Cantilever Erection of Prefabricated Long Span Bridges in Czechoslovakia

Les ponts préfabriqués de grande portée construits en encorbellement en Tchéchoslovaquie

Freivorbau mit Fertigteilen bei weitgespannten Straßen- und Eisenbahnbrücken in der Tschechoslowakei

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New system

Cantilever concreting in situ is a common method of bridge construction, and in Czechoslovakia has found widespread application for spans up to 120 m. A more recent and even more promising technique is the cantilever erection of bridges, with essentially the same static systems and structures, from prefabricated members. This procedure transfers most of the work into permanent well equipped workshops, and thus cuts the erection time proper to a minimum. Since the work in the shop is better organised and more easily supervised, a better quality of concrete can be obtained and a lot of material saved. The key factor of course is that no time is lost on the site in waiting for the concrete to harden.

A feasibility study that examined the potentialities of this method under current domestic conditions arrived at the following conclusions:

1. The prefabricated beam segments, their manifacture and the erection procedure must be standardised so as to serve for both road and railway bridges of various static systems (single- and multi-span frames, continuous beams, etc.), of various spans (from about 50 to 120 m), and of various widths.

2. The erection work on the site must not last longer than

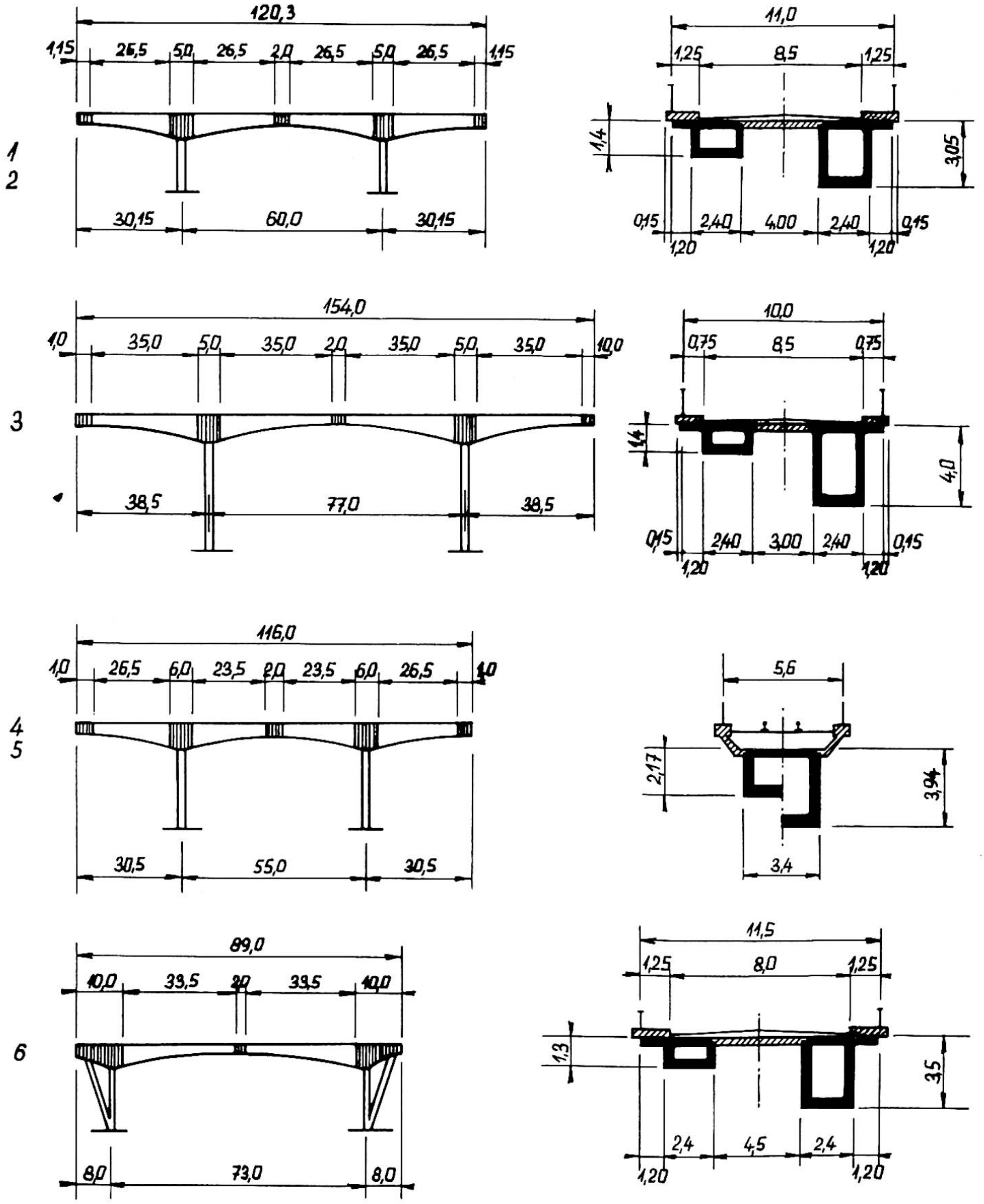

Fig. 1. Sketches of various types of the first bridges which have been erected by the new method.

a third of the time needed for the cantilever concreting of an equivalent monolitic structure.

3. In the cross section, the bridge must be composed of the least possible number of precast elements, preferably two or three only, so as to reduce the number of operations to be performed on site.

4. The prefab members for bridges of various spans and widths must all be made in the same standard steel moulds.

5. The weight of the individual members must at first be restricted, to 20 tons for road bridges and 35 for railway bridges, before further experience suggests some revision of these limits.

