# Footbridge in Podebrady
# The benefit of unusual combination of concrete and steel

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## Summary

In December 2002 a new bridge for pedestrians and cyclists was opened over the navigation channel in the spa town of Podebrady at a location of scenic beauty. The superstructure of the footbridge consists of a slender continuous deck slab supported by I- and Y-shaped twin steel tube struts and steel tube strut frame acting compositely with the concrete deck slab in the main span, of 31 m length. Both for construction and for operation this structure is very economical and blends in with the local environment and landscape.

**Keywords**: footbridge; hybrid structure; composite section; frame; partial prestressing; aesthetics.

## 1. Introduction

The town of Podebrady is situated in flat and fertile lowlands of the River Labe on the ancient route from Prague to Eastern Bohemia and Poland. The growth of the town was influenced by discovery of strong carbonated mineral springs in 1905. Since that time the town has been changing to a spa resort, specialized in heart cures and vascular diseases. Traffic calming and the improving of the environment is a permanent task when considering all future developments. Pedestrian and cycle transport has a long tradition and has a significant impact on services and recreation for both residents and spa guests in Podebrady.

The new footbridge, at the lock in Podebrady, can be found in an attractive location with scenic beauty within the vicinity of a historical castle. The path passes through the park at the Skupice River tributary, elegantly spanning the navigation channel, along the site of the monumental hydroelectric power station on the Labe to the lake with a recreational area. To cross the main stream of the Labe the existing footbridge above the weir barrier was restored and opened to the public after a long closure. The footbridge is part of a long distance cycling route along the Labe River.

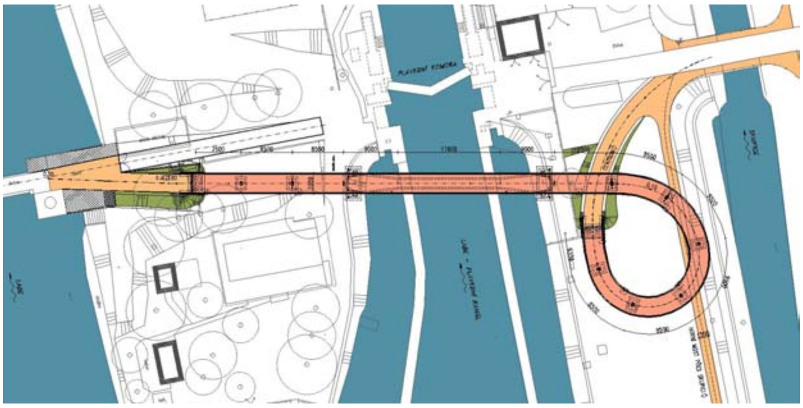

*Fig. 1 The footbridge layout*

## 2. Aim and conceptual design

Three variants of the structure on two alternative route alignments were studied in 2001 during selection of the most suitable structural concept. The authors looked for an adequate, elegant and economical structure, which provides users with a comfortable and valuable route with interesting views of landscape and at the same time blends in with the environment when looking from the town.

For implementation, the straight route above the upper lock head gate, with a spiral ramp on the left bank was selected due to its location. It is farther from the castle and in the shade of greenery. The descent ramp to the existing bridge over the Skupice River tributary is sensitive termination of route. This is due to the need to avoid another bridge over the Skupice, which would spoil the vista to the castle along the bank path. As the most convenient structural concept we chose a slender continuous deck slab supported by subtle steel struts and strut frame in the main span. This arrangement is in harmony with landscape close to the river with spreading trees, which is naturally dominated by the castle and the power station towers. The structural form is subordinated to smooth functionality and the structural concrete and the steel show their material merits. Naturalness and simplicity of both the whole and details is a consequence of minimalist conception. During evaluation the Client appreciated, apart from very advantageous total cost, the simple clean lines, innovative use of steel/concrete composite interaction in the main span and the respect for all greenery.

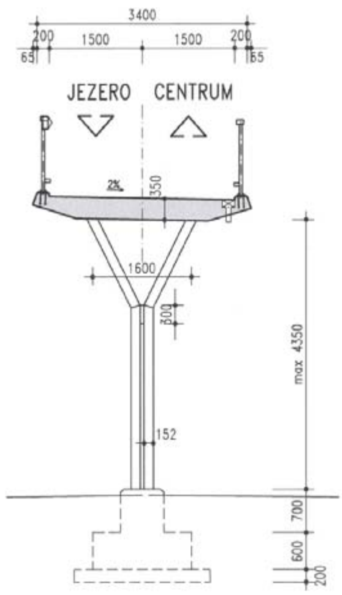


*Fig. 2 Cross section*

The total length of the footbridge is 122 m, which consists of 13 spans. The main obstacle is a navigation channel 28 m wide with required headroom of 7 m. The pedestrian path is 3 m wide. Due to the limited length available, the maximum permissible longitudinal gradient of 8.3% was applied. The reinforced concrete deck slab, only 0.35 m thick, was designed for the whole length of the bridge, but above the frame it is partially prestressed. The small thickness is possible because all spans above the ground are not longer than 9.5 m and the main span of 31 m is supported, in the central 17 m long section, by a coupled steel frame with inclined struts. The legs of the frame stand astride for better lateral stability. The other slender and partly rocking steel supports are not restricting to the volume changes of the concrete slab. The guided elastomer bearings and the expansion joints are placed at the abutments only. The upper surface of the bridge deck has a sprayed waterproofing applied to it. Lighting is installed within the handrails and the crossing is designed with respect to the disabled.

