Cable Connections in Stayed Girder Bridges

WALTER PODOLNY, JR.

THE HISTORICAL DEVELOPMENT of cable-stayed bridges and geometric configurations have been presented previously.[4,11,12] This presentation will only discuss the details of the connection of the cables to the girder and to the tower. The design and structural details of individual components of cable-stayed bridges are similar to those of both girder and suspension bridges. General considerations applicable to all geometric types of cable-stayed bridges will be presented first. Saddles and terminal fittings for cables will then be presented in general terms. Specific cable anchorage details will then be presented on a case-study basis of selected existing structures. This paper may, therefore, be considered as a state-of-the-art of cable connections in stayed girder bridges.

GENERAL CONSIDERATIONS

The choice of the geometrical configuration and number of cables in the system is subject to a wide variety of considerations. A small number of cable stays results in large cable forces which require massive and complicated anchorage systems and reinforcing of the bridge girder(s). A relatively deep girder is required to span the large distance between cables. A large number of cable stays, approaching a continuous supporting elastic media, simplifies the anchorage and distribution of forces to the girder and tower and permits the use of a shallower girder(s). The structural attachment of the cables to the tower is greatly simplified when they are distributed over the height of the tower, rather than converging at the top of the tower.

In all configurations the cables may be continuous and allowed to pass through the tower, supported on saddles, or terminated at the tower. With few cables and large forces, it may be somewhat impractical and uneconomical to terminate the cables at the towers and confine the anchorages within the dimensions of the tower. With a large number of small cables distributed over the height of the tower, terminating the cables at the tower is more practical.

Cable saddles can be either fixed rigidly to the towers or supported on expansion bearings on the tower. Where the saddles are fixed, the rigidity of the system is increased. When the base of the tower is fixed and the cables are distributed over the height of the tower, the top saddle may be fixed and all or a few of the lower saddles allowed to move to reduce bending moment in the tower. Thus the choice of geometry and cable attachment can be seen to be subject to conditions particular to a specific application.[16]

The distribution of cables along the girder should be such as to attempt to balance the economics of the additional steel that may be required in the girder to accomodate the horizontal thrust of the cables and the increased costs of additional cable anchorages.

CABLE SADDLES

Cable saddles and clamps are designed expressly for each particular installation and are similar to those used for conventional suspension bridges (see Fig. 1). The cable saddles may be constructed from fabricated plates or steel castings with grooves in the form of an arc, through which the cables pass. The profile of the saddle transverse to the cables is formed to fit the desired cable configuration. In some instances lead, zinc, or aluminum filler may be used to insure the proper seating of the individual strands of a cable. The geometry of the cable arrangement and the contact area between cable and saddle required to obtain suitable bearing pressures determines the radius to which the saddle is constructed. The radius must also be of sufficient magnitude to maintain the stresses in the outer fibers of the cable, due to bending around the saddle within allowable limits. Between end span and center span a differential force will generally occur at the cable saddles, unless they happen to be on rollers or rocker bearings. When movement of the saddle is not provided for, these forces are resisted by friction and shear; when this is not sufficient, additional clamping force and frictional area from shear plates between layers of strands is required.[16]

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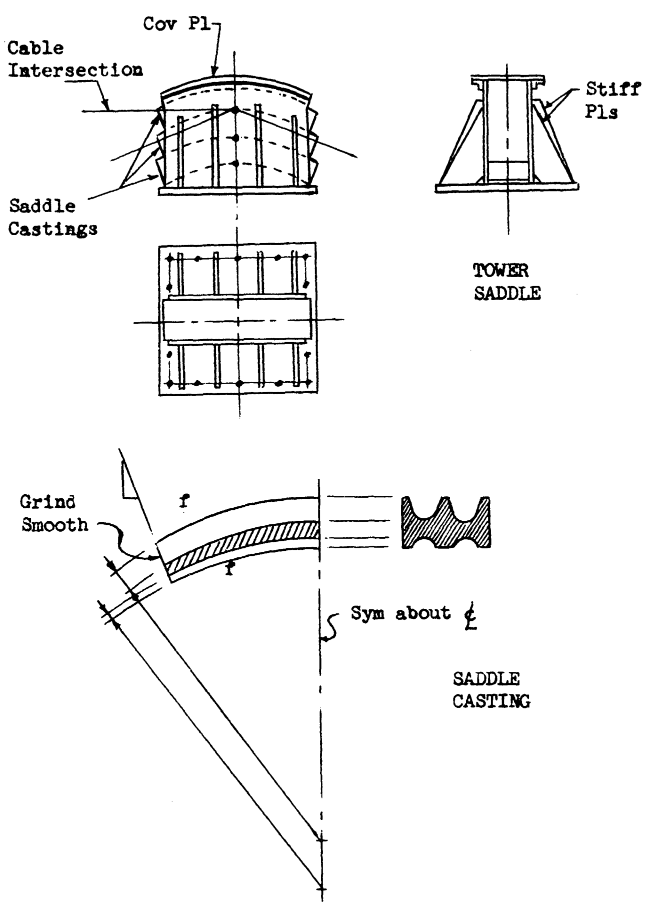


Fig. 1. Cable saddle

CABLE FITTINGS

Structural strands have terminal fittings which allow connection to other parts of a structure. These will vary in size according to the diameter of the strand. There are several varieties of end fittings, depending upon the material to which the cable is to be connected and the method of making the attachment. Because fittings are subject to the same tension loads as the cable to which they are attached, they are designed and built to properly distribute the load carried. End fittings are generally designed so that the breaking strength of the cable will not exceed the yield strength of the fitting.

Basically, there are two types of end fittings (sockets): zinc poured and swaged. In preparation for attaching a poured socket, the wires at the end of a cable are broomed out, carefully cleaned, and immersed in a flux solution. The wires are then carefully placed in the basket of the socket, which is then filled with molten zinc. Properly attached poured sockets develop 100% of the strength of the cable. With swaged fittings, the cable end is inserted into a close tolerance hole in the end of the fitting, which is then placed in a die block of a hydraulic press. The die block is then closed under controlled pressure such that the softer steel of the fitting flows plastically around the harder steel wires.[2,13]

The Japanese have reported[9] that the pouring temperature of the zinc alloy when filling the socket affects the fatigue strength of the wires at the socket (Fig. 2).

The Germans have reported[18] that a casting temperature of 450°C results in decreased fatigue strength and/or fractures in, or in the vicinity of, the cable anchorage. Thul has reported[18] improved results in tensile, fatigue, and creep tests using a cold casting material composed of steel balls, zinc dust, and an epoxy resin mixture. However, no conclusion has been reached with regard to the aging resistance of this resin anchorage. The use of a parallel wire cable with button heads bearing on a steel anchorage plate (similar to a prestressed post-tensioned anchorage system), which closes the end of the conical cavity in a steel socket, the void being filled with a special mixture of metals and epoxy resin, has been reported to increase the amplitude of stress by an order of magnitude of almost twice that for zinc-filled sockets.[1]

The attachment of the cable and the end fitting will depend upon the designers' choice of connection. An open and closed socket for a strand or cable will enable it to be pinned or penetrated by a pin, in order to make the connection (see Figs. 3a and 3b). A closed bridge socket may be used to connect a cable to an anchor plate, as in Fig. 3c. When attaching a cable to a structural member, a tensile socket with internal thread (Fig. 3d) or a tensile socket with both internal and external threads (Fig. 3e) may be used. The washer and nut will transfer the load in direct bearing and also allow a means of adjustment. Bearing type sockets are illustrated in Fig. 3f. They are furnished with or without internal threads. The internal threads are provided to accommodate the tensioning

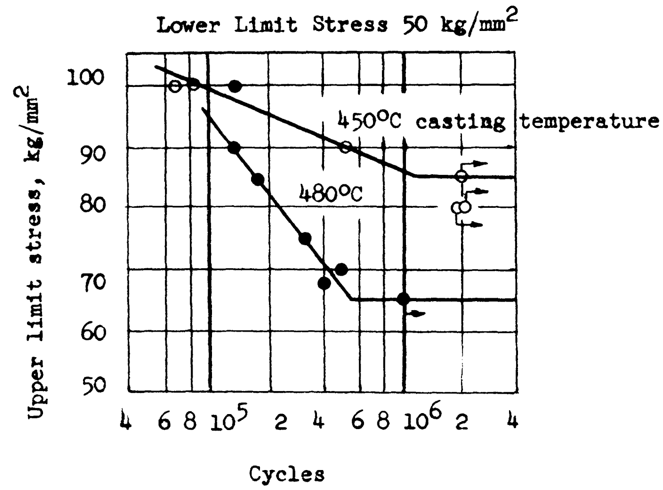


Fig. 2. Fatigue test of 5mm diam. wire with zinc-copper-alloy filled sockets (courtesy of DER STAHLBAU)

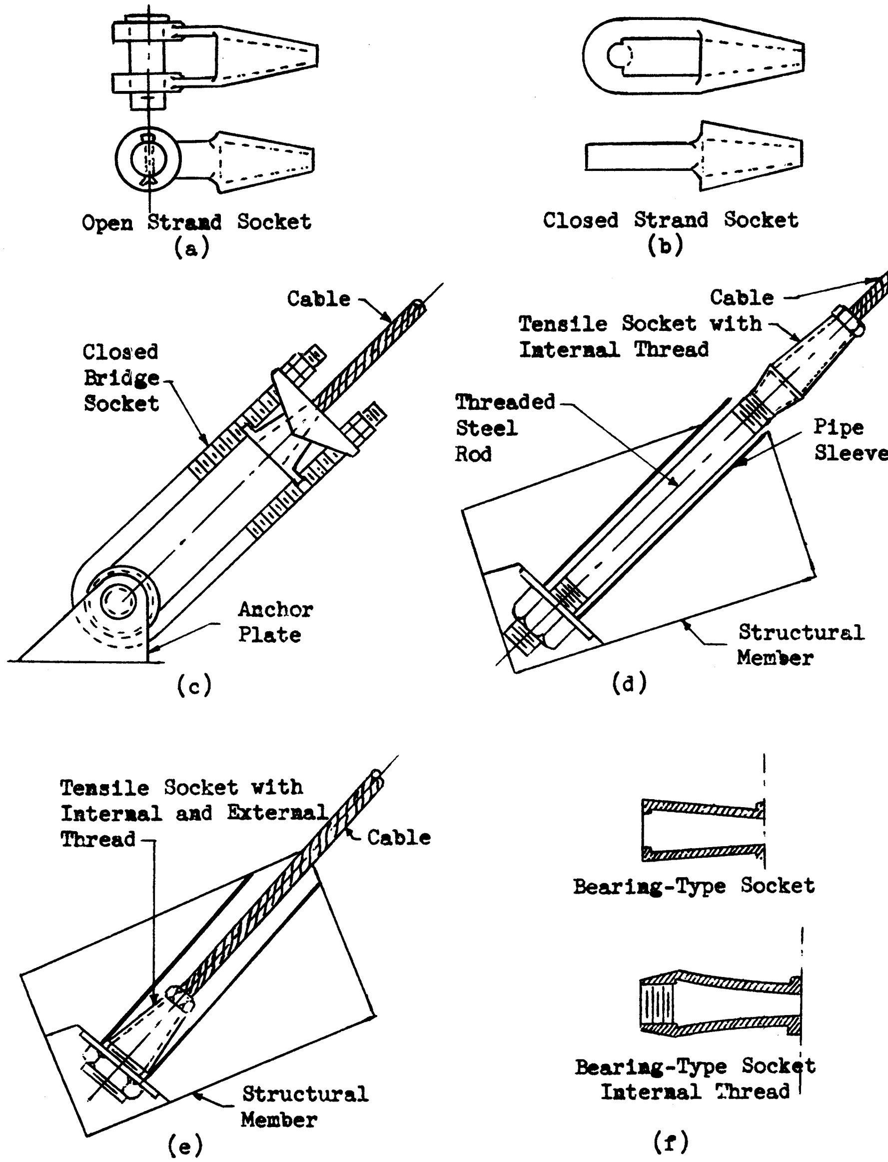


Fig. 3. Cable end fittings

jack. Adjustment of assembly length is by shimming. The use of bearing sockets may be considered as analogous to the concept of dead end and jacking end hardware as used in a post-tensioned, prestressed concrete application.

The preceding discussion has been concerned with so called "standard" terminal fittings as used in structural strand and rope construction. Occasionally unusual design criteria may require that a specialized connector be fabricated for a particular application. Normally, a minor change in the design of the structure will allow the substitution of a standard connector resulting in reduction of fabrication and construction time and costs. The BBRV type of terminal hardware as used in prestressed, post-tensioned concrete has been used with button headed parallel wire cables in some cable-stayed applications.

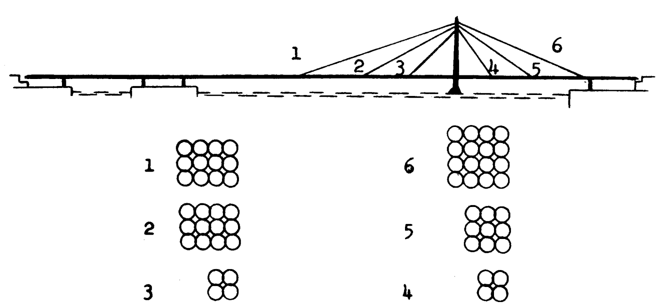
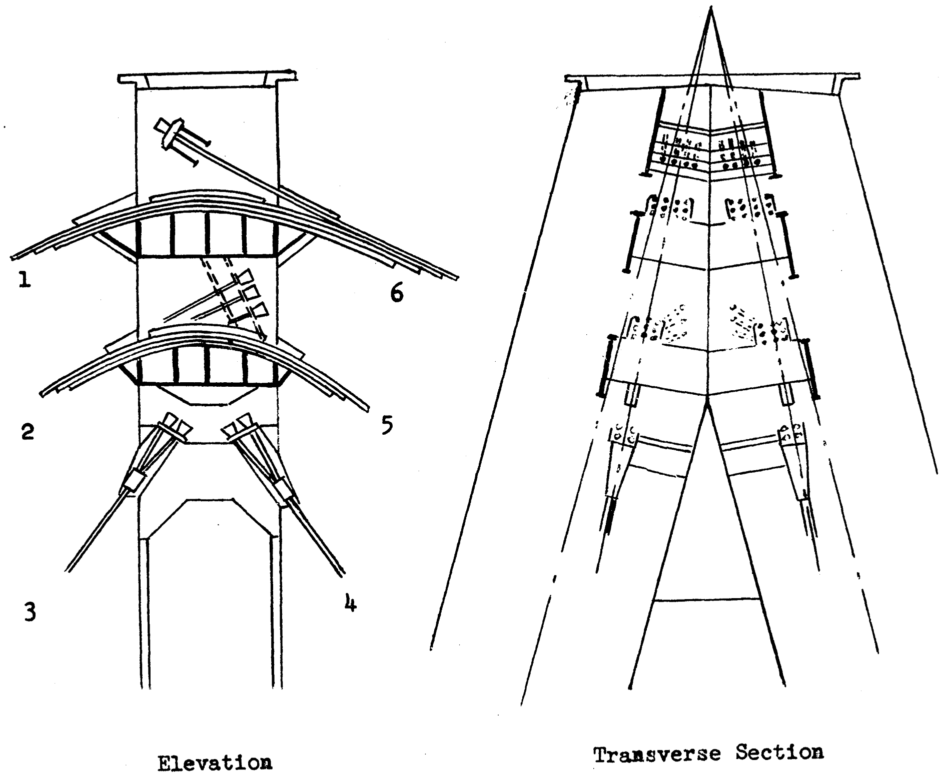


Fig. 4. Severin Bridge at Cologne (courtesy of ACIER STAHL STEEL)



(*a*) *Anchorage of strands to pylon*

(*b*) *Anchorage of additional strands—Cable 2*

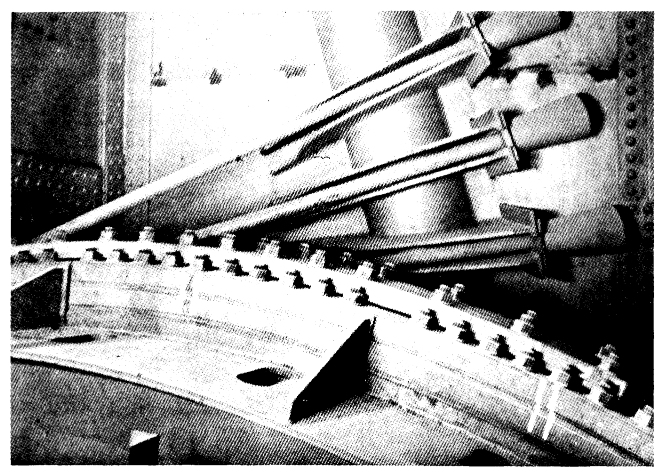
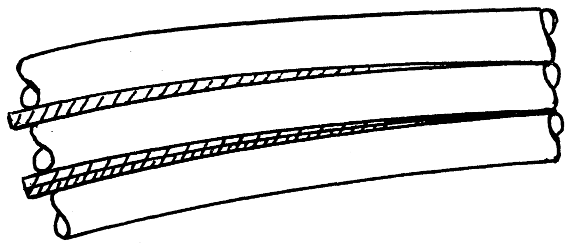


Fig. 5. Severin Bridge at Cologne (courtesy of ACIER STAHL STEEL)

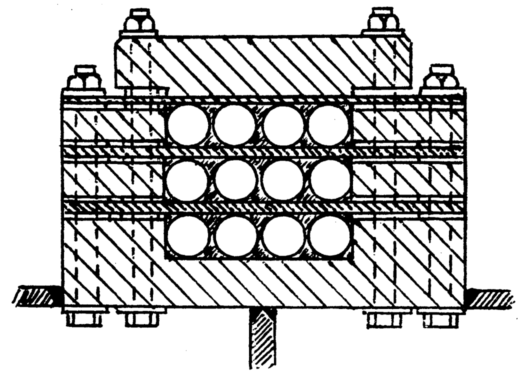
THE SEVERIN BRIDGE AT COLOGNE

The general orientation of this structure, along with the number of individual strands in the cables, is shown in Fig. 4. Generally, the cables are continuous through the tower, where they rest on saddles and are clamped thereto (Fig. 5a). Cables 1 and 6, and also the other cables, in elevation, intersect on the pylon center line. Viewed transversely, they are offset from the bridge center line on each side. The cable system center line coincides with the two theoretical cable planes extending from the girder attachment to the upper theoretical cable connection point at the top of the pylon. The cable sag caused by cable dead weight is vertical, which offsets the inclined plane in space. As a result, the saddles are oriented in a steeper plane determined by the tangent direction of the cable planes.[5,8]

Where the number of strands in a cable are different on one side of the pylon than the other (cables 1–6 and 2–5), the additional strands were anchored directly to



(a)



(b)

Fig. 6. Friction plates—Severin Bridge (courtesy of DER STAHLBAU)

the pylon (see Figs. 5a and 5b). In the case of cables 3 and 4, a saddle to allow for continuity would have resulted in too small a curvature; they were therefore terminated in the pylon.

Differential tensions in the cables at the top of the pylon are maintained by friction. Friction is present as a result of the normal force between the cables and the saddles. In addition, the clamping bolts on the saddle lid exert pressure on the cables. These combined friction forces were not sufficient to provide a required factor-of-safety of 2.5 over the differential cable tensions. Additional friction surface area was provided by horizontal plates inserted between the layers of strands, and fixing them to the saddle bearing and cover; thus the number of friction planes was increased from 2 to 6, and the potential frictional force was tripled, under the same cable pressure (see Fig. 6b). The friction plates are tapered as shown in Fig. 6a to provide a gradual transition between nonpressure and pressure areas.[5,8]

Figure 7 shows a general view of the attachment of the cable to the girder. The sides of the rectangular shaped cable assembly are tilted against vertical webs and strand socket plane (see Fig. 8). Up to the point of cable splay, the strand center lines are parallel to the tangent plane of each cable. This plane is slightly distorted against the theoretical cable plane, due to the cable sag.

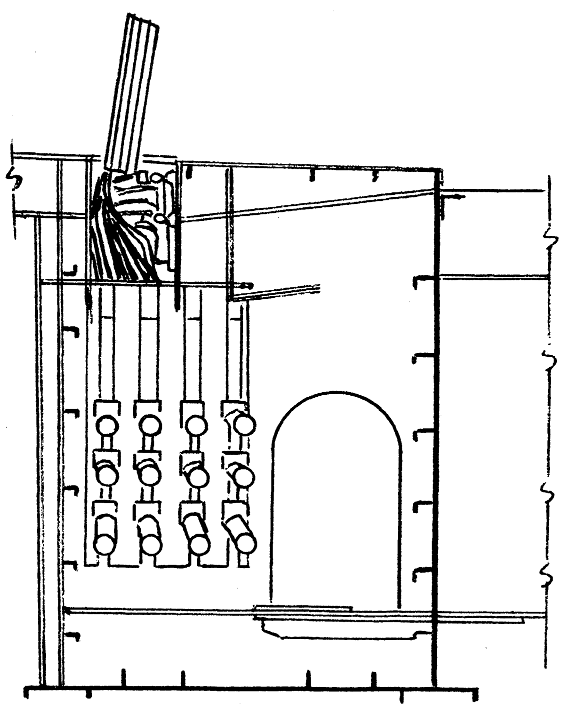


Fig. 7. Attachment of cable to girder—Severin Bridge (courtesy of ACIER STAHL STEEL)

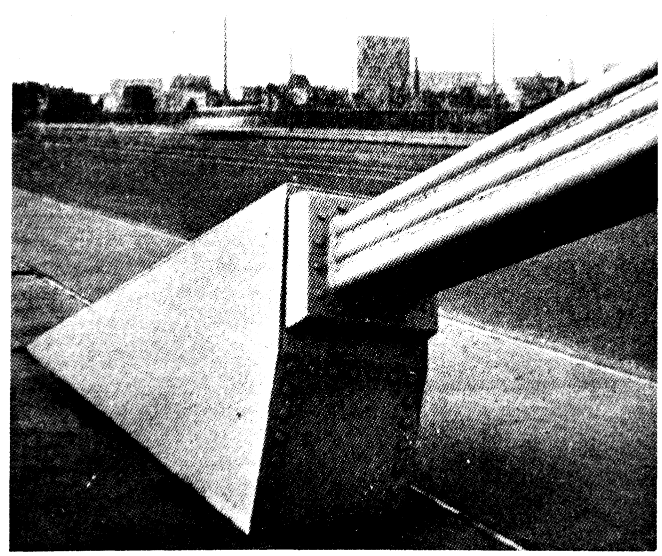
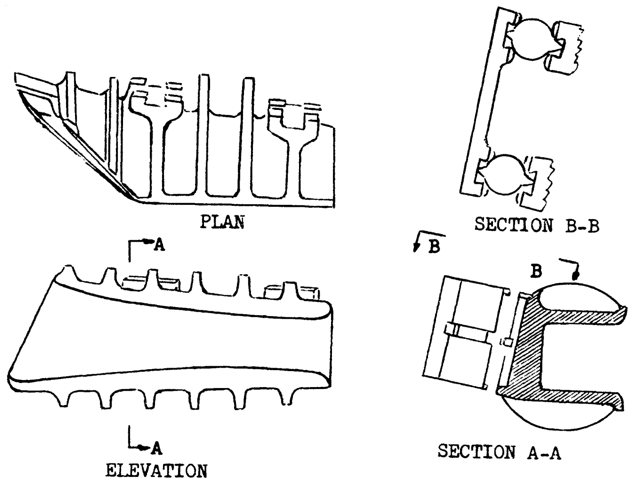
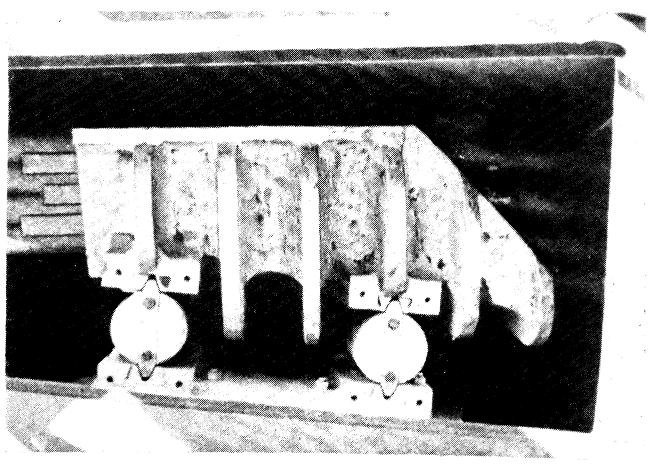


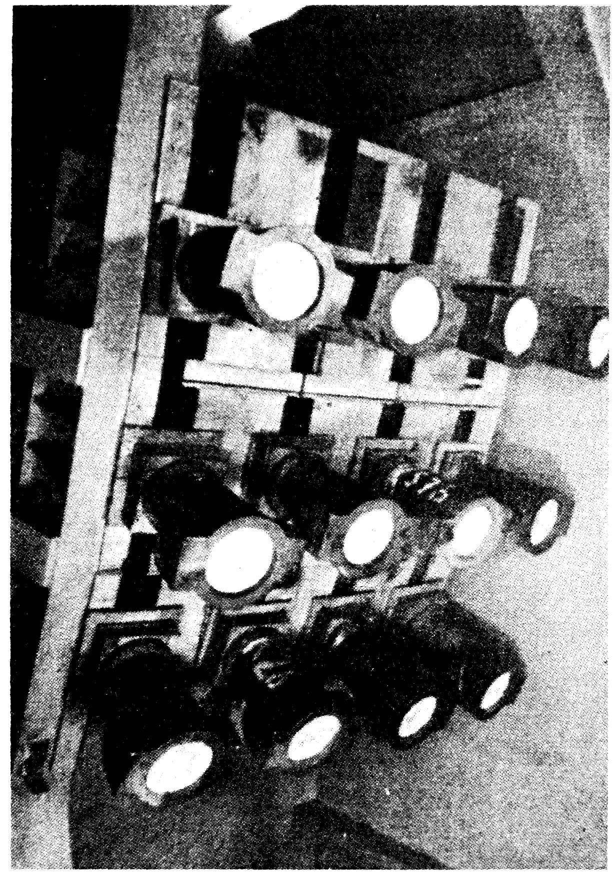
Fig. 8. Rectangular shaped cable assembly—Severin Bridge (courtesy of DER STAHLBAU)



(*a*) *Guide bearing* (*courtesy of DER STAHLBAU*)



(*b*) *Top view of guide bearing*
(*courtesy of ACIER STAHL STEEL*)



(*c*) *Anchorage at main girder*
(*courtesy of DER STAHLBAU*)

Fig. 9. Severin Bridge

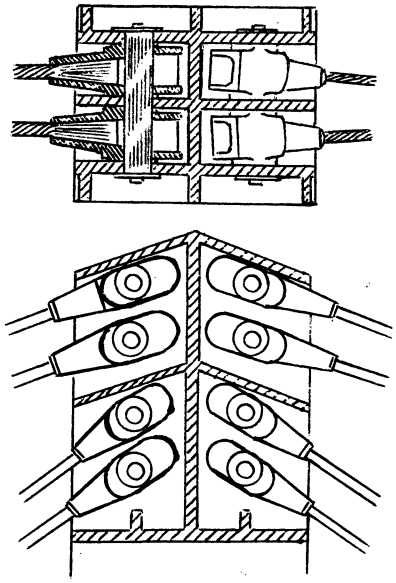
Where the cable enters the girder, the individual strands flare in three directions; upward, downward, and inward, before they reach their bearings. As a result of this spatial geometry, a special saddle or guide bearing is required (see Figs. 9a and 9b). The installation of strand sockets along a circular arc inside the main box girder is illustrated in Fig. 9c.[8]

THE STRÖMSUND BRIDGE, SWEDEN

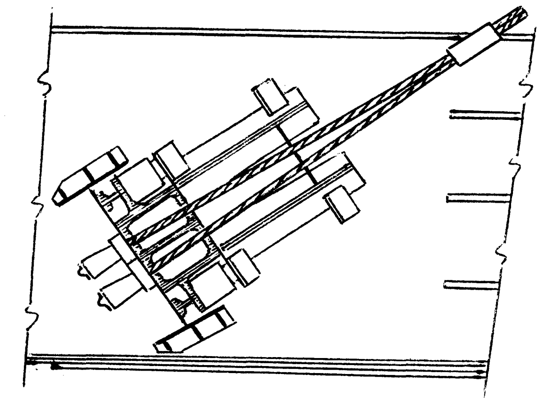
The cable anchorages on this structure are quite simple. The cables terminate in open strand sockets at the head of the pylon (Fig. 10a). The cables terminate in bearing sockets (shimmed for adjustment) at the transverse box beam between the girders (Fig. 10b).[19]

THE GALECOP BRIDGE, HOLLAND

This structure consists of twin single-plane cable-stayed superstructures on a skew of 39°. Each orthotropic deck has a width of 113 ft-6 in. and is supported on six girders. The center two girders are stiffened by the two centrally located cable-stay systems and pylons. The pylons pass through openings in the deck and are fixed to the piers. At the top of the pylon the twelve 75 mm ($2\frac{61}{64}$-in.) diameter strands are divided into two groups of six each and supported on two saddles. At the girder, the strands are flared into two layers of six each, terminating in bearing sockets and adjustment shims which transmit the cable force to the inclined diaphragms connecting the two center girders (Fig. 11).[14]



(*a*) *Pylon connection*



(*b*) *Girder connection*

Fig. 10. Strömsund Bridge, Sweden

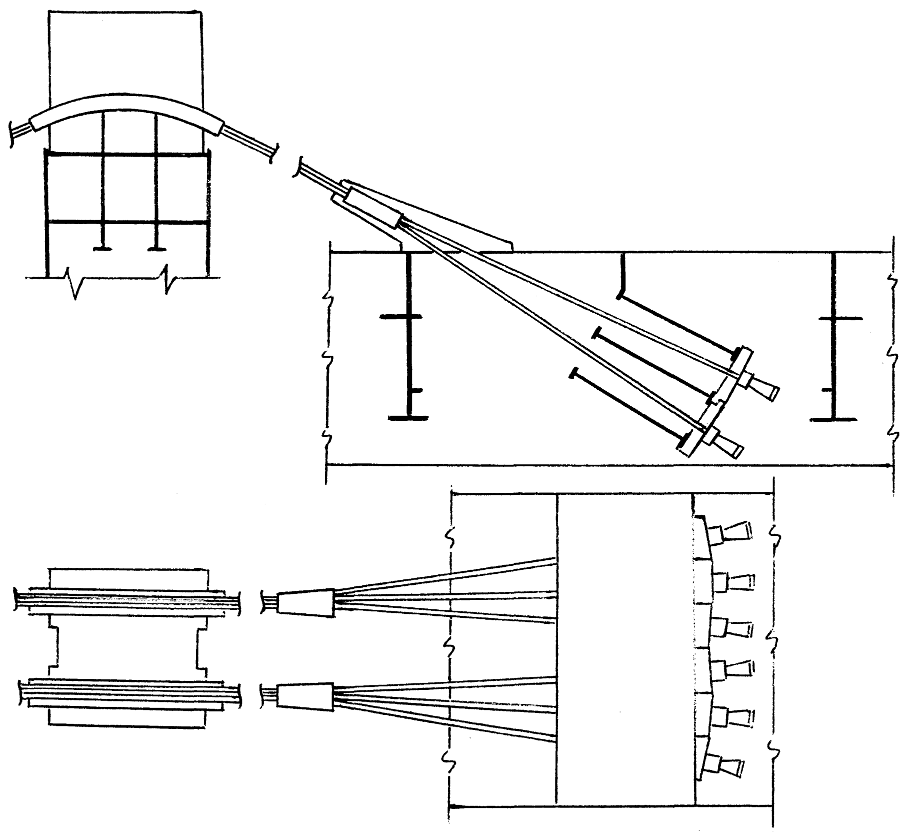
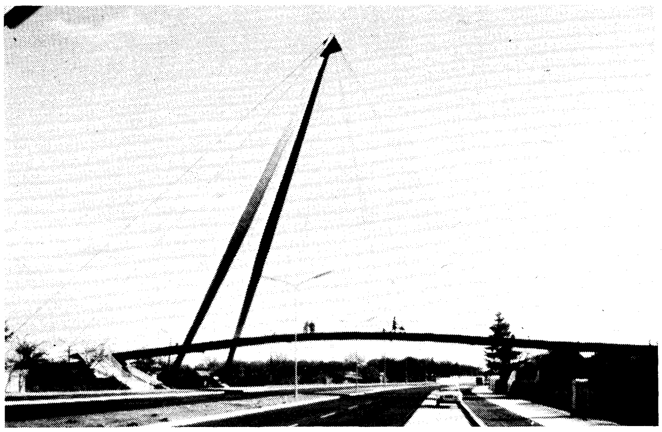


Fig. 11. Galecop Bridge, Holland
(courtesy of British Constructional Steelwork Association)



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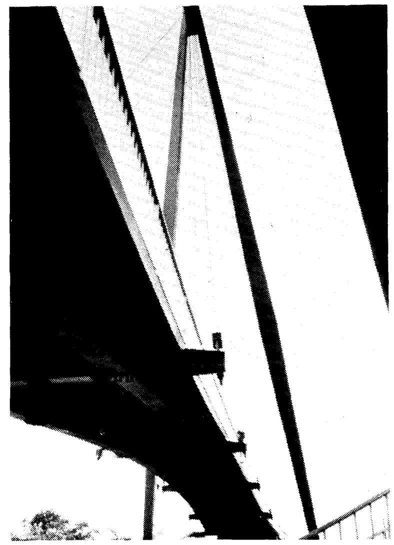

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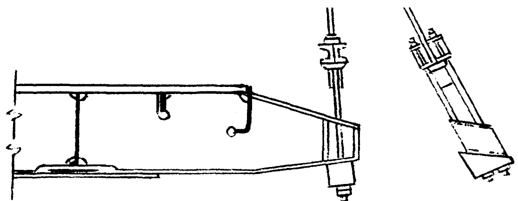


(c)

Fig. 12. Raxstrasse footbridge, Vienna

RAXSTRASSE FOOTBRIDGE, VIENNA

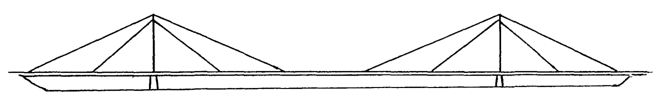
This structure has an inclined A-frame pylon with anchored backstays and eight cable stays supporting the deck on either side at the fifth points (Fig. 12a) attached to extended floor beams. The cable stays have bearing-type sockets and adjustment is made by means of threaded rods (Figs. 12b and 12c).

PAPINEAU-LEBLANC BRIDGE, MONTREAL

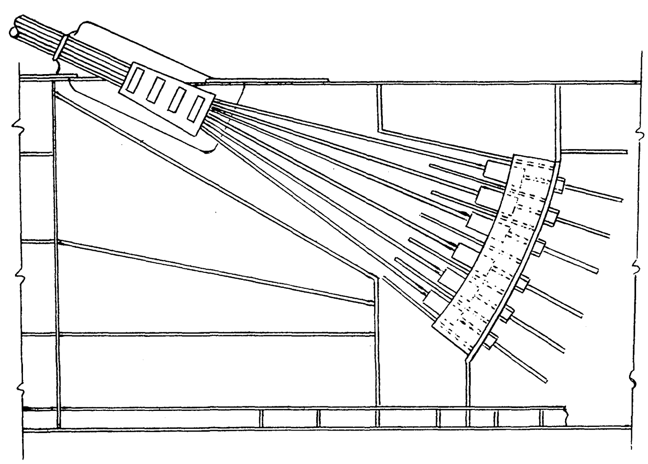
The cable configuration, in elevation, is depicted in Fig. 13a. Each stay is divided into two bundles of 12 strands each, to facilitate anchorage on each side of the center web of a two-cell box-girder (see Fig. 13b). The outer stays are composed of $2\frac{5}{16}$-in. diameter strands and the inner stays of $1\frac{5}{8}$-in. diameter strands.

Analysis of the displacements and forces in the cables at the pylon indicated that strand slippage would occur if saddles for both the outer and inner stays were fixed. Therefore, the saddle for the outer stays is allowed to slide on plastic.

At the cable connection to the girder, the cables terminate in a socket which has internal threads to accomodate ASTM A354 threaded rods. The rods pass through a curved bearing plate where load is transferred, and adjustment is made by nuts and washers bearing on the curved plate. The back face of this plate was finished to accommodate the bearing surface of the washers.[3,17]



(a) Elevation



(b) Anchorage at boxgirder

Fig. 13. Papineau-Leblanc Bridge, Montreal

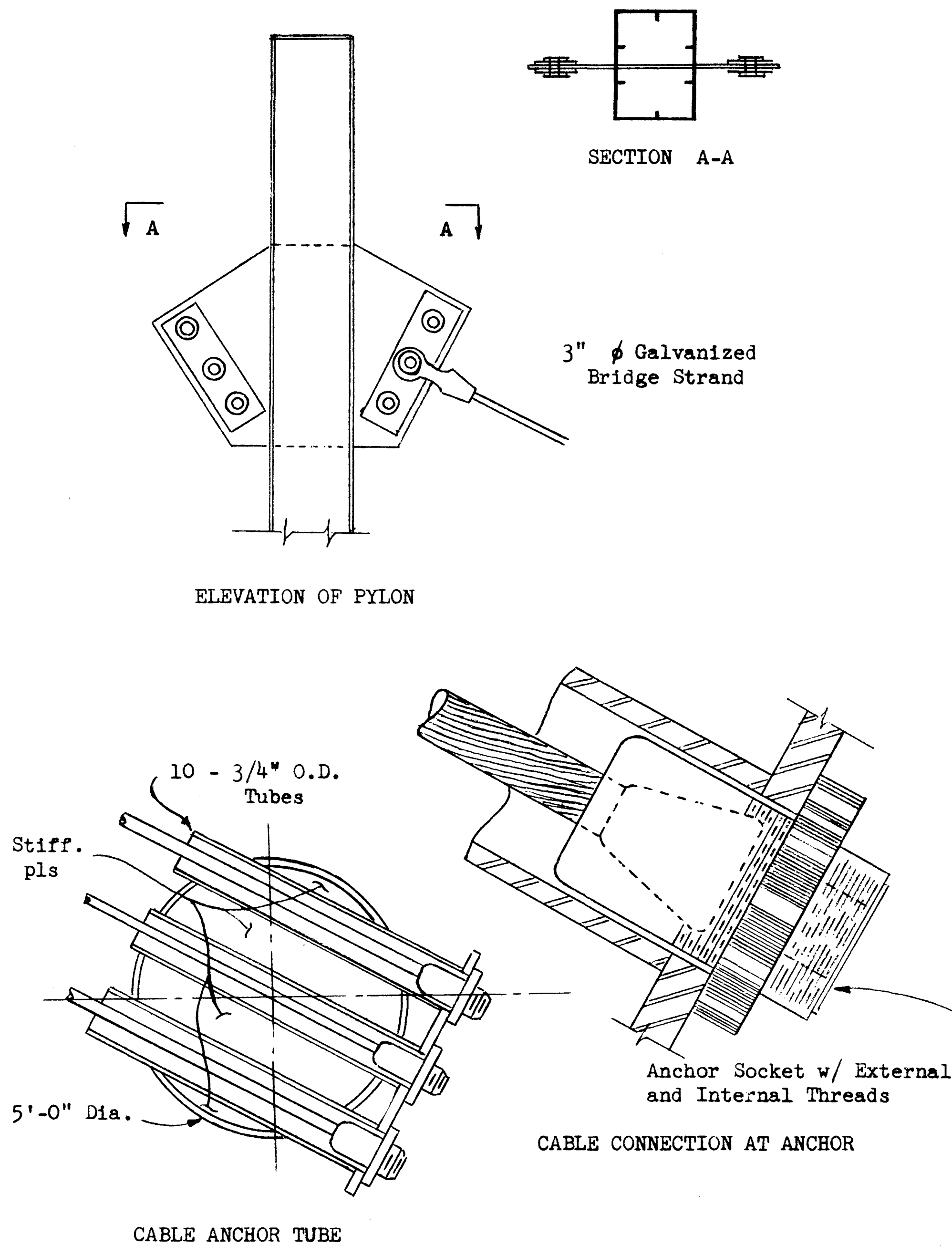


Fig. 14. Cable connection details—Sitka Harbor Bridge

SITKA HARBOR BRIDGE, ALASKA

The 450-ft main span structure designed by the Alaska Department of Highways is noteworthy for its unusual connection of stays to girder (Fig. 14). The 47-ft long by 5-ft diameter transverse tubes frame through the box-girders and project past each side of the deck (see Fig. 15). Pipes $10\frac{3}{4}$ in. in diameter pass through the tube ends; the 3 in. diameter galvanized bridge strands pass through the pipes and have bearing sockets bearing against 20-in. by 60-in. plates (Figs. 14 and 15). The annular space between the strand and the pipe is filled with a polymer sealer. The transverse cable anchor tube was selected because of its equal bending resistance in all directions. At the top of the pylon the three 3-in. diameter strands, arranged in a vertical plane, connect by open sockets to a heavy plate centered in the pylon.[7]

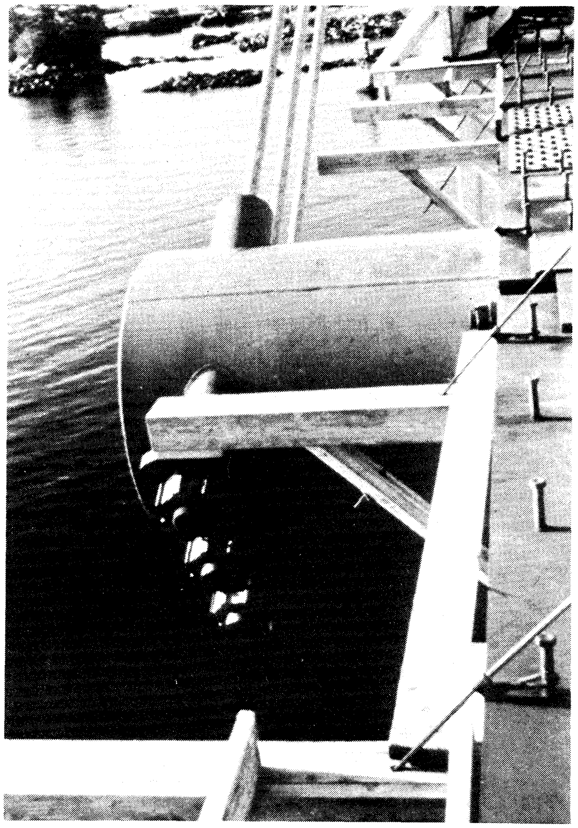


Fig. 15. Sitka Harbor Bridge

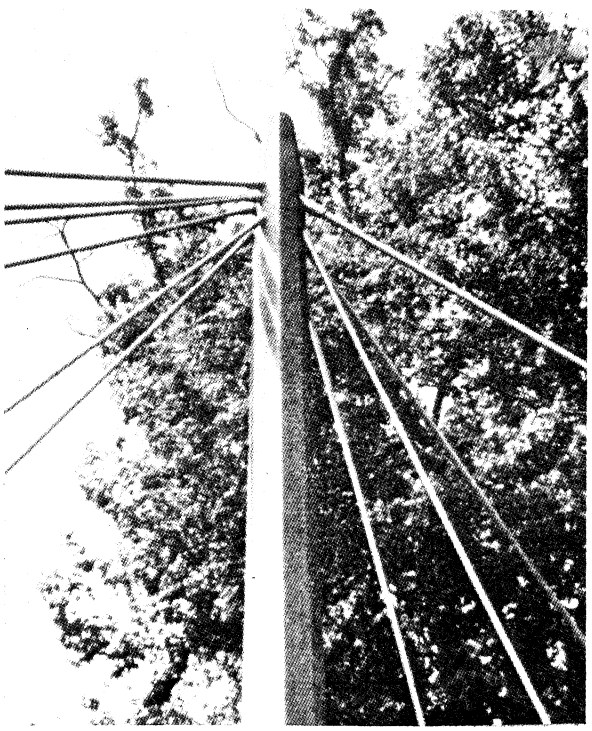
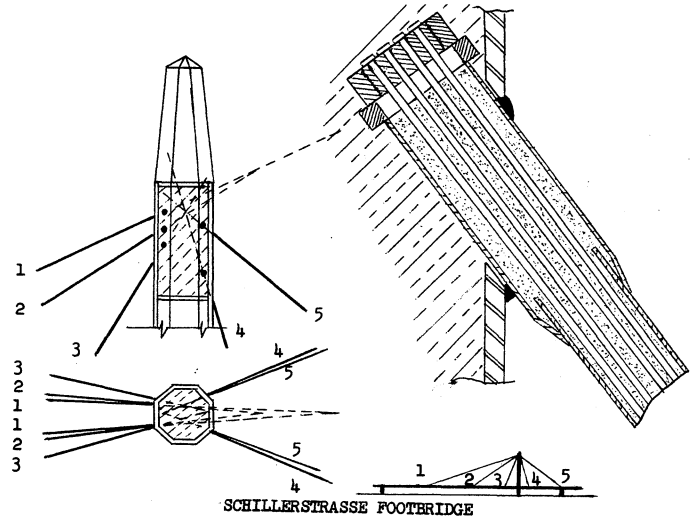
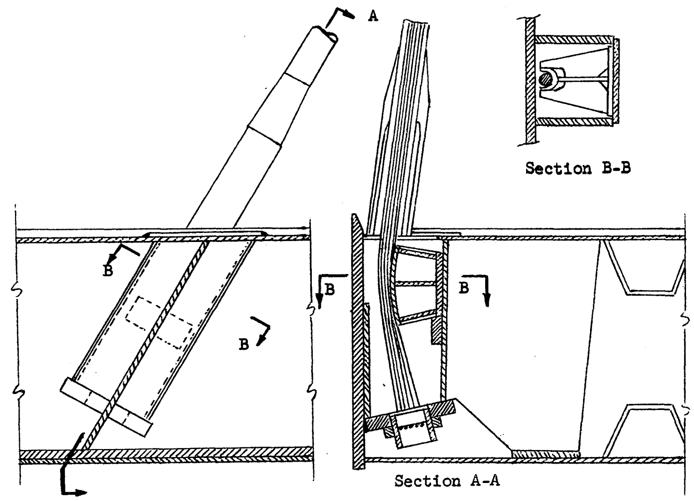


Fig. 16. Schillerstrasse footbridge, Stuttgart (courtesy of DIE BAUTECHNIK)



(*a*) *Anchorage at pylon*



(*b*) *Anchorage at superstructure*

Fig. 17. Schillerstrasse Footbridge, Stuttgart (courtesy of DIE BAUTECHNIK)

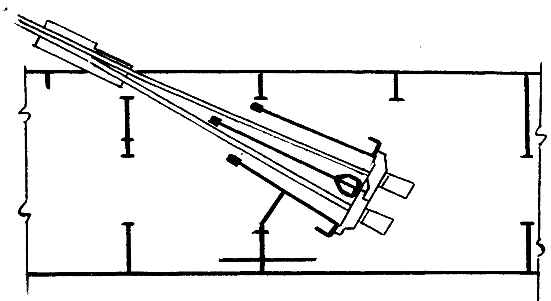
FOOTBRIDGE OVER THE SCHILLERSTRASSE, STUTTGART

The slim octagonal pylon of this structure has a very slight taper (see Fig. 16) and at the top only a 1000 mm (3 ft-3⅜ in.) high by 490 mm (1 ft-7$\frac{5}{16}$ in.) octagonal space is available for the cable anchorages (Fig. 17a).

This structure is the first cable-stayed bridge to utilize parallel wire strand. The cables are composed of a varying number of 6 mm (¼-in.) diameter wires, Table I, and are in actuality the familiar prestressed concrete post-tensioning tendon with BBRV anchorages.

Table I

Tendon	1	2	3	4	5
No. of wires/tendon	44	28	20	22	90



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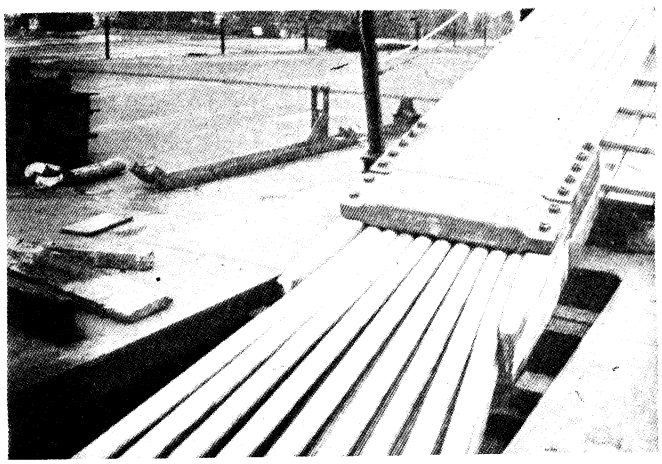

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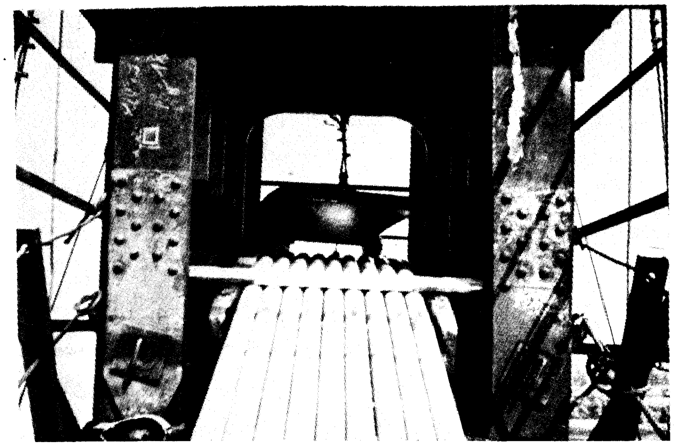
Fig. 18. Details at box girder—Rhine River Bridge at Maxau (courtesy of DER STAHLBAU)



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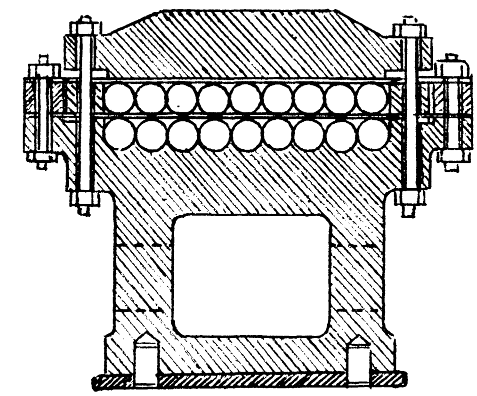


(*b*)

Fig. 19. Details at pylon—Rhine River Bridge at Maxau (courtesy of DER STAHLBAU)

The use of the substantially shorter and smaller diameter BBRV anchorages resolves the difficult problem of fitting the 10 cable anchorages into the pylon head. For the anchorage installation a pipe or trumpet is welded to the pylon wall in the direction of the cable, with the anchor at its upper end and inside the cavity. With the cable and its anchorage in place, the anchorage cavity in the pylon is filled with high strength concrete, thus providing a bearing medium for the anchorage and also increasing the strength of the octagonal cross section tension ring.

The anchorage at the superstructure, Fig. 17b, is parallel to the cable axis in elevation, but requires a half-tube built-up saddle for the curvature required at the anchorage body.

The cable is wrapped with a 2.5 mm ($\frac{3}{32}$-in.) wire and encased in a polyethylene tube with sufficient clearance to allow pressure grouting. Cement mortar grout is introduced under pressure at the lower anchorage and an air vent is provided at the upper anchorage to indicate when the mortar has traveled the length of the cable.[10]

THE RHINE RIVER BRIDGE AT MAXAU

This structure has a single plane, fan type cable configuration located in the median strip. The superstructure is a single rectangular box-girder with side cantilevers. The cable force is transmitted to the box-girder through inclined transverse diaphragms (see Fig. 18a). The radial diaphragms allow a flow of force from the cable to the box-girder cross section and along its length. However, this force is not immediately distributed through the cross section. This is because of the large opening in the top flange (deck); see Fig. 18b. A stiffening and reinforcing of the top flange of the box-girder is therefore required at this location.

Figures 19a and 19b show a view of the cables entering the pylon and the saddle arrangement, respectively. The use of additional friction plates to accomodate the differential force in the cable from one side of the pylon to the other is also illustrated in Fig. 19b.[15]

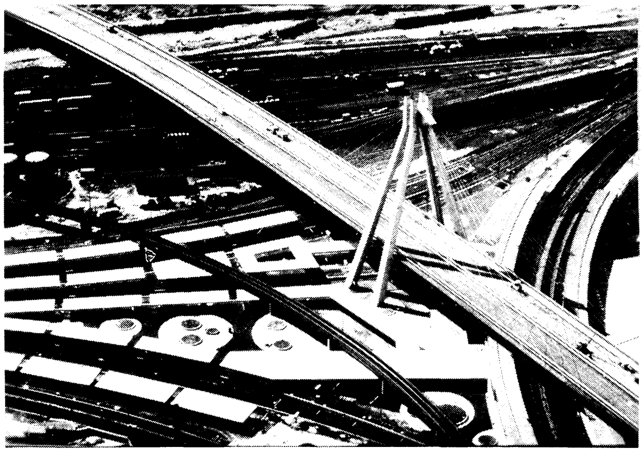


Fig. 20. Aerial view—Ludwigshafen Bridge (courtesy of DER STAHLBAU)

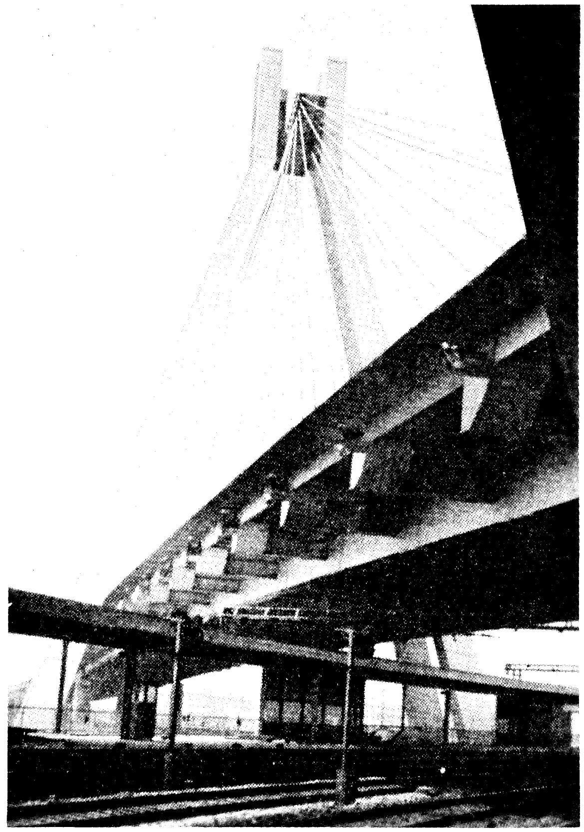
LUDWIGSHAFEN BRIDGE

In 1968, at Ludwigshafen, Germany, an old dead-end railway station was converted into a modern through station. Road and rail are now routed at five different levels, the highest of which is formed by an elevated roadway, the main section of which is formed by a cable-stayed girder bridge structure with a converging cable arrangement (Fig. 20).

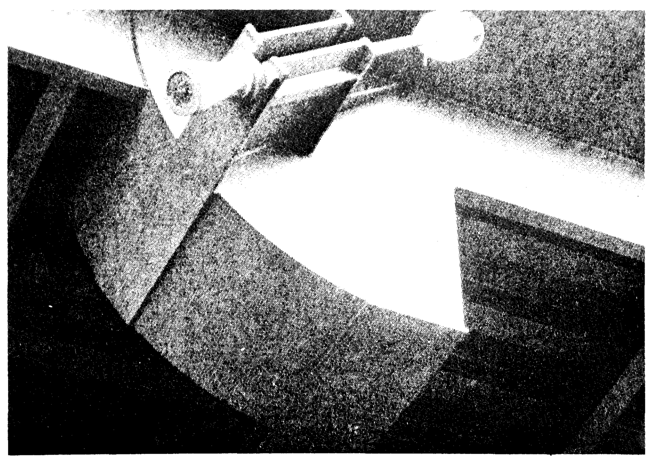
The four-legged tower, A-shaped on all sides, is approximately 250 ft in height. The elevated roadway is an orthotropic deck and is approximately 80 ft in width. Figure 21a shows the bracketed cable attachment. A close-up showing the bearing socket is shown in Fig. 21b. The large number of guy cables coverging at the top of the top of the tower (Fig. 22) called for an architecturally distinctive and interesting solution for anchorage elements at the upper ends of the cables.[6]

SUMMARY

American designers and builders have expertise and experience with cable assemblies in bridge structures and to some degree in cable-supported roof structures. However, with regard to the size of cables and fittings as they pertain to cable-stayed bridges and their design, our experience is limited. The experience gained in other countries should not be disregarded; however, practices vary from country to country and those experiences should be evaluated with regard to practices in this country. Certainly, this is an area where the need for thought and research is indicated. At the very least, as an interim measure, the designer of cable connections should consider the desirability of providing access for inspection, as well as jacking equipment for adjustment of the cable, should this become a requirement during the life of the structure.



(a) Bracketed cable attachment



(b) Bearing socket

Fig. 21. Ludwigshafen Bridge (courtesy of DER STAHLBAU)

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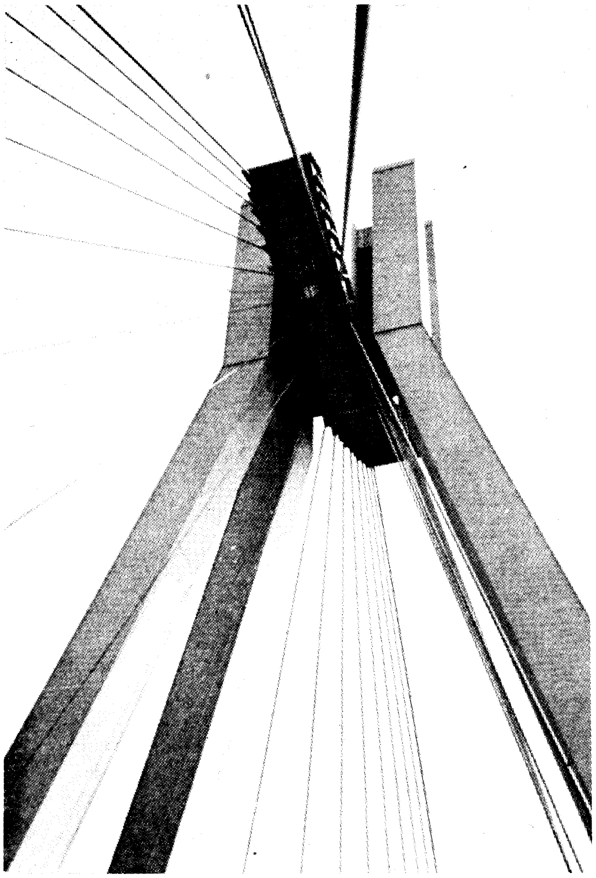

Fig. 22. Cable anchorage at tower—Ludwigshafen Bridge (courtesy of DER STAHLBAU)

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