Some of the bridge types that have already been constructed in Czechoslovakia since 1964 on these lines are shown in Fig. 1.

Research and Technology

The practical work on sites was preceded by research (at the Research Institute for Civil Engineering in Bratislava, Czechoslovakia) dealing with following problems:

a) The state of stress resulting when the segments are assembled and prestressed were investigated on a 1 : 10 scale perspex model, where the deformations were measured by resistance strain gauges attached at 160 points (1). Some of the results are shown in Fig. 2. The concentration of stresses in the first segment which is attached by prestressing is much higher than is usually expected according to the beam theory. This makes due reinforcement in the top slab of the segment and high mortar quality in the joint necessary.

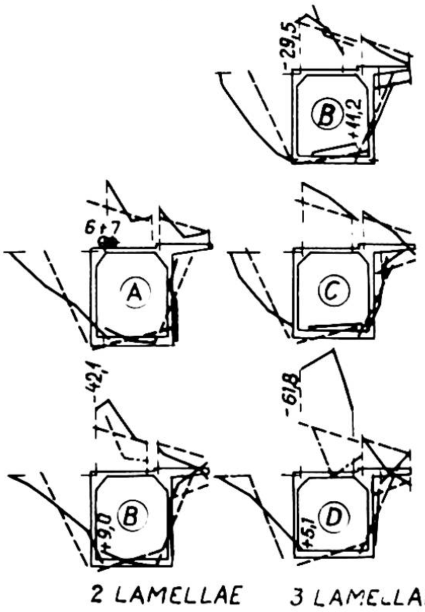

Fig. 2. Model investigation of stresses (---theory, ——measurement); bottom: the first joint behind anchoring

b) the range of vertical and horizontal deformations to be expected in separate, unconnected cantilever arms during the erection, was examined on a 1 : 50 model as a guide for the design of the erection carriage-crane (1).

c) Trials were run with the grouting of 3 cm wide joints with a specially composed mortar, which permits prestressing just 16 to 18 hours after injection.

d) A production line was tried out for the manifacture of large precast box-section members in universal steel moulds.

e) The requisite performance and design details of the erection crane and other accessories were established.

f) The state of stresses and deflections in build-up structures were investigated on 52 girders, I-section, 5 m long, 0,5 m high, made either monolitic or composed of six elements each, prestressed by 4 cables of 12 ∅ 4,5 mm (quality 120 / 160) see Fig. 3. Following parameters have been investigated:

f_1: various types of joints - made of concrete with a width of 3 and 8 cm, reinforced concrete (width 14 cm with overlapping loop reinforcement), or by gluing;

f_2: effect of loading resulting in the maximum normal stress (type A, Fig. 3), the maximum shear stress (type C) and the combination of both (b);

