Short Span Segmental Bridges in Czechoslovakia

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Recently, two distinct types of precast prestressed segmental bridge design have been developed in Czechoslovakia. These designs are suitable for both urban and highway bridges with spans ranging up to 150 ft (45 m). The first design (Fig. 1) consists of box segments transversely connected by the top flange while the second alternative (Fig. 2) utilizes segments of open, double-tee cross sections.

The development of these bridges was preceded by the successful construction of several segmental overpasses (Fig. 3). Although these bridges were built under different social and economic conditions, some of their structural features and construction methods have interest and applicability to projects in other parts of the world.

The following features are common to all the bridge structures described herein:

1. The superstructure consists of precast match-cast segments with a specified cube strength of about 7000 psi (50 MPa). Short-line horizontal casting was used to produce all constant-depth segments while adjustable forms allowed for both horizontal and vertical curves and variations in superelevation. The segments of the box cross s tions were cast in forms similar to th developed by Campenon and Bernard.[1,2] T double-tee members were cast in forms ing a new concept. The segments are c in one-day production cycles and the curi of the concrete was accelerated by steami the freshly cast components.

2. To control temperature and humid variations, deicing salts, and different cre and shrinkage ratios of the segment sl and webs, the joints between segments w covered with epoxy resin during assemb Also, the faces of the segments were p vided with multiple keys and erected cantilever. This made it easier for the p cast segments to adjust to their proper sition after temporary post-tensioning.

3. The erection process was designed such a way that the structural configurati of the bridge would not be affected by t redistribution of creep caused by volume stress changes.

4. During the course of erection, the perstructure was gradually post-tension by two systems of tendons: straight tend placed in the deck and draped tendons plac

Presents an overview of the design features and construction techniques used in some recent precast prestressed short span segmental bridges in Czechoslovakia.

in the webs. Because of the relatively low segment depth, no work in the low cells of the box girders was possible. Therefore, all tendons were anchored in the upper part of the section. The tendons were formed by six, 7-wire strands 0.612 in. (15.5 mm) in diameter anchored by their own anchorage system. The tendons are situated along the entire length of the bridge in both the upper and lower faces of the superstructure. Since the stresses in the tendons after losses are lower than permissible stress levels, in cases of unexpected overloading, the prestressing steel can act similar to mild steel reinforcement, thus limiting the width of cracks in the joints. Note that the Czechoslovakian Building Code prohibits the use of unbonded tendons.

OVERPASSES

Overpass bridges for field and forest roads represent a specialized group of bridges. They are characterized by the fact that the right angle of crossing and the width between railings are always constant and their

Fig. 1. Bridges (DS-W type) in Prague.

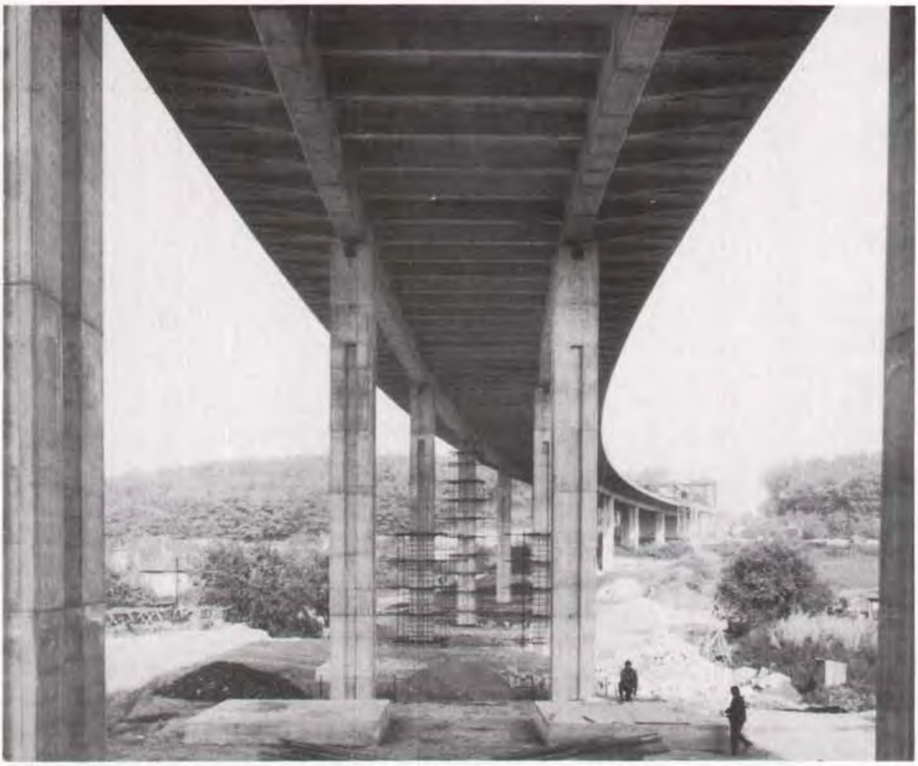

Fig. 2. Bridge (DS-T type) across the Rokytka River in Prague.

spans vary only slightly. This makes it possible to standardize them as whole bridges of variable spans.

The bridges were first designed as continuous beams or slant-leg portal frames (see Fig. 4) with classical abutments. After obtaining additional design experience, the abutments were replaced with precast end beams and prestressed tie rods. This new design then served as a model for designing a standardized bridge. Varying the spans of the bridge was made possible by either shortening or omitting central or end segments (see Fig. 5).

The superstructure is assembled with segments of double cell, trapezoidal box cross sections (Fig. 6) and end cross beams. The segments, with widths of 21 ft (6.5 m), are cast simultaneously with fascia, and end cross beams with short wings. Diaphragms are designed in segments above the intermediate supports. The weight of typical segments is 17 tons. Fig. 7 shows a continuous box girder bridge.

The bridge deck is supported by precast columns. Since the intermediate supports are very slender, the stability of the bridge is secured in the transverse direction with two tie rods supporting the end cross beam (see Fig. 9).

The arrangement of the prestressing steel resulted from the designed method of assembly. During erection of the central span, the draped tendons placed in the webs were gradually tensioned. Next, the side spans were erected and the straight tendons placed in the deck segments were tensioned. These tendons were then secured with continuous tendons after erection was completed (see Fig. 10a).

Construction of both continuous beam or slant-leg portal frame bridges is generally

Fig. 3. Overpass bridge across the Highway Prague-Brno.

Fig. 4. Erection of side spans of overpass bridge.

the same. Fig. 10 shows the erection sequence of the latter bridge type. The central part of the superstructure is erected symmetrically from the middle of the bridge on staging. Erection then begins with the placement of the central segment onto the top of four jacks. Next, the second and third segments are temporarily prestressed to the first segment, supported by jacks, and post-tensioned by the draped tendons. Finally, the jacks supporting the first segment are removed and the procedure is repeated (see Fig. 10b) until the segments reach the temporary towers situated near the slant legs.

The segments of the side spans are then erected, forming cantilevers on each side of the temporary towers (see Figs. 4 and 10c). Each segment is first temporarily prestressed to the already assembled structure and the straight tendons are positioned. When the last segments are supported, the end cross beams are temporarily prestressed and the continuous tendons are tensioned. After tensioning, the erected superstructure is dropped onto the intermediate supports so that the static arrangement of the structure corresponds to the three-span continuous beam. The precast supports are adjusted to the deck (Fig. 10d), the pockets in the foundations are cast, and temporary towers are removed.

The continuous beam is also erected in a similar way; however, the intermediate towers are not necessary since they are formed by the piers. The erection of the bridge structure itself is carried out within 2 weeks.

Since 1974, more than 40 overpasses of this type have been built and construction of other structures is in progress. To date, the structural performance of all such bridges has been excellent.

