FRAME BRIDGES ON V-SHAPED SUPPORTS

Antónia Királyföldi - Gábor Pál

In this paper, we present the bridges built in Hungary on V-shaped supports from the World War II until today. The frame structures of this type of bridges have structural and economic advantages compared to conventional structures. The unique partly pre-cast partly monolithic structures built in the last years have combined the benefits of the two construction methods. The article explains the design aspects and the construction solutions of the bridges.

Keywords: bridge, design, frame bridges on V-shaped supports

1. INTRODUCTION

During the years after the World War II the intensity and volume of bridge building was so great, that several new types of structures appeared and were applied. The reason was mainly the reconstruction of the demolished bridges, but building new ones were necessary, too, for the modern highways, railway lines and channels.

One of the new structure types was the frame bridge on V-shaped substructure. It proved to be convenient to bridge over railway lines for sake of the bigger and safer highway traffic. Hungary was a pioneer in construction of such bridges. Of course, it is possible, that in other countries - mainly among mountainous ones - similar structures were applied formerly (Arup, 1964).

The advantages of a frame on V-shaped support are: smaller construction height, the middle span is shorter. The three spans are supported by two foundation bodies. These are not allowed to sink or slip on the ground and the connection to the pavement of the road is fix. At the beginning of its existence it was regarded as a monolithic reinforced concrete structure.

Let us mention here, that bridges with inclined legs have similar advantages (Bölcskei, 1953). Furthermore, it may be proved that at multi span structures with repeatedly changing spans a more convenient moment distribution can be reached (Tassi, Rózsa, Schlotter, 2006).

Fig. 1: The first bridge with V-shaped supports (Photo: P. Gyukics)

2. V-SHAPED SUPPORT FRAME BRIDGES IN HUNGARY

2.1 The first bridge with V-shaped supports

The first bridge on V-shaped supports was a 9.0+18.7+9.0 m span reinforced concrete slab over a railway line, near Dunaújváros, to give a two level crossing for the new highway No. 6 (*Fig. 1*) (Bölcskei, 1951, 1956).

2.2 Footbridge over M7 motorway near Velence

The building of motorway M7 started in 1961, causing new structural requirements for bridges. All the crossings of a motorway must have two levels, the width of a motorway is big (28.0 or 35.5 m), the crossings are mainly skew, there are high embankments and deep cuttings, the scaffolding for monolithic bridges is costly and hinder for road-building. That time the existing prefabricated, prestressed concrete girders had 3.0-12.0 m length.

In 1965 the motorway building reached the northern shore of Velence lake, by a deep cutting of a hill, previously wine yard. The claim, that in this beautiful surrounding an elegant rest-place should be built, which should be reached from the left and the right traffic lanes alike, to be realized by a foot bridge, which follows the 8% slope of the hillside, and crosses the 2×3 traffic lanes of M7 with one span (Királyföldi, 2000).

The soil of the hill is a sandy silt with low load-bearing capacity, not more than 100 kN/m^2.

