OPARNO BRIDGE – MODERN TECHNOLOGY FOR CLASSICAL ARCH

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SUMMARY

The bridge over the Oparno valley is a classical arch structure of 135 m span erected by modern technology on the D8 motorway from Prague to Dresden. The arch bridge fits well into the preserved landscape area "Ceske Stredohori" with minimum interference; it is elegant, durable and sustainable structure, with a limited number of maintenance requesting details. The bridge is designed as a structure, which makes benefit from the use of high strength concrete, which resulted in material savings. The paper describes the design process including structural variations during construction and checking procedures on site.

Keywords: *Arch bridge, free cantilevering, cable-stays, aesthetics, sustainability, HPC, load test.*

1. INTRODUCTION

Implementation of a new motorway section D0805 in a sensitive natural environment required careful preparation and search for adequate and reasonable structure which can be accepted both by public and all relevant authorities. A special attention had to be paid to the aesthetical integration of the bridge into the preserved landscape, its durability and sustainable construction. The arch bridge across the Oparno valley is a classically shaped arch bridge which was erected by modern construction technology. The arch was built using a cantilever casting method with temporary stays and pylons. The technology required a careful deflection control. The construction method minimizes the interference of the building activity with the environment – no access to the preserved Oparno valley during construction was allowed. Both the bridge designers and contractors believe that the initial aim has been fulfilled. During the detail design the use of high strength concrete was approved and this variation resulted in material savings including transport limitations in the affected area. Both the design and construction of the Oparno Bridge were approved without major comments and this bridge was one of the first completed structures on the D0805 section of the D8 motorway in 2010. However the whole new section of the D8 motorway should be opened for the traffic at the end of 2016 due to administrative obstacles applied by environmentalist green groups and landslides problems in other parts of the D8 motorway section.

2. BRIDGE DESIGN

2.1. General

The bridge over the Oparno valley is an arch structure which carries a 4 lane D8 motorway from Prague to Dresden. Two parallel almost identical bridges were under construction since 2008, the bridge was completed in 2010. The span of the arch is 135 m which is the second largest arch span in the Czech Republic. Since the Oparno valley is a part of the preserved natural area in the mountains called "Ceske Stredohori", special requirements and limitations had to be met during construction of the bridge. The location of the bridge in a beautiful countryside was one of the main reasons why an arch bridge concept was chosen for erection. The client (Road and Motorway Directorate of the Czech Republic) intended to build an admissible bridge for the strict environmental authorities. The arch bridge fits into the landscape with minimum interference. It is elegant, durable and sustainable structure, with a limited number of maintenance requiring details.

Fig. 1. *Visualization of the Oparno Bridge.*

2.2. Bridge foundations

Both arch and piers foundations were designed in the form of spread footings located in the steep valley slopes where they rest on the weathered rock layers of gneiss or sandstone in the depth of 3-5 m under the ground level. Stepped arch foundations are loaded by high vertical and horizontal forces. On the level of footing bottom there is a minimum bearing capacity of 600-800 kPa required, therefore the foundation area is 12-14 m long and 30 m wide. The piers between the abutments and arch footings are provided by the prestressed ground anchors to stand up to the uplift due to temporary cable-stays. With respect to available land acquisition some footing pits had to be ensured by sprayed concrete with anchored reinforcing mats or timber sheeting.

2.3. Piers and abutments

Standard abutments with hung-up wing walls have rounded edges and stone claddings from a local quarry. Both piers on the valley slopes and piers above the arch are designed as articulated walls with dimensions of 5.50 x 1.10 m (0.80 m above the arch). Pot bearings are installed on the last side piers only; all other piers are fixed to the bridge deck with hinges. The pier heights are variable from 10 m to 31 m depending on the ground level; piers above the arch are up to 17 m high.

