or fixed at the lower end and hinged (usually with a concrete hinge) at the upper end or hinged at the both ends. Decks can be continuous over the whole length of the structure (expansion joints are then usually at the ends of the bridge), or they are divided by expansion joints above supports of the arch and in some cases also near the top of the arch. Depending on required displacements and on the overall arrangement of the structure, the deck at its ends may be supported by an easy way e.g. with use of bituminous or metal sheets, or it can be supported by bearings or pendulum supports.

Sometimes struts are not used and the upper deck is supported only at piers and at midspan of the arch. According to the deck span length the deck itself may be done as a slab or as a girder structure with longitudinal beams and transvers cross-beams.

Decks of bow-string bridges and arches with an intermediate and lower deck are usually composed of a deck slab, cross-beams in the places of ties, relatively large longitudinal edge beams (acting at bow-string structures also as a tie in the longitudinal direction) and of smaller longitudinal intermediate girders. If the

FIGURE 9. Expansion joints in the deck (left – expansion joint near abutment, Uherský Ostroh, 1927; right – expansion joint between the ends of arches, Štěchovice, 1939).

FIGURE 10. Ribbed UHPFRC layer around existing abutments and wing walls (left – preparation of the shape and reinforcement, right – casting the UHPFRC layer) – Meziboří at Litvínov.

arches of such structures are fixed to their foundations, decks are usually separated by expansion joints; they can be placed near springers of arches from the side of the span (at one or at the both supports of the bridge), they may be lead between the ribs of the arches, they may be at the both of these places or a joint can be placed at midspan (Figure 9).

3. Principles of repairs, strengthening and widening

For a repair of vaulted and arch concrete structures, quite standard procedures can be used. Nevertheless, special methods of repairs and strengthening may be also needed and convenient in some cases (see e.g. Figure 10). A brief survey of methods will be added at the conference.

4. Principles of determination of historical and structural value of structures

For the final decision "what to do with an existing structure", technical, economical and environmental parameters should be principally considered. Nevertheless, at old structures, some other parameters should be considered too to evaluate their structural and historical value. For that, the questions below are proposed:

- Was the structure in the time of its construction innovative by its material and/or structural solution?
- Was its span length and/or overall dimensions in the time of construction exceptional?
- Has the structure an exceptional aesthetical solution?
- Has the structure an interesting (extraordinary) history?
- How many similar structures (of a similar arrangement and span or dimensions) have been built?
- How many similar structures is still existing?
- Are the other still existing similar structures in a better technical state or at a better place (from the point of view of their protection – e.g. at a path with a less intensive traffic) – if yes, how many?
- Others – for example, is the bridge a part a pro-

tected urban or natural area etc.?

Depending on the number of points obtained from answers to these questions, final solution how to handle historical structures can be adopted – for example it is possible to use a repair of the structure by a less or more standard way, bridging an existing vault by a new horizontal superstructure (steel, concrete etc.) or embedding the existing structure by new load-bearing and protective layers, inside which the existing structure can be preserved. If possible and in needed cases, the existing structure can be further used only for a light traffic (pedestrians and cyclists), while heavier traffic can be deflected to a new path with a newly built structure. Valuable structures should be protected by such a way, while in many other – mostly standard – cases, existing structures will be probably replaced by new ones at the end of their service life. If a highly-valued structure has to be removed because of its poor technical state, it is possible to build its replica at the same place. Otherwise, modern structures will be probably the best solution, although even they may keep "genius loci" of the place by a similar principal concept, if it is convenient.

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References

[1] I. Seidlerová, J. Dohnálek. *Dějiny betonového stavitelství v českých zemích do konce 19. století [History of Concrete Construction in the Lands of Bohemian Crown until the End of the 19th Century].* ČKAIT, Praha, 1999. ISBN 80-86364-01-1.

[2] Archives of the National Heritage Institute. Valdštejnské náměstí 162/3, 118 01 Praha 1.

[3] N. Belisová. *Osud má jméno Dolský mlýn [Name of the destiny is Dolský Mill].* Polart, 2016. ISBN 978-80-87286-21-0.

[4] Museum of the City of Hranice. Masarykovo náměstí 71, 753 01 Hranice.

[5] Information banner at the bridge, City of Peřimov. 50.6240689N, 15.4422336E.

[6] City Museum of Bechyně. Náměstí T.G.M. 140, 391 65 Bechyně.

[7] Archives of the Department of Concrete and Masonry Structures, Faculty of Civil Engineering of the Czech Technical University in Prague.