The possible structures were a beam, an arch or a frame

Fig. 2: Footbridge over M7 motorway near Velence

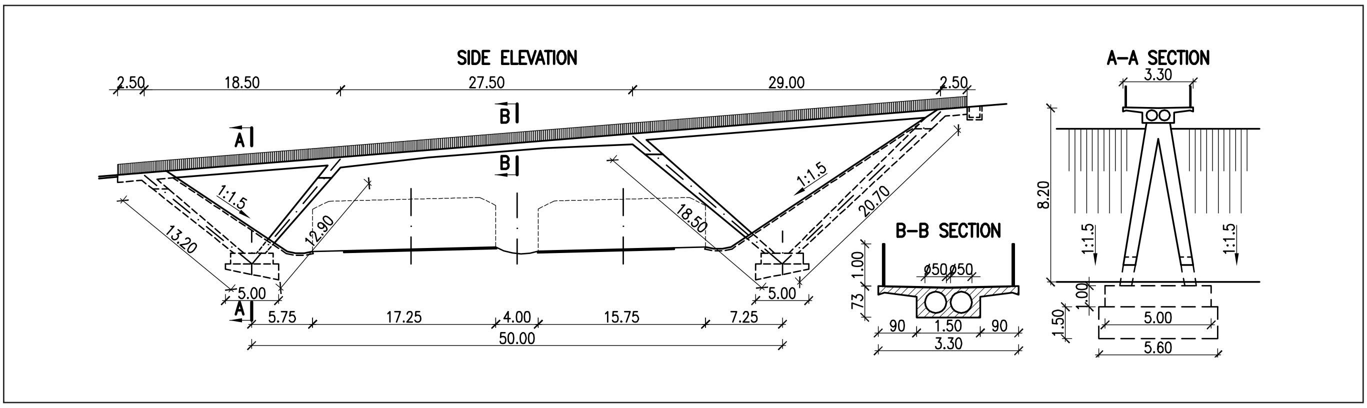


Fig. 3: Drawing of the footbridge over M7 motorway near Velence

bridge, the material had to be monolithic reinforced concrete. The beam and the asymmetric arch proved to be strong and heavy structures with complicated deep foundations, showing to the traffic of M7 an unbecoming picture. So remained the frame, slender, asymmetric and easy standing on its high V-shaped supports (*Fig. 2*).

The superstructure has a beam**,** with 18.6+27.5+29.0 m span, the inner piers are 12.9/18.5 m high, the outer ones 13.2/20.7 m high, the piers are double to give stability. The distance of hinges is 50.0 m. The foundation bodies are 5.0×6.2 m^2, with 75 kN/m^2 compression stress under them (*Fig. 3*). The outer piers are under the slope of the cutting with rubble-stone covering. The left side gully gets the rainwater from the bridge, the right-side one from the hillside.

The plans and the calculations of the foot-bridge were made following the requirements of the Hungarian Standard of Highway Bridges 1956 (live load 4 kN/m^2). The calculations were made by use of Cross-method, the independent control by force method.

Up to now only the left side of elegant rest-place was built: a coffee bar, the right side restaurant and look-out tower is only a plan.

2.3 Bridge over the road to railway station in Balatonvilágos

The M7 motorway crosses in its 93 km point the road in 70° skew direction. The road is running in 7% slope, in deep cutting (*Fig. 4*). The soil is dry, fat clay under a thin humus cover. The bridge of the M7 is a reinforced concrete slab over V-shaped supports, designed and built in 1968; designed by the rules of Standard 1956, calculated by use of deformation method. The slab is 70 cm thick with 11.0+14.0+11.0 m spans. The total width is 28.0 m but built in two phases: I. 15.5 m, II. 12.5 m. The foundation bodies are 4.0 m wide (*Fig. 5*). The plans of the V-supported bridges of M7 were designed by the Bridge-1 Department of the Road and Railway Designing Bureau (UVATERV Co.), built the bridge construction company (HÍDÉPÍTŐ Co.).

2.4 Bridge over M0 motorway under earth-road and footpath

The bridge stands in the rest-place of Anna-mountain (Fig. 6). It has a 7.0 m wide carriageway between two footpaths, each 2.1 m wide. The superstructure is a 5.7 m wide, 1.9 m deep box girder with 2×2.25 m cantilevers, the spans are 21.5+35.6+12.3 m. The asymmetry comes from the 6% slope of the road. The V-shaped supports have 5.3×0.7 m^2 slabs for the inner, and two-two 1.0×1.0 m^2 columns for the outer legs (*Fig. 7*). The distance of the hinges is 48 m, they stand on simple foundation. The monolithic structure was built 6.7 cm higher, to compensate the calculated deformation of the box girder. The detail designs and the calculation were made by the Bridge Department of FŐMTERV in the years 1991-1992, following the prescriptions