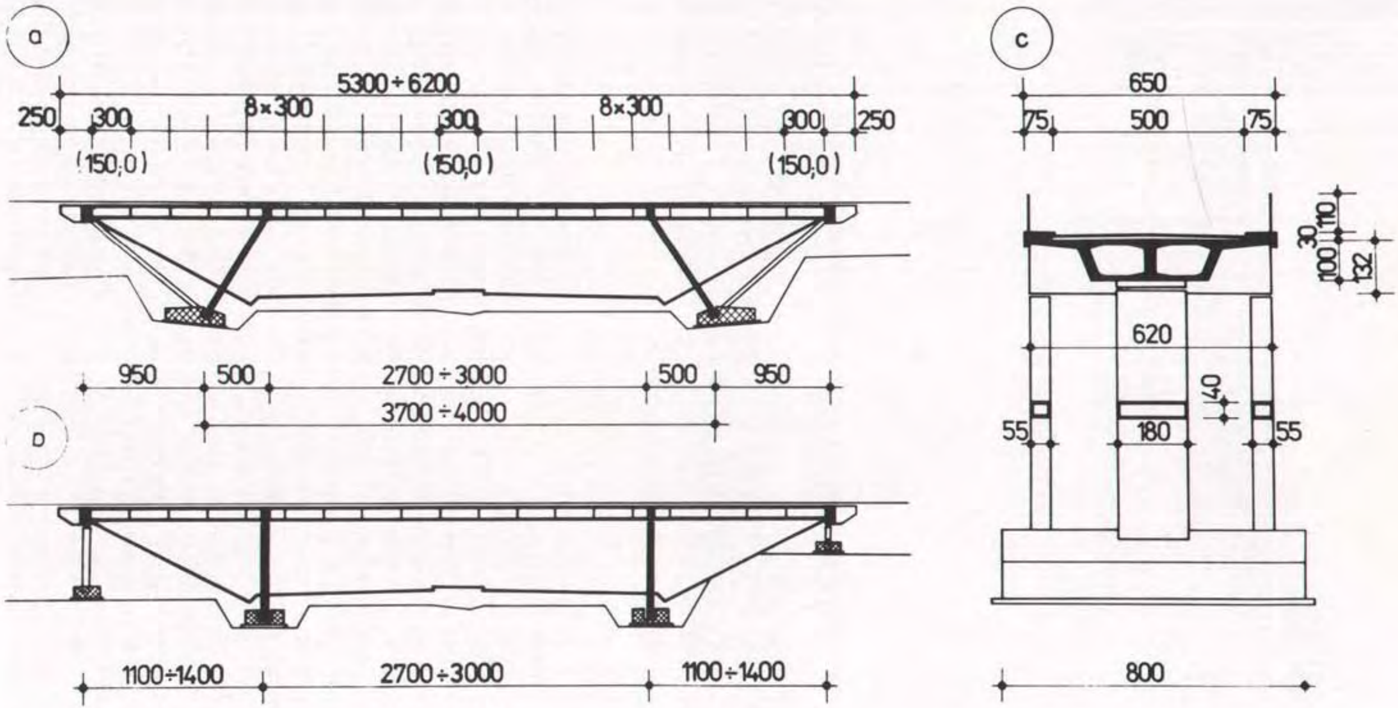

Fig. 5. Overpass bridges: (a) elevation of slant leg portal frame; (b) elevation of a continuous beam; (c) cross section.
Note: 1 cm = 0.3937 in.

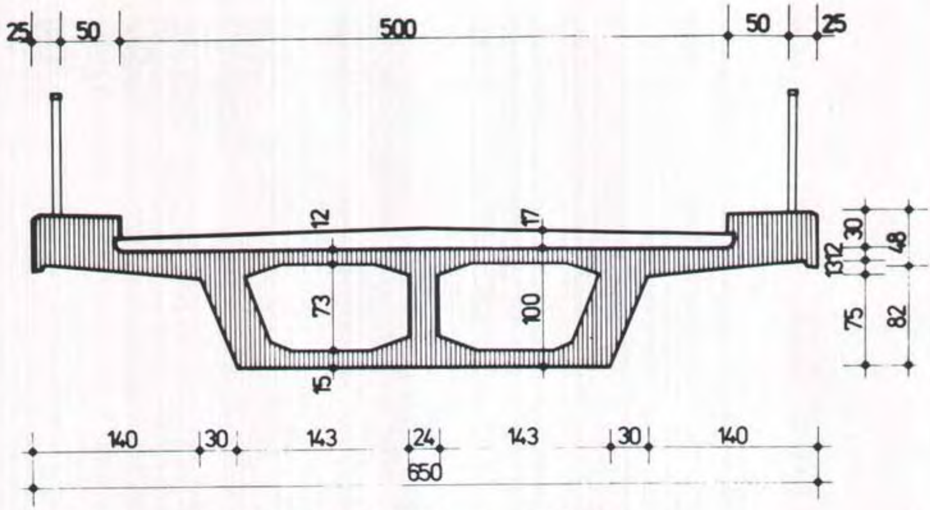

Fig. 6. Cross section of segment. Note: 1 cm = 0.3937 in.

Fig. 7. Continuous box girder bridge.

Fig. 8. Slant leg portal frame.

Fig. 9. Slant leg portal frame — End cross beam and tie rods.

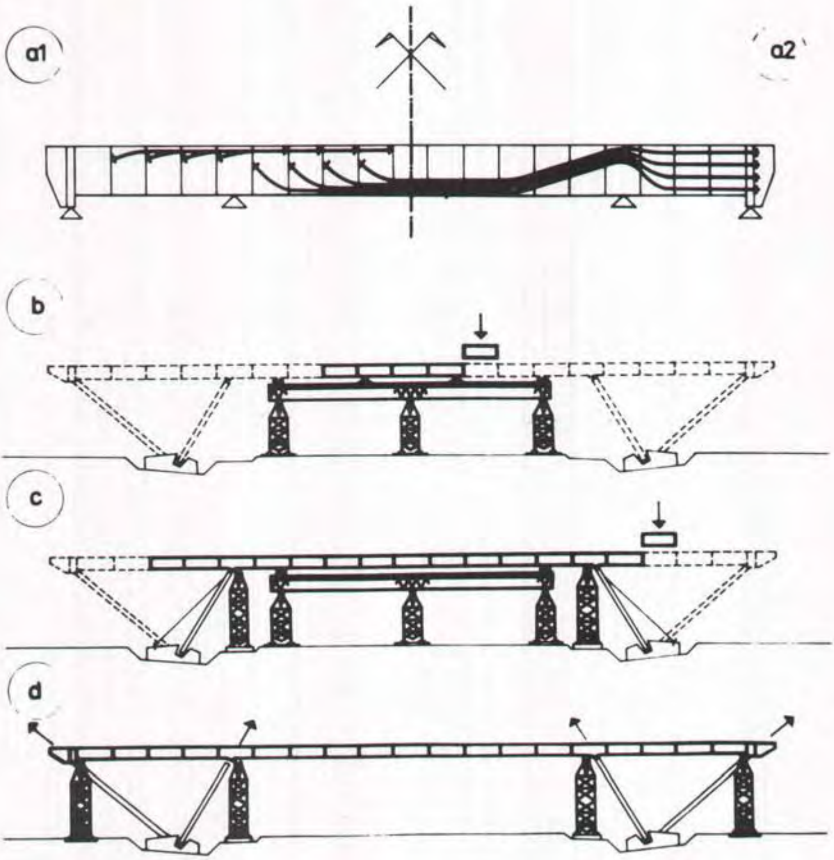

Fig. 10. System of prestressing tendons and erection sequence: (a) draped and straight tendons; (b) continuous tendons; (c) erection of central span; (d) erection of side spans; (e) adjustment of precast supports.

