The bridge over the Mura River in Slovenia

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Summary

The article presents the conceptual design and the structural solutions for the longest Slovenian bridge over the Mura River, consisting of two separated 833.0 m long and in all 28 m wide bridge structures. The main span over the river is 80.0 m long while the characteristic structural span amounts to 40 m in length.

The design particularity is the 2.40 m deep steel deviator underneath the superstructure at the main span, leading the external tendons outside the bridge profile. Launching in the final position over the final and temporary supports was achieved with only one launching equipment, although the bridge has a double curved (Rh = 2400 m, Rv = 40000 m) geometry and is 833 m long. The construction of the bridge took 3 years.

Keywords: bridge ; prestressing ; external tendons ; cables ; deviator ; incremental launching

1 Introduction

In October 2003 a 15 km long section of the motorway between cities Maribor and Lendava was opened that will improve the traffic connections in the direction of Hungary and also bring nearer the most eastern Slovene region Prekmurje. South of city Murska Sobota the motorway crosses the river Mura and its inundation area.

In this place the inundation zone of the river Mura is the narrowest, only a good kilometre wide, which was one of the criteria to locate the motorway in this area. The river Mura, having a lowland character with meanders and backwaters in the lower river course, here is partly improved in the riverbed width of 70 m. The most pretentious, unique and innovatory structure in this part of the motorway is the 833 m long bridge across the Mura, the longest bridge (across water) in Slovenia.

2 Design competition and tender invitation

The structure design and the way to the final design and the form of the bridge respectively, were made gradually. In the bridge outline scheme the principal parameters were defined, as the most convenient position, characteristic axes and road elevation, cross sections of the road and the bridge, analysis of the optimal structure length as well as hydraulic, shaping and other conditions for bridging the river Mura.

The next phase began in May 1998, when the Investor DARS in cooperation with the Engineering Chamber of Slovenia and expert associations made an open invitation to collect structural solutions for the bridge over the Mura. In the appointed time 13 solutions were received, made by 5 different design groups. Three prizes were awarded and two solutions were bought off.

For the invitation to contractors (from March to September 2000) the Investor DARS in accordance with tender conditions used the results obtained by design competition. For the tender documents the first- and third-awarded solutions were used, while the second-awarded solution had already been eliminated as too expensive and too complicated for the construction. Additionally to both official variants the Investor also allowed special offers that had to be in accordance with the invitation solutions and tender conditions. For the first-awarded solution at the open invitation (Harfa 1- cable stay bridge) the Investor permitted a 10% price bonus in comparison with other offers. This was the first such case of the invitation with a bonus in Slovenia and the only one for the present.

To the international construction invitation 16 offers of 6 bidders were received (3 domestic companies, GIZ Gradis, Gradis NG and Ceste in mostovi Celje, one mixed association, SCT + Primorje + Grasetto (Italy), and two foreign companies, Konstruktor Split (Croatia) and Zueblin Stuttgart (Germany).

The commission of the Investor assessed all special offers as technically unsuitable and not comparable with the tender variants and eliminated them from further treatment. In accordance with the tender criteria as the most satisfactory offer the least expensive solution Brod3 (girder with prestressed tie) of GIZ Gradis Ljubljana (12.5 millions EUR), upon the design of Ponting Maribor, was selected.

3 Conceptual design

The bridge over the river Mura and the inundation zone crosses a naturally very intense biotope, due to specifically rhythmic floods containing also rare and jeopardized animal and vegetable species. The inundation flat land is densely overgrown with high trees, and the riverbanks with dense bushes. Morphologically the area between embankments is practically flat with smaller depressions at the location of former – today dead - branches of the river. At this place the river bed is 70 m wide, and the inundation zone between safety embankments a good kilometre.

The main idea of the design was to create a structure of a suitable shape, yet at the same time of good quality, durable and economical one, which by a unified technology solves the structural problem of bridging equable smaller spans at the inundation area and – as an exception – one larger span over the river.