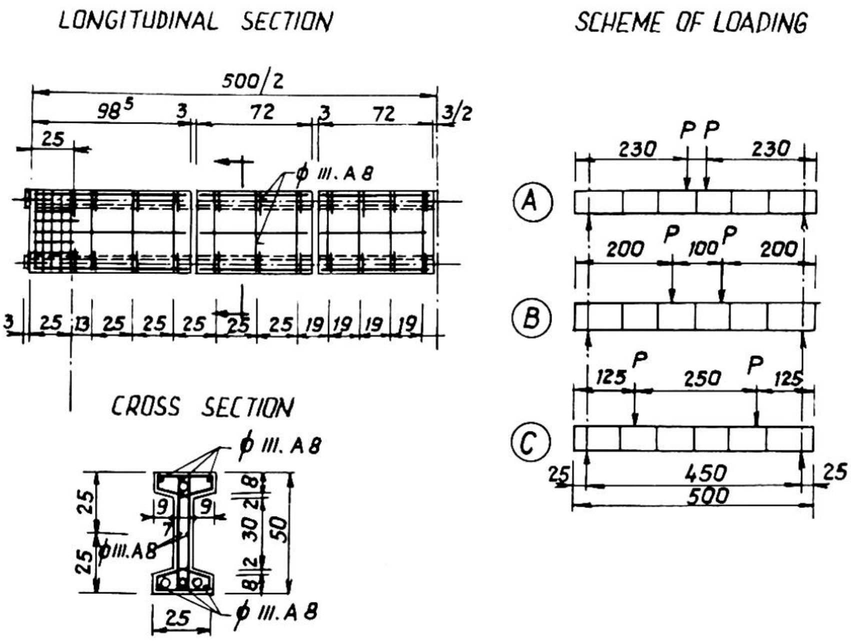

Fig. 3. Prestressed test girders (I-cross section)

f_3: amount and position of stirrup reinforcement - including skew stirrups;

f_4: range and magnitude of pulsating forces - in value up to 100, 125, 150 %, ore more, of the permissible design load. The process of loading and some results of the tests of a repeatedly loaded I-cross section beam are shown in Fig. 4.

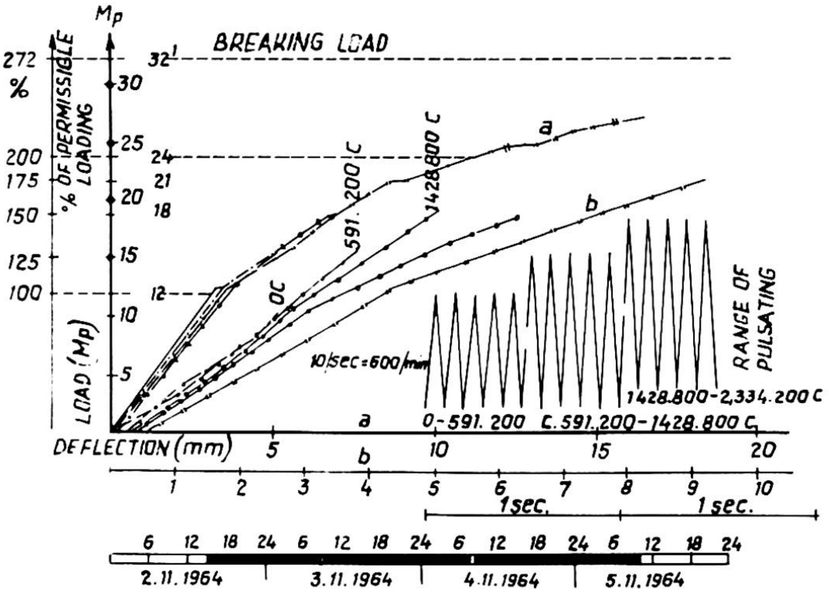

Fig. 4.
Test results - deflection and cracks - of one I-shaped girder subjected to pulsating forces.