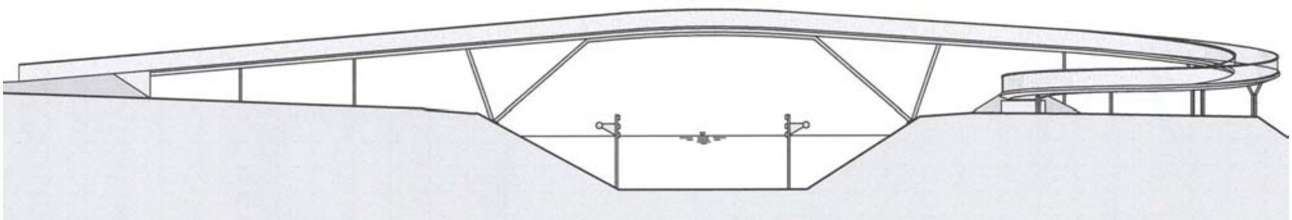

*Fig. 3 View of the footbridge*

## 3. Foundation

The foundation was complicated due to deposits of loose sandy backfill up to 5 m thick, which lay on the disintegrated marl bedrock. Abutments and ordinary supports rest on the shallow foundations 1 m deep. The top layer of soil was compacted and improved with cement. The foundation blocks are of class C25/30 concrete and the abutments, with short parallel wings, are of class C30/37 concrete.

Each of the foundation blocks of the main span is supported by 3 micropiles, 10-11 m long with 5 m root embedded into the rock. Micropiles stand astride around the inclined axis to resist considerably skew loading with maximum reaction of 27 tonnes each. Reinforced concrete blocks under the frame of the main span were cast-in in two phases, the first one up to the setting level before erection of the frame, the second one up to the final shape level.

## 4. Steel members

All internal supports between abutments are designed in steel tube. The outstanding feature of this solution is lightness, ease and fast speed of construction and very low consumption of materials. The steel members of the substructure are protected by a 4-layer coating 320µm thick. The steel struts close to the main span are designed in the Y-shaped twin tubes Ø150/12mm of S235 steel. Other more distant and lower supports are designed as rocking struts in the I-shaped twin tubes Ø150/8mm of the same steel. All strut end connections are designed as hinges, whereas upper end connections of Y-shaped supports are fixed to the deck slab. These Y-shaped supports contribute to the lateral stability of structural system.

The strut frame consists of Ø 273/12mm tubes of the S355 steel. In the middle part of the main span, which is 17 m long, the tubes act compositely with the concrete deck slab. The shear connection is ensured by large-toothed longitudinal rib with 3 transverse plates at both ends. The outside back-inclined frame legs are fixed to the deck slab. The strut frame is fixed at all foundation foot-blocks by anchored bolts that were used for precise setting and embedded later in concrete.

*Fig. 4 The steel supports*

## 5. Superstructure

The slender reinforced concrete deck slab is designed of the class C35/45 concrete. The durability of the structure and its resistance to de-icing agents was increased by use of high performance concrete with air content of 2%. The deck above the strut frame is partially prestressed by 8 profiled unbonded tendons of the Monostrand type ϕLs15.7 mm and apart that, its middle section is coupled with the steel strut frame.

Due to the sharply curved spiral ramp with minimum radius of 8 m, the reinforcement detailing became complicated, both for design and execution. The crack control was decisive at the top deck level fibres close to supports, namely with respect to the superstructure shape, slenderness, point supports and reinforcement stresses at bending. For the exposed parts of superstructure above the supports, the durable protective coating is applied with sufficient ability to seal the eventual cracking.

## 6. Structural analysis

For the analysis of the first construction stage (middle part with strut frame), a detailed 3-D frame model was prepared with all relevant members. The individual members of the scaffolding and permanent structures including boundary conditions were step by step activated, loaded and released with respect to the proposed method of construction. This model was used for optimising scaffolding profiles, steel tubes of the frame, deck prestressing and construction program. Further it was used for setting formwork initial levels, stress checking and deflection control.

*Fig. 5 Truss girder after erection*

The behaviour of the structure under service loading was studied on the extended 3-D frame model of the whole footbridge, where the initial state from the first stage was taken into account. All sections of the reinforced deck, steel struts and strut frame were verified considering the time-dependent material properties and from which the structural camber was determined.
The prestressing in the first stage is required due to high negative bending moments close behind the ends of the coupled part of the frame (by 70% higher than in other spans) and for reducing shrinkage effects in the concrete deck. The average stress level resulting from prestressing is relatively low – cca 1.5 MPa. The structure was verified as a reinforced one with external loading by unbonded prestressing.
In view of the complex bridge geometry, considerable attention was given to analysis of the temperature effects and the concrete volume changes. Both analysis and experience showed that for extremely curved and slender structures the temperature gradient caused by the sun shining is very important for torsional effects and the proper arrangement of supports.