FOOTBRIDGE OVER THE TRAMLINE IN BRNO

In planning the overpass crossing over the high speed tramline in the city of Brno, it was necessary to design a footbridge with a very small horizontal curvature radius of 148 ft (45 m) and variable elevation (see Fig. 11). Despite the complexity of the bridge's geometry, it was possible to build the structure using segmental construction.

The two-span footbridge was designed using segments and end cross beams which were manufactured in the same forms as the above mentioned overpass structures. The side supports were formed by precast columns. The columns of the lower end of the bridge are fixed while the columns of the upper end are hinged. The intermediate support is formed by a very slender octagonal precast column (see Fig .15) which is situated eccentrically to the logitudinal axis of the bridge with respect to the redistribution of torsional moment.

The requirement to use existing manufacturing equipment affected the arrangement of tendons and the erection process. For this reason, the deck was post-tensioned using continuous tendons that were tensioned after the superstructure was

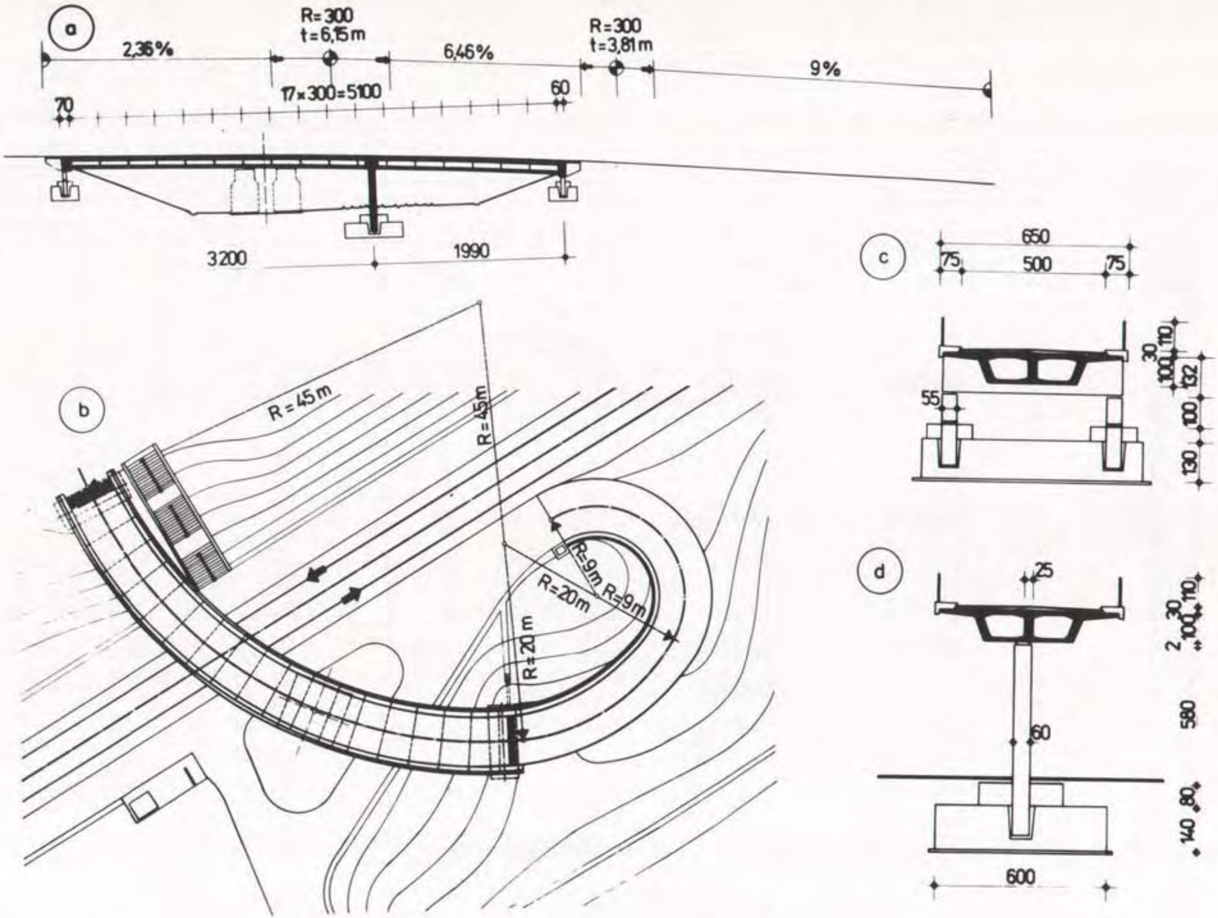

Fig. 11. Footbridge over tramline in Brno: (a) elevation; (b) plan; (c) cross section over upper side support; (d) cross section over intermediate support. Note: 1 cm = 0.3937 in.

erected. The segments were placed continuously from the lower end of the structure to its upper end in successive cantilever. The static effects were controlled by temporary towers that supported each successive segment.

Erection began with placement of the first two segments on jacks situated on a short staging (see Fig. 12a). After post-tensioning (Fig. 13), the inside jacks were removed and the end cross beam was prestressed to them. The remaining segments were then erected using the cantilever method of progressive placement (see Figs. 12b through 12d).

During the erection process, the segments were gradually prestressed using 2 × 2 continuously coupled cables placed in the top flange. Since the hydraulic jacks only supported the erected segment during its erection (inducing a very small force), the superstructure was stressed by only negative moment load which was later balanced during post-tensioning. After erecting all the segments and the end cross beam (see Fig. 12e), the pockets in the foundations were cast. Then, the superstructure was post-tensioned by the continuous tendons and the temporary towers were removed. The entire erection sequence can be seen in Fig. 12.

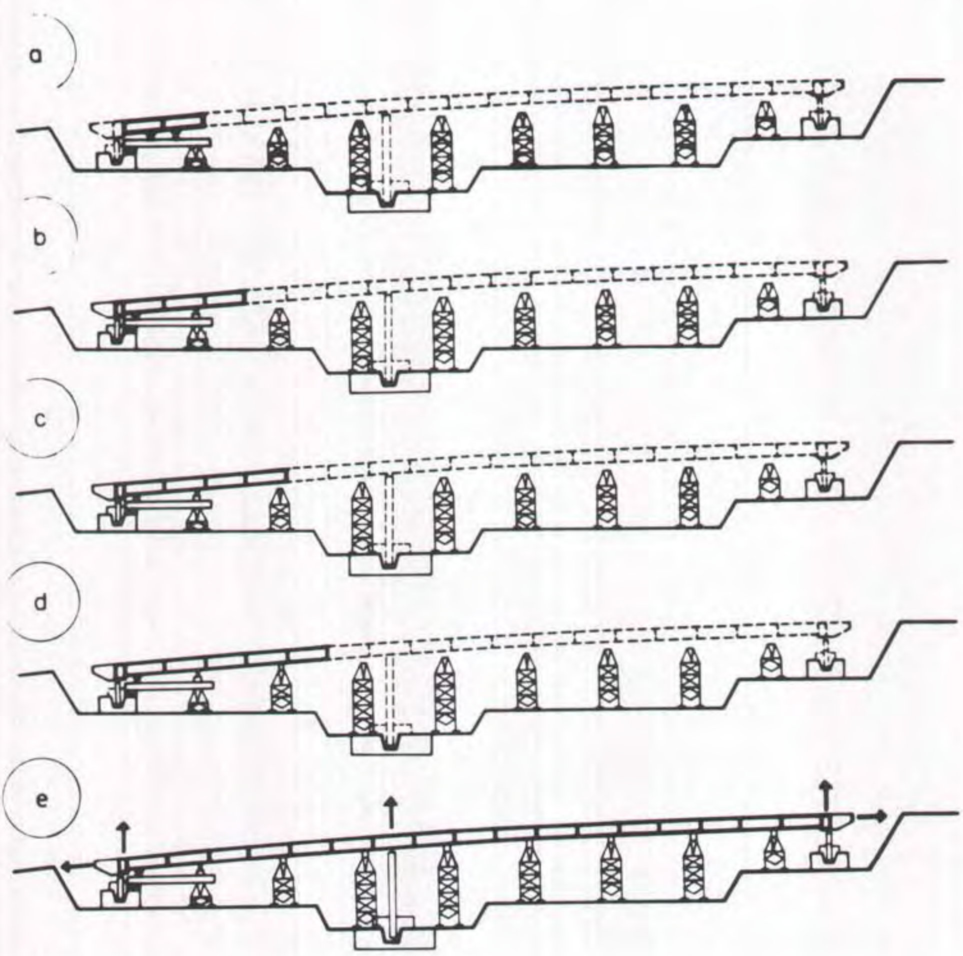

Fig. 12. Erection sequence.