In those tests the following values were determined: deflection (by means of dial deflectometers and electromagnetic recording indicators), normal stresses and deformations (resistance strain-gauge strips), shear and main stresses in the web of the beam (strain-gauge rosettes), stress in the stirrup reinforcement (resistance strain-gauge and mechanical dilatometers), cracks, their form and size during pulsating (conductive laquers and automatic registration equipment were used) etc. Table 1 shows how far the load bearing capacity of these build-up and composite structures falls behind that of monolithic ones. The monolithic beam had safety factors (i.e. ratios of breaking loads to working loads) around 2,7 to 2,9. The load-bearing capacities of all the other structures with different types of joints were lower, but were practically the same in glued girders as in those joints which have been filled with cement mortar or reinforced concrete. The values attained in all cases depended more on the quality of the joint than on these types (2,3).

Load-bearing capacities of prestressed concrete I-section beams Table 1

Type of loading	Max. effect of	Breaking load of (1)	build-up beams
		3 cm joints gaps (cement mortar)	14 cm gaps (r.c. filling)
static	bending moment	77 - 81	81 - 87
	shear forces	87 - 92	79 - 85
repetitive	bending moment	80 - 86	90 - 93
	shear forces	92 - 95	84 - 89

(1) in per cent of the values for corresponding monolithic beams.

Eight hollow box beams, 8 m long, composed of 9 segments each and prestressed by 4 cables, with joints filled with cement mortar or glued together, were tested dynamically with a big vibrator, changing frequences and force. The different behaviour of beams, the durability of joints, the state of resonance and big amplitudes was observed; the glued joints proved as the best of all.

There is a very close interdependence between the method by which the segments are manufactured, the static and dynamic load-bearing capacities of the structures built up of them, and the way in which the bridge maintains its vertical alignment - both in the course of erection and in service.

Two different methods were found suitable for the manufacture of the segments: Either each segment can be made separately, e.g. in the upright position; this involves the use of joints wider than 2 cm, which must be filled in with concrete or reinforced concrete. Alternatively, a horizontal chain of segments can be produced by concreting each of them end-to-end onto the one before it, which yields either "dry" (unfilled) joints, or narrow gaps, some 2 mm across, for gluing with an epoxide- or polyester-resin based cement. The first of these methods is suitable for structures with haunched beams, the second for constant cross section with unchanging section heights, and for particularly fast erection jobs. Both methods can also be combined with each other, but at the price of special measures which increase the costs.

"Dry" joints require no subsequent filling; the individual segments are laid close to each other and can be prestressed immediately afterwards, regardless of weather conditions. This method is a real labour-saver, but rules out any vertical correction once the construction work has begun (e.g. to take up wrong inclinations at the point where a precast structure meets the monolithic springing). There is also the danger that water will infiltrate into the joint.

"Wet" joints 2 to 4 cm wide are filled with cement mortar, those 5 to 10 cm wide with concrete, wider ones with reinforced concrete, i.e. the reinforcement loops must project into the joint gap.

Joints that are glued with epoxide or polyester resins allow the prestressing cables to be tensioned after a mere one or two hours, provided the ambient temperature stays above 10^{o} C.

The first series of bridges in Czechoslovakia employed separately made segments and wet joints; those in the road bridges were 3 cm wide and filled with cement mortar, those in the railway bridges 18 cm wide and filled with reinforced concrete. This technique was selected - without having in this time the results of the research program mentioned above - mainly on account of the previously exisiting designs, which envisaged beams of a variable height. Manufacture of segments chains in the horizontal position and using glued joints are principles of the renewed technology on sites in Czechoslovakia now.

