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New Bridge Across the Vltava in Prague

Nouveau pont sur la Vltava à Prague

Die neue Moldaubrücke in Prag

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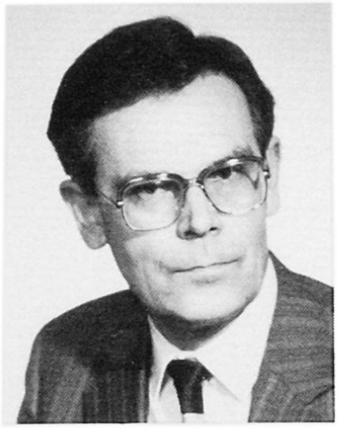

Jiří Hejnic, born 1935, received his civil engineering degree from the Czech Technical University in Prague, Czechoslovakia, in 1958. In 1976 he was awarded a PhD for his work on thermal stresses in concrete bridges. He has designed several large prestressed concrete bridges built in Czechoslovakia.

SUMMARY
A big and very irregular prestressed concrete bridge across the river Vltava, in Prague, is at present under construction. The paper presents information concerning the design, structural analysis, model tests and construction of the bridge. Some interesting results of measurements made during the construction are also included.

RESUME
Un pont en béton précontraint, de forme très irrégulière, sur la rivière Vltava est en construction à Prague. L'article présente le projet, l'analyse structurale, les essais sur modèle et la construction du pont. Certains résultats intéressants de mesures en cours de construction sont aussi mentionnés.

ZUSAMMENFASSUNG
In Prag wird eine grosse und sehr unregelmässig geformte Spannbetonbrücke über die Moldau gebaut. Der Beitrag umfasst eine Beschreibung der Brücke, die Ergebnisse der statischen Berechnung und der Modellmessungen sowie den Bau der Brücke. Einige interessante Ergebnisse der Kontrollmessungen auf der Baustelle werden zusätzlich gezeigt.

1. INTRODUCTION

As other European big cities the capital of Czechoslovakia, Prague, is building its transport system, too. The problems of automotive transport is being solved by construction of the basic higway system. The overall length of roads incorporated into this system will exceed 200 km and will be longer than, for example, the completed Prague - Brno motorway. By the end of 1983 more than 63 km were already in use, the most important of which was the North - to - South Expressway, linking up with the operating D 1 (Prague - Brno - Bratislava) motorway in the South and the designed D 8 (Prague - Ústí n. L.) motorway in the North.

At present the greatest importance for Prague traffic has the East - to - West connection which is under construction now. The most complicated and costly structure of this part of the system is the new bridge across the Vltava below the Barrandov Hill having the name of Antonín Zápotocký, the former president of the Czechoslovak Socialist Republic. The bridge will be of great importance also for further development of the City which has been spreading for decades southwards along the Vltava. During this period major housing estates have grown in this territory but in spite of this development, however, the river Vltava has remained an obstacle for the higway traffic at a distance of almost 12 km.

Fig. 1 - Photo of the architectural model of the bridge

In the period 1971 - 1977 the Institute for Traffic and Structural Engineering Design prepared a number of variants of the central ring in this sector, including also 13 alternatives of a bridge across the Vltava. The resulting, thirteenth variant, whose initial design was prepared in 1977, subordinates its form fully to the traffic engineering design (Fig.1).

2. DESCRIPTION OF THE BRIDGE STRUCTURE

The extent of the Antonín Zápotocký Bridge is determined by the width of the Vltava river bed and the highways on both bridgeheads, the skew of the crossing and the width of the bridge itself. Structurally the bridge has been designed as a continuous six span girder spanning 34,66 + 61,00 + 71,00 + 72,00 + 66,00 + 45,99 m (Fig.2). Along the major part of its lenght the width of the bridge is variable in accordance with the alignment of the individual lanes branching off the bridge. However, even the smallest width of 40 m means that Antonín Zápotocký Bridge, with four lanes in each direction and pavements on both sides of the bridge, will be the widest of Prague bridges.

Both halves of the bridge, representing separate superstructures, have different plans determined by the traffic engineering design, and are supported by common piers whose form corresponds with structural, technological and architectural requirements. The upstream half of the bridge is joined by a two span ramp connecting the left bank Chuchle radial with the central ring. The actual Vltava river bed is overcome by three main spans (71+72+66 m) at an angle of $53^{\circ}26'$.