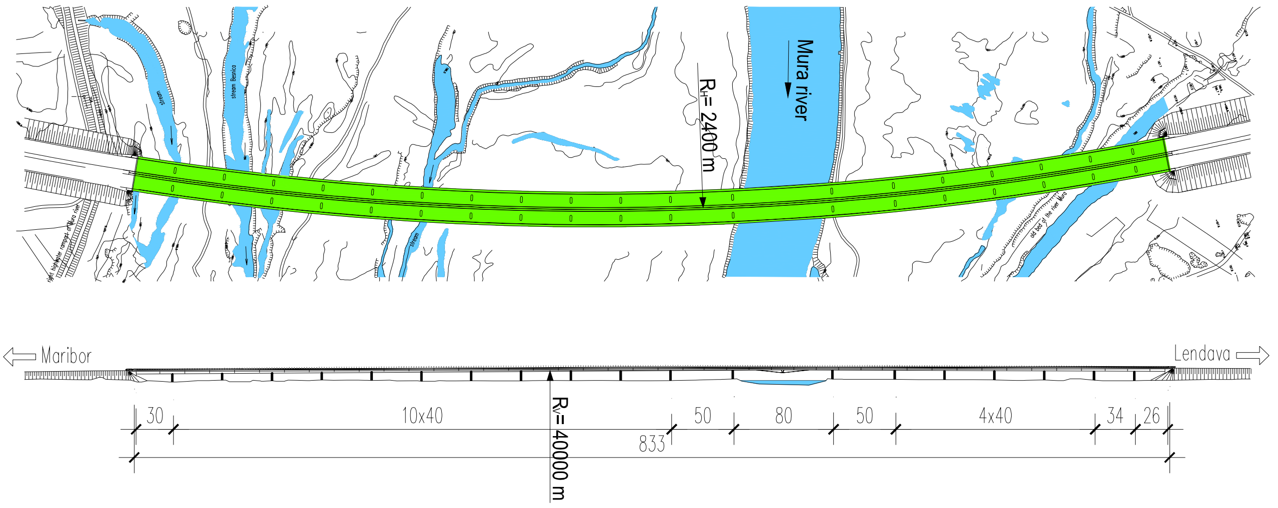

Fig. 1 General view of the bridge

In cooperation with the motorway designer the route was placed in the space in such a way that use of incremental launching would be possible. This means that along the total bridge length it has a constant curvature, namely the axis in the ground plan radius 2400 m, and the elevation in the convex curvature 40.000 m with symmetrical tangents 1.3%. The space curvature of axes with two radii is theoretically not realizable, yet we have calculated that the design structure can be adjusted to this form with negligible imposed loading. This is possible due to gentle curvatures with regards to the structure rigidity.

Bridging the river without piers in the water required the span of minimum 80 m, which for a girder structure of constant cross-section would mean a thickness of approximately 3,6 to 4,0 m (1/22-1/20) and for using the launching technology without supports it would require the spans of 50 m. With the elevation 10 to 12 m above the ground smaller spans are more economical in spite of deep foundations. Therefore in the greater part of the bridge (about 90% of the length) economical spans of 40 m for the launching technology were selected and a corresponding structure height of 2,80 m (L/14,2), which makes possible launching without supports. The lack of stiffness in the main 80 m span where the slenderness relation is almost L/29, was solved with a prestressed tie acting as an elastic support. The stiffness was additionally increased by thickening the bottom slab above the piers at the main span (by this technology this is possible without troubles), and the deformation of the main span was reduced by transition 50 m spans (n x 40 + 50 + 80 + 50 + n x 40), »lifting« the main span with their weight.

The design with the prestressed tie is a very pretentious and relatively expensive concept, therefore it is not often used in the bridge construction practice. In our case the use of this design at a shorter length of the structure (only one longer span) made possible an economic execution of the remaining much longer part, which all together resulted in a winning combination.

4 Technical description

The bridge over the Mura consists of two separated parallel bridge structures, one for each driving direction, of the total width 27.93 m and length 833 m. The structure runs continuously over 20 spans with the main span of 80 m over the Mura, without piers in water, and with typical spans of 40 m in both inundation areas.

The route axis of the structure is in the ground plan radius 2400 m, the longitudinal alignment in the convex curvature 40.000 m with symmetric tangents 1.3%. The structure cross fall is constant 2.5%, the walkways are inclined inwards with the inclination 4% (fig. 2).