The first bridge

The first bridge in Czechoslovakia built by the cantilevering of precast elements is a 10,5 m wide road bridge near Sirník in East Slovakia. Its main part has three spans of 30,15, 60,00 and

30,15 m, respectively. By its structural system, the three-span bridge is a frame with a hinge in the centre of the middle span, with two pairs of piers in the river, forming the columns of the frame. Its expansion bearings on the end supports are adapted to take up the tensile or thrust reactions too. The cross section of the bridge (Fig. 5) is made up of two box-section beams with outside cantilever brackets carrying the footwalks. The height of the beam varies from 1,40 to 3,05 m. The gap between the two beams is covered with ribbed r.c. panels, 4,40 m long and 2 m wide.

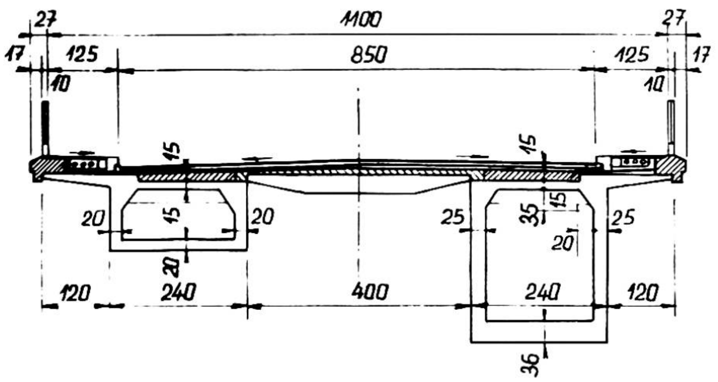

Fig. 5.
A cross section of the Sirník bridge.

The upper slab of each beam is reinforced with up to 39 prestressing cables, laid into wide shallow channels which were subsequently filled with concrete mix. The cables are anchored at the faces of each beam segment, by embedding from below in the widened corner parts of the upper slab. Each cable consists of 24 7 mm in diameter, made of a special steel with a tensile strength of 140 and yield point of 100 kp/cm^2. In places where the live load imposes positive bending moments on the structure, i.e. near the outer support and around the centre of the middle span, similar cables also reinforce the bottom slab of the box-section beams.

There are nine beam segments on each side of every pier, a total of 72 in the whole bridge. They are 3 m long or 2,50 m next to the piers, and were cast from grade 500 concrete mix. The 3 cm joints between them were filled with a special quick-setting mortar. The 2-m section in the centre of the middle span, which contains the hinge, is monolithic; it was concreted in situ from a suspended scaffolding. The river piers each consist of two columns 2,20 m by 2,40 m in cross section and 6 to 8 m high; they are made of grade 250 reinforced concrete and thin precast r.c. lining boxes. The foundation slab rests on 38 hollow r.c. piles, 70 cm in diameter and 6 to 9 m high. The end supports of the bridge consist of r.c. columns and cushions, on piles 35 cm square in cross section.

The static system of the structure alters in the course of its erection. While the segments are being mounted, the system is statically determinate, consisting of symmetrical cantilevers fixed in the columns of the inner piers. Once the thrust bearing connect these T-shaped structures to the outer supports, we have two systems of frames with span of 30.15 m and with cantilever arms 29 m long. These arms are then loaded with the 2 m long monolithic centre section with the hinge; the result is a single continuous three-span frame with a hinge in the middle. The highest stress in the lower slabs of the beams in 165 kp/cm^2, while the upper ones have a reserve of compressive strength that never falls below 13 kp/cm^2. Calculation showed that in the five years after the bridge is completed, the vicinity of the middle hinge would settle by 91 mm - due to creep and shrinkage of concrete; the bridge was therefore given the same amount of extra lengthwise camber.