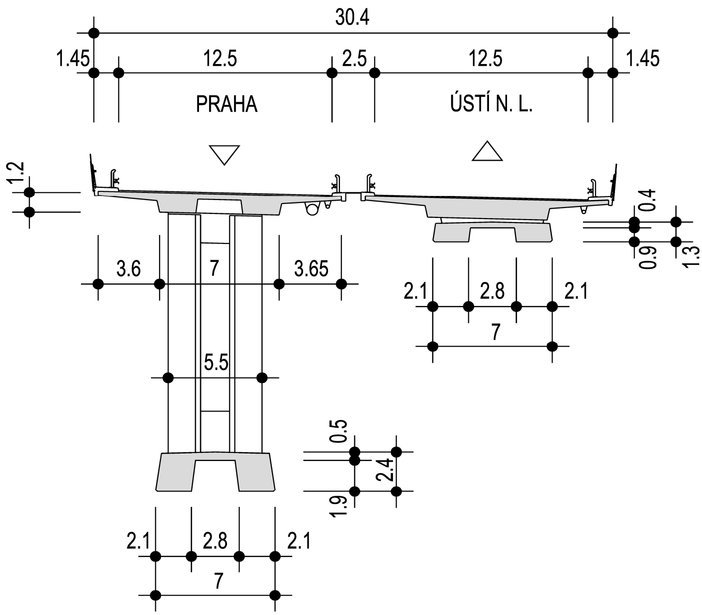

Fig. 2. Typical cross section at the arch base and crown.

2.4. The arch and the deck

The concept of the final design was prepared in the 1998 and then very long period for the land acquisition and construction permit for the whole motorway route was necessary. In that time the concrete class C30/37 was proposed both for the arch and the bridge deck with respect to available supply from concreting plants which are in a remote distance. After the tendering the contractor proposed higher class of the concrete to enable lightening of structural parts, construction equipment, material and transport savings. The reinforced arch of the concrete class C45/55 has variable thickness of 1.30-

2.40 m and width of 7.00 m, inclined side faces and two ribs connected by the upper slab. The reinforcement is spliced by overlapping as the contractor preferred this arrangement. The axis of the arch is straight, while the bridge deck horizontal alignment is slightly curved; the difference is up to ± 0.35 m. Bridge deck is a prestressed continuous beam of the class C35/45 with a flat double T section 1.20 m deep and 14.30 m wide. The shape was again selected with respect to the efficient use of the materials.

3. BRIDGE CONSTRUCTION

The construction of the bridge described in detail in the paper written by Vítek et al. [4]. In this paper some issues are mentioned only.

3.1. Piers and abutments

Due to steep slopes of the valley the access to the foundations was not easy for heavy machines. During the first excavations, it had been found that the geological conditions differ from those assumed in the tender design and foundations of the arch had to be moved downward and the span of the arch slightly increased. Foundations of the arch were excavated first; they carry also the highest piers used for supporting the arch by back stays. The large foundations were cast in parts, it was necessary to fix there a lot of reinforcement for the arch. A number of bars of 40 mm in diameter were used. The piers were cast into a self-climbing formwork designed by PERI. The height of one segment is 3.6 m. The speed of movement of the formwork can reach up to 250 mm/min. The formwork surface is made of timber. Concrete was cured properly and after demoulding covered by a PE membrane so that its fast drying was avoided. In the piers there are several openings, which are used for stays during the casting of the arch.

3.2. Bridge arch

The arch was built using a cantilever casting technology with temporary cable-stays and temporary pylons, no access to the valley during construction was allowed. The arch of the inverted U shaped cross-section is made of concrete of the class C45/55, which allowed for finding a good balance between the weight and load carrying capacity. At the bottom the bars 40 mm in diameter were used for reinforcement. The cantilever casting method of the arch required development of special form travellers for segmental arch construction. The length of the segment up to 6 m was found as optimal, considering the weight of concrete and the length of the reinforcing bars. One half of the arch is composed of 14 segments. The first two segments of the arch cannot be cast using the form traveller, since there is no space for its anchorage on the foundation. Therefore a classical formwork was used for the two segments and then the form traveller was assembled and prepared for casting.