The depth of the superstructure is constant - 3.0 m - along the major part of its passage across the Vltava river bed. The depth of the remaining part is variable from 3.0 m to 1.6 m in the place over the abutments. The haunch is so designed that the planes, in which the depth of the superstructure is constant, are perpendicular to the axis of the central ring regardless of the continuously variable skew of the bridge. Both halves of the bridge superstructure have a box cross section with four webs of a constant thickness of 60 cm; the ramp has a box cross section with two webs 80 cm thick. The upper flange of the box girder is 23 cm thick in the more regular part of the bridge; in the ramp with a clear width of 6.30 m the thickness rises to 35 cm. The thickness of the lower flange increases from 15 cm towards the supports to 90 cm in the haunches.

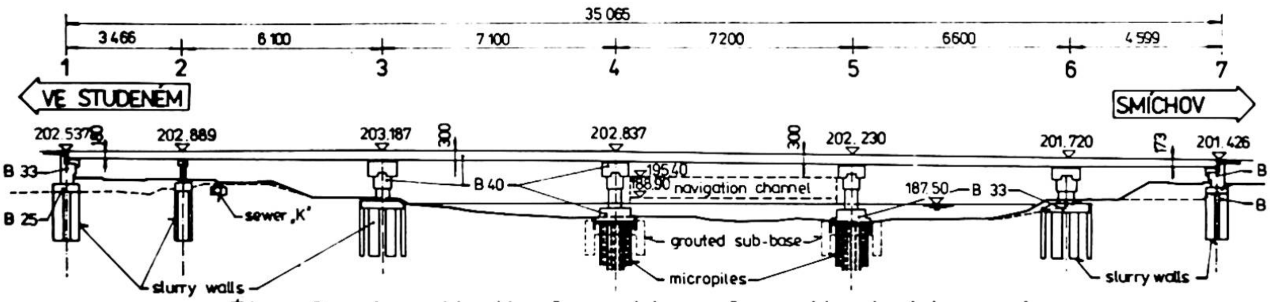

Fig. 2 - Longitudinal section along the bridge axis

While the design of the superstructure has been more or less conventional, the form of the four main piers both in the river bed and on both river banks designed by Ing. arch. Karel Filsak in unusual, while fully complying with the requirements imposed on the substructure of this bridge. The piers meet the Vltava water level or the ground level by a rounded shaft, supporting an oversized prestressed concrete capping beam following the direction of the river flow and river banks respectively (Fig. 3). The superstructures are supported by four bearings, supported, in turn, by bearing walls, perpendicular to the capping beam direction. Apart from visually relieving the superstructure and equalizing the differences in height, longitudinal gradient and transverse pitch of the bridge deck, these bearing walls have also an important structural function by decreasing the skew of the bridge bearing.

The superstructure and the major part of the piers is of Class 40 concrete, mild steel reinforcement of class 10 425 in dia. from 10 mm up to 32 mm. Prestressed concrete reinforcement consists of steel cables of 1 dia. 5,5 mm and 6 dia. 5,00 mm tempered steel wires. The tendons, consisting of 12 dia. 15,5 mm cables, have a nominal load bearing capacity of 2 000 kN. Vertical prestress of pier capping beams and the webs of the superstructure and the longitudinal prestress of the bridge deck flanges above supports will be ensured with dia. 32 mm prestressing bars of class 10 607 steel. In transverse direction the superstructure is not prestressed, being designed as a reinforced concrete structure.