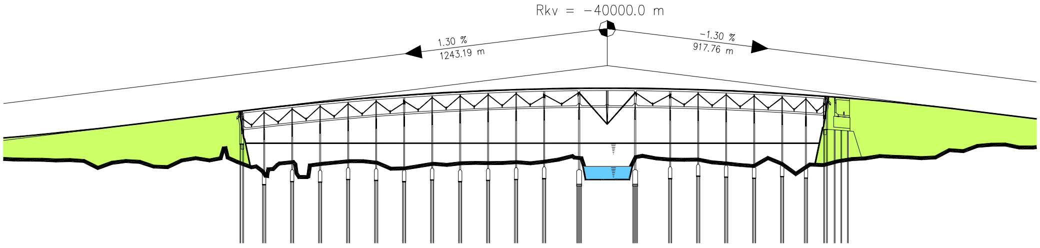

Fig. 2 Elevation

The static system is a continuous girder with a prestressed tie in the main span, with theoretical spans as follows:

30.0 + 10 x 40.0 + 50.0 + 80.0 + 50.0 + 4 x 40.0 + 34.0+26.0 = 830.0 m

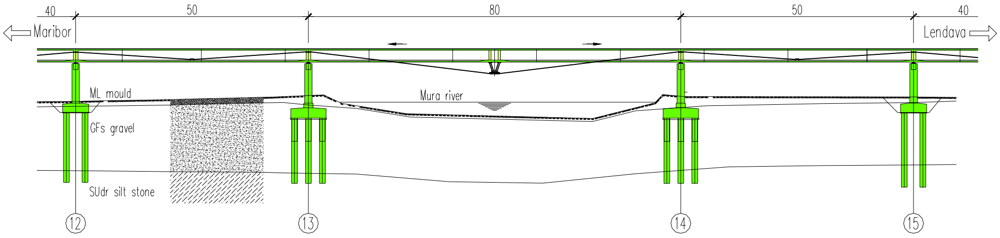

Fig. 3 Longitudinal section through the main span

The cross-section of the concrete superstructure is a hollow trapezium box of a constant static height 2.80 m over the entire length of the bridge. The width of the upper – carriageway slab is 13.9 m, the width of the lower box slab is 5.00 m, both-side cantilevers are 3.1 m long. Thickness of inclined webs is 40cm, upper slab from 22 cm to 50 cm and bottom slab from 25 to 50 cm.

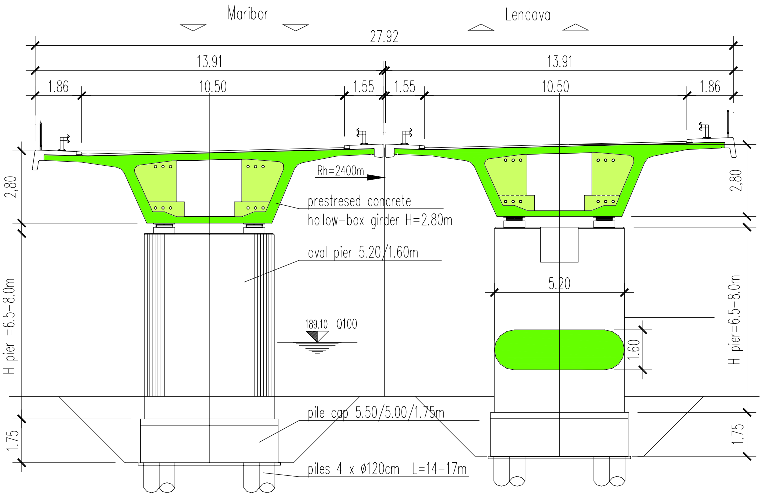

Fig. 4 Cross section through the typical pier

The bridge has no piers in the river, while in the inundation area it has 38 piers in total (19x2) with the height from 7.0 to 8.5 m and an oval cross-section. Such a shape is hydraulically convenient for outflow of inundation or periodic waters in old riverbeds.

The foundations are deep on concrete piles of 120 cm diameter and 15 to 20 m long. For each typical pier 4 reinforced concrete piles are used. Each of the two main – river bank piers with fixed bearings for longitudinal forces are founded on 10 piles of 120 cm diameter.

4.1 Prestressing and tendon protection

Prestressing of the structure is in a close connection with the structure design and construction technology. In the tender design two types of prestressing are anticipated, i.e. classical stressing in the concrete cross-section with subsequent bond for the construction phase, and with external tendons in a double extruded plastic protection and in a flat form (e.c. tendons MCC of the manufacturer VT), regulating the loads in the final exploitation phase.