Fig. 13. Post-tensioning of the first two segments.

Fig. 14. Erection of the end cross beam.

Fig. 15. Finished structure.

The footbridge was erected precisely in the designed shape without any shims or concrete joints. These excellent results enabled progressive placement technology to be used for other types of bridges.

DS-W BRIDGES

The DS-W bridges are designed with box girders transversely connected by the top flange (see Fig. 16). The shape of the structure was designed on the basis of detailed structural analysis[3] which showed the suitability of this type of structure for bridges of various widths, skew crossings, and curvatures. This type of construction is also being used to design bridges with complex geometry conditions.

The box beams consist of segments with the dimensions shown in Fig. 17. The ends of the bridges are always perpendicular while the intermediate supports may be skew. These supports are formed by slender precast columns connected to the deck by concrete hinges. The hinge in the longitudinal direction of the bridge makes rotation of the superstructure possible, and rotation in the transverse direction ensures stability (see Fig. 18).

Diaphragms are designed only in pier segments. The typical segment weight is 20 tons while the weight of the pier segments is 25 tons.

Originally, the first bridge structures were transversely connected only by post-tensioning recognizing the pressure reserve in the joints. Because of the relatively high live to dead load ratio, the amount of prestressing was quite large.

For this reason, full-scale tests were carried out on the connection between two segments. The test segments were supported under their webs and then the 3.3 ft (1 m) wide joint between flanges was reinforced with mild reinforcing steel and cast. The segments were loaded not only by a concentrated force placed on the deck, but also by different positions of the supports corresponding to the rotations and deflections of the bridge girders.

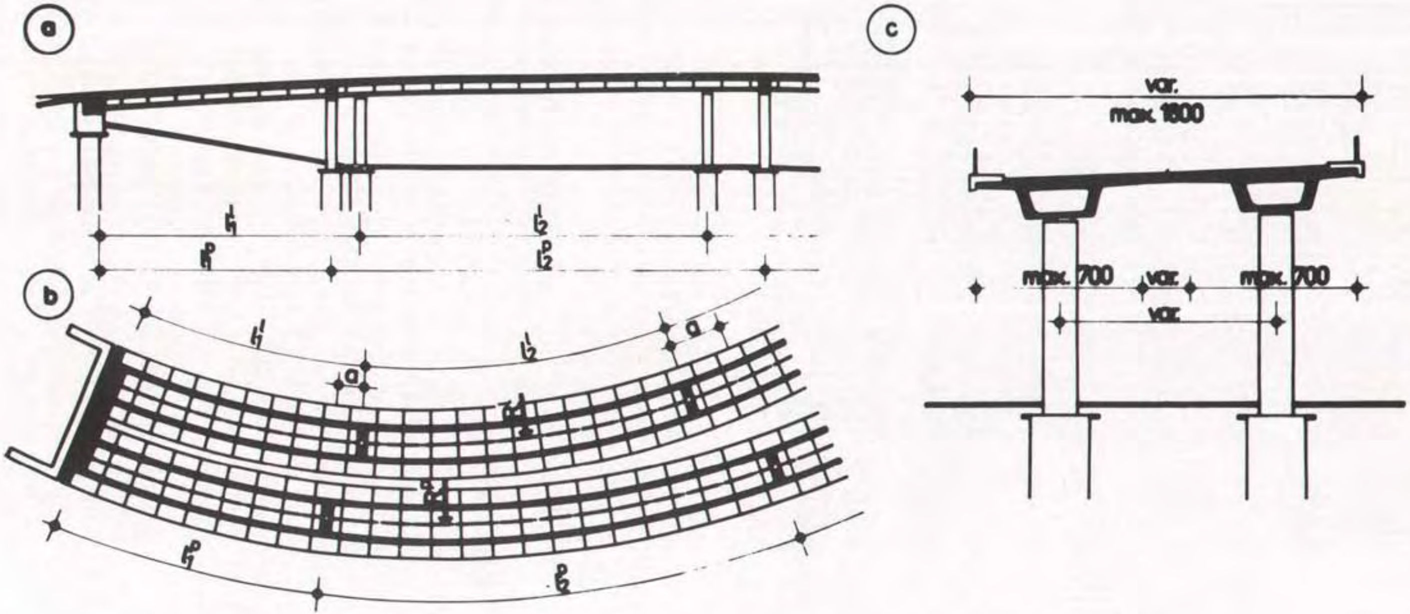

Fig. 16. Arrangement of DS-W type bridges: (a) elevation; (b) plan; (c) cross section. Note: 1 cm = 0.3937 in.

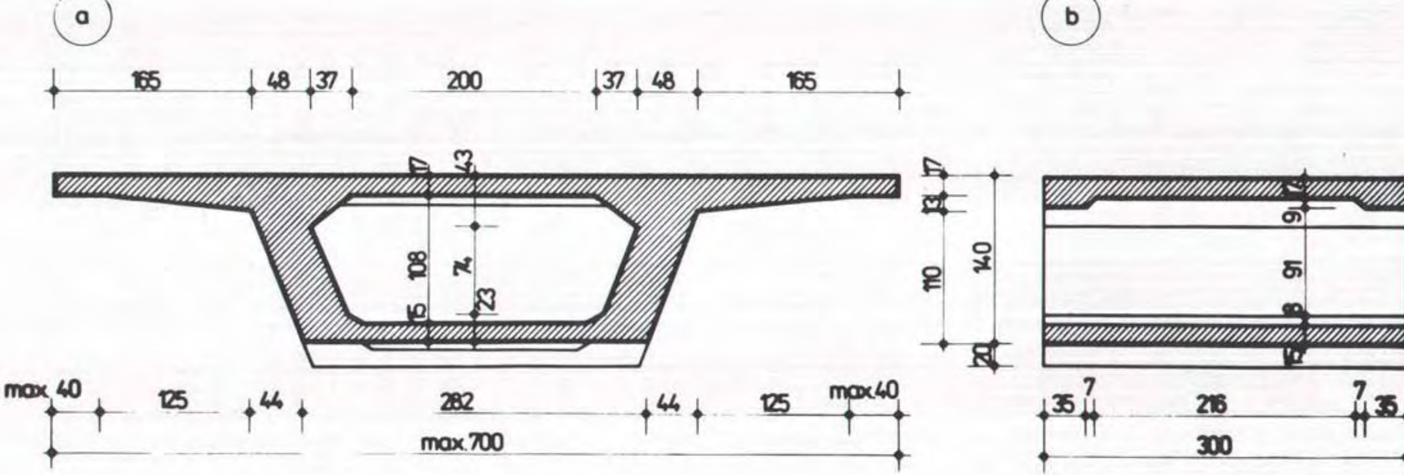

Fig. 17. Segment of DS-W type bridge: (a) cross section; (b) longitudinal section. Note: 1 cm = 0.3937 in.