Fig. 4: Bridge over the road to railway station in Balatonvilágos

Fig. 5: Drawing of the bridge over the road to railway station in Balatonvilágos

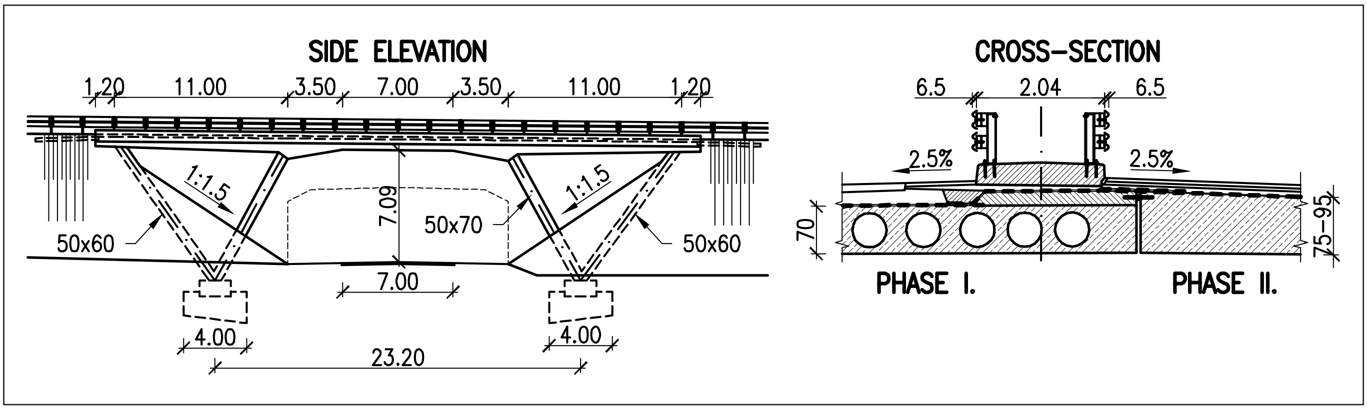


Fig. 6: Bridge over M0 motorway under earth-road and footpath

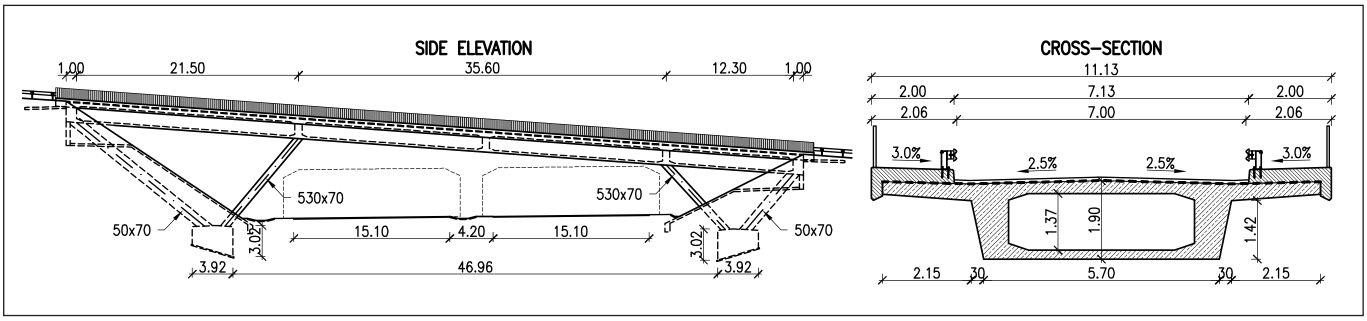


Fig. 7: Design of bridge over M0 motorway under earth-road and footpath

of MSZ 07-3701-86 Hungarian Standard. The bridge was built in 1992-1994 by Asphalt-Road Building Company.

2.5 Bridge over the junction of highways 8 and 72

Till the year 2008 the connection of highway 72 to highway 8 was a complicated one level junction. For the safety of traffic it had to be reconstructed to two levels. The building of the necessary bridge was not permitted to hinder the traffic, so it cannot be a monolithic structure (Királyföldi, Tassi, 2009). The crossing is skew, α=75° (*Fig. 8*).

The junction is on the eastern slopes of Bakony mountain. The southern-side of the highway 8 is showing a cutting slope of big dolomite-slabs. So the intention of the bridge designer was obvious that this is the convenient place for a frame bridge supported by V-shaped legs. The monolithic supports can be built out of the clearance of highway 8, and prefabricated, prestressed concrete girders can be put over them in a few hours. The traffic can bear such a short hindrance. It means a new situation, that the connection between the monolithic support and the prefabricated superstructure must be perfect. The idea and the design for permission were made by Speciálterv Ltd.