For the bridge over the river Mura the contractor Gradis GP Ljubljana proposed and also introduced a new technology of prestressing with the Dywidag system, as follows:

- Dywidag AS150 – stressing system of strands 150 mm2 with subsequent bond
- Dywidag MC external – system of external tendons with cement grouting into PEHD pipes
- Dywidag W external – system of external tendons with mono-tendons in PEHD pipes (grease and double hard plastic material)

The system AS150 has been used for ordinary centric prestressing, with 15 strands tendons, each stressed with the force 2800 kN. Typical tendons were 40m long (over two segments) and composed with a couplings into a tendon of 833m length. In the cross-section of the superstructure there are 12 such tendons, assuring over 4,0 Mpa of centric pressure in the construction phase, preventing the occurrence of tensile stresses in the upper and bottom edge of the structure during launching and thus also the appearance of cracks in the structural concrete.

For eccentric stressing two types of external tendons were used. In the part of the superstructure where the tendons are placed only inside the box, the tendons of the MC system with cement grouting were used, while in the part with cables outside the structure (in the spans 50-80-50) the tendons of the W system, protected with grease, double plastic material and intermediary cement grouting were used. Both systems make possible the replacement and additional stressing of tendons, which is particularly important to control the strains in the main span 80m. Very interesting are the solutions for the MC system, where naked strands are protected with cement grouting in plastic pipes, yet in spite of this a limited length of additional prestressing up to 20cm pull-out is possible, which is quite enough for tendons to the length of 200m.

Prestressing of the system W tendons over the main three spans took place according to a special protocol: due to the influence on the structure deformation it was performed at the same time with the temporary supports removal and the resulting changes of static influences and systems.

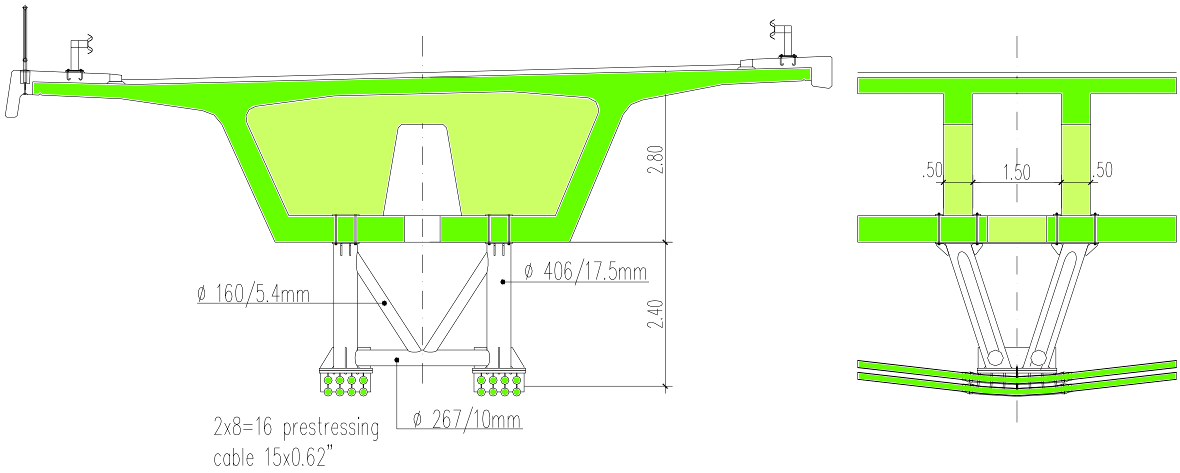

Fig. 5 Steel deviator in the main span

4.2 Prestressed tie and steel deviator

On the largest span 80.0 m the loads, deformations and stresses due to dead load are regulated with external tendons, conducted over a 2.40m high spacer outside the superstructure. For the traffic load the main deviator together with external tendons represents an elastic support of the continuous girder structure.

The steel structure of the deviator carries the deflection force of 12 tendons, or with 4 spare ones 16 tendons in total, that will be stressed with the force of 2800 kN each. The geometry of the bridge and tendons is such that the tendons break up on the deviator for 6,6° in the vertical direction with the deflection force V = 10304 kN, and for 0,4° in the horizontal direction with the force H = 650 kN on the total structure of the main deviator. Transfer of these forces into the concrete box of the superstructure is solved by two cross girders of the thickness 50 cm at the place of entering.