The heaviest of the segments weighed 18,5 tons each. All the prefabs were made in a separate open-air plant served by two 10-ton gantry cranes, where they were cast individually in the upright position - Fig. 6. Universal steel moulds were used. After

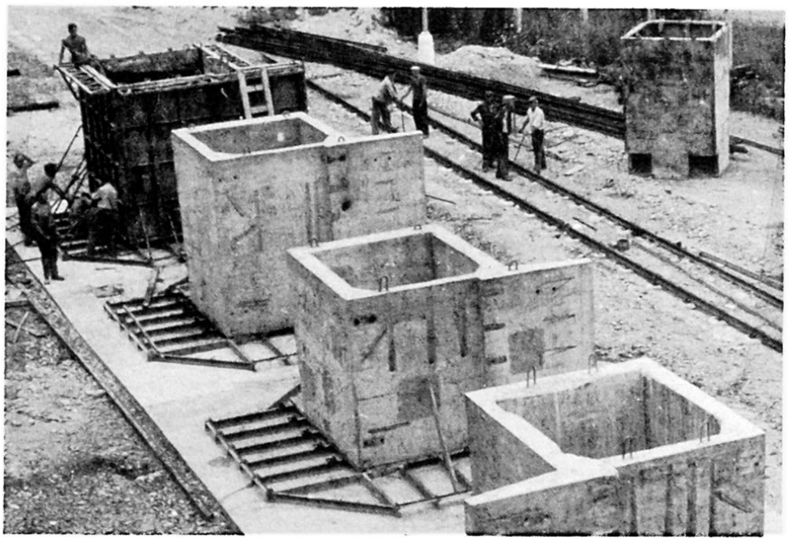

Fig. 6.
Beam segments on the line.

three days the segments were lifted off their bases and taken to the open storage area, to wait the road journey to the site.

On the site, the segments were mounted by means of an erection carriage crane - Fig. 7 - designed for the use both road and rail-

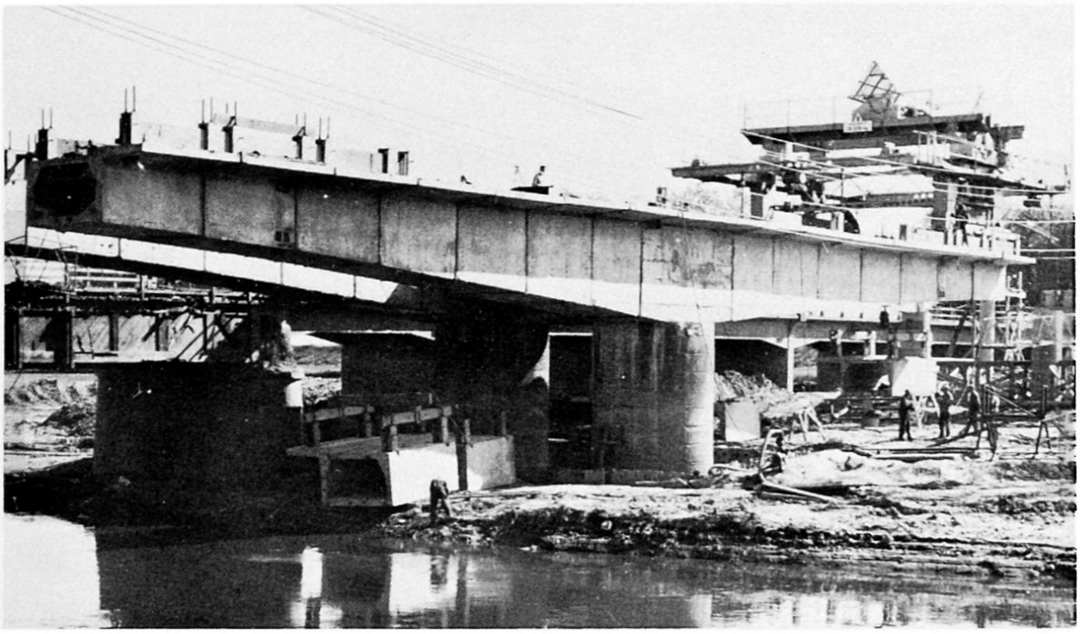

Fig. 7. Half of the Sirník bridge shortly before its completion.

way bridges. It is essentially a chassis with a frame, overhanging it on all sides, which carries on overhead travelling crane with one - for road bridge - or two crabs - for railway bridge. The segments had been placed, the cables were prestressed, the roadway panels laid, the middle part concreted and the pavement finished.

