Post-Tensioning Details for Long-Span Concrete Bridges

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At the turn of the century, J. A. L. Waddell was one of the pre-eminent bridge engineers in the United States. His volumes on "Bridge Engineering," published around 1915, represent a comprehensive treatment of the art and science of bridge engineering up to that time. In one of those volumes, he notes that the essence of bridge engineering lies in the development of good details.

This observation remains unchanged today and thus much of the detailing for long-span concrete bridges relates to the installation and anchorage of post-tensioning materials. For this reason, it seems appropriate to consider the most significant post-tensioning details for long-span concrete bridges, including some remarks on cable stays.

TENDON ANCHORAGES

Bearing Plate Anchorages

Until the early 1970's, nearly all post-tensioned bridges in the United States and Canada were built using bearing plate type anchorages. In the United States, these anchorages were generally proportioned on the basis of the 3000-psi (20.68 MPa) bearing stress at service load contained in Section 1.6.6 (B)(4) of the "AASHTO Standard Specifications for Highway Bridges."[1]

While these anchorages remain very serviceable for some aspects of post-tensioning of long-span concrete

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NOTE: This paper is based on a presentation given at the Segmental Concrete Bridge Conference in Kansas City, Missouri, March 9-10, 1982. The Conference was sponsored by the Associated Reinforcing Bar Producers — CRSI, Federal Highway Administration, Portland Cement Association, Post-Tensioning Institute, and Prestressed Concrete Institute.

Describes various types of post-tensioning anchorages and couplers developed for use in long-span concrete bridges. Illustrations are presented for a variety of applications of transverse deck post-tensioning, vertical web post-tensioning and longitudinal post-tensioning.

bridges, the bearing plates for multiple strand tendons are relatively large (see Fig. 1). For this reason, use of bearing plate anchorages for larger multiple strand tendons [especially anchorages proportioned on the 3000-psi (20.7 MPa) specification] sometimes becomes awkward in the thinner concrete sections which are desirable for long-span concrete bridges.

One possible refinement which would provide some relief for bearing plate anchorages for multiple strand tendons would be to proportion the anchorage plate on the basis of the bearing stress formulas contained in the PTI "Guide Specifications for Post-Tensioning Materials."[2] In many cases, this would reduce the required bearing plate area, and it would therefore make the use of bearing plate anchorages for multiple strand tendons more feasible for long-span concrete bridges.

As reflected by the use of bearing plate anchors for the 1¼-in. (32 mm) diameter 150 ksi (1035 MPa) bars used to post-tension the Kishwaukee River Bridge shown in Fig. 2, bearing plate anchors for bar tendons are more compatible with the section dimensions of segmental bridges. This reflects the lower force involved per tendon for single bar tendons.

The threadbar system with bearing plate anchors is also very well adapted to use for vertical prestressing of webs where the extremely small seating loss of the bar system provides an additional advantage for these shorter tendons. Nonetheless, the economic pressure to use a smaller number of larger, multiple-strand tendons for the longitudinal post-tensioning of segmental bridges has resulted in the use of anchorage types which can be used in smaller cross sections, or smaller build-outs.

Confinement Anchorages

Anchorages which operate essentially on the basis of confinement of the bursting or splitting stresses exerted in the anchorage area by the tendon have been in use for many years throughout Europe.[3] In most cases, the confinement is provided by a helical coil of reinforcement placed around the anchorage as shown in Fig. 3. The bell anchorage for threadbar tendons shown in Fig. 4 also operates on the confinement principle.

Confinement anchors offer the advantage of substantially reduced anchorage space requirements, and the confinement reinforcement inherently provides control of cracking in the immediate anchorage zone. Confinement anchorages have been used successfully on nearly all of the major segmental bridges, providing significant improvement in the details for the build-outs for intermediate tendon anchorages. Anchorages of this type are also more adaptable for use in thinner web or deck slab sections.

Bond Anchorages

Again, our European counterparts long ago developed and used fixed-end anchorages based on bond of the tendon material to the concrete.[3] In North America, this type of anchorage has been adapted to the strand system, and the details shown in Fig. 5 have been used very successfully on a large number of projects with a fairly large variation in tendon sizes.

The problems with this type of anchor in a portion of the deck slab of the Lewiston-Clarkston Bridge appear to be related to the bond characteristics of the particular 0.6-in. (15 mm) diameter strand used in that case. Since the force

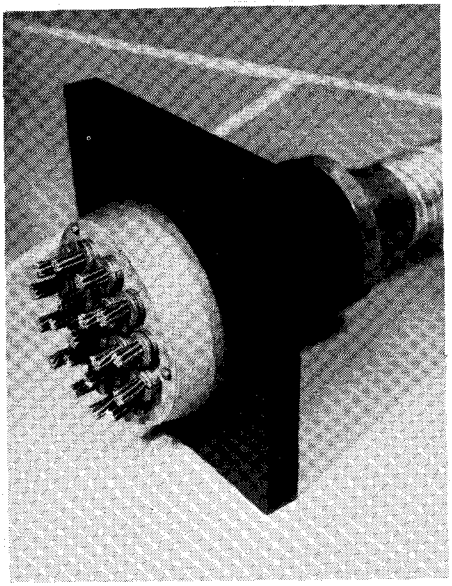


Fig. 1. Bearing plate anchorage for multiple strand tendon for conventional box girder bridges cast in place on falsework.

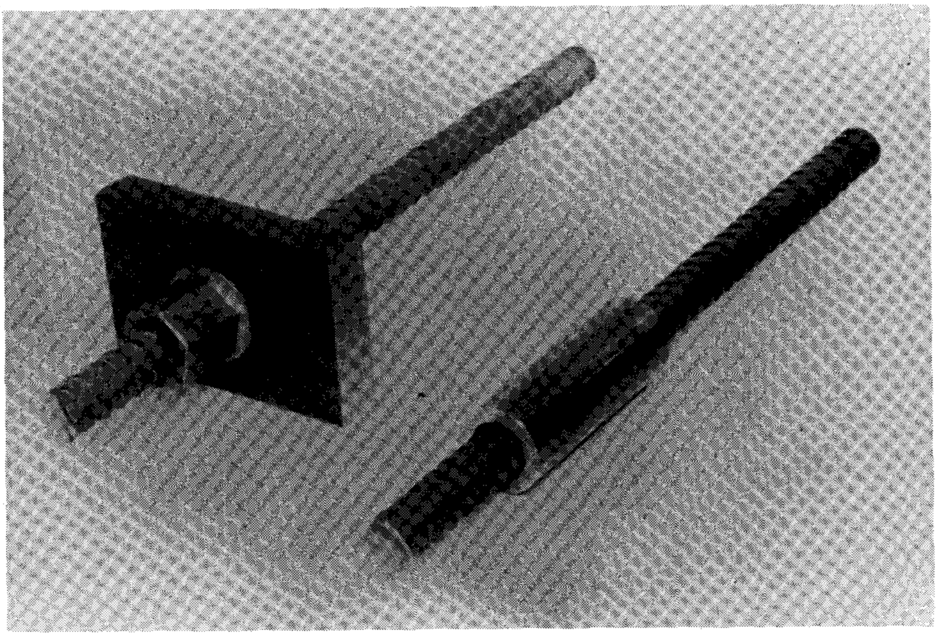


Fig. 2. Bearing plate anchorage for 1¼-in. (32 mm) diameter threadbar tendons, used in post-tensioning the Kishwaukee River Bridges. Bearing plate anchors for bar tendons are more compatible with the section dimensions of segmental bridges.

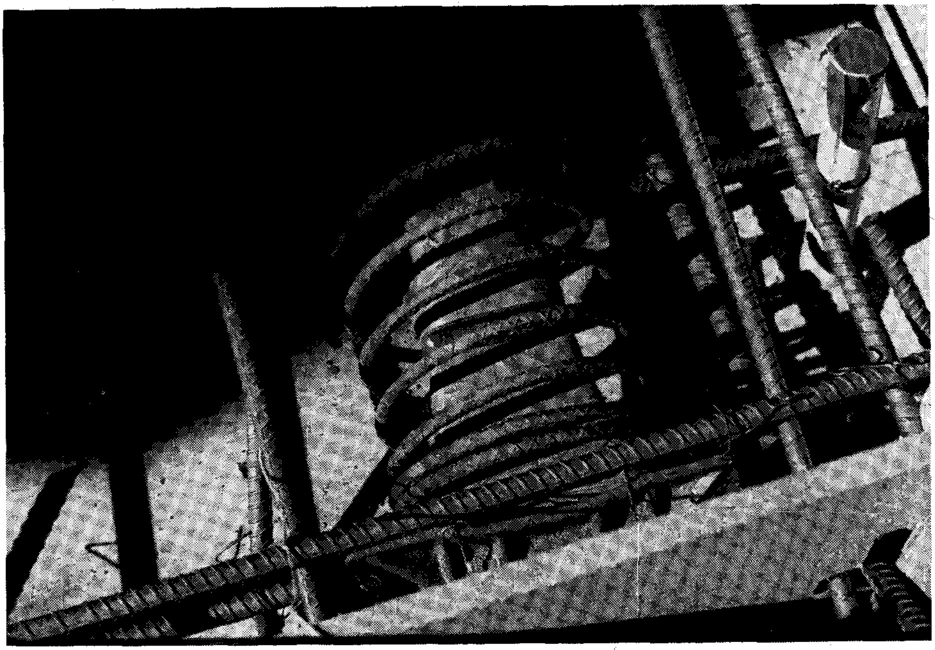


Fig. 3. Confinement anchorage for multiple strand tendon, showing the helical coil of reinforcement placed around it.

per 0.6-in. (15 mm) diameter strand is 42 percent greater than the force per 0.5-in. (13 mm) diameter strand, and the surface area is only about 20 percent larger for 0.6-in. (15 mm) diameter strand, use of bond anchorages of this type for 0.6-in. (15 mm) diameter strand is obviously more demanding than for 0.5-in. (13 mm) diameter strand. However, this anchorage has generally functioned very well in many thousands of applications for both 0.5-in. (13 mm) diameter strand and 0.6-in. (15 mm) diameter strand anchorages.