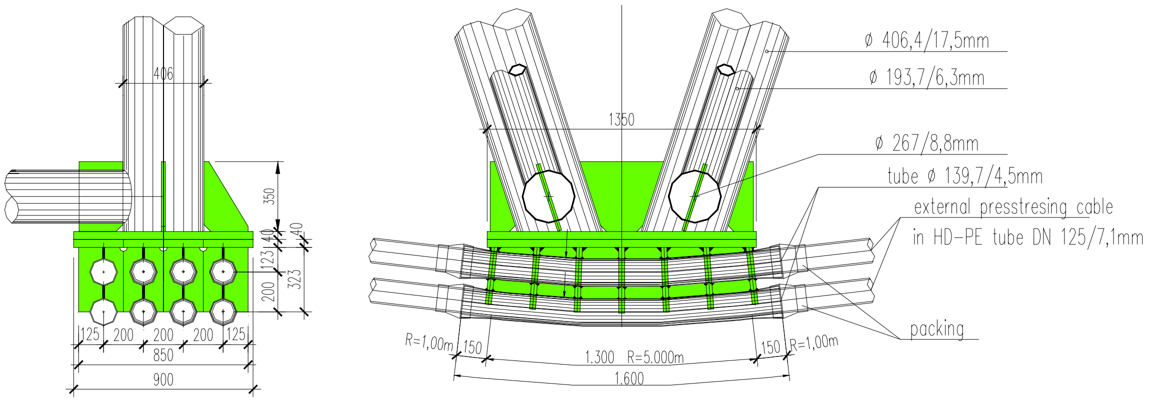

Fig. 6 Detail of saddle

The deviator is a space frame structure consisting of steel round pipes and a deviator saddle. In the cross-section along the bridge it has two pyramidally placed columns in the form of the letter V, in the transverse direction it is a frame with stiffness diagonals in the form of the letter K. At the bottom of the pyramid there are two saddles, each with 8 curved pipes (radius R = 5 m) in two rows (2x4), through which the tendons run. The force transfer and the corresponding saddle stiffness are assured by the system of longitudinal and transverse steel plates to support the pipes (fig 6).

The deviator is made of steel plates, thickness 20 to 40 mm, and round pipes of steel quality St 52-3, size ϕ 406,4/17,5 mm for V deviators, ϕ 267/10 mm for horizontal cross girders, ϕ 191/5,4 mm for diagonals and ϕ 139,7/4,5 mm curved in R = 5,0 m for the deviator pipes in the saddle.

4.3 Tendon transition outside the structure

As long as the external tendons are placed inside the box structure, the anchorages and the tendon line modification points can be performed with relatively simple and known details, such as cross girders and concrete deviators of various modes. If the tendons are to be placed out of the box, considerable complications occur. For the transitions of tendons through the bottom slab specially shaped perforations with edge strengthening were made, limiting the weakening of the slab to the smallest length possible (see Fig. 8).

The weakening of the otherwise closed box section is particularly dangerous in the stage of launching the structure over supports, when the inclined webs lose the interacting shore (bottom slab), balancing the horizontal component of the reaction. Therefore, in the phase of launching, a temporary steel structure was embedded in the weakened area, consisting of three steel profiles IPB 300, sheet metal and anchors, which are partly removed after launching.

To reduce the weakening in the cross-section as much as possible, the tendons were jointed in the form of a sheaf, for which it was necessary to embed the deviator pipes into the cross girder at the opening for the tendon transition. Thereby also the free length of tendons was broken in two, which is convenient due to vibrations. We have also estimated that the course of tendons in the sheaf is aesthetically more suitable than the fan-shaped one. For the transition of 16 tendons (among them 4 spare ones) two openings were necessary, each of them 0.90 m wide and 4.00 m long (Fig. 7).