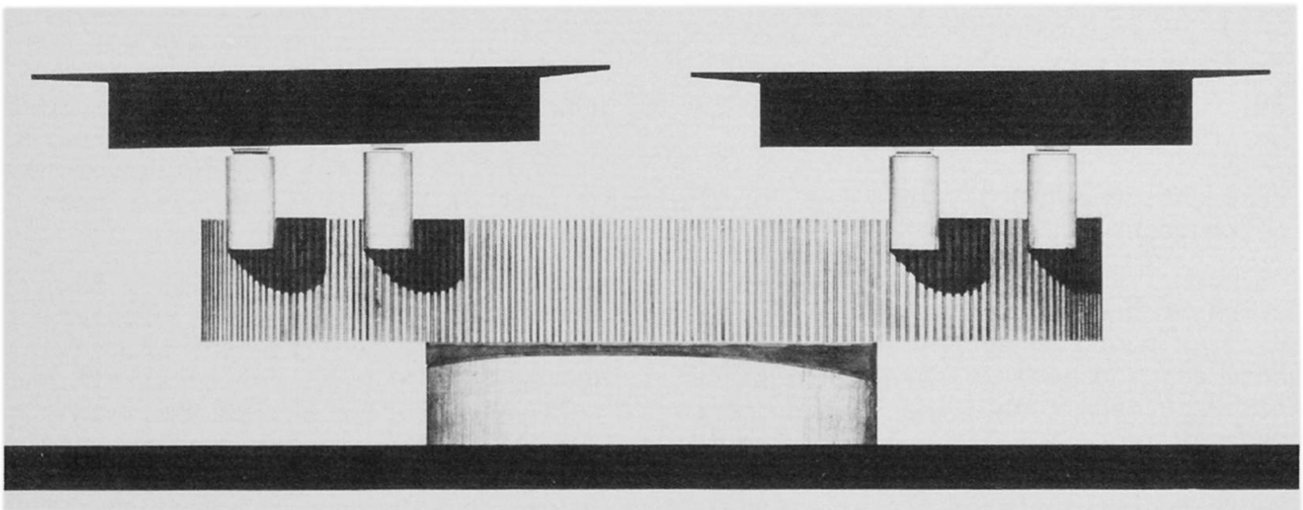

Fig. 3 - Architectural view of the bridge pier with superstructure

3. STRUCTURAL DESIGN

For the purpose of a detailed structural analysis it was necessary to define first mathematically the complex form of the bridge structure in space, i.e. to formulate a digital model of the bridge. For this purpose a general program for a 9825 T Hewlett Packard calculator was prepared to solve, on the one hand, the calculation of the coordinates of bridge edges, and that of structural characteristics of cross sections on the other, and, finally, to draw the individual cross sections on a plotter (Fig. 4). More than 650 such drawings were used directly as shuttering drawings in the phase of working drawing design.