During the casting of individual segments of the arch, they were subsequently suspended on temporary stays. If the cantilever becomes longer, a temporary concrete pylon on the pier above the footing of the arch is erected and used for installation of additional stays maintaining the stability of the arch. Before casting the closing joint in the top of the arch, the stays were used for final adjustment of the position of the individual cantilevers. After completion of the arch, two pairs of piers supported by the arch were cast. The construction technology required a careful deflection control and it was demanding on labour and management, but it was chosen as the most efficient technology in local constrained conditions.

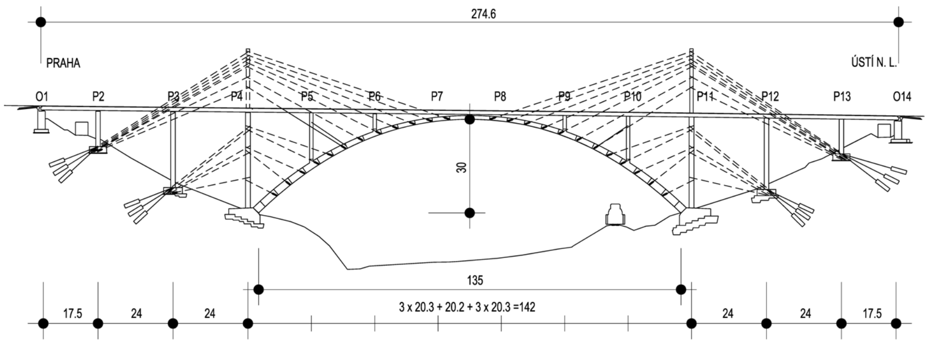

Fig. 3. Construction technology for arch bridge with back stays.

Fig. 4. Progressing cantilever construction.

3.3. Bridge deck

Bridge deck is a continuous girder with spans in range of 17.5 to 24 m of double T shaped cross-section. The casting procedure was considered from many points of view; finally an overhang movable scaffolding system (MSS) with two main top beams above the concrete deck was developed again in co-operation with PERI and STRUKTURAS. The main longitudinal beams are supported on special steel supports over the piers. At the ends of the main beams, there are long cantilevers which are used for the moving of the MSS into a new position. Above the longitudinal beams, the transversal frames carry the weight of the formwork and fresh concrete using the stays coming through the concrete deck. Two MSS sets are used – each moving from the abutment to the centre of the arch.

3.4. Sequence of construction

After completion of foundations and piers outside the bridge arch, the bridge deck is built from both abutments by MSS. Simultaneously the arch is cast from the footings. The three spans which are supported by piers outside the arch form a tie and allow for erection of the temporary pylon. After closing of the arch, a part of the stays and the temporary pylon are removed and form travellers are moved along the arch down to foundations. Then the MSS is used for casting of the central part of the bridge above the arch. The casting procedure must be symmetrical to avoid excessive stresses in the arch. When the first bridge is completed, the equipment (form travellers for the arch and MSS) will be moved and the second bridge will be erected.

Fig. 5. *Free cantilevering of the second arch.*

4. OPTIMISED DESIGN FOR SUSTAINABILITY

Considering current environmental issues, it is necessary to evaluate and verify the impact of design optimization and value engineering on the environmental performance. The beneficial use of a higher concrete class is reflected in the reduction of concrete volume, lower consumption of cement and thus reduction of CO_2 emissions which are proportional to cement consumption. The conceptual design is the most significant phase where the environmental issues are influenced. The comparison between the reference tender design and detail design of the Oparno Bridge is shown in the following Tab. 1:

Table 1. *Material and cement saving due to proposed variation.*

		Arches	Piers	Deck	Total
Tender Design	Concrete Class	C30/37	C30/37	C30/37	
	Concrete Volume [m^3]	4 243.0	2 077.7	6 140.0	12 460.7
	Cement Mass [t]	1 654.8	810.3	2 394.6	4 859.7
Detail Design	Concrete Class	C45/55	C35/45	C35/45	
	Concrete Volume [m^3]	2 563.2	1 996.1	5 164.4	9 723.7
	Cement Mass [t]	1 102.2	838.4	2 169.1	4 109.6
Change	Concrete Quantity [%]	-39.6	-3.9	-15.9	-22.0
	Cement Quantity [%]	-33.4	+3.5	-9.4	-15.4

Cement consumption relevant for the concrete classes is as follows: C30/37... 390 kg/m3, C35/45... 420 kg/m^3, C45/55... 430 kg/m^3. As regards durability all proposed modifications have increased the performance of concrete. The concrete of arches C45/55 can be considered as truly high performance concrete. Its mix design contains 30 kg/m^3 of fly ash, 30 kg/m^3 of milled limestone, 4.2 l/m^3 of superplasticizer, w/c ratio of 0.4, air content of 2.0-4.5 %.

Fig. 6. *Load test.*

The total reduction of concrete volume of 2737.0 m3 and cement mass of 750.1 t represents quite significant allowance to protection of environment due to more than 15% reduction of the CO_2 emission. Further reduction of the impact of bridge construction on the regional environment was gained by the reduction of material transport. The saving was achieved mainly due to optimized structural design with higher strength of concrete however the materials still remain in the standard range of concrete technology. In spite of the reduction of sectional areas the designer kept the given depth of sections and therefore the consumption of the reinforcement remained virtually the same as in the tender design. The saving is relevant to utilization of compressive strength in the sectional design, i.e. most beneficial effect is received for arches and practically no reduction is achieved for the piers, where the governing design aspect is slenderness of structural elements.

The load test of the bridge was carried out in 2015 after completion of the noise barriers and other bridge accessories. The compliance between calculated theoretical and measured values was excellent, the ratio was mostly close to 0,85.

5. CONCLUSIONS

The Oparno Bridge was completed in the autumn of 2010. In spite of complicated geotechnical conditions and demanding technology of construction both the time schedule and the final price of cca 400 million CZK (15 mil. EUR), i.e. 48 700 CZK/m^2 (1830 EUR/m^2) was kept. The economic aspects of arch bridge construction caused that arch bridges can be seen quite seldom. Nevertheless, a large span arch can be both economic and viable alternative to the other types of bridges. The arch bridges are distinctive and characteristic elements of the landscape and form its significant landmarks.

The consumption of main materials of the arches and deck is quite low:

Concrete:	0.938 m^3/m^2
Reinforcement:	172 kg/m^2
Prestressing steel:	19.3 kg/m^2

The main participants involved on this project are as follows:

Client:	Road and Motorway Directorate of the Czech Republic
Designer:	PONTEX Consulting Engineers Ltd
Contractor:	METROSTAV, a. s., Division 5

REFERENCES

[1] KALNÝ, KVASNIČKA, BROŽ, VÍTEK, The Oparno Arch Bridge, *Proceedings of the fib 2009 Symposium in London, June 2009*

[2] KALNÝ, KVASNIČKA, BROŽ, VÍTEK, Arch Bridge at Oparno, *Proceedings of the 5th Central European Congress on Concrete Engineering, Baden, Sept. 2009.*

[3] KALNÝ, KVASNIČKA, NĚMEC, BROŽ, VÍTEK, The Oparno Arch Bridge – Application of Modern Technology for Classical Structure, *Proceedings of the 3rd fib International Congress, Washington, 2010.*

[4] VÍTEK, KOLÍNSKÝ, Construction and Monitoring of the Oparno valley Bridge, *Proceedings of the the 8th International Conference on Arch Bridges, Wroclaw, Poland, 2016.*