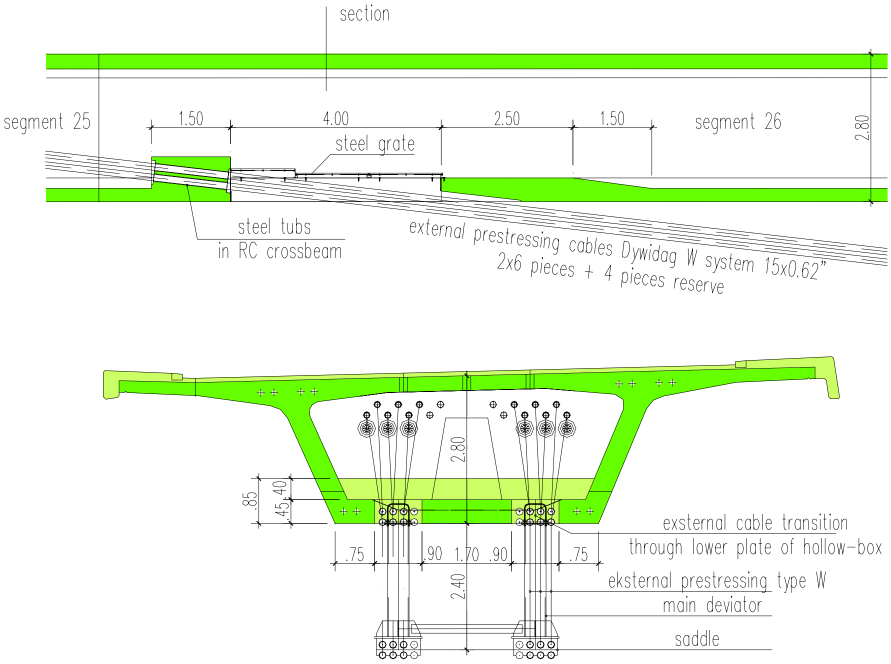

Fig. 7 Section through the perforation in the bottom slab for the cable outlet

5 Structural analysis

The bridge over the Mura is a unique structure with new structural solutions. In the literature there are only some cases known of using the prestressed ties on bridge structures, yet they are not directly comparable with the execution of the Mura bridge. We had no experience of our own available neither the foreign ones for the comparison and guidance at the design, design analysis and the construction itself. Therefore, an exact analysis of all phases during the construction and of all influences for the structure exploitation was essential, while the work was pretentious and extensive.

The structure has been analysed as a space prestressed frame structure. In the analysis and structural design DIN norms and partly Eurocode Nr. 2 were considered, as well as the seismic load in accordance with Eurocode Nr. 8 Part 2 – Bridges. For steel elements Eurocode Nr. 3 was taken into account.

6 Construction

The bridge construction began in November 2000 with earth works and foundations and was completed in October 2003 with the final works. The superstructure was constructed by the method of incremental launching, the left and the right bridge structure consist each of 43 concrete segments of average length 20 m. In the spans 50 m + 80 m + 50 m temporary supports were additionally used, so that for the loads in the construction stage the typical span of 40 m was decisive.

The structure of the length over 800 m and in such a pretentious geometry was launched by only one set of hydraulic equipment Eberspeacher AH123. As the anticipated forces were at the limit of the launching possibilities, special attention was paid to this problem. The left and the right bridge have 16.000 tons each. At the active abutment the hydraulics pushed upwards with the inclination of approximately 1%, at the end abutment the elevation has the direction 1.3% downwards. The intermediate temporary bearings had different inclinations at each pier, in accordance with the vertical curvature R = 40.000 m. Therefore the conditions and the resistance force at each pier were different. On the basis of the Designer’s detail analyses the Contractor decided to use only one set of hydraulic launching equipment of capacity V = 15700 kN and H = 6080 kN. For the last pushing, when due to the lack of the vertical reaction the friction mode of moving is not sufficient any more, the Contractor prepared a pulling device, that can pull the structure additionally with a steel frame and the equipment for tendon prestressing.