Fig. 18. Construction of DS-W type bridge in Brno-Reckovice, Czechoslovakia.

The loading was repeated in several cycles and finally the ultimate strength of the connection was determined. The cracks which developed under service load were smaller than 0.08 in. (0.2 mm) and they closed immediately after unloading. Also, sufficient ultimate strength was found to exist over the entire connection area.

For this reason, girders with an axial distance of less than 21 ft (6.5 m) are connected only with mild reinforcing steel. Segments with larger axial distances are connected with mild reinforcing steel and post-tensioning to reduce the secondary effects due to creep and shrinkage of the concrete.

During erection, the box girders are continuously post-tensioned using two systems of tendons which distribute loading during both erection and service life of the bridge (see Fig. 19). Straight tendons are placed in the deck slab and are uniformly distributed along the deck width and anchored at the slab stiffening near the joints.

One group of tendons (Cables B) is situated only near the supports, while the second group (Cables C) is gradually tensioned and coupled along the entire length of the bridge. The function of these tendons during erection is to balance the negative moment in the cantilever and, during placement of additional segments, produce uniform compression of the intermediate spans.

Also during erection, the draped tendons (Cables A) are gradually tensioned from the face of the segments which are being assembled.

The segments are manufactured in forms described in Ref. 3. Segment geometry was determined by a computer program and manufactured according to the design level line and real measured values of segments which had previously been cast.

The superstructure itself is erected in cantilever from one end of the bridge to the other. The segments are placed in position either by a mobile crane which moves on land or by a portal crane moving on a track situated along both sides of the erected bridge portion (see Fig. 21). Stresses in the assembled cantilever are reduced by using one or two temporary towers to distribute loads.

The erection sequence is illustrated in Fig. 20 and shows the assembly of the end and first intermediate spans. Span length is 82 and 98 ft (25 and 30 m), respectively.

The end span is erected in three stages:

1. The first segment is placed on the abutment and temporary tower. After anchoring to the abutment, the second and third segments are erected and prestressed with Cables C (Fig. 20a). Then, the third segment is supported and Cables A are tensioned.

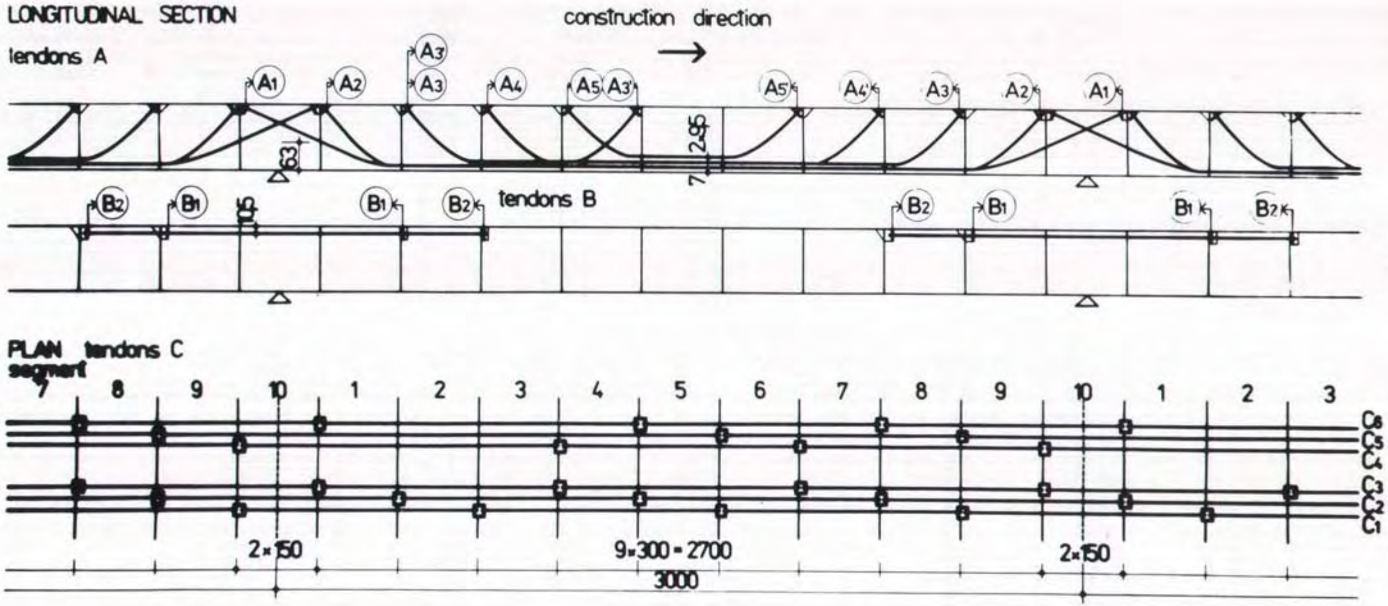

Fig. 19. System of prestressing tendons.

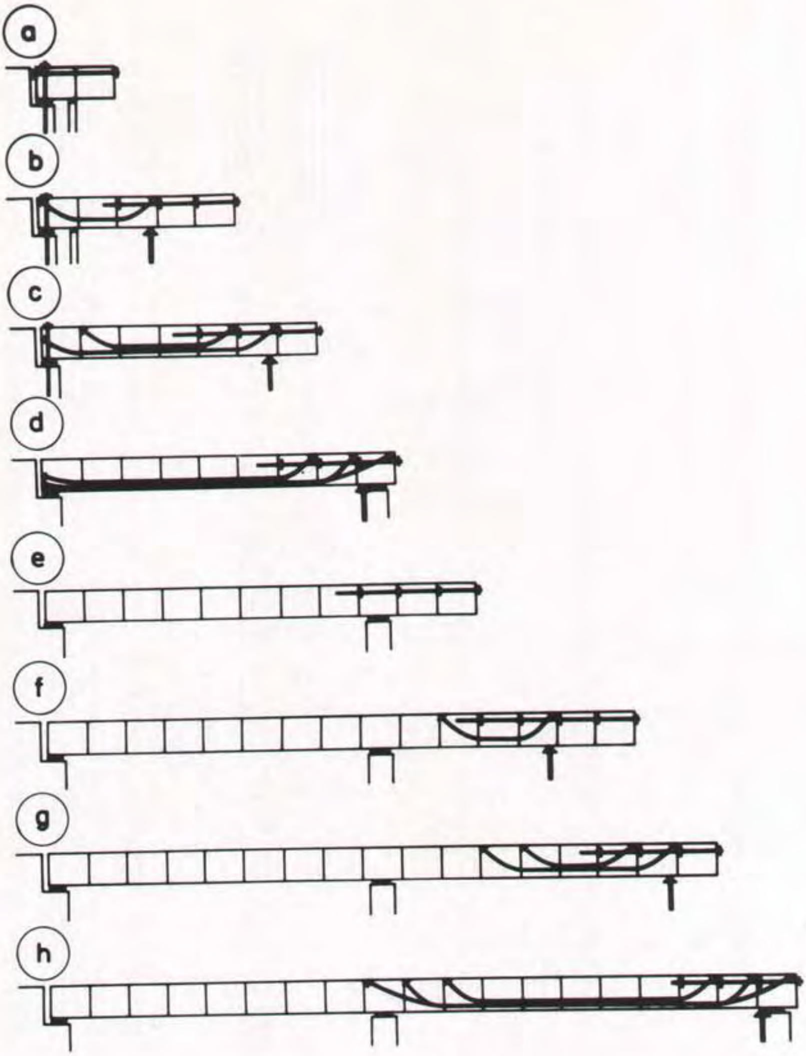

Fig. 20. Erection sequence.