The static behaviour of the bridge and its deformations were closely observed throughout the construction. Measurements covered the settling of foundations, vertical deflection of the pier heads, vertical and horizontal displacements of the structures (Fig. 8) of the cantilever end during all phases of the work, the stresses in the concrete, prestressed reinforcement; statical and dynamical testing of the finished structure before rendering to service confirmed the predicted behaviour as assumed.

Further examples

The massive saving of time and materials on this job - in comparison with cantilevering by casting in situ - led to the ap-

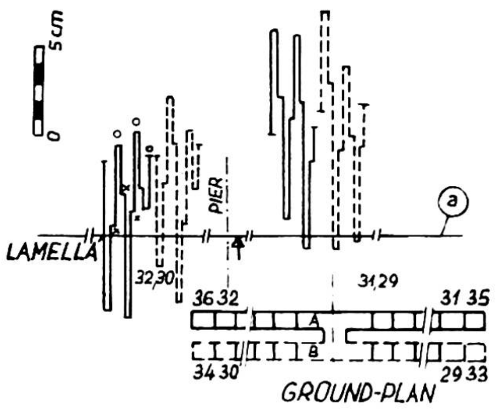

Fig. 8. How the ends of the cantilever arms deflected by mounting the segments 33 to 36.

plication of the same technique to a number of other bridges.

The road bridge at Margecany - Fig. 9 - has the same dimensions and the same static system as the one near Sirník, except for the fact that the middle piers are higher.

The road bridge at Košické Hámre has three spans of 38,5, 77,0 and 38,5 m, respectively and has middle piers rising 34 m above the ground level. The entire load-bearing structure , consisting of 104 segments and 70 roadway panels, was erected in three winter months.

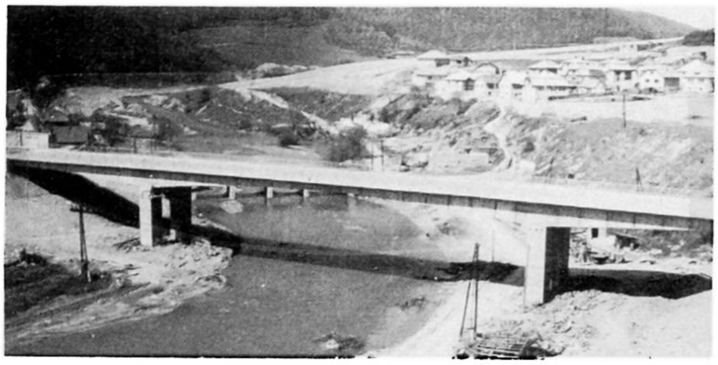

Fig. 9. The road bridge at Margecany.

The road bridge near Jaklovce is a frame with a single 73-m span as outlined at the bottom of Fig. 1, with overhanging ends and oblique tie members. It was erected from the end supports towards the centre, with the aid of temporary supports 11,5 m from the frame columns. The two halves were joined in mid-span by in-situ concreting and prestressing.

The railway bridge at Margecany (Fig. 10) has three spans, of 30,5, 55,0 and 30,5 m, with beam depths from 3,94 m over the middle piers to 2,17 m in the middle, but with no hinge in the centre. The solid r.c. middle pier, 1,65 by 3,40 m in cross section, is 14,7 m high and stands on flat foundation. The segment, weighing up to 35 tons each, were manufactured in the same way as those for the road bridges. The erection work was done with the same carriage, using a modified wheel spacing, two crabs, and suspension ropes spaced to by-pass the plan outline of the cantilever arms. Reinforcement loops protruded into the 18-cm joint gaps, which were