Fig. 8: Bridge over the junction of highways 8 and 72

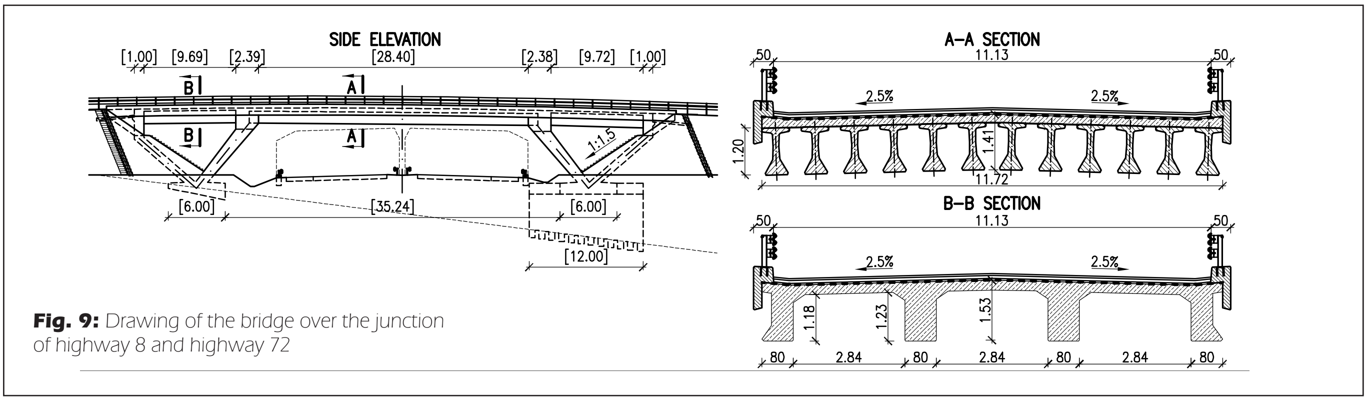


Fig. 9: Drawing of the bridge over the junction of highway 8 and highway 72

The spans of superstructure are 11.8+30.0+11.8 m, the distance of hinges is 41.2 m, the foundation bodies are 6.0×12.0×1.2 m^3 blocks, the inner and outer columns are pegged down.

The detail design was won by Kánya Ltd, and the first step was a survey on the spot. The left side of highway 8 was beautiful with the big slabs of dolomite, but on right side there was a line of 15-20 m high pine trees, and behind them a strong slope downwards. There was the question: is the level of rock horizontal or does it lay in a slope. It proved that the level of dolomite rock lies in a 12% slope under the pavement of highway 8, so under the foundation level of right side V-support is a 4.0 m thick cover of wet soil, which has a slight load bearing capacity (*Fig. 9*).

This problem could cause a change in the symmetric structure of the design for permission: a left support 5.5 m high, 30.0 m span bridged with prefabricated girders and a right support with 9.5 m height causing a big asymmetry - when the foundation would be over a rock. To dig out such a deep pit beside the right traffic-lane of highway 8 was a bit dangerous work. So there remained a deep foundation and symmetry was preserved.

The deep foundation could be a double pile-wall or slurry-wall. The soil mechanics specialist's proposal was the pile-wall, with Ø60 cm bored piles, bored 80 cm deep into the rock. So the monolithic V-supports were built, the piles were bored from the level of the carriageway, without any accident, their longitudinal bars are bound into the foundation block.

Well known task was to lifting and placing the 12 prefabricated girders - each has a 23.1 t mass - over the cross-beam of the inner skew columns, not causing the calculated 15 cm deformation. It was not a big problem that the scaffolding of the monolithic V-support was built strong enough to bear the weight of the girders and the slab over them with only 1-2 mm deformation. The traffic was hindered for 3.5 hours.

The structural cap-beam over the inner columns has a great importance. Even without the weight of the prefabricated girders and the monolithic slab it has to resist vertical and horizontal moments and shear forces. The reinforcement of the end cross girder and the longitudinal bars of the slab have to produce the convenient connection between the supporting elements and the superstructure. This construction of bars, then the concreting process had to be made over the traffic.

When the concrete of the slab became hardened the scaffolding was demolished, no deformation could be measured. The results of the load test verified the terms of the design. The calculations were made by use of UT 2-3.401-414 Standard by use of AXIS VM9 program, the independent control calculation was made by the Department of Structural Engineering of Budapest University of Technology and Economics. The bridge was built by Colas Hungary Company.

2.6 Frame bridge over the M31 motorway

The three-span motorway-overbridge spanning over the M31 at the cross section 7+073.58 km (*Figs. 10-11*) was designed by the Speciálterv Ltd. in 2008.

The road going through the bridge has a regulation width of 8.50 m, and a straight horizontal alignment with a right angle to