2. This stage includes the erection of an additional three segments in cantilever (Fig. 20b), the supporting of the sixth segment and removing the support from the third segment.

3. During the final stage, the last three segments of the end span are erected in cantilever after the rectification of alignment is done on the temporary supports (Fig. 20c). After supporting the cantilever with the rectification support, Cables A are tensioned, the temporary support under the sixth segment is removed, the first span is rectified in elevation, and the concrete hinge is cast (Fig. 20d).

The erection of the intermediate spans is also carried out in three stages:

1. The first four segments are erected (Fig. 20a). After supporting the fourth segment, Cables A are tensioned and the reaction of required intensity is induced.

2. Erection of an additional three seg-

Fig. 21. Erection of DS-W segment by a portal crane.

ments is carried out (Fig. 20f), the support tower under the fourth segment is removed and the reaction of required intensity is induced.

3. Finally, the last three segments are erected (Fig. 20g), the cantilever is supported by a rectification support, Cables A are tensioned, the temporary support under the seventh segment is removed and the reaction corresponding to the given stage of erection is induced and the concrete hinges are cast (Fig. 20h).

The magnitude of the forces of the temporary support is determined so that the moment above the support may constantly have the same value as the moment which appears after erecting the first four segments. A computer then determines static effects and monitors the structure during erection.

The DS-W bridges were successfully designed for two overpasses with very small horizontal curves of 230 and 427 ft (70 and 120 m), respectively, and for four urban viaducts in Brno. All the structures are performing superbly and the correctness of the structural and construction details has been verified.

DS-T BRIDGES

The DS-T bridges represent the latest type of construction developed and combine the advantages of both simple manufacture and erection with low concrete and steel consumption. These bridges are comprised of

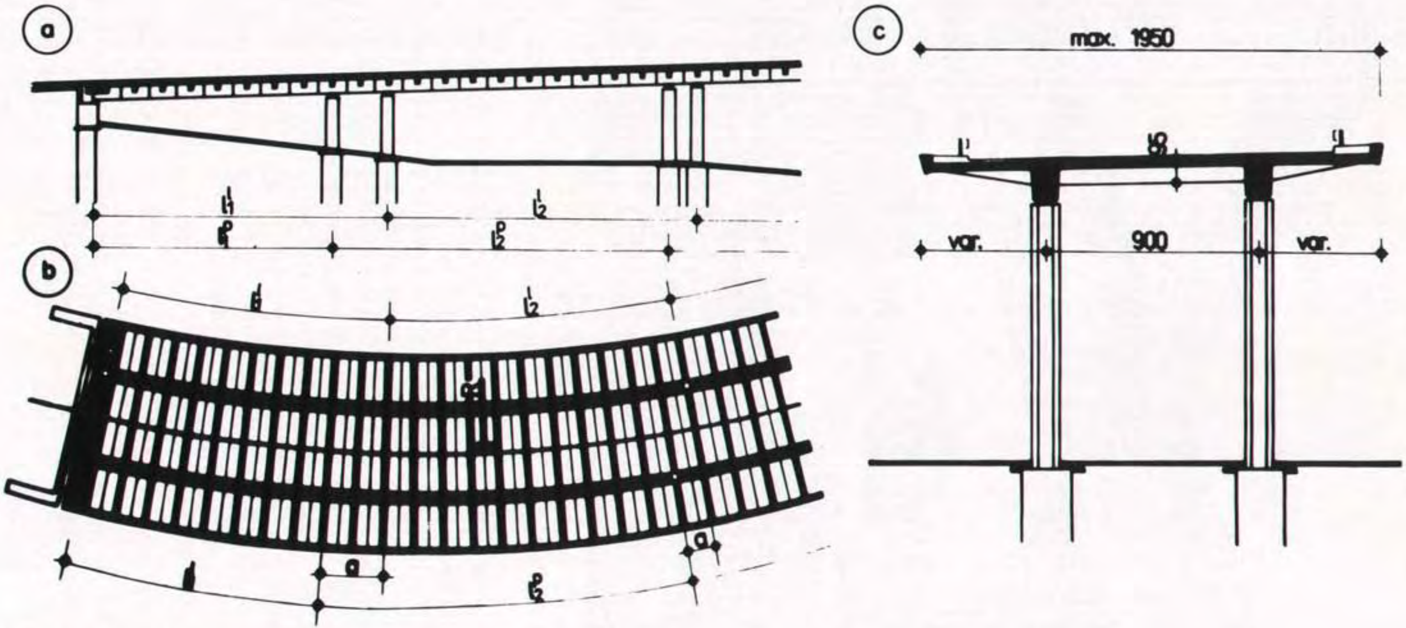

Fig. 22. Arrangement of DS-T type bridges: (a) elevation; (b) plan; (c) cross section. Note: 1 cm = 0.3937 in.

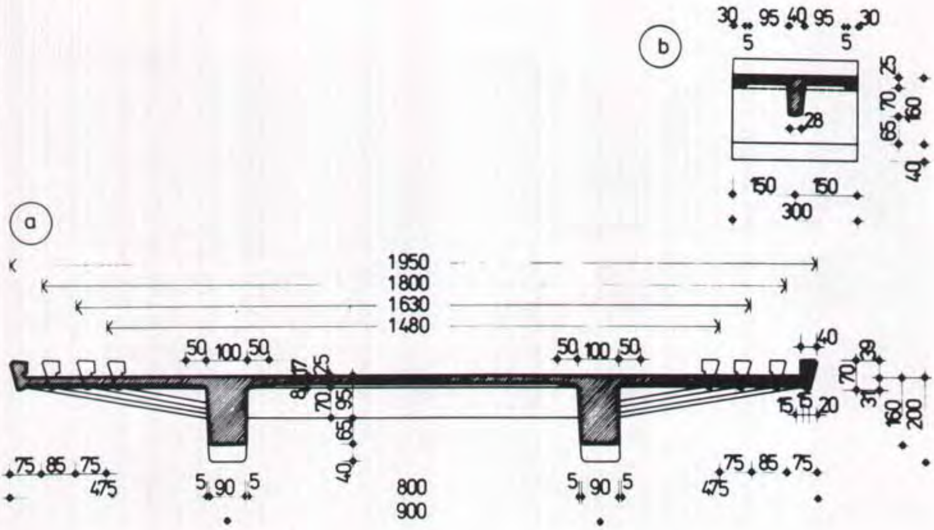

Fig. 23. Segment of a DS-T type bridge: (a) cross section; (b) longitudinal section. Note: 1 cm = 0.3937 in.

open cross section segments which are formed by two girders: the deck slab and fascia beams (see Figs. 23 and 24). Each segment is reinforced by a cross beam at midspan while the deck slab is strengthened near the faces. Segment depths are 5.2 and 6.6 ft (1.60 and 2 m) and various segment widths are obtained by changing the projection of the cantilevers.

DS-T bridge construction was designed on the basis of a very detailed analysis by both the grillage idealization and finite element methods.[3] The analysis also showed that DS-T construction may be applied for bridges with small horizontal curves, 820 ft (250 m), and for bridges with the intermediate supports skew. Fig. 22 illustrates a typical arrangement of a DS-T structure. The ends of this type of bridge are always perpendicular and the abutment segments are reinforced with monolithic cross beams near expansion joints. On slender, intermediate monolithic supports, the superstructure is placed with the help of the pot bearings.

DS-T structures are gradually post-tensioned during erection by two systems of cables — straight and draped tendons — in the same way as in the previously discussed DS-W bridges (see Fig. 19). Furthermore, a finite element analysis shows that the approaching of tendons to girders does not affect distribution of normal stress from the straight tendons. Therefore, these tendons are uniformly distributed in the deck for simple manufacture.