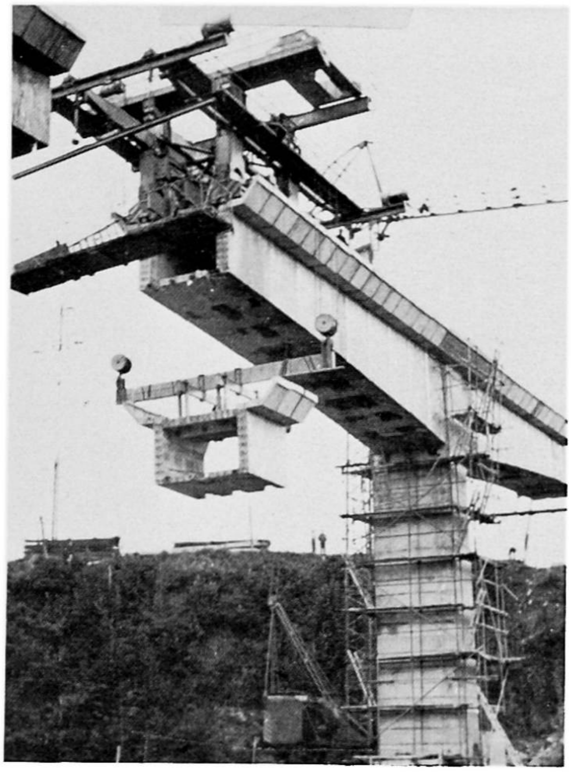

Fig. 10. Single-beam railway bridge at Margecany.

filled with a mix having a high initial strength and could be prestressed after 36 hours.

Although all these bridges were of a predominantly experimental character, the technical results and economies achieved are very favourable. This new method saved an average of about 4 % of the concrete, 10 % of the prestressed reinforcement and a full two thirds of the on-site erection time needed for the well-established and matured technique of cantilever in-site concreting. Some data of the speed of erection - by the first experimental bridges, using cement mortar joints - are shown in Table 2. The introduction of modified manufacturing and erection processes by bridges, that are built in Czechoslovakia now, such as glued joints, new equipment for mounting of segments with weight till 60 tons, allows to build bridges with more than 120 m spans, with a speed of erection more than 45 linear meters a week, by further cuts of materials and costs.

Table 2: Weekly output by first bridges.

Bridge	Middle span (m)	Weekly output segments average	segments peak	l.meters of erection average	l.meters of erection peak
Sirník	60	2,95	5	8,50	11
Margecany (road)	60	3,43	7	11,45	18
Košické Hámre	77	4,70	8	12,50	18
Margecany (rail)	55	2,50	4	8,05	12

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(2) Borovička, L. - Haas, J.: Report to the V.Cs. Conference on Prestressed Concrete, Bratislava, 1965, pp. 255-269

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SUMMARY

Technological and economic studies for the new method of erection of precast prestressed cantilevered bridges in Czechoslovakia were judged. Designs were preceded by experimental and technological research, especially in examining the state of stresses and ultimate bearing ratio of precast prestressed structures composed of elements, under static and dynamic load. Manifacture of hollow segments and processes on sites - incl. the first railway bridge in the world built by this method - are described. Savings of materials and time are mentioned.

RÉSUMÉ

En Tchécoslovaquie, on a étudié la technologie et économie de la construction des ponts en encorbellement aux voussoirs préfabriqués. Les recherches profondes théoriques et technologiques, p.e. les tensions et la capacité portante des poutres expérimentales, composées des voussoirs, ont précédé les travaux de projets. La fabrication des voussoirs et l'assemblage aux chantiers des divers ponts - aussi du premier pont de chemin de fer dans le monde construit par cette méthode - sont décrits. L'économie de matériel et la vitesse des travaux sont mentionnées.

ZUSAMMENFASSUNG

Die technologische und ökonomische Anwendbarkeit des Brückenfreivorbaues mit Fertigteilen in der Tschechoslowakei wurde untersucht. Vor der Ausarbeitung der Projekte wurden verschiedene Fragen der Theorie und Technologie erforscht, insbesondere der Spannungszustand und die Tragfähigkeit der aus mehreren Fertigteilen zusammengesetzten Spannkonstruktionen. Die Herstellung der grossen kastenförmigen Lamellen und deren Montage auf Brückenbaustellen - inkl. der weltersten mit dieser Methode erstellten Eisenbahnbrücke - wird beschrieben. Einige Material- und Zeitersparnisse sind angegeben.

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