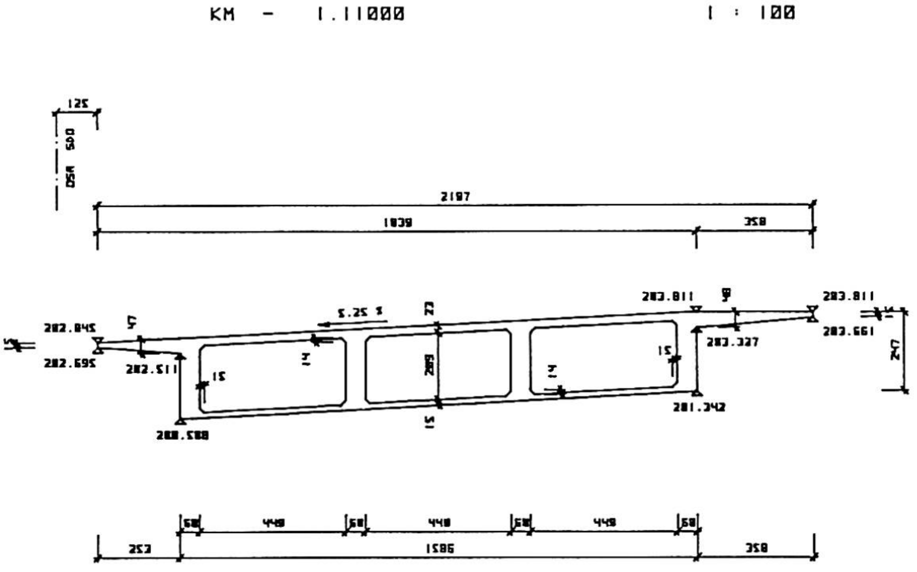

Fig. 4 - Cross section drawing generated on the HP 9825 T plotter

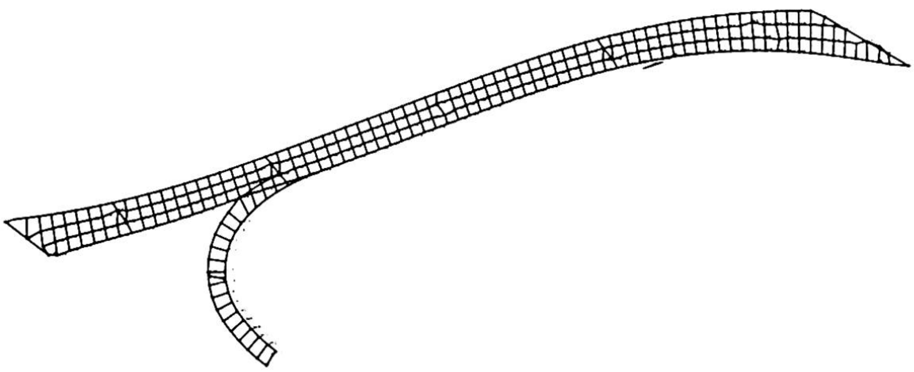

Fig. 5 - Statical scheme of a grillage for one superstructure

Structural analysis was elaborated by several methods and supplemented with model tests and measurments. One superstructure was replaced with a grillage of 360 nodes and 610 bars, solved for more than 200 loading stages (Fig. 5). To create the most effective combination of loading states a special program was prepared. The most irregular parts of the structure, such as the first right bank span, the ramp and its connection with the bridge structure, were designed by the finite element method. With regard to the irregularity of form and the necessity of the solution of the bridge as a spatial structure a new program system was devised. For the design of Antonín Zápotocký Bridge a technological line was set up, consisting of Hewlett Packard 9825 T calculator for data preparation and design of reinforcement, the IBM 370 computer for the major part of structural analysis and the Kongsberg DC 300 plotter for graphic output.

The number of unusual tasks involved in structural analysis included also the design of prestressed concrete capping beams of bridge piers. In case of pier No. 5, situated near the connection of the ramp with the central ring bridge, whose capping beam is stressed most of all beams, the internal forces attain the following magnitudes: the bending moment M = 307 MNm, torque K = 22 MNm, and shearing force T = 55 MN. The extraordinary forces applied to the capping beam are also reflected by its dimensions: height 5,0 m, width as much as 4,2 m. With regard to the state of stress of the structure and reinforcement arrangement it was necessary to concrete the beam without working joints; the almost 600 cu.m.

of Class 40 concrete had to be placed in a continuous process, without any interruption. Since the contractor could not ensure the cooling of the concrete mix or its components, it was necessary to analyze also the state of stress of the structure due to the development of hydration heat.

4. MODEL TESTS

In the time of the preparation of working drawings three models of parts of the bridge were also manufactured and tested. The reason for it was the extremely irregular form of the superstructure, complexities of load combinations and the overall arrangement of the piers as well as the new method of structural analysis. The model tests were intended to verify the correctness of assumptions of structural analysis, ascertain the actual state of stress and strain of the superstructure and the limits of load bearing capacity of the bridge pier. Altogether two models of the most irregular parts of the superstructure were made of resin concrete and one model of the bridge pier of cement concrete.

The models of the superstructure on the scale 1 : 30 were not prestressed and were tested only in regions of permissible stresses of the model material for design loads. The resin concrete used made it possible to manufacture models of very complex shapes at good workability and without the origin of dangerous internal stresses or volume changes. The unfavourable effects of creep were reduced in model tests to the minimum by the selected load magnitude and the organization of tests. The load was applied, on the one hand, in the form of concentrated loads, and in the form of surface loads on the other. The model loading and the test evaluation was ensured by the Building Institute of the Czech Technical Iniversity,Prague (Fig.6).

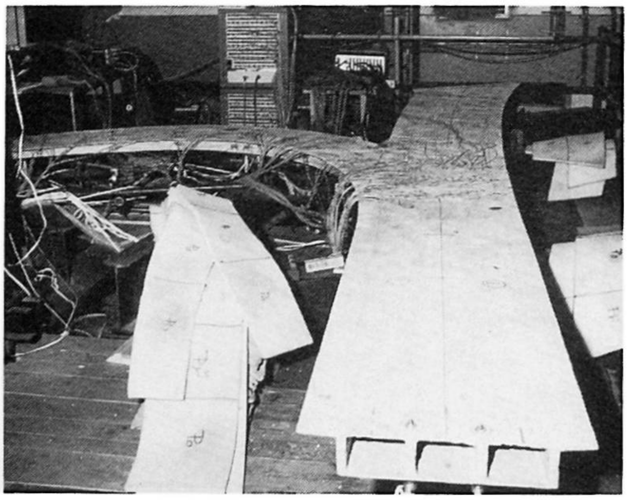

Fig. 6 - One model of the superstructure of resin concrete

The pier model on the scale 1 : 10 was prestressed with cables and bars analogously with the pier prototype and loaded until failure. The capping beam of the model was prestressed with 9 dia. 15,5 mm single cables, and 4 dia. 12,5 mm wire cables which replaced the tendons with a smaller diameter of curvature. The region between the bearing walls and the outer bearing wall were further prestressed verticaly with dia. 10,5 mm bars of Class 10 607 steel, similarly as the piers, to reduce the effect of torsion and transverse flexure. The loading test of the model was carried out by the Building Research Institute in Veselí n. L.