The draped tendons are placed in the girders and anchored in the top part of the section. The segments are reinforced with mild reinforcing steel in the transverse direction of the bridge. Transverse prestressing was used in only one case, namely, the bridge across the Rokytka River in Prague, where the segment widths of 64 ft (19.50 m) were extended by monolithic fascias.

The segments weigh a maximum of 63 tons and are manufactured in a stationary precasting plant using a special method of match casting. In contrast to the forms designed by Freyssinet International which provide a blank end and a soft mold bottom to enable the twisting of segments, the new method utilizes equipment formed by two mutually independent elements: a fixed form and a manipulator (see Figs. 25 and 26). After stripping, the segment cast is not shifted in the contact position on mold bot-

Fig. 24. Segments of a DS-T type bridge.

tom, but is lifted, shifted, and placed on the manipulator. The contact joint is always on the same level as the contact segment and is pressed to the rear, perpendicular edge of the form. Since the form bottom is always plane, twisting is obtained by turning the contact segment along its longitudinal axis.

The form itself consists of two fixed frames, outside and inside shutters, and a movable front end. The frames are situated under the girders and contain two squeeze-out rollers which, after stripping, slightly lift the segment before it is removed from the form. The required segment shape is formed by turning the movable front end (see Fig. 27). The manipulator makes it possible to adjust the contact segment into a position parallel with the rear edge of the form and to press the segment to the form to stabilize that position in casting.

Note that the manipulator is formed by two frames placed on top of each other so that the lower frame enables the lifting of the manipulator while the upper frame enables the turning of the vertical axis. Turning the segment along its longitudinal axis is achieved by using different heights of guiding inlays shaped identical to the squeeze-out roller heads in the form.

The production equipment is further supplemented with a device for guiding the segment onto the manipulator, a walkway, and trucks equipped with a winch for pulling out the tubes forming the tendon ducts.

The basic operations involved are as follows:

1. Placing the reinforcing cage into the open mold
2. Adjusting the contact segment on the manipulator
3. Adjusting the movable front end
4. Adjusting segment parameters
5. Forming the tendon ducts
6. Casting the segment
7. Taking out the tubes forming the tendon ducts
8. Measuring the segment after casting
9. Form stripping
10. Moving the contact segment into storage and placing the newly cast segment on the manipulator

The reinforcing cage is assembled inside a wooden template where the tubes for the tendon ducts and the inserts for forming pockets for the tendon anchors are placed. Concrete is supplied to the mold via a con-

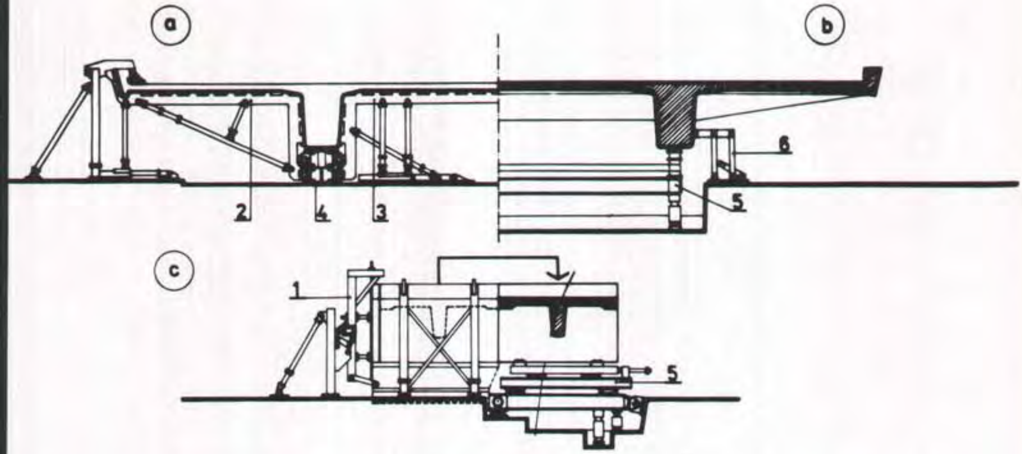

Fig. 25. Forms for DS-T type segments: (a) cross section of form; (b) cross section of contact segment on manipulator; (c) longitudinal section; (1) movable front end; (2) outside shutter; (3) inside shutter; (4) frame; (5) manipulator; (6) guiding device.

veyor belt. First, one girder is filled to the lower edge of the slab, and then the other. The slab with the cross beam is then cast, followed by the fascia. Next, the concrete is compacted by means of internal and surface vibrators. Hardening of the concrete is accelerated by steaming.

During the manufacturing process, much emphasis is placed on the precise adjustment of segment dimensions and on subsequent segment measurements after casting. The values of segment depths and lengths which were adjusted and measured are shown in Fig. 27. Length was measured using a slide measuring gage and theodolite; depth values were determined by levelling. The adjusted values were set by a computer program which determined the dimensions of manufactured segments according to the designed level line and real measured values in segments which had already been cast.

The superstructure of a DS-T bridge is assembled in cantilever from one end of the bridge to the other (see Fig. 29) and resulting stresses are controlled by using temporary supports (see Fig. 30). The arrangement of the basic assembly composition is illustrated in Fig. 28.

Segments of common spans are erected by a special portal crane, KPJ-90, which travels on the girders of the deck being assembled. The storage of segments behind the abutment is operated by another portal crane travelling on tracks situated along the abutment wings where the first three segments of the end span are also assembled.

Fig. 26. Forms for DS-T type segments.

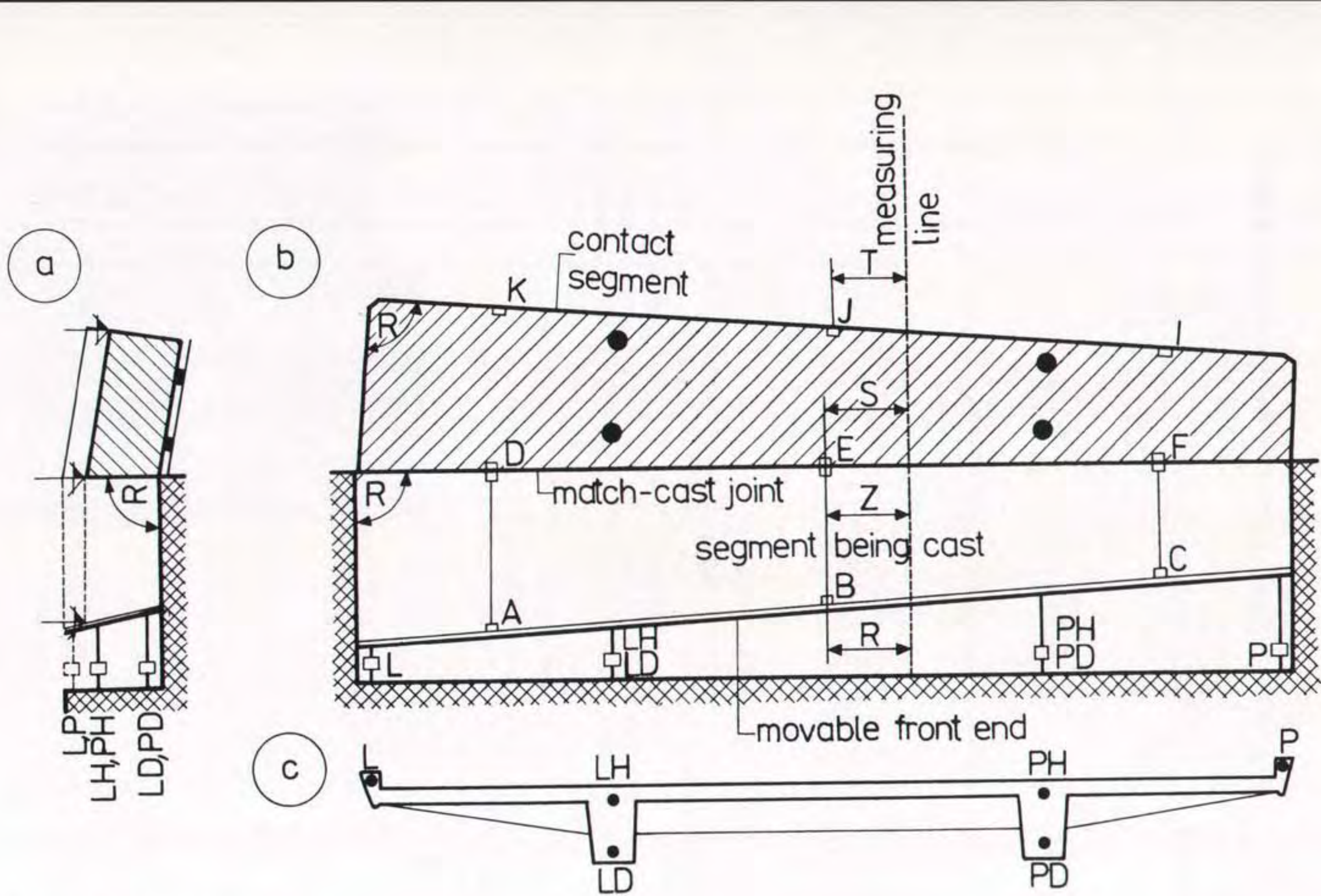

Fig. 27. Segment geometry.

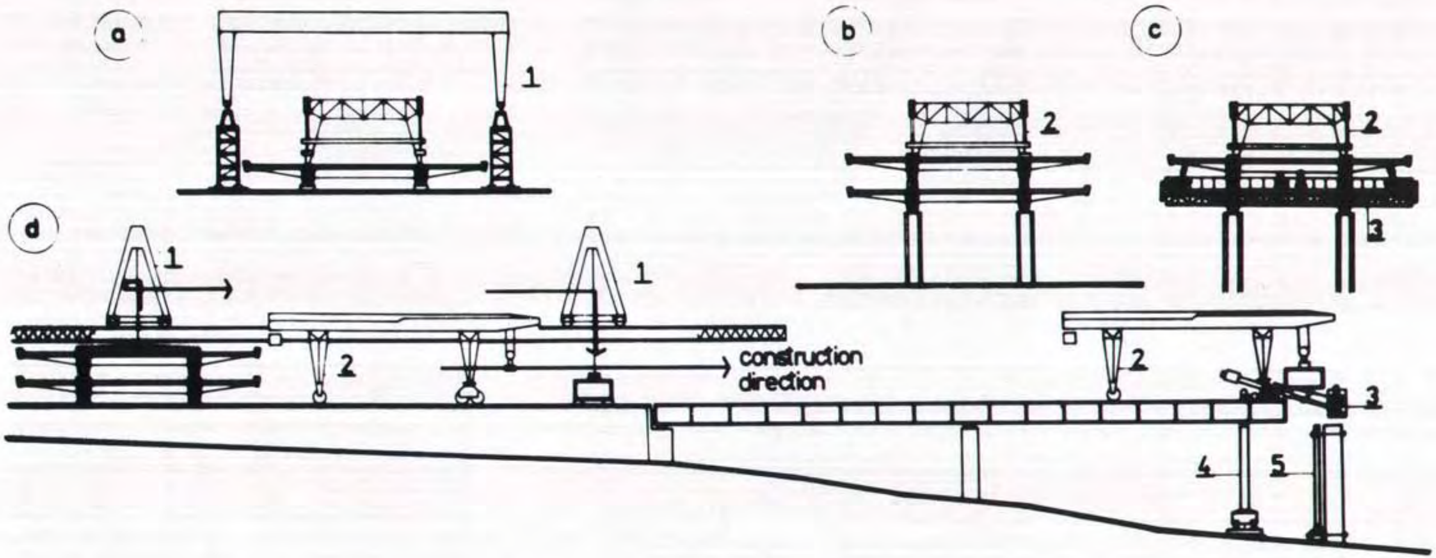

Fig. 28. Erection sequence for DS-T type bridges: (a) cross section behind abutment; (b) cross section by deck; (c) view from face of erected cantilever; (d) elevation; (1) portal crane; (2) portal KPJ-90 crane; (3) service walkway; (4) temporary support; (5) rectification support.

During erection of common spans, the portal crane turns the segment and shifts it in front of the KPJ-90 crane which is travelling behind the abutment. The crane then takes the segment and lifts it to the face of the erected cantilever (Figs. 31 and 32). After the segment is prestressed with four temporary tendons, the crane returns for the next segment. The prestressing tendons are tensioned from the service walkway, independent of the crane.

However, since the erection sequence depends on finishing the earthwork behind the abutment and on transporting and assembling the KPJ-90 crane, some bridges must be erected using the portal crane only if the above conditions cannot be met.

The erection process of individual segments is the same as outlined for the DS-W bridges and illustrated in Fig. 20. At

Fig. 29. DS-T type bridge at Valasske Mezirici during construction.

Fig. 30. Temporary support of DS-T type bridge at Valasske Mezirici.

present, four segmental bridges with a total length of approximately 0.6 mile (1 km) have been constructed and bridges with a total length of 1.3 miles (2 km) are currently under construction. In addition, the attention given to precise manufacture, careful assembly, and the effects of creep and shrinkage has enabled bridges 1300 ft (400 m) in length to be assembled without steel shims or concrete joints.

CONCLUSION

Low concrete and steel consumption, easy manufacturing, speed of construction, and bridge aesthetics demonstrate the advantages of using segmental construction for both long and short span bridges. In addition, the positive economic benefits of precast segmental construction are making future technological developments successful.

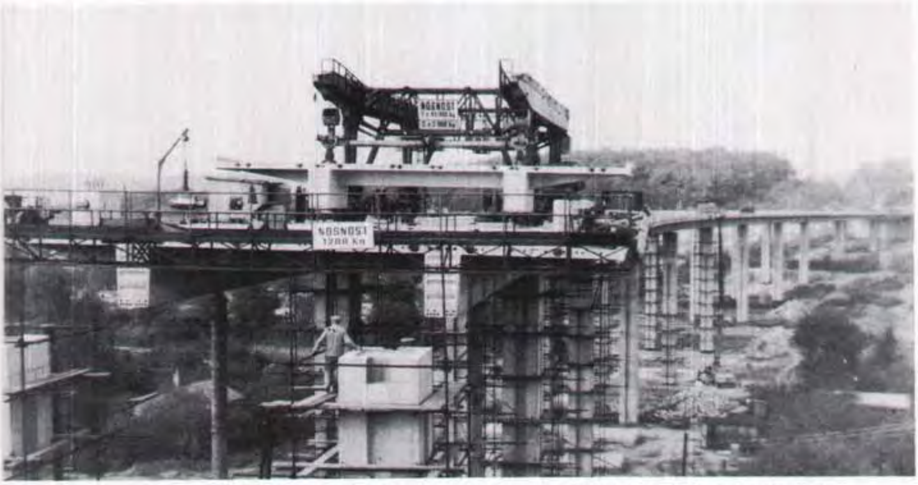

Fig. 31. Portal crane KPJ-90 on deck of bridge across Rokytka River in Prague.

Fig. 32. Erection of bridge segments across the Rokytka River in Prague.

This technology has been applied for the design of Czechoslovakia's first cable-stayed bridge across the Elbe River, where construction began early in 1985. It is our hope that others, too, will challenge current design practices and further develop this advanced technology.

ACKNOWLEDGMENT

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