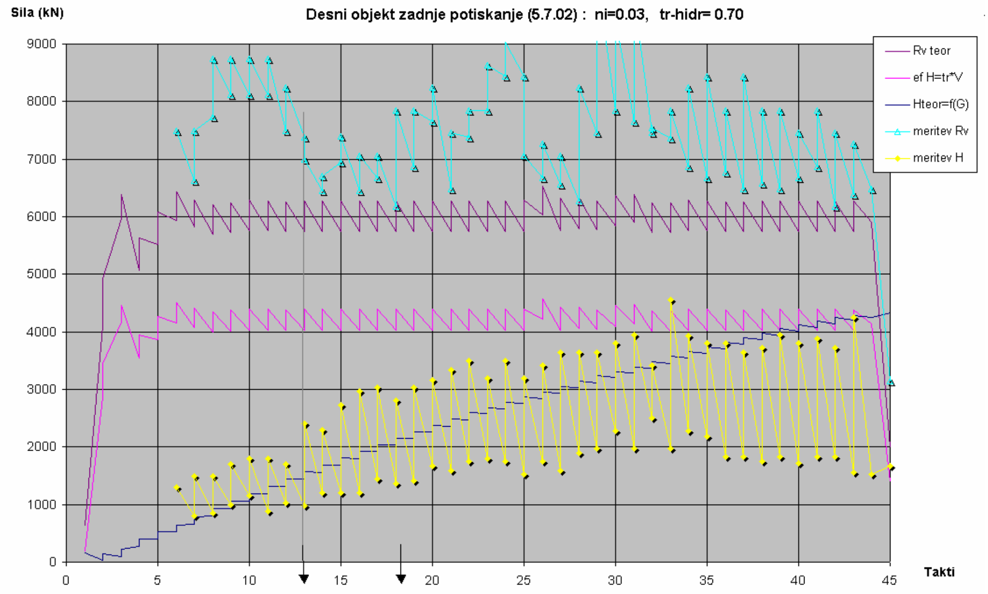

Fig. 8 Force diagram for incremental launching (no of segment / force kN)

Due to the extraordinary length and mass as well as due to pretentious geometry we followed precisely the forces during launching, registered and analysed them. The statements were very interesting. The pushing force namely did not grow linearly with the length and mass increase, as it could be expected. First a great friction influence was noticed in the formwork casting yard, due to various causes (different slip slabs, smaller specific pressure, influence of concreting and formwork) much bigger than on temporary sliding bearings. Therefore at the beginning of launching greater pushing forces are necessary than the theoretical ones. When a large number of segments is completed, e.c. more than ten, the share of the segment being still on the launching rail in the casting yard, becomes smaller and later, after more than 20 segments, negligible.

Even more interesting are the measurements at larger lengths, when the superstructure elastic deformation occurs, which is noticeable only at lengths greater than 500 m and depends on the force size, friction coefficients and stiffness characteristics of the superstructure and piers. The top of the pier elastically follows the movement of the superstructure, up to the movement causing a reaction in the pier that is equal to the friction force or initial friction. As the stiffness of individual piers is different as a rule (pier height, concrete and reinforcement characteristics, foundation conditions etc.) moving the very long elastic superstructure over a number of piers is a very complex dynamic system. This is partly evident also from the pushing forces measurements at the beginning and in the middle of each segment, which is shown for the right structure in the diagram in Fig. 8.

Fig. 9: Crossing the river with the first structure - November 2001

Fig. 10: The river, inundation zone and bridge during construction – May 2002

Fig. 11: Tendons under the structure

Fig. 12: The main span of the bridge

7 Conclusion

- By using the prestressed tie in one span the entire bridge - in spite of very different spans - could be executed with a concrete structure of a constant height;
- Therefore the technology of incremental launching in the total length of the structure could be used with the help of only one casting yard and one set of launching equipment;
- In this way an economic and durable structure of good quality was obtained;
- Consecutively new details of the deviator under the structure, the transition of tendons through the bottom slab had to be solved and many structural analyses to be made;
- The measurements during the construction, the loading test and the successful use of the structure proved the correctness of presumptions in the design.

8 Credits and bridge data

Owner	DARS Motorway company in the Republic of Slovenia, d.d., Celje	
Design	PONTING Consulting and design d.o.o., , Maribor	
Contractor	GIZ Gradis, Construction Company Ljubljana d.d. with subcontractors	
Cables and prestressing system	DSI - Dywidag System International	
Bearings and expansion joints	Mageba Switzerland	
Consulting	DDC, d.o.o., Ljubljana	
Construction and service dates	November 2000 – October 2003	
Size of the structure	Length 833m, width 27.92m, surface area 23.257 m^2	
Value of construction works	13 millions EUR	
Material consumption for whole bridge	Concrete	25000 m^3
	Reinforcement	3121000 kg
	Tendons	486588 kg