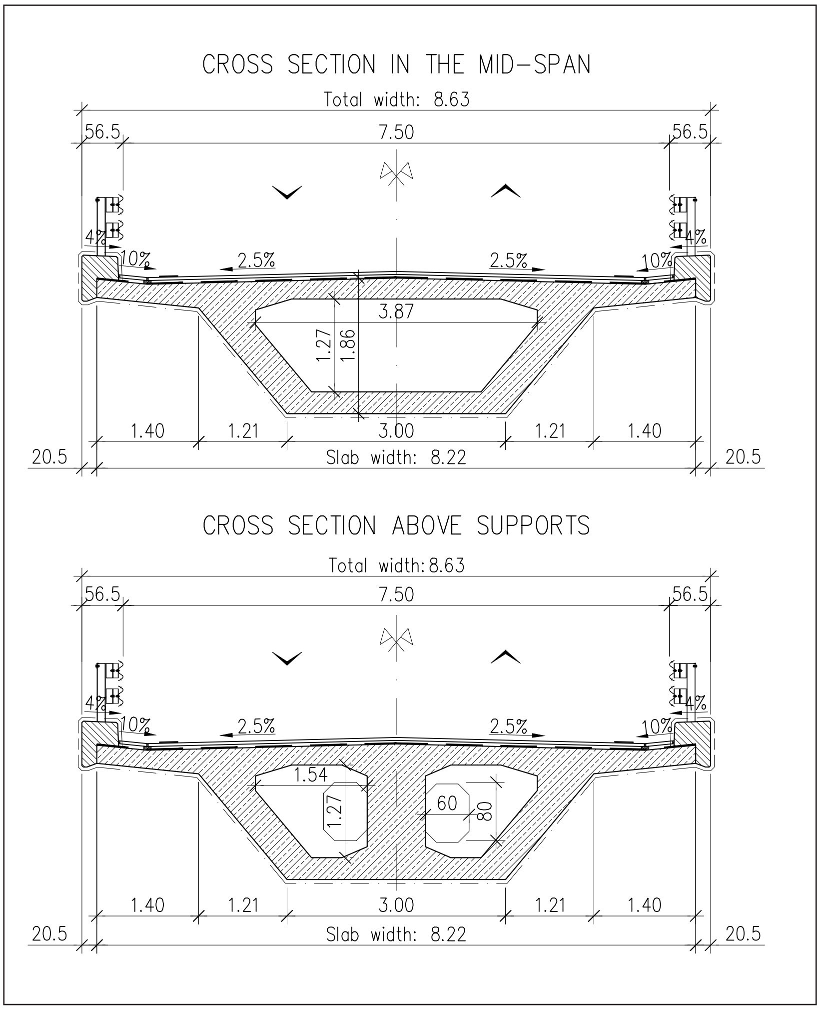
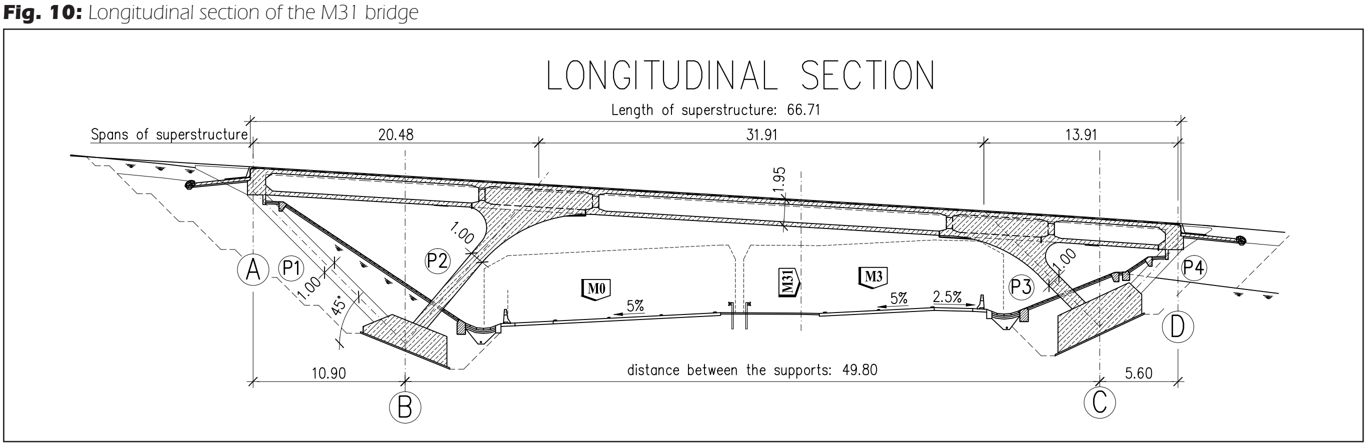


