

Design and Construction of Cable-Stayed Bridges in the Czech Republic



Jiri Strasky, Ph.D.

Consultant
T.Y. Lin International
San Francisco, California

For 22 years, **Jiri Strasky** worked as chief design engineer with Dopravni Stavby, Olomouc — a leading state company for the construction of bridges in Czechoslovakia. In this position, Dr. Strasky was responsible for the development and design of precast segmental, stress-ribbon and cable-stayed bridges. After political changes in 1989, he opened his own design office and was appointed professor of concrete structures at the Technical University of Brno. In the United States, he served as a special consultant in the design of the first stress-ribbon bridge built in North America and for the recently completed Wisconsin Avenue viaduct. For his design work, he received the Fritz-Schumacher Prize from the University of Hannover, Germany, and an Award of Excellence from the Portland Cement Association. Currently, Dr. Strasky is a consultant with T.Y. Lin International in San Francisco.

The author discusses the design, analysis and construction of two innovative precast, prestressed concrete cable-stayed bridges recently built in the Czech Republic. The first bridge was built across the Elbe River near Podebrady and the second bridge was built over a major railroad junction in Prague-Vrsovice. The decks of these bridges comprise a spine box girder assembled of precast, match-cast segments and cast-in-place overhangs supported by precast concrete struts. External prestressing was used to strengthen the deck. To confirm the validity of the design, a static and dynamic analysis of the structural system was conducted together with model testing. The author shows how this system, with some modification, can be applied to other cable-stayed and segmental concrete bridges.

Two cable-stayed bridges using precast, prestressed concrete segmental construction (see Figs. 1, 2 and 8) were recently erected for a freeway in the Czech Republic. One bridge was built across the Elbe River near Podebrady while the other bridge was built over a major railroad junction in Prague-Vrsovice.

The bridges combine the high quality and speed of construction of precast segmental structures with the structural continuity of cast-in-place concrete (see Figs. 3 and 4). The deck of the main span and approach spans of these bridges consists of a spine box girder assembled of precast, match-cast segments and cast-in-place overhangs supported by precast concrete struts.

Both bridges are suspended in the bridge axis on composite steel pylons that are fixed into the deck (see Fig. 5a). The stays are arranged in a semi-fan shape and are formed by strands grouted in steel tubes. The approach spans are post-tensioned (suspended) on draped external tendons placed in the bridge axis (see Fig. 5b). The precast concrete segments were erected in progressive cantilevers by a special crane moving on the deck.



Fig. 1. Elbe River Bridge.

The design of the Elbe River Bridge received an Outstanding Structure Award at the Fédération Internationale de la Précontrainte (FIP) 1990 Congress in Hamburg, Germany.

DEVELOPMENT OF THE STRUCTURAL SYSTEM

One goal in precast concrete segmental design is to develop elements that can be used for both the main span and approach spans. Several design strategies have been used to achieve the desired similarity of elements. The common solution is to provide for each direction of traffic a twin box girder bridge of constant depth supported in the main span by cable stays from pylons placed in the road axis or along its sides.^{1,2,3} In this arrangement, the stay forces are transferred into the box girders through cast-in-place or precast concrete diaphragms.

One disadvantage of this solution is that the erection process (especially the equipment) becomes expensive. Because the box girders of the main span have to be erected simultaneously, it is usually necessary to double the expensive erection equipment. Furthermore, the speed of erection depends upon the speed of producing the transverse diaphragms.

A less widely used solution has been to design the segments of the structure to correspond to the width of

the freeway. Such large segments are very heavy and thus require special erection cranes. However, this type of structure is economical for large scale bridges.⁴

An alternative solution to the problem, however, can be found in the design of several cast-in-place concrete structures built in Europe.^{5,6,7} This solution consists of constructing a spine

concrete box girder first, then widening the deck of the structure by constructing concrete overhangs in place, supported by precast concrete struts. The supporting struts used on existing structures have been formed of single bars, a truss or slabs (see Fig. 6). The truss and slab struts, taken together with the top slab, form a pseudo three-cell box girder (see Fig. 7). This method of con-



Fig. 2. Vrsovice Bridge.

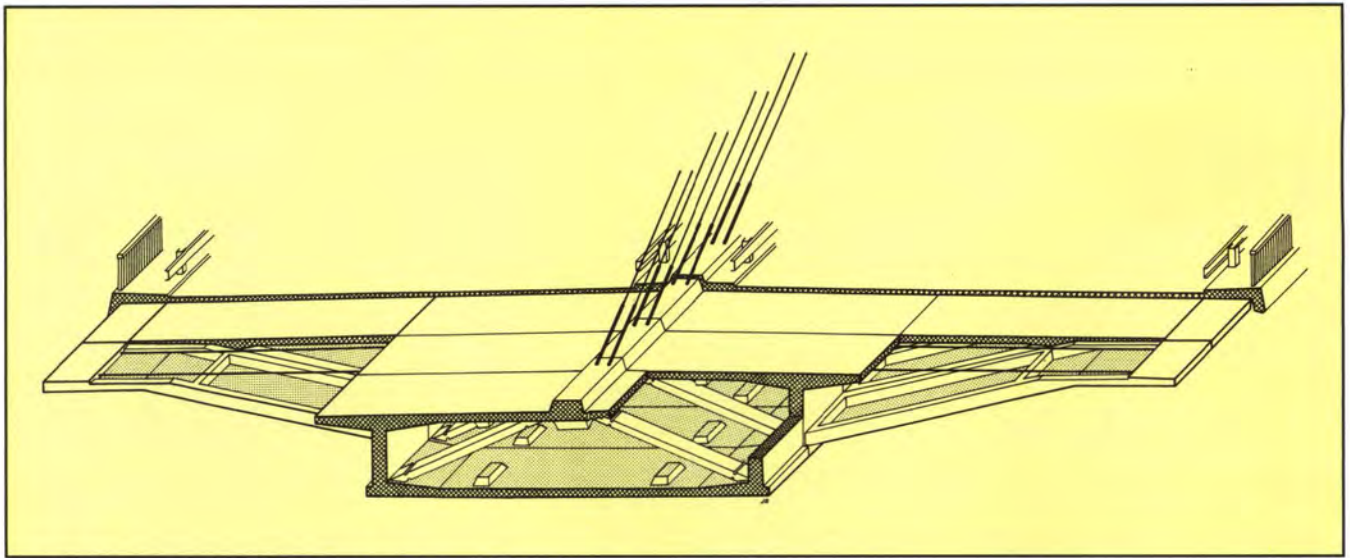


Fig. 3. Structural members of the deck.



Fig. 4. Elbe River Bridge — deck.

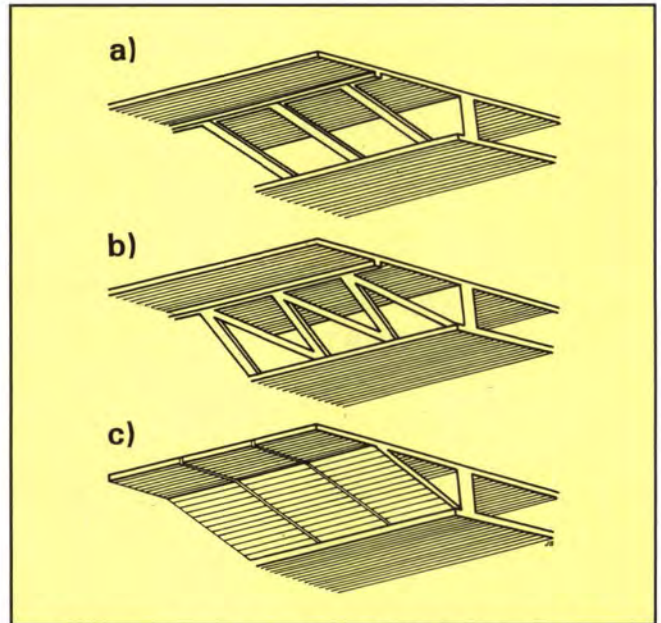


Fig. 6. Precast struts formed by: (a) single bars, (b) a truss and (c) slabs.

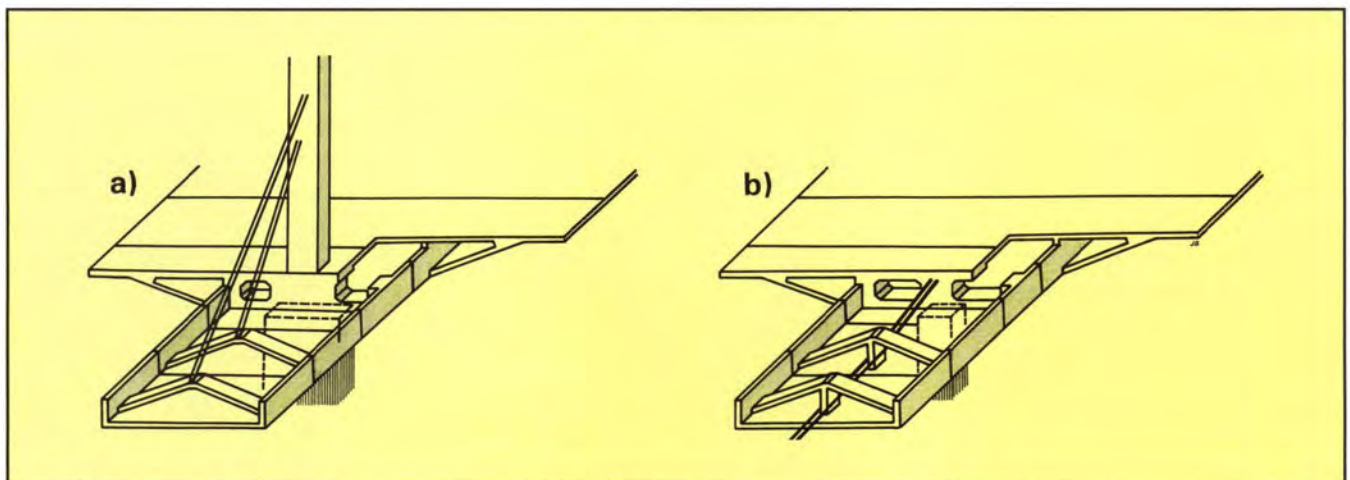


Fig. 5. Suspension of the deck on: (a) stay cables and (b) external post-tensioned cables.

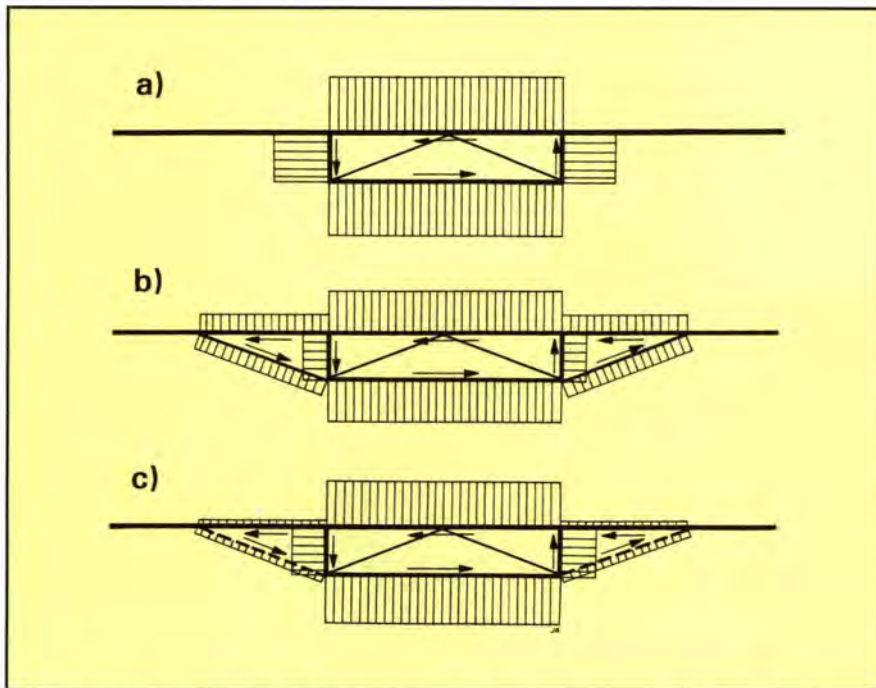


Fig. 7. Shear flow in the: (a) one-cell box girder, (b) three-cell box girder and (c) pseudo three-cell box girder formed by a one-cell box girder with overhangs supported by a truss or slab struts.

struction produces significant savings in the cost of scaffolding.

The precast concrete segmental design developed for the two projects discussed in this paper evolved from the latter cast-in-place solution. We were faced with two practical constraints: (1) a design that used precast

concrete segments light enough to be easily transported on trucks or trains, and (2) a construction sequence that allowed the structure to be erected rapidly with the use of a single common portal or truck crane.

One goal was to create a design that minimized the bending stresses in the

cable-stayed structure by obtaining the minimum depth of the deck that also provided sufficient torsional stiffness. In this design approach, the pseudo three-cell box girder offered the advantage of a minimum depth structure while the truss and slab struts contribute to the torsional resistance of the structure.

The approach was to design a precast spine box girder and, after erecting it, to widen it using cast-in-place concrete overhangs (see Figs. 3 and 11). Although truss supports were considered, we elected to support the overhangs on precast concrete slab struts. This approach fulfilled the design objectives as well as the practical construction constraints. In addition, the slab struts give the cross section of the superstructure an excellent aerodynamic shape and eliminate the problem of birds nesting in the open spaces and causing possible deterioration of the concrete.

DESCRIPTION OF THE BRIDGES

Elbe River Bridge Near Podebrady

The Elbe River Bridge near Podebrady carries the Prague-Hradec Kralove Freeway. The freeway axis is

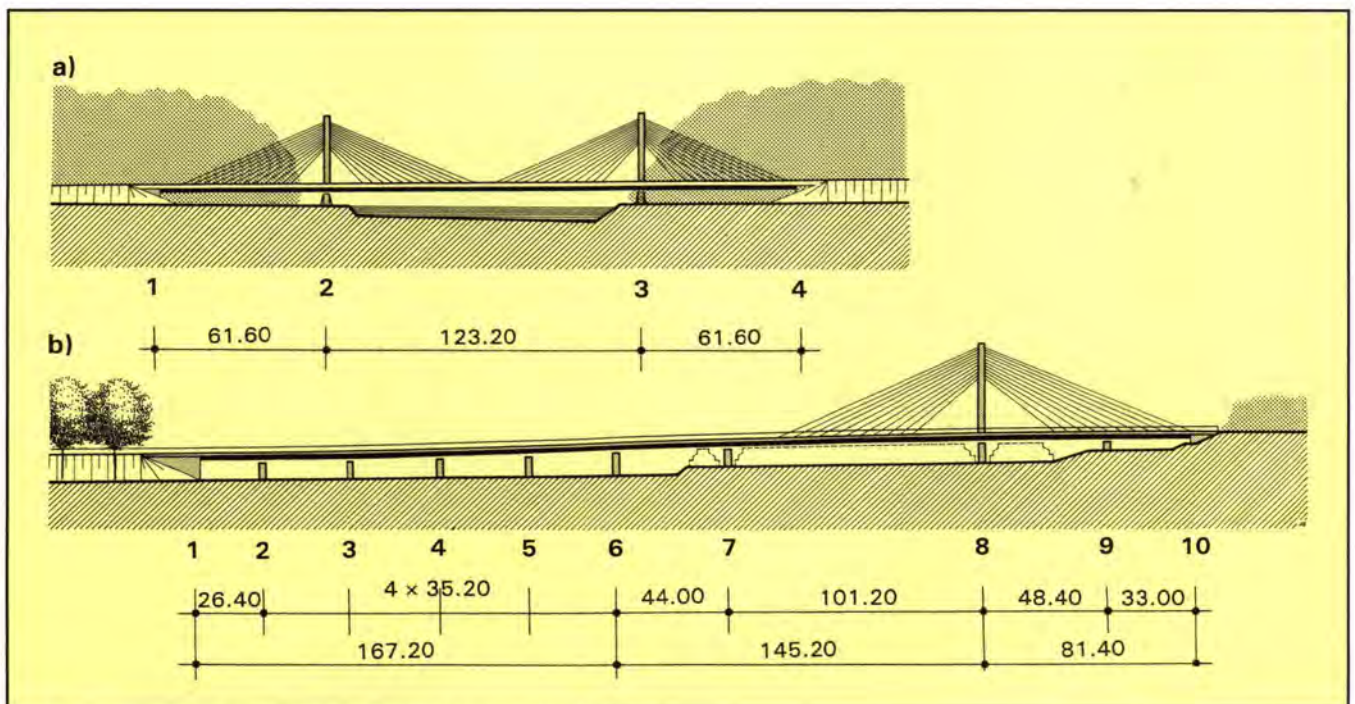


Fig. 8. Elevation: (a) Elbe River Bridge and (b) Vrsovice Bridge.

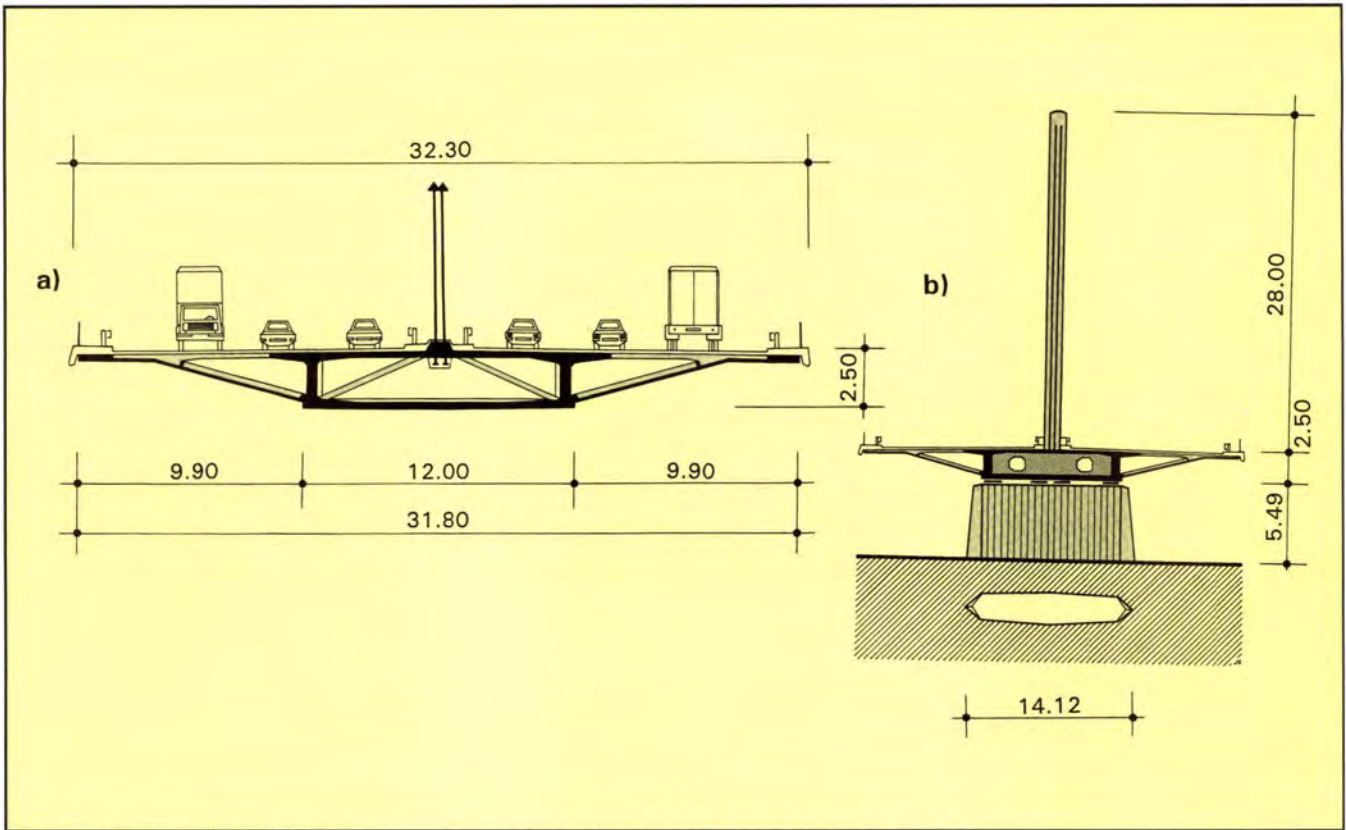


Fig. 9. Elbe River Bridge: (a) typical cross section and (b) pylon elevation at Pier 2.

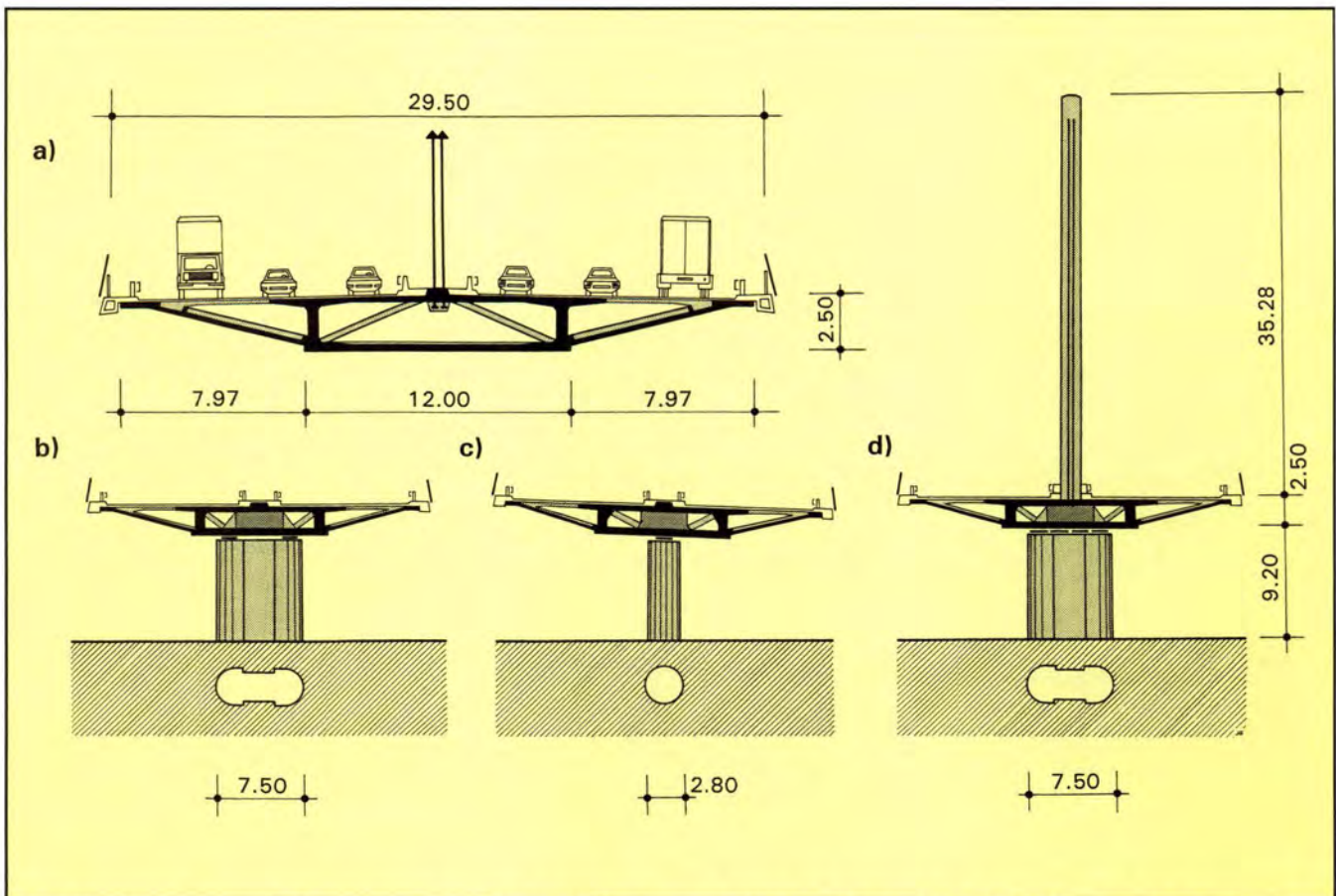


Fig. 10. Vrsovice Bridge: (a) typical cross section, (b) Pier 6 elevation, (c) Piers 2 to 5, 7 and 9 elevation and (d) pylon elevation at Pier 8.

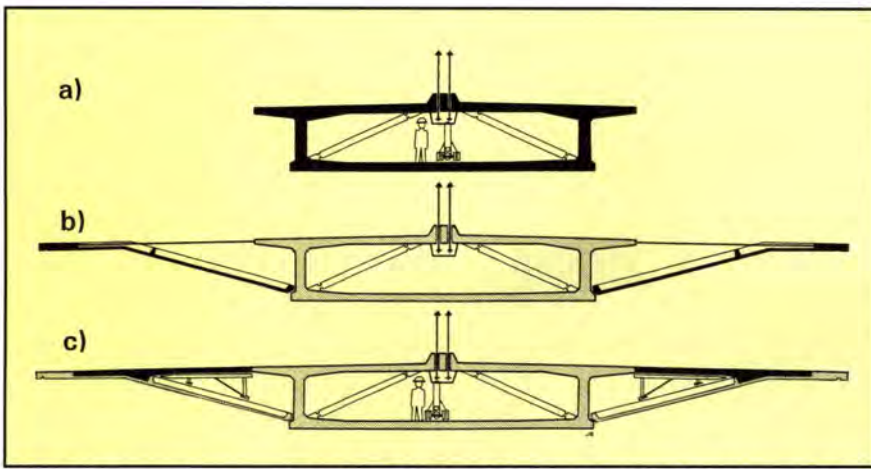


Fig. 11. Progressive assembly of the deck: (a) box girder spine, (b) precast slab struts and (c) cast-in-place roadway slab.

straight with a longitudinal gradient of 0.6 percent. A small construction depth of cable-stayed structure (see Fig. 1) was chosen for this location to minimize the environmental impact by reducing the amount of fill materials. The cable-stay design permitted uninterrupted construction without any in-

terference with navigation on the river.

The new bridge consists of three spans, 202.1 — 404.2 — 202.1 ft (61.60 — 123.20 — 61.60 m) in length (see Fig. 8a). The deck is 106.0 ft (32.30 m) wide, suspended in the bridge axis on two single pylons

91.9 ft (28.00 m) high (see Fig. 9). The stay cables, arranged in a semi-fan shape symmetrical to the tower, are anchored in the deck at intervals of 7.22 ft (2.20 m) and in the pylon at intervals of 1.64 ft (0.50 m). The deck is supported by pot bearings placed on the low abutments and massive piers founded on slurry walls 59.7 ft (18.20 m) long. At Pier 2, the bearings are fixed; the other bearings are movable in the longitudinal direction of the bridge.

Vrsovice Bridge

The Vrsovice Bridge carries part of the main roadway communication system of Prague over the large railroad switching yard in Prague-Vrsovice, the mainline railway tracks and several local roads (see Fig. 2). The new bridge consists of nine continuous spans with lengths of 86.6 — 4 x 115.5 — 144.4 — 332.0 — 158.8 — 108.3 ft (26.40 — 4 x 35.20 — 44.00 — 101.20 — 48.40 — 33.00 m) (see

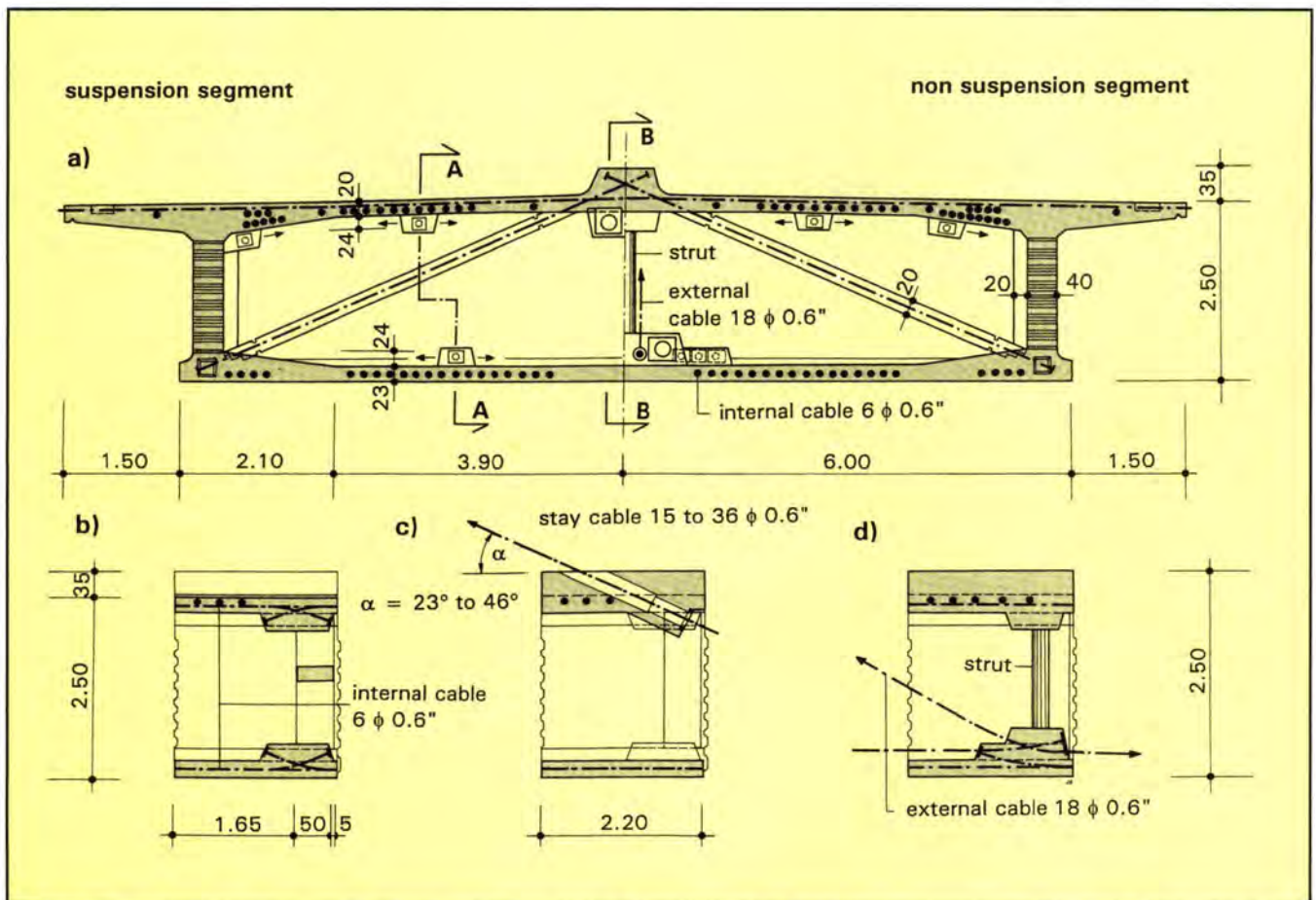


Fig. 12. Typical span segment: (a) elevation, (b) Section A-A, (c) Section B-B — suspension segment and (d) Section B-B — non-suspension segment.



Fig. 13. Elbe River Bridge — typical segment.

above Piers 6 and 8 and is fixed at the end abutments. Therefore, for torsion, the structure is designed as three spans, 548.6 — 476.4 — 267.1 ft (167.20 — 145.20 — 81.40 m) in length. On the end abutments and at Pier 9, the bearings are also anchored against uplift.

The highway axis is straight in the suspended part of the bridge, then follows curves with radii as small as 1033.5 ft (315 m). In the straight section, both sides of the highway are of 2 percent cross grade, which changes in the curved portion to a one-sided grade of 4 percent. The longitudinal profile is in two vertical curves with a gradient varying from 4.20 to 0.52 percent.

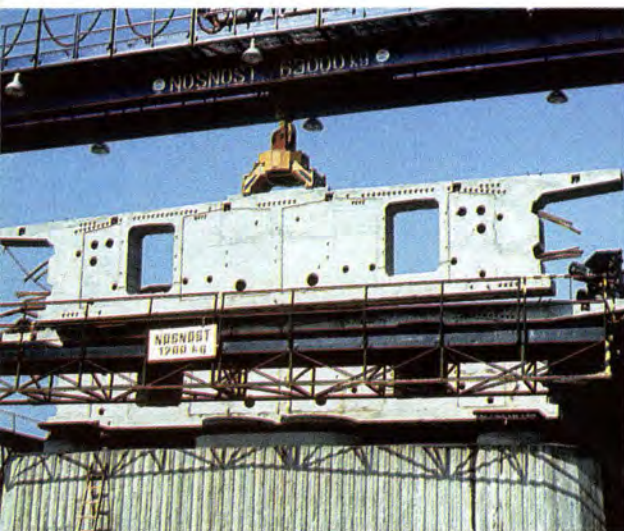


Fig. 14. Elbe River Bridge — pier segment.

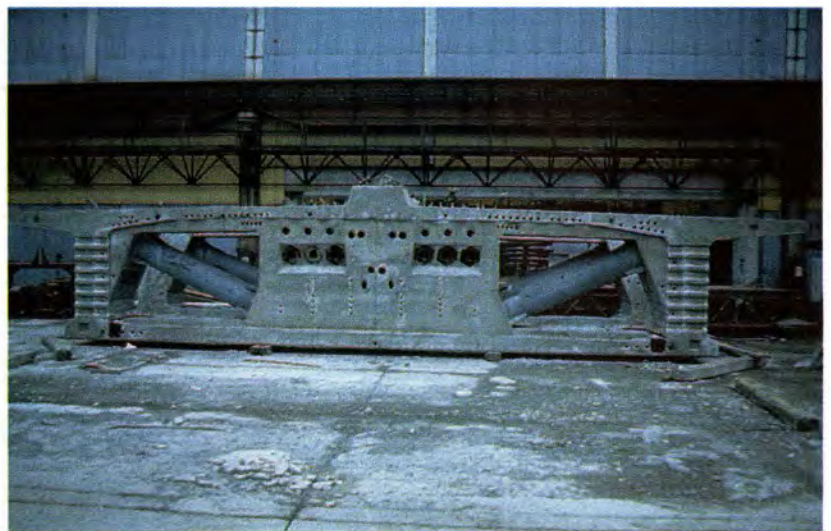


Fig. 15. Vrsovice Bridge — pier segment.

Fig. 8b). The deck is 96.8 ft (29.50 m) wide. The last three spans are suspended on a single steel pylon 115.7 ft (35.28 m) high, which is fixed into the deck above Pier 8 (see Fig. 10). The stays, arranged in a semi-fan shape symmetrical to the tower, are anchored in the deck every 14.4 ft (4.40 m) and in the pylon every 3.4 ft (1.04 m).

The deck is situated on one bearing at Piers 2, 3, 4, 5, 7 and 9 and on two bearings at the abutments and Pier 6. Four bearings are used at Pier 8 to accommodate the transfer of large vertical forces from the pylon. Bearings below the pylon are fixed; the other bearings are movable in the direction of Piers 8 to 1 and 8 to 10. In torsion, the deck is elastically constrained

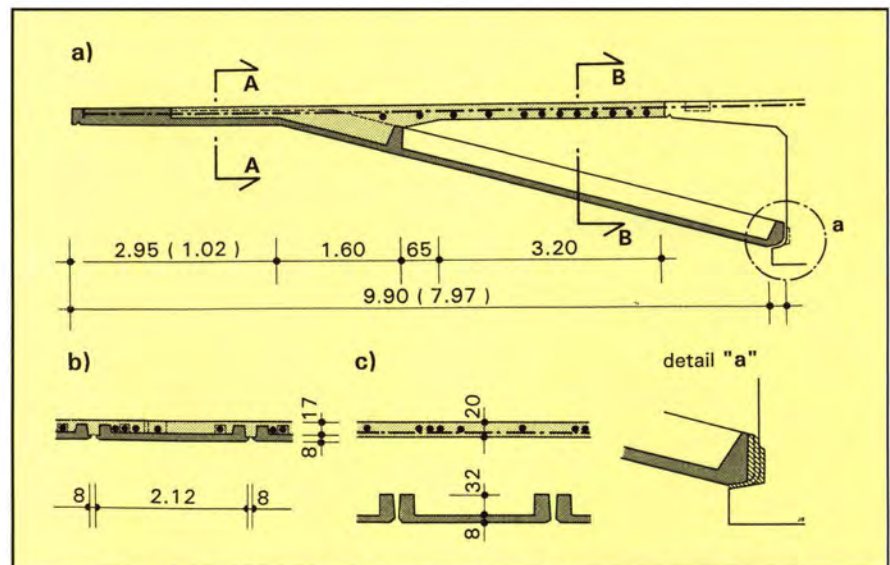


Fig. 16. Overhang: (a) typical section, (b) Section A-A and (c) Section B-B.

DECK DESIGN

The decks of both bridges comprise a precast concrete box girder spine and overhangs constructed of precast concrete slab struts and cast-in-place concrete deck slabs (see Figs. 3 and 11).

Box Girder Spine

The spine box girders on both bridges consist of two kinds of precast

concrete segments — typical span segments and pier segments. The segments of the box girder were match-cast to ensure constructibility and high quality in the on-site construction.

Typical Segments

On both bridges, a typical segment is 49.2 ft (15.00 m) wide, 7.22 ft (2.20 m) long and 8.2 ft (2.50 m)

deep (see Figs. 12 and 13), and weighs 49 tons (45 t). Within each segment, prestressed tie rods intersect in the center of the top slab and extend to the lower corners of the box section. These rods were concreted before the production of the segments and were placed in the reinforcing cage as precast concrete members. The tie rods function in the typical segments by transferring the force from the stays into the lower corners of the box section.

Typical segments of the Vrsovice Bridge also have deviation blocks located at the centerline of the segment (on the bridge axis) and a single vertical strut extending from the deviation block to the intersection of the tie rods in the top slab. The vertical strut consists of a steel tube filled with concrete which was cast simultaneously with the segments.

Pier Segments

Pier segments for both bridges have the same dimensions as typical seg-



Fig. 17. Elbe River Bridge — typical slab strut.

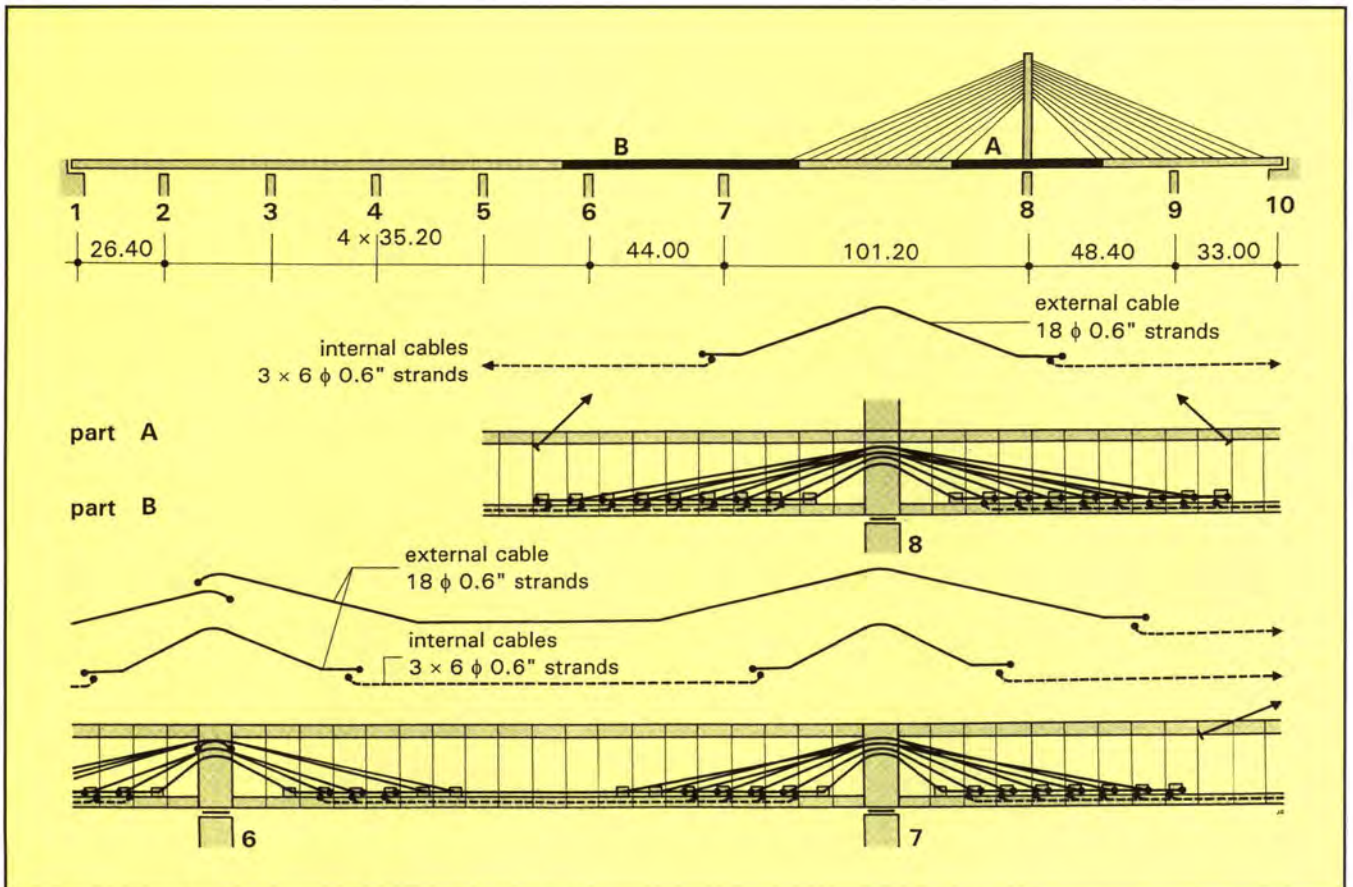


Fig. 18. Vrsovice Bridge — layout of the external cables.

ments but are strengthened to accommodate the transfer of larger forces. Pier segments of the Elbe River Bridge are solid concrete diaphragms, with manhole openings to permit passage for inspection and maintenance (see Fig. 14). The 175 ton (160 t) weight of these pier segments was greater than the capacity of the available transport equipment. To facilitate erection, each pier segment was match-cast in three parts; the three sections were then transported to the bridge site and connected together by epoxy resin. Each pier segment is supported on four bearings beneath the diaphragm, with one situated at each web and two placed directly under the pylon.

Because the Vrsovice Bridge crosses over a high density railroad switching yard, mainline railroad tracks and several busy city streets, very slender piers were required in the design. Therefore, the pier segments for this bridge have a wide central concrete web and diagonal steel tube struts which extend from the upper corners of the box section to the bottom of the



Fig. 19. Vrsovice Bridge — testing of the external cables.

web directly above the bearings (see Figs. 10 and 15). The steel tube struts are filled with concrete which was cast simultaneously with the segments. To enable these pier segments to be easily transported, they were cast in two parts and later connected by epoxy resin after being transported to the bridge site and hoisted into place.

Overhangs

The decks on both bridges were widened by constructing concrete overhangs extending 32.5 or 26.1 ft (9.90 or 7.97 m) from each side of the girder.

The overhangs consist of precast concrete slab struts, reinforced by ribs at the edges (see Figs. 16 and 17), and a cast-in-place concrete deck slab.

During construction, the precast concrete struts serve as partial formwork for casting the deck overhangs; once the struts are cast monolithic with the deck slab, they support it. The struts, which weigh 8.8 tons (8 t) each, are 3.15 in. (80 mm) shorter than the segment and are connected to the spine by an epoxy resin-

filled joint (see Fig. 16). Continuity between the spine girder and the overhangs is achieved by prestressing and by lapped splices of reinforcing bars.

Internal Tendons

The decks of both bridges are prestressed longitudinally and transversally by internal tendons of six 0.6 in. (15 mm) diameter strands. Transverse internal tendons are nearly uniformly distributed throughout the top slab of the deck.

Longitudinal internal tendons are situated in the upper and lower slab of

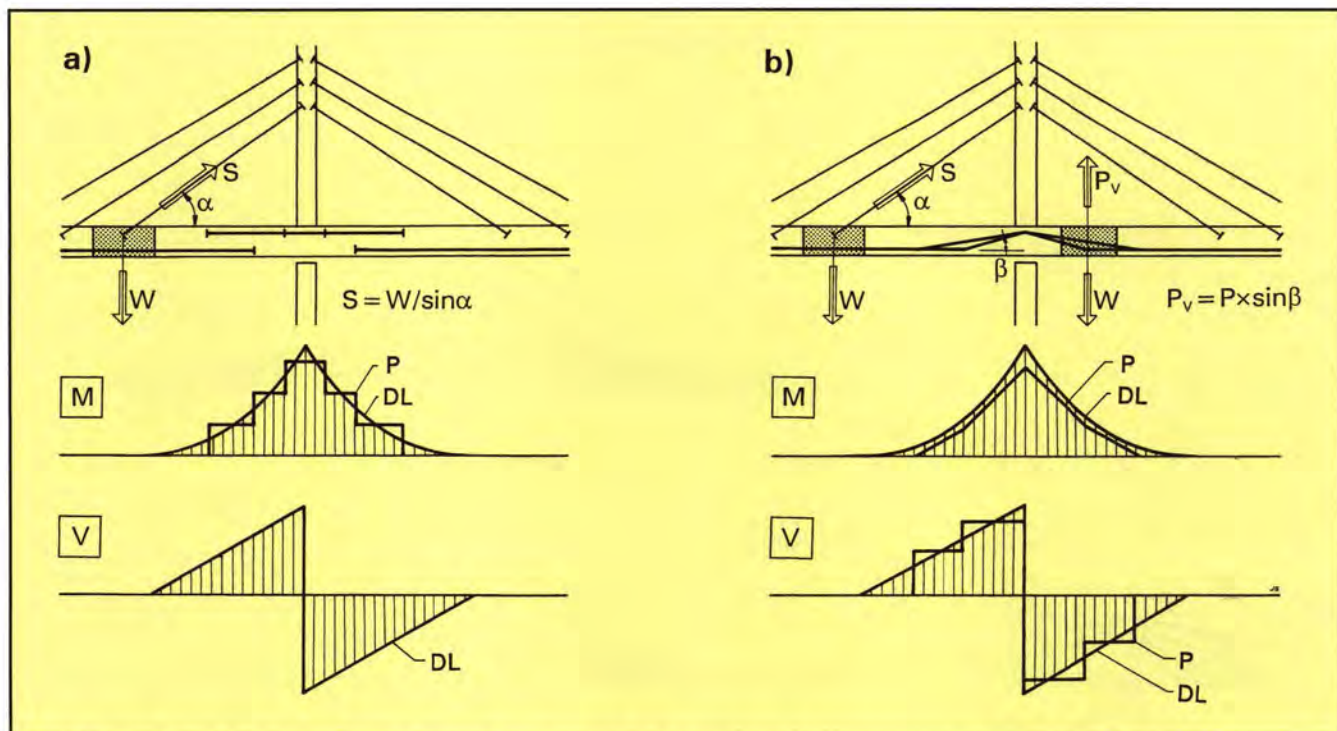


Fig. 20. Static effects in the deck due to dead load, forces in the stays and of prestressing: (a) Elbe River Bridge and (b) Vrsovice Bridge.



Fig. 21. Elbe River Bridge — erection of the pylon.

the box girder and are uniformly distributed along the width of the deck (see Fig. 12). In addition to prestressing the structure, these tendons are designed to serve the same function as continuity reinforcing steel in joints in cases of accidental overloading.

External Tendons of the Vrsovice Bridge

In addition to the internal tendons, the deck of the Vrsovice Bridge is also post-tensioned by draped external tendons (see Fig. 18). Throughout the box girder of the Vrsovice Bridge, short external tendons are anchored in blocks at the bottom slab, deviated near the top of the pier diaphragms and anchored again in blocks at the next bottom slab (see Fig. 19).

At the blocks, the short external tendons overlap (or are linked) with the straight internal tendons of the bottom slab. The approach spans are also provided with long continuous external tendons which are anchored in a pier diaphragm, deviated in blocks situated on the bottom slab and anchored again at the next pier diaphragm.

DISCUSSION OF DESIGN ASPECTS

The stay cables of both bridges were arranged in such a way that the vertical component of each stay balances that part of the dead load which acts between two stays. On that non-suspended portion of the girder between the two stays nearest the pylon, the dead load is acting on two symmetrical cantilever segments extending outward from the pylon.

In these cantilever segments, the bending moment due to the dead load is balanced by straight internal prestressing tendons placed in both the top and bottom slabs of the box girder spine (see Fig. 20a). However, it was still necessary to transfer the shear forces to the bearings. In the Elbe River Bridge, these shear forces were transferred by strengthening the webs of the segments near the pylon by increasing the web thickness.

In terms of torsion, the Vrsovice Bridge was designed as three long sections which produce much larger shear stresses. The slender piers required for

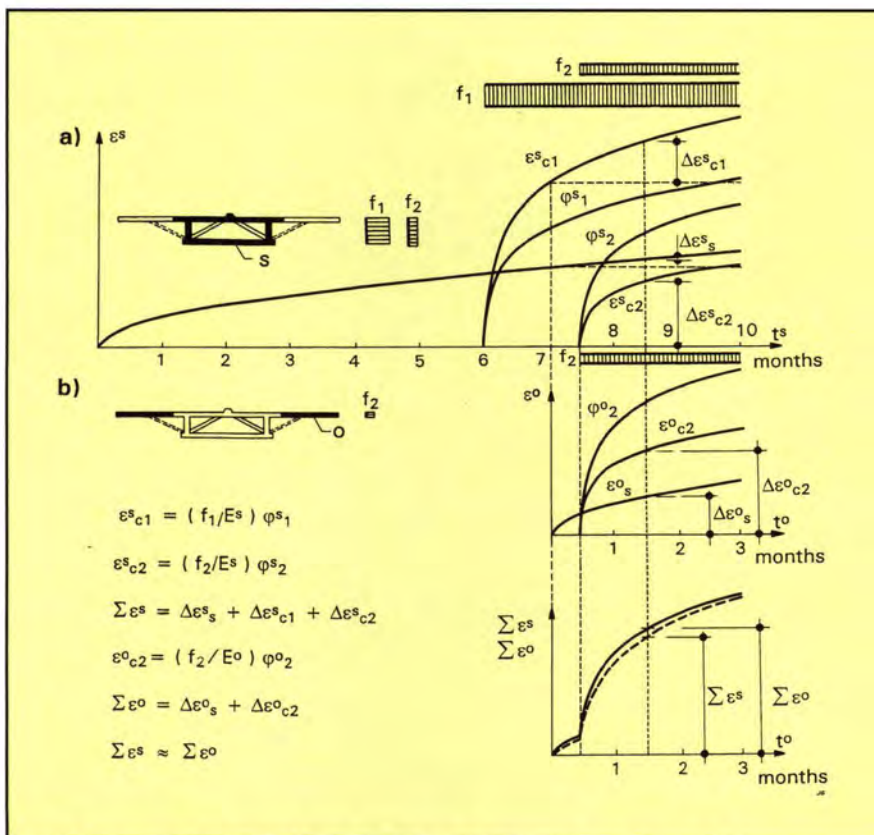


Fig. 22. Strain in the deck due to dead load, forces in the stays and of prestressing: (a) box girder spine and (b) cast-in-place roadway slab.

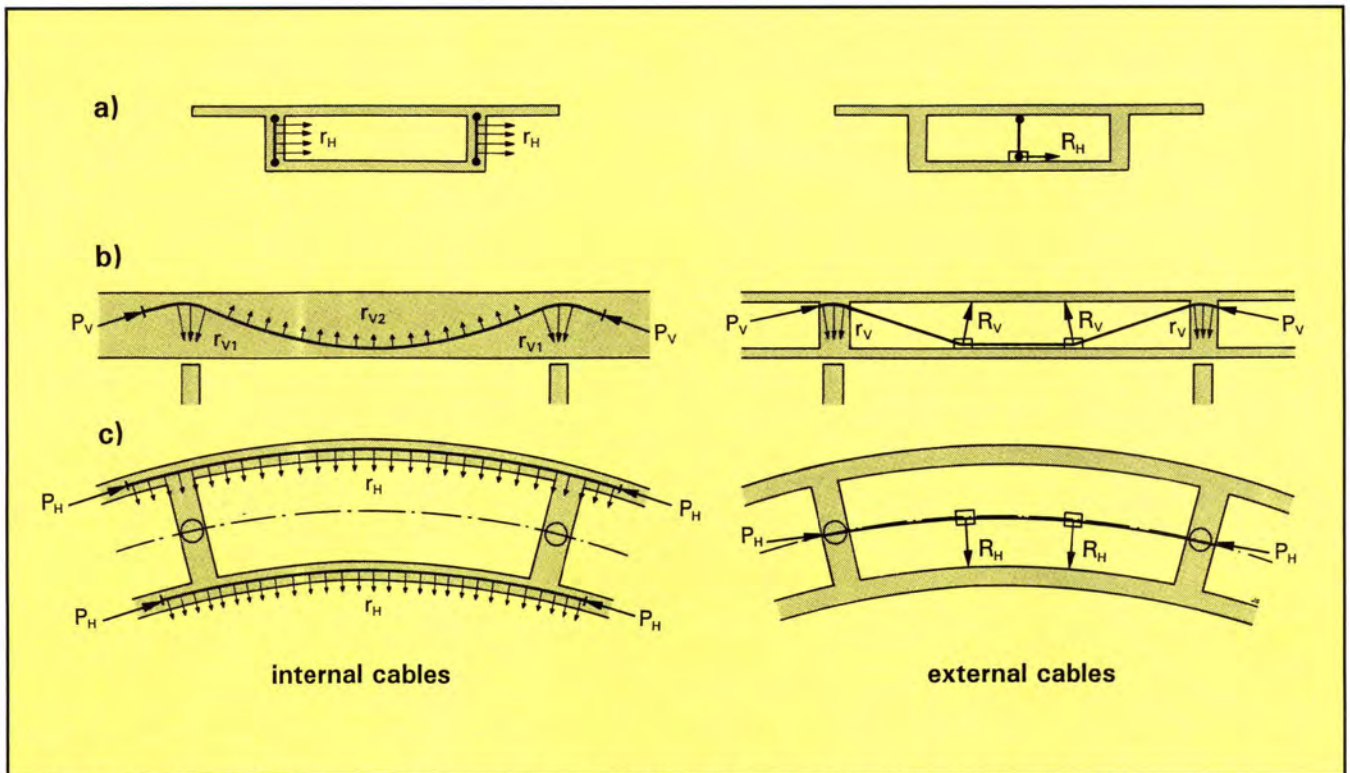


Fig. 23. Equivalent prestressing load in the curved deck: (a) cross section, (b) elevation and (c) plan.

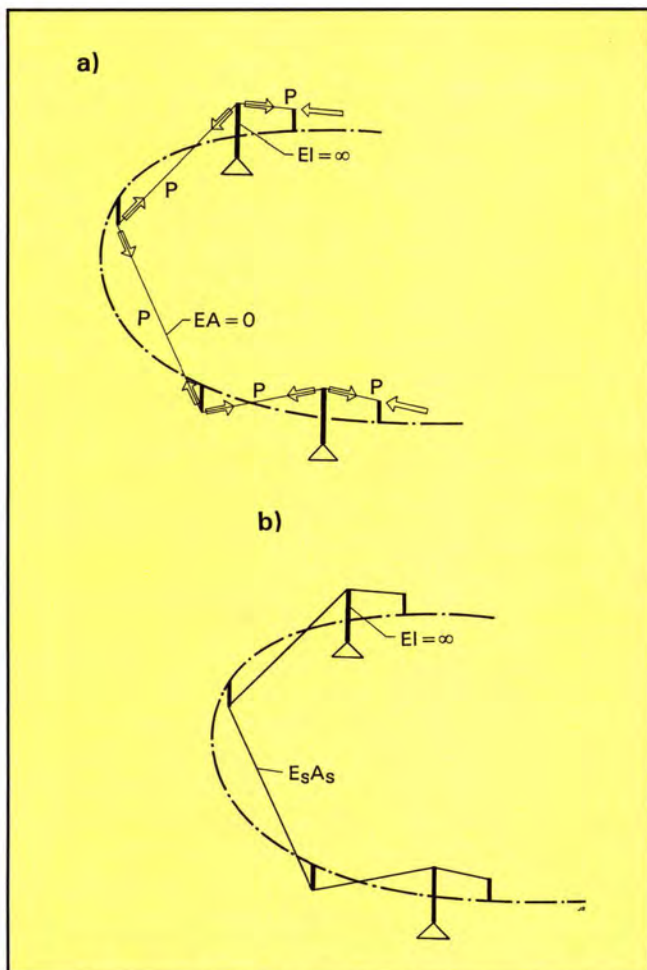


Fig. 24. Static modeling of the external cables: (a) for post-tensioning and (b) for service.



Fig. 25. Elbe River Bridge — reinforcing steel of a typical segment in the wooden template.

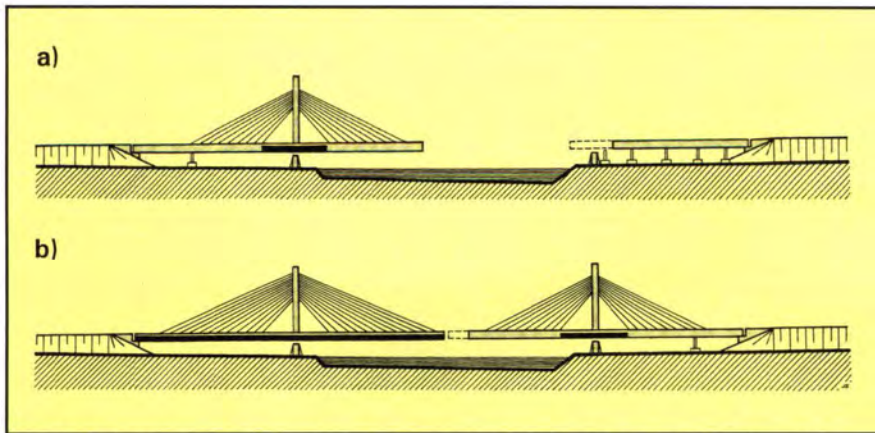


Fig. 26. Elbe River Bridge — Construction sequences: (a) erection of the side spans and the left cantilever of the main span and (b) erection of the right cantilever of the main span.

the location made the heavy solid diaphragm pier segments of the Elbe River Bridge impractical. Thus, an alternative design strategy was to use draped external tendons which act in a way similar to the stay cables — they function to balance not only bending moments but also shear forces due to the dead load (see Fig. 20b).

The short draped external tendons allow large shear forces to be transferred from the segment webs directly into the wide central web of the pier segment supported by the bearings. The vertical component of the prestressing force is transferred from the



Fig. 27. Elbe River Bridge — erection of a typical segment of the side span.



Fig. 29. Elbe River Bridge — lowering of a typical segment of the main span.



Fig. 28. Elbe River Bridge — turning of a typical segment of the main span.



Fig. 30. Elbe River Bridge — erection of a segment of the right cantilever of the main span.



Fig. 31. Elbe River Bridge — erection of a precast slab strut.



Fig. 32. Elbe River Bridge — movable formwork for casting of the deck slab.

deviators by the single, concrete-filled steel tube vertical strut into the intersection of the prestressed tie rods in the upper slab of the segments. The reduction of the shear stress in the webs also decreases the bending moment in the diaphragm at the pier segment. Thus, the short external tendons reduce the stresses in both the longitudinal and transverse directions.

The span-length draped external tendons were added in the approach spans where longitudinal and transverse stresses were greater than near the pylon. The arrangement of these tendons allows them to function in the same way as the short external tendons near the pylon.

Pylons

The single steel column pylons of constant shape are fixed into the deck. A central wall, positioned with the bridge axis, divides the pylon into two cells; the stay cables are anchored on this wall in the upper part of the pylon. Since the total weight of the steel structure exceeded the capacity of the available erection cranes, the pylons were assembled of two or three sections, respectively, and the sections were connected by contact joints (see Fig. 21). The pylons of the Elbe River Bridge are 6.4 x 5.6 x 91.9 ft (1.95 x 1.70 x 28.0 m); the pylon of the Vrsovice Bridge is 7.2 x 6.0 x 115.7 ft (2.20 x 1.83 x 35.28 m).

The lower part of each pylon was made composite by concrete infilled from below upwards. Since the con-



Fig. 33. Elbe River Bridge — progressive assembly of the deck.



Fig. 34. Elbe River Bridge — erection of the closure segment.

crete is completely enclosed in the steel section which maintains close to 100 percent humidity, there is little shrinkage due to evaporation, and the concrete experiences very little creep.

This type of pylon will maintain a relatively constant vertical force throughout the life-cycle of the structure; the design, therefore, does not require contingencies to accommodate long-term creep and shrinkage and the subsequent mitigation of long-term deflections and deformations. Because

this type of pylon eliminates the need for these long-term contingencies, considerable economy is achieved in both design and construction. This pylon also facilitates rapid and progressive erection of the deck, leading to further economies in construction.

Cable Stays

The deck of the Elbe River Bridge is suspended on 4 x 21 stays arranged in a semi-fan shape symmetrical to the

pylon. Each stay is formed by two cables of 15 to 18 0.6 in. (15 mm) diameter strands grouted in the steel tubes. In the case of the Vrsovice Bridge, the deck is suspended on 2 x 14 stays of similar arrangement of two cables of 30 to 36 0.6 in. (15 mm) diameter strands grouted in steel tubes.

The construction sequence was designed in such a way that the steel tubes and the cement mortar used for the grouting are prestressed and act to transfer the stay tension due to live load and temperature changes. The strands were tensioned before grouting, and when the cement mortar reached 50 percent of its strength and the closing joint of the steel tubes was welded, the tension in the whole stay cable was released. The prestressing force was so high that, when it was released, there was no residual tension in the mortar even under full live load. This arrangement not only increases the stiffness of the bridges, but it also reduces the fatigue stresses on the strands.

STATIC AND DYNAMIC ANALYSES

The bridges were analyzed using advanced structural theory and our own computer programs. This capacity enabled us to analyze the behavior of the

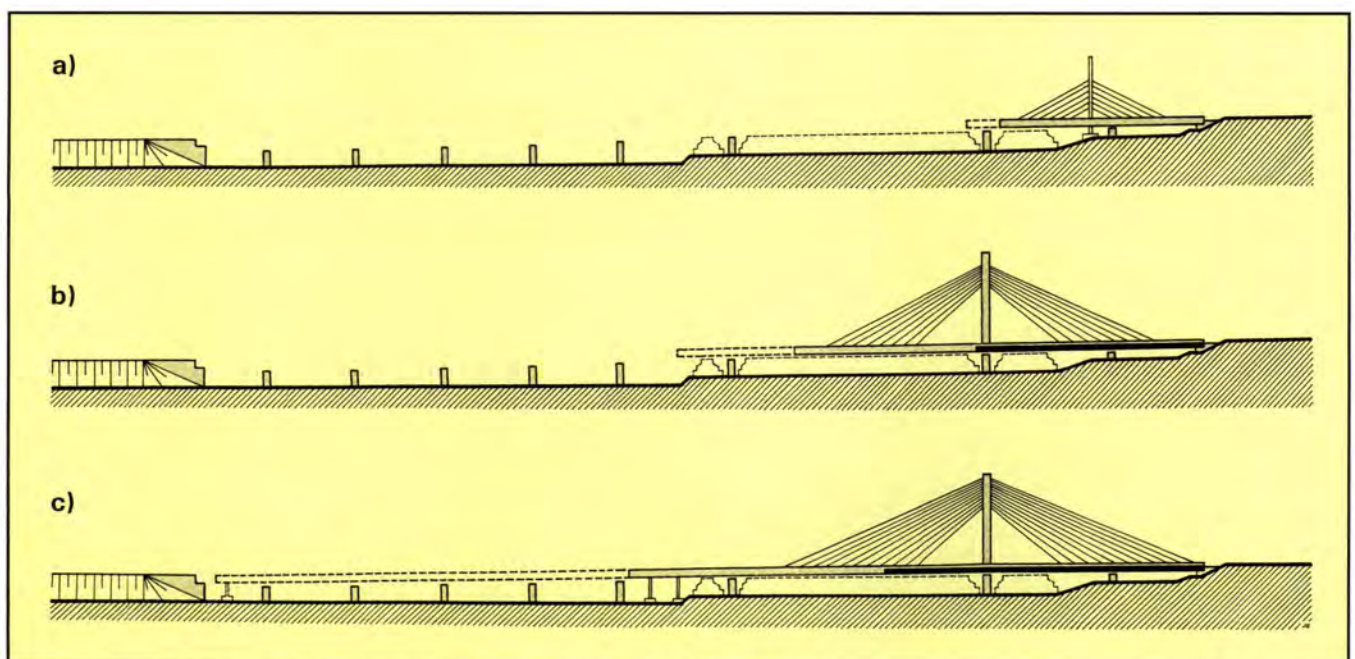


Fig. 35. Vrsovice Bridge — Construction sequences: (a) erection of the side spans over the railway, (b) erection of the main span and (c) erection of the approach spans.



Fig. 36. Vrsovice Bridge — erection of the side spans over the railway.

structures during erection and under service loads, and also to predict their geometrical and physical nonlinear characteristics. Both two-dimensional

and three-dimensional analytic models were developed for the structures; the three-dimensional analytic models were assembled from both bar and

plate elements. The results of the analyses were verified on epoxy models. Details of anchoring of the stay and external cables were verified on full-scale concrete models.

For the time-dependent analysis, a new computer program was developed⁸ which expresses the influence of different ages of concrete members in both the longitudinal and transverse directions of the structure. This program allowed us to determine the level of prestressing of a segment cross section of the spine box girder and of the segment overhang. By determining similar curves between the precast and the cast-in-place concrete elements, it was possible to minimize the redistribution of forces caused by their different ages.

Fig. 22 illustrates that when the level of prestressing of the cross section of the spine box girder and of the overhang are 1450 and 435 psi (10 and 3 MPa), respectively, and the difference in age of the concretes is six months, the strain in both segments is constant in time. By maintaining this



Fig. 37. Vrsovice Bridge — erection of the main span.



Fig. 38. Vrsovice Bridge — erection of steel tubes of the stay cables.



Fig. 39. Vrsovice Bridge — erection of a segment of the approach spans.

interval in casting of the precast concrete segments and the cast-in-place overhangs, there is no redistribution of internal forces in the deck after it is constructed.

Careful attention was given to the analysis of the influence of the exter-

nal tendons, especially in the plan curvature of the approach spans. Whereas the internal tendons in the plan projection load the structure by uniform radial forces that cause pure compression, the external tendons load the structure by concentrated forces in the

deviators (see Fig. 23). Since the centroid of the external tendons does not coincide with the axis of the girder, additional stresses are produced. Also, the external tendons directly load the bottom slab but do not load the webs.

The modeling technique to deter-



Fig. 40. Vrsovice Bridge — progressive assembly of the deck.



Fig. 41. Study of a bridge with the low pylons.

mine the effect of the external tendons was this: Each tendon was modeled as a bar extending from one deviator to another and each bar was assigned zero stiffness during its post-tensioning (see Fig. 24). After post-tensioning, the values of the actual stiffnesses were determined and added to the stiffness of the structure. In this way, it was possible to describe the actual behavior of the external tendons under service load. The ultimate capacity of the structures was verified by the computer program developed at the Technical University of Brno⁹ on the basis of the theory published in Ref. 10.

CONSTRUCTION PROCEDURE

The span segments were match-cast in two steel forms, using the long-line method for the Elbe River Bridge and the short-line method for the Vrsovice Bridge. A wooden template was used to assemble the mild steel reinforcement and the concrete tie rods which had been cast in advance (see Fig. 25). For the Vrsovice Bridge, the assembly

included the steel tube vertical struts in typical non-suspension segments and the diagonal steel tube struts for the pier segments which were cast simultaneously with the segments.

Erection of the Elbe River Bridge

The side span segments of the Elbe River Bridge were erected in two progressive cantilevers from the abutments by a portal crane moving on tracks placed on trusses alongside the assembled segments (see Figs. 26 and 27). The static load effects in the erected cantilevers were reduced by temporary supports.

After epoxy resin was applied, each segment was first connected to the previously erected structure by post-tensioning nine prestressing bars uniformly distributed along the section. These post-tensioned bars caused uniform compression in the joint between the erected segment and the cantilever and held the segment until the longitudinal tendons anchored in the blisters of the upper and lower deck slab were tensioned.

In the second stage, a truck crane erected the steel pylon and its lower part was concreted (see Fig. 21). To erect the middle span, each segment was placed on the self-propelled truck and transported to the special erection crane. The crane shifted the segment in front of the face of the assembled structure and turned it (see Fig. 28). After the epoxy resin was applied, the segment was lowered (see Figs. 29 and 30) and connected to the erected structure by post-tensioning of the prestressing bars and cables.

The erection of the stay cables followed two segments behind the erection of the segments of the main span. After the stay cables were assembled on the previously erected side spans, they were shifted along the deck to erection position, where they were suspended on electric hoists and lifted to design position. The lower end of each cable was inserted into the deck, the other end was anchored in the pylon and the cable was then tensioned from inside the deck. Cables were tensioned simultaneously in pairs symmetrical to the pylon.

The overhangs of the side spans were constructed at the same time as

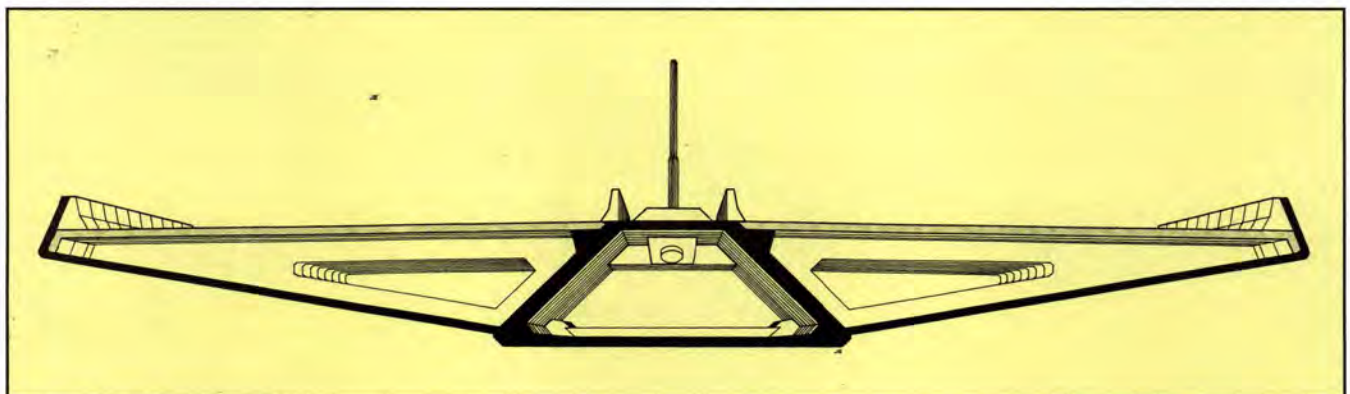


Fig. 42. Typical section of the structure studied.

the box girder segments of the middle span were being erected. Before they were hoisted into place, the deck slab end of the precast struts were fitted with prestressing bars (see Fig. 11). These assemblies, looking very much like wings, were erected in sets of 2 x 5 from the piers on both sides of the pylon, using a truck crane located either on the ground or on the deck (see Fig. 31).

The lower ends of the struts were positioned onto the support ledge of the spine box girder and the prestressing bars were inserted into the holes in the top slab of the girder. The struts were positioned by adjusting the bars. Moveable formwork was designed for casting the deck slab. Two temporary tracks were laid on the top of the struts and the formwork was placed on the tracks (see Fig. 32). When the deck concrete was poured, in sections of 36.1 ft (11 m), that portion of the overhang was completed and the formwork was pushed on the tracks to the next position, locked into place, and a new casting commenced (see Fig. 33).

After all the segments were erected (see Fig. 34), the middle joint with the last section of the overhangs was concreted and post-tensioned. Then the forces in the stay cables were adjusted.

Erection of the Vrsovice Bridge

The Vrsovice Bridge was erected by a cantilever method of construction proceeding from Abutment 10 to Abutment 1 using a construction sequence similar to that used for the main span of the Elbe River Bridge (see Fig. 35). A portal crane advancing on tracks on both sides of the structure was used to erect the span from Abutment 10. All other spans were erected using an erection crane situated on the face of the erected cantilever.

A temporary pylon (see Fig. 36) was used near Pier 9 to support the two adjoining spans while the steel pylon was erected at Pier 8 and its composite concrete portion was cast. Once the steel pylon was in place, as the next span advanced (see Fig. 37), the stay cables were erected in symmetrical pairs and tensioned using a system similar to that used for the Sunshine Skyway Bridge in Florida⁴ (see Fig. 38).

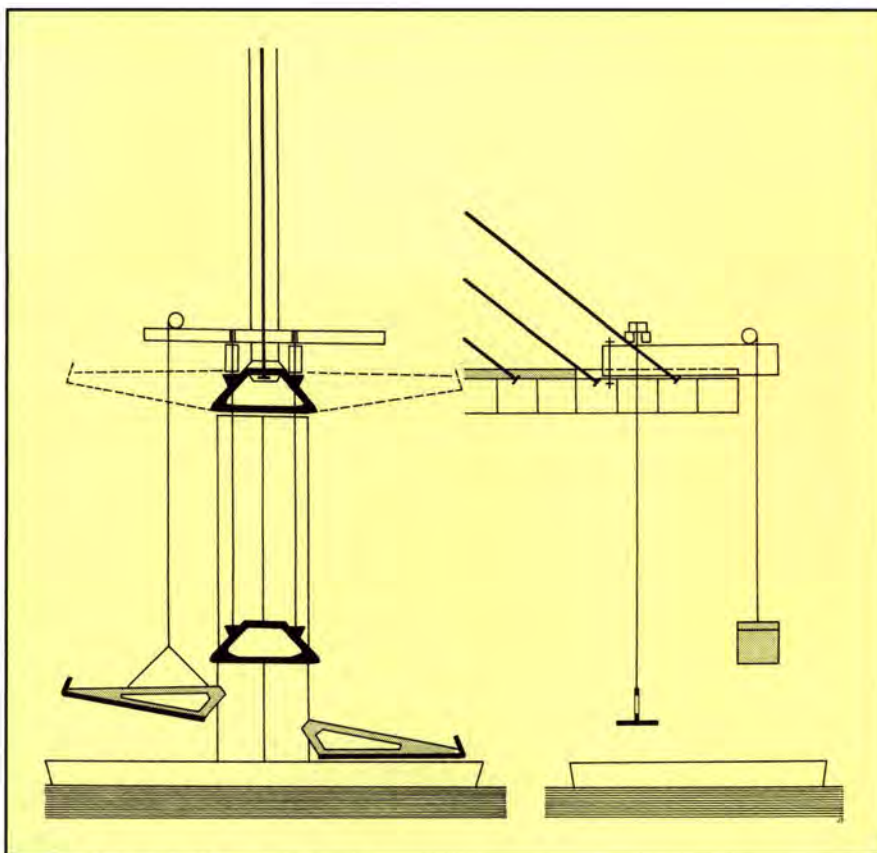


Fig. 43. Erection of the main span.

The span between the pylon and Pier 7 is not only much longer than the other spans, but it was constructed over heavy surface traffic. To increase the safety of construction, the stability of the structure was increased by temporarily anchoring the constructed portion to Piers 9 and 10, and balancing the advancing cantilever by plac-

ing the struts on the completed spans on the other side of the pylon.

The approach spans were erected after the main spans were completed (see Figs. 39 and 40). Due to the plan curvature, the approach spans were erected using temporary supports — two for each span. The struts and cast-in-place overhangs were erected in the

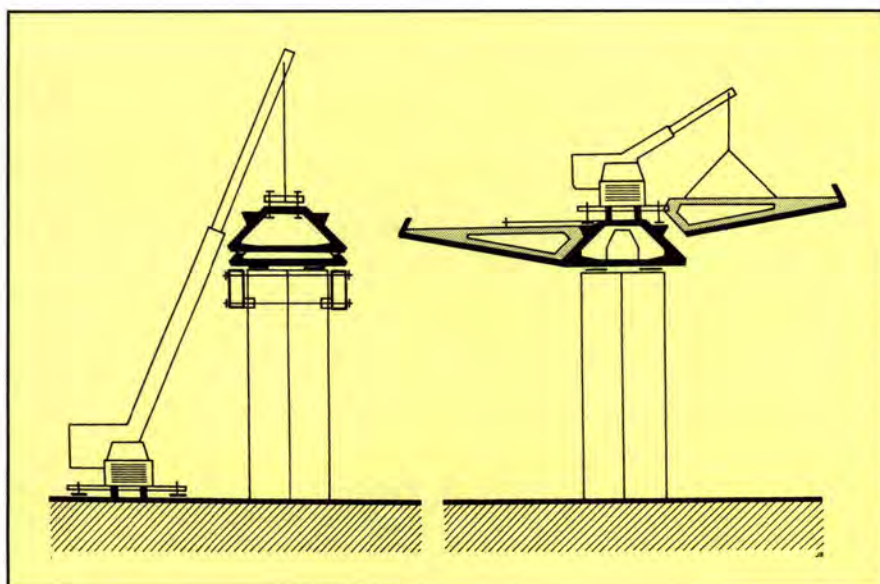


Fig. 44. Erection of the approach spans.

same way as those of the Elbe River Bridge. During the erection of the spine box girder, only internal and non-continuous external tendons were post-tensioned. After the overhangs were cast, the remaining external tendons were post-tensioned. During erection of both bridges, the segments were weighed. Subsequently, the forces in the stay cables were adjusted in accordance with the actual weight of the segments supported. The forces in the stay cables were monitored during erection of the bridges and under service load. After the bridges were completed, detailed static and dynamic loading tests were performed.

FURTHER APPLICATIONS

The differences between the design of the Elbe River Bridge and that of the Vrsovice Bridge were not simply localized solutions to the specific requirements of the particular sites. While circumstance directs design, there emerges from these two designs an approach, or design philosophy, to the design of precast, prestressed concrete cable-stayed bridge decks. These design ideas have been refined and further developed in some recent and proposed bridge projects.

A third bridge, similar in type to the two bridges described here, was designed for a crossing of the Ohre River. The bridge was of somewhat larger scale than these two bridges, having a total length of 2988 ft (910.80 m) with a main span of 554.5 ft (169.00 m). Unfortunately, realization of this bridge awaits the improvement of economic conditions in the Czech Republic.

In a design study of a bridge using a similar deck, we studied the possibility of suspending the deck on a low pylon and substituting a low concrete wall for the stay cables (see Fig. 41). By adjusting the area to compensate for the reduced angle of the support, our calculations indicated that such a structure could have the same stiffness as the high pylon supported bridges. This type of structure could easily be used where, for reasons of aesthetics, a high pylon is undesirable.

In Europe, the deck slab of precast concrete segmental bridges is usually protected by a waterproofing mem-

brane and an overlay. The design philosophy for bridges in the United States is quite different, especially in regions with severe winter weather where deicing salt is used. Instead of using a protective membrane, the deck is often designed as a replaceable composite concrete slab. The author believes that the lack of a replaceable concrete deck on segmental bridges is the main design factor preventing further applications of segmental technology.

Some designers have proposed designs in which, according to them, it is possible to replace the roadway slab.¹¹ However, it would be rather difficult to accomplish the task following their procedures. During the replacement operations proposed, after the removal of the deck, the post-tensioning of the whole cross section is transferred into the part remaining, which is loaded not only by higher compression, but also by additional bending. After casting the new deck slab, the additional post-tensioning is, due to creep of the concrete, also transferred into the old concrete.

As a member of the engineering design staff of T.Y. Lin International, San Francisco, California, the author completed a design study of a segmental structure in which the cast-in-place composite top slab can be easily replaced without significant effects on the structure (see Fig. 42). The design is based on the deck type described previously for cable-stayed bridges. The deck is formed by a precast spine box girder which, after erection into position, is widened by a cast-in-place roadway slab. The overhang of the slab is supported by precast concrete struts stiffened by ribs.

Alternatively, the struts and ribs could be precast with the spine girder and erected as one unit. The trapezoidal one-cell spine girder is designed so that its top width allows the placement of erection cranes (see Figs. 43 and 44) as well as the casting of a top roadway slab corresponding in width to the whole roadway.

The inclined webs of the trapezoidal segment combine the function of the webs and the tie rods of the Czech bridges, transferring the force from the stays into the bottom corners of the cross section. The segment has the

sufficient torsional stiffness necessary for erection or for transferring the torsion due to live load in the approach spans. This torsional stiffness can be increased by casting the joints between the struts in larger spans.

Following the design solution of the Vrsovice Bridge deck, the structure is post-tensioned in two stages. After the segments of the spine girder are erected, they are post-tensioned; when the roadway slab is cast, the whole structure is additionally prestressed by post-tensioning the external tendons and by adjusting the forces in the stay cables. Thus, it is possible to replace a damaged roadway slab simply by demolishing and removing it, and casting a new roadway slab. The whole structure is then post-tensioned in the same way as when the original roadway slab was cast — by adjusting the forces in the stay cables or external tendons — without incurring significant additional effects.

CONCLUSION

The successful completion of constructed bridges and design studies described herein illustrate the development of an approach to the design of cable-stayed bridge decks that may be appropriate to a wide range of bridge structures and sites. They are presented not only as structures which fulfill certain goals, but also as means of expanding the applications of concrete segmental construction as well as cable-stayed bridge technology.

Credits

Owners:

Elbe River Bridge — Directory of Freeways, Prague, Czech Republic
Vrsovice Bridge — City of Prague, Czech Republic

Design:

Jiri Strasky and Ilja Husty, Strasky, Husty and Partners, Brno, Czech Republic, and Slavomir Kolcava, PRIS, Brno, Czech Republic (formerly Dopravni Stavby Projekce, Brno)

Contractor:

Dopravni Stavby & Mosty, Olomouc, Czech Republic
Development of the stay cables — Vojtech Mencl and Miroslav Spudil
Technology of the production and erection — Miroslav Korenek

REFERENCES

1. Carr, F. H., "Simple Bridge Design Pays Off Handsomely," *Engineering News-Record*, June 1989.
2. Podolny, W. Jr., and Scalzi, J. B., *Construction and Design of Cable-Stayed Bridges*, John Wiley & Sons, New York, NY, 1986.
3. Podolny, W. Jr., "Concrete Cable-Stayed Bridges and the Feasibility of Standardization of Segmental Bridges in the United States," FIP '90, XI Congress, Hamburg, Germany, June 4-9, 1990.
4. Soast, A., "Skyway Bridge Boasts a Record and Innovations," *Engineering News-Record*, September 1986.
5. Podolny, W. Jr., and Muller, J. M., *Construction and Design of Prestressed Concrete Segmental Bridges*, John Wiley & Sons, New York, NY, 1982.
6. Menn, C., *Prestressed Concrete Bridges*, Birkhäuser, Basel, Boston, Berlin, 1990.
7. Missbauer, P., and Maag, W., "Schweizerische Nationalstrasse N9 Lausanne — Simplon — Pont de Chandoline," FIP '90, XI Congress, Hamburg, Germany, June 4-9, 1990.
8. Navratil, J., "Time-Dependent Analysis of the Frame Structures," Technical University, Brno, Czech Republic, 1991.
9. Zak, J., "Computation Model for Structural Design of Prestressed Concrete Structures," Technical University, Brno, Czech Republic, 1991.
10. Kang, Y. C., and Scordelis, A. C., "Nonlinear Analysis of Prestressed Concrete Frames," *Journal of the Structural Division*, ASCE, V. 106, No. ST2, February 1980.
11. Stelmack, T. W., and Trapani, R. J., "Design Provisions for Replaceable Segmental Bridge Decks," Third Bridge Engineering Conference, Denver, CO, 1991.