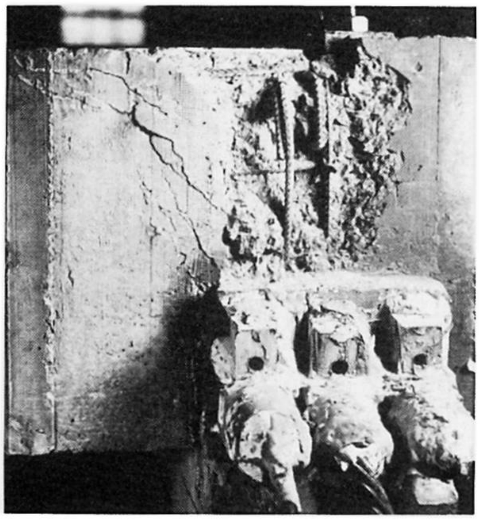

Fig. 7 - Crushed bearing wall after pier model test

The model failed under the combination of crushing of the outer bearing wall and its shearing - off along the capping beam surface (Fig. 7). Almost simultaneously also the load bearing capacity of the capping beam was exhausted, which was destroyed above the pier shaft by mighty horizontal cracks and began to crush in its lower part. The loading test of the model has proved that dimensions of the pier, its prestressed and mild steel reinforcement were correctly designed and its parts have approximately identical load bearing capacity. The tests ascertained the following most important factors:

- safety margin against ultimate strength s = 2,64
- cube strength of Class 40 concrete after 83 days from manufacture = 42,8 N/mm^2

The model tests have proved the principal agreement of structural design with the test results and have confirmed the safety of the designed structure. A detailed description of the tests, their principal results and their use for the bridge design have been described in [1].

5. CONSTRUCTION

With regard to the irregular shape of the bridge the whole superstructure is concreted on steel centering. For both the design and the contractor the irregular form of the bridge meant increased labour requirements, in the case of construction imposing also high requirements on deficient professions of carpenters and reinforcement makers.

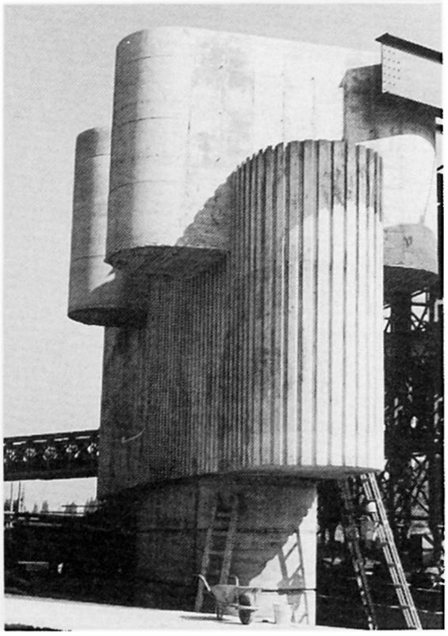

Fig. 8 - Ramp pier on the left hand river bank

The work on the site began in July 1978 by founding two river bed piers and, subsequently, by founding abutments and both river bank piers. The river bed piers are founded on a pile frame of micropiles, built in a double cofferdam under the protection of two-phase grouting consisting of a clay - cement and subsequently chemical mix on the basis of water glass and ethyl acetate. The piers and abutments on both Vltava river banks are founded on slurry walls 80 cm thick. In the construction of the bridge substructure the high quality of work and the manufacture of architectural concrete of various textures were accentuated. By autumn 1981 the reinforced concrete piers and abutments were completed, as seen in Fig. 8 showing the ramp pier on the left river bank. The labour requirements of the four prestressed capping beams of the river bank and river bed piers are considerably higher than those of analogous reinforced concrete structures.

Fig. 9 - Construction phases of the superstructure

The construction of the superstructure proceeded from all three abutments continuously. The concreting was carried out in three phases successively - the lower flange, the webs and diaphragms of the box girder, and finally the upper flange of the bridge deck with cantilever ends. The concreting proceeded to the length of one construction phase, corresponding with the length of the span between the cross sections of zero bending moments due to the dead weight of the structure. The individual operations were coordinated in time so that at least two spans were in construction and the teams of specialized workers could pass from one workplace to another (Fig. 9). The site of the upstream half of the bridge superstructure was serviced from a temporary steel bridge connecting both river banks. After the completion of one half of the bridge it is used for both public and site transport, and the supports of the temporary bridge are used to support the centering for the concreting of the downstream half of the bridge.

With regard to construction the organization of concentrated concreting is worth mentioning. In the course of these operations the volume of Class 40 concrete placed in one operation attains as many as 600 cu.m.. The concrete mix contains a plastifier with retardation effect, called Ralentol.

After its first use in the construction of the motorway bridge in Beroun the new Mono 2 000 kN prestressing system was used in the construction of the Antonín Zápotocký Bridge. More than 360 kilometres of dia. 15,5 mm cables of this system were successfuly applied and prestressed in the piers and the superstructure. For vertical prestress by means of dia. 32 mm bars of Class 10 607 steel the grout-free technology was used to reduce the labour requirements, based on the nut and bolt anchorage of bars, which are provided with a coating on the basis of atactic propylene, protected with polyethylene foil to prevent the bond between prestressing reinforcement and concrete and to protect the bars from corrosion. This technology was used for the first time in Czechoslovakia.

6. EXPERIMENTAL RESEARCH

According to the irregular form of the bridge and the new methods of structural analysis, not only model tests but also experimental research of strains , stresses and temperature was carried out on the Antonín Zápotocký Bridge during the construction and in the time of the static loading test. The observations enable the verification of the assumption of structural design of the bridge as well as the assessment of the load bearing capacity of the structure in its performance. In four prestressed main piers (in the river bed and on both river banks) and in the superstructure 518 acoustic strain gauges and 256 acoustic thermometers were built. In the superstructure the strain gauges and thermometers were fitted in 18 characteristic cross sections of the structure. The creep and shrinkage of concrete was observed directly in the piers and in special large specimens concreted of concrete mixes from the characteristic parts of the construction phases of the superstructure. The strain gauges built in these sections were used for the determination of the moduli of elasticity of concrete, too. For measurements of creep and moduli of elasticity hydraulic jacks built in piers and control specimens were used.

Fig. 10 - Completed half of the bridge under test loading

The measurements of hydration heat made on the piers and abutments, where about 600 cu.m. of concrete were placed in continuous process, showed principal agreement with the values of heat distribution obtained from the calculation. Experimental research made in the time of prestressing the Mono 2 000 kN tendons and during decentering had to control the state of deformation as well as the state of stress, and was used also by the contractor for precise planning the constructional phases. Before the static loading test measurements of values of the moduli of elasticity of superstructure were made, the mean value being 32 350 N/mm^2 for the stress of 3,3 N/mm^2 and 31 417 N/mm^2 for the stress of 6,6 N/mm^2. The stresses during the loading tests can be obtained directly from the strain values, as in short time measurements concrete creep and shrinkage can be neglected. Also the temperature changes were measured with maximum value of 0,6°C, which corresponds the change of strain $0,3.10^{-6}$ which is under the precision of strain gauges used.

In the time of the static loading tests eight test loading positions were studied. One of them with 30 trucks in both largest spans is shown in Fig. 10. The deformations for the test loadings were calculated by the designer using the same grillage scheme for the superstructure as in structural analysis. The measured values of deformations were similar to the calculated, the mean value of this ratio being 0,901. The strains were measured in 18 cross sections of the superstructure for all 8 test loading positions. An example of calculated stresses from measured strains for the last left bank span is on Fig. 11, where the values in brackets show the comparison with structural design values. In structural characteristics of the bridge the cornices and other parts of reinforced concrete were not calculated, and so the results of stresses in the upper flange are measured smaller than calculated. The measurements have proved a good agreement with design assumptions.

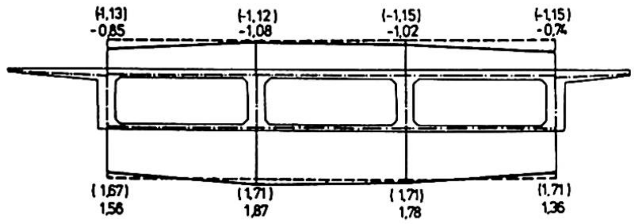

Fig. 11 - Measured and calculated stresses for test loading

7. CONCLUSION

The Antonín Zápotocký Bridge is the biggest bridge under construction at present in the framework of the basic highway system of Prague. Although - with regard to the approved traffic engineering design - it was impossible to apply any of the newly developed,progressive construction methods, it was an endeavour of all partners in this project to create a work which could represent with dignity the contemporary period of development of the capital of Czechoslovakia.

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