Fig. 11: Cross-section of the M31 bridge

Fig. 10: Longitudinal section of the M31 bridge



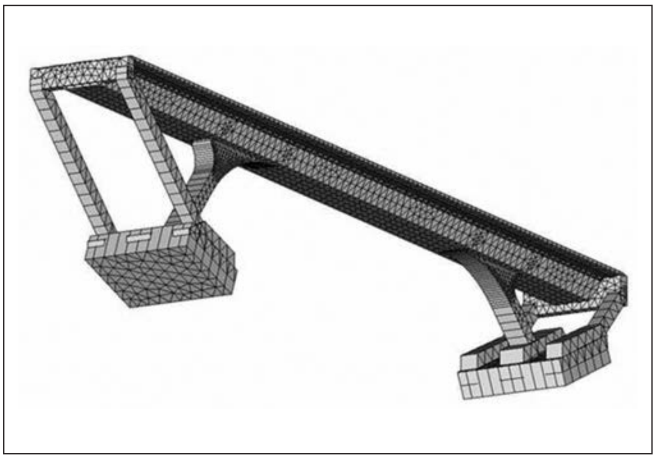


Fig. 12: The model of the M31 bridge in 3D by the Finite element software

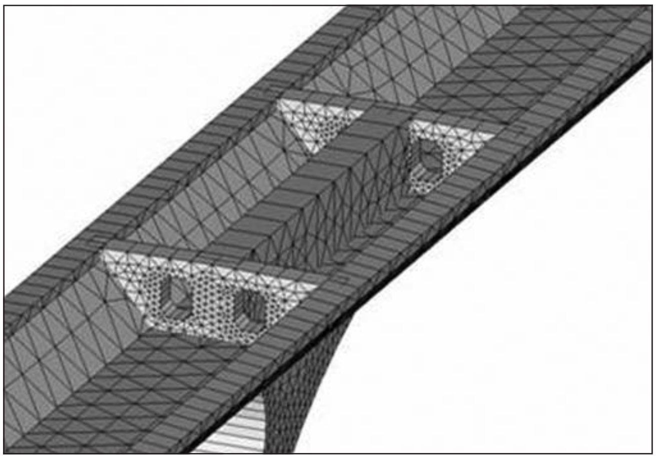


Fig. 13: The part of the M31 bridge deck underneath, above the internal leg. (from the finite element software)

the obstacle. The motorway under the bridge has a regulation width of 34.82 m and has the longitudinal alignment at cut. Due to the 6% gradient of the longitudinal axis of the bridge deck, the arrangement of the supports are asymmetrical 10.90 + 49.80 + 5.60 m. The total length of the bridge is 68.70 m.

The inclined pillars (legs), the bridge deck and the supports joins in rigid connections. The end points A and D are supported by angled columns. The end structural beams are joint with the wing walls as perpendicular cantilevers. These beams have a width of 130 cm.

From the end points of the superstructure to the abutments the load is transferred by two pairs of legs with cross section of 1.00 m × 1.00 m in each case. The obliquity of the legs is 45° at the end structural beam „A" and 46° at the „D". The superstructure is also supported by two inner legs, each with a cross section of 1.20 m × 1.00 m. The two inner legs have angles of 45° to the horizontal line (*Figs. 10-11*).

The 1.86 m deep box girder has observing room capable for crawling on its whole length and reduced cross sections are above the supports.

In order to achieve a uniformly distributed load on the ground with uniform stress the flat foundation was placed obliquely with a slope of 22° and 25° according to the directions of the reaction forces from the legs of the frame. The distance between the axes of the abutments is 49.80 m and the sizes of the abutments are 6.00 m × 8.62 m.

The load bearing capacity of the structure was designed for the load of „A" type according to the Hungarian regulations (ÚT 2-3.401:2004). It was an important design aspect to take care about the stiffness of the superstructure due to the large span made of cast-in-situ concrete without post-tensioning. The longitudinal axis of the deck has a constant grade with a straight line so the aesthetic aspect for this case did not allow us any visible deflection along the span. Calculation of the structure's expected shape was based on the design assumptions set up by considering the cracked section in the modelling of the structure in two different finite elements software – AxisVM (*Figs. 12-13*) and Sofistik.

The bridge is made of cast-in-situ concrete. The concrete used for the superstructure and the V-shaped legs have the class of C40/50 and C20/25 for the supports (according to the Hungarian standards ÚT 2-3.414:2004 and ÚT 2-3.413:2005). The bridge was opened for the public in 2010 (*Fig. 14-15*).

2.7 Bridge over the Perkáta creek, on the bypass of the main road No. 62

The three-span V-leg frame concrete bridge, located at the cross-section of 15+520.70 km on the bypass of the main road No. 62 was also designed by Speciálterv in 2008. The bridge currently is in process of construction and it is to span over the Perkáta creek and an earth road (*Figs. 16-17*).

The regulation width of the bridge deck is 12.00m, and the horizontal alignment is a straight line with a skew of 70° to the axis of the obstacle. The vertical alignment is a straight line with a slope of 1.37%. The total length of the deck is 51.36 m. The position of the upper supports of the frame's legs underneath the bridge deck are at 11.50(10.81) + 25.40(23.87) + 13.50(12.69) m, and the distance between the abutments on the ground level is 37.43(35.17) m (The values in parenthesis are perpendicular measurements.).

Fig. 14-15: The M31 bridge during the construction works (left) and before opening (right)

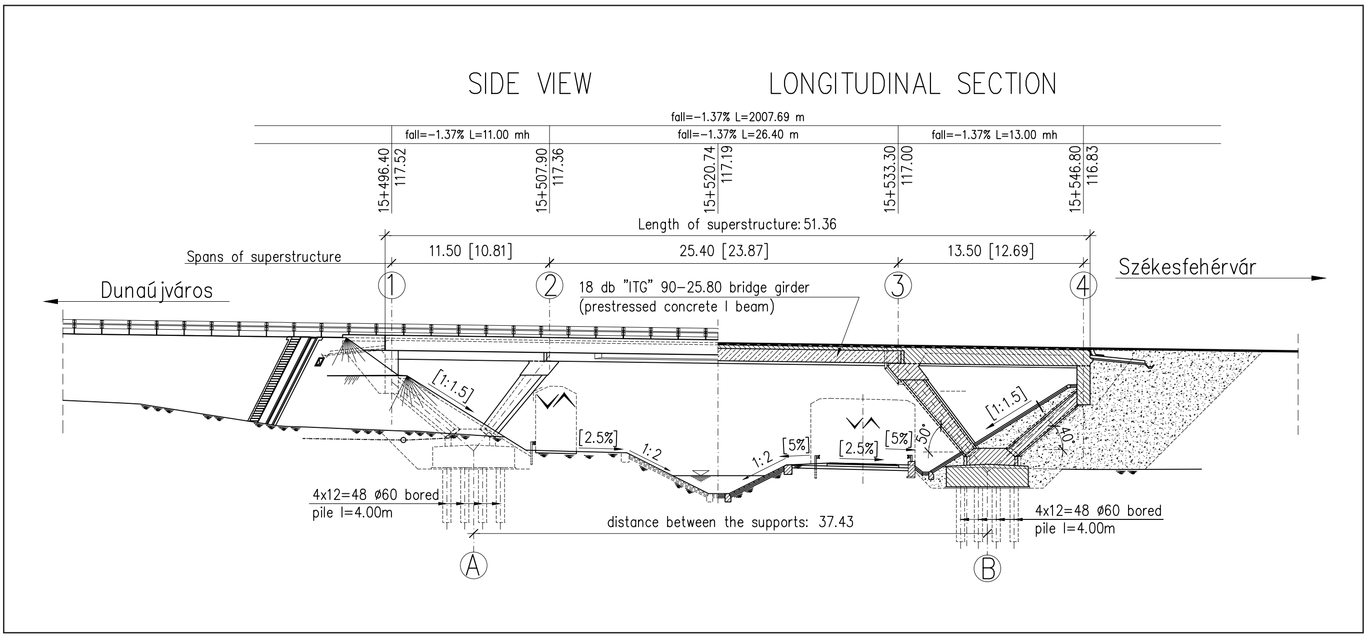


Fig. 16: *Side view and longitudinal section of the Perkáta bridge*

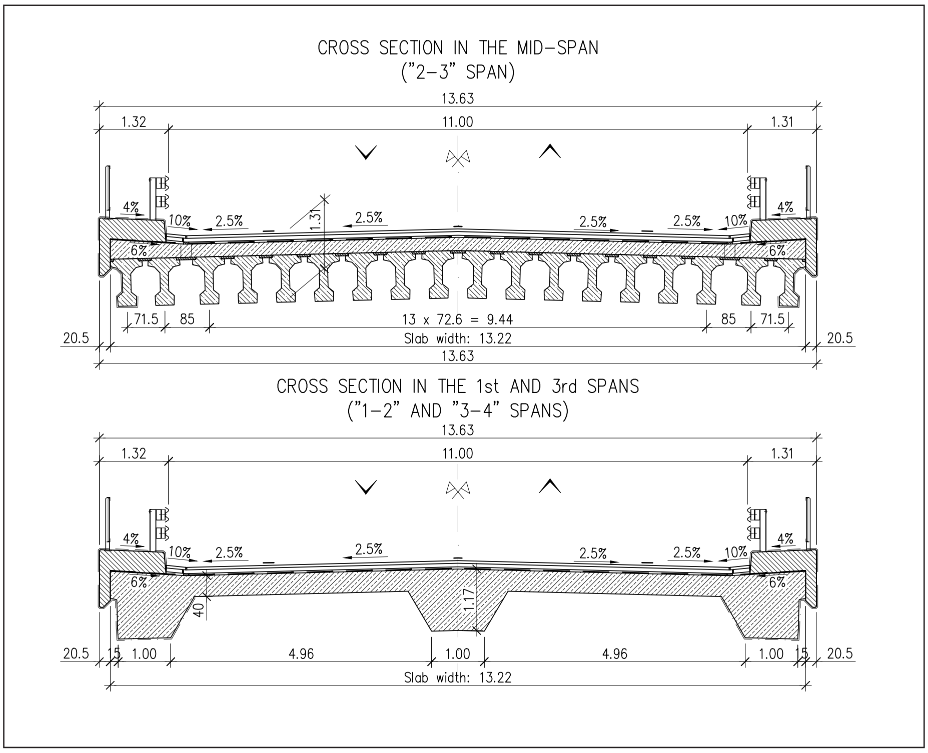


Fig. 17: *Cross-section of the Perkáta bridge*

The load bearing capacity of the structure was designed for the load type of „A" (according the Code ÚT 2-3.401:2004).

The bridge is similarly arranged to the bridge at the 8-72 junction, so at the end spans the structure is a monolithic frame and at the internal span is a composite structure with prestressed prefabricated "I" girders and monolithic slab. The monolithic legs have V-shaped arrangements. The prefabricated prestressed concrete beam marked by ITG is 25.80 m long and 90 cm deep. The beam seats are everywhere at least 40 cm. The prefabricated girders are set on technical plastic bearing plates with the sizes of 20×35×2 cm. The reinforced concrete joist head of the ITG beam is very suitable for the complex loads above the inclined frame legs.

The hidden abutments give the foundations for the pillars and columns of the frame. In this case the ascending columns are the inclined frame legs in the bank.

The bridge has a deep foundation made of CFA bored piles with a diameter of 80 cm. There are 2×5 piles at each support with a length of 4.00 m bored in a 5.00 m thick grey silty sand ground layer. The large pile-closing beams have a cross-section size of 560×150 cm. On each of these beams are standing three inclined columns to each direction, one pointing to the internal, the other to the external main girders. The No. 2 internal legs have 85×100 cm size at the bottom and 125×100 cm at the top, whilst the column No. 3 is also 85×100 cm at the bottom but 133×100 cm at the top. Both of them have a bottom surface with an angle of 50° to the horizontal axis. The sides of the abutments are parallel, the size of the outer columns (at the side of the back filling) cross-section is 90×100 cm, and the longitudinal axis has an angle of 40° to the horizontal.

The bridge is made of a combination of cast-in-situ concrete and precast concrete elements. The cast-in-situ concrete used for the bridge deck and the V-shaped legs have the class of