*Fig. 6 Under the main span*

## 7. Dynamic behaviour

Lightweight footbridges have to be analysed in loaded and unloaded state for satisfactory vibrational behaviour. On the 3-D frame model a dynamic analysis was carried out to find natural frequencies and their shapes. The model was used for the study of the most suitable support arrangement, member stiffness, end connections and other details. It was found that reasonable changes of member properties and state of loading have no significant influence on the structure. Among the decisive factors belong to mass and stiffness of the bridge deck and geometry of the strut frame. Both are positive with substantial damping features.

*Table 1 Review of natural frequency modes*

| Mode | Frequency [Hz] | Direction | Remarks |
|---|---|---|---|
| 1 | 0,8 | Transversal | Local effect - part of ramp curved in plan |
| 2 | 1,6 | Longitudinal | Small amplitude, excitation not probable |
| 3 | 2,8 | Longitudinal | Small amplitude, excitation not probable |
| 4 | 3,4 | Transversal | Main span, out of dangerous range 1 Hz |
| 5 | 4,4 | Vertical | Main span, out of dangerous range 2 Hz |

*Fig. 7 The main span*

*Fig. 8 The project completion in 12/2002*

At longitudinal vibrations there are also secondary enforced vertical deformations of the main span caused by stiff triangle supports. Excitation of this mode by pedestrians is not probable. Due to its own arrangement and system of supports the structure has sufficient viscous and structural damping. The dynamic analysis proved that the footbridge is not sensitive to the live loading, and that neither structural adjustments nor dynamic response analysis was necessary. After the bridge opening this conclusion was confirmed.

## 8. Method of construction

The contractor and the designer proposed jointly, for the main span, a method of construction that represents technically interesting and unusual features. The basic idea was to use permanent strut frame as a part of scaffolding with formwork for casting-in the concrete deck slab, i.e. idea of self-supporting scaffolding. This method of construction required difficult time-dependent analysis, but that enabled elegant and fast construction of the main span over the navigation channel.

The scaffolding was carried out as two steel truss girders that were "suspended" on the strut frame. In the middle section the frame steel tubes formed an upper part of the truss girder, the diagonals and the vertical members were welded straight onto the connecting plates. The suspended scaffolding formed the continuous truss girder of 3 spans on the inclined permanent struts without any temporary supports. The scaffolding and the strut frame worked together in several construction stages. The state of stresses in the frame is substantially influenced by this method of construction.

*Fig. 9 Scaffolding and formwork*

The steel strut frame and scaffolding were fabricated integrally and then assembled from 4 units on site close to the bridge. The whole steelworks of weight 17 t was lifted by heavy crane and installed into its final position. Four inclined strut legs were laid on bearing plates, each plate rested on 4 anchorage bolts embedded into the concrete blocks. This arrangement enabled easily instant contact for all legs. Both lifting and seating lasted 15 minutes only, then precise rectification by bolts was applied to comply with all designed levels and coordinates. When the designed position was reached, all legs were welded to the anchorage plates and the space between the plates and the foot-blocks was filled with special high strength mortar. The selected method of construction caused higher stresses in the first stage of construction (therefore S355 class of steel was required) but also provided substantial saving in construction time and the scaffolding costs.

*Fig. 10 At the navigation channel*

*Fig.11 The spiral descent ramp*

## 9. Conclusion

The contracting company JHP s.r.o. executed a project with total value of 10.8 mil. CZK (338.550 EUR), that consists of 19 structural units. The main unit was the footbridge over the navigation channel having cost of 7.06 mil. CZK (221.300 EUR), that represents only 16.400 CZK (514 EUR) per superstructure's square meter. The footbridge was open for public on the 16th December 2002 after no more than 4 months from the commencement of contract implementation.
The low cost of construction works does not always mean an advantage. Regarding the footbridge in Podebrady it was not certainly
achieved on account of quality and durability of the structure. The innovative design caused a keen interest of contractors during tendering. And the speed of construction and attained consumption of materials give really very low figures (comparable depth of the structure is 0.325 $m^3/m^2$, consumption of structural steel for the frame and all supports is 27.8 kg per $m^2$ of superstructure). We believe that good functionality and low consumption of materials are basis for ecologically favourable appraisal.
The search for elegant structures that are ecologically viable, technically possible and economically reasonable is a challenge for the consulting engineers and the most exciting part of their work. The optimum means always to find equilibrium not only in given forces but also to all given contextual conditions. Whether the aim is fulfilled that is left for the opinion of public for whom the work is destined.
The footbridge in Podebrady received the award "Outstanding concrete structure in 2001-2002" from the Czech Concrete Society.

*Fig.12 Play of simplicity - fluent curves of the concrete deck on the subtle steel supports*