Fig. 18: *Perkáta bridge under construction*

Fig. 19: Perkáta bridge under construction

C35/45 (according ÚT 2-3.414:2004 and ÚT 2-3.413:2005), whilst the precast concrete structure members have the class of C40/50.The class of the concrete used for the pile-closing beams is C25/30.

The bridge is in process of construction (*Figs. 18-19*). The bridge structure has been finished and the road expectedly at the end of 2012 will be ready for opening to the public.

3. CONCLUSIONS

Our renowned ancestor was seriously interested in the difference which can be reached by creating spatial structures instead of plane ones (Bölcskei, 1951, 1953, 1956). So came the V-support in bridge building and branchy columns for halls (Bölcskei 1963).

During the decades bridges over V-supports were built, at the beginning only with monolithic reinforced concrete slabs, beams, box girders; now, because it is a claim, combinations of monolithic V-support and prefabricated girders. The results are giving hope of further possibilities to develop the V-shaped supports, having good conditions in calculation and in technology.

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Antónia Királyföldi (1932) MSc, civil engineer (1961), engineer specialist in reinforced concrete construction (1974). She worked 1950-1991 in UVATERV design bureau, her main task was designing bridges for M7, M1 and M0 motorways. She was designer of more than 100 different bridges. From 1972 she had been teaching as assistant at the ancestor of the today Department of Structural Engineering of Budapest University of Technology and Economics; from 1990 to 2005 she took part in the engineering education in foreign languages. She was given the Honorary Associate Professor title in 2003. She is active at Civilplan Ltd. Member of Hungarian Group of ***fib***.

Gábor Pál (1970) MSC civil engineer (Budapest Technical University, 1994), 1994-1999 designer (FŐMTERV Co.), 1999 onwards executive of SpeciálTerv Ltd. His scope is to manage the 30 plus organisation of designers, and to control and expertly lead the civil engineering design work of the company. Main designer of the Metro station of Kelenföld railway station and more than 100 different bridges. Member of Hungarian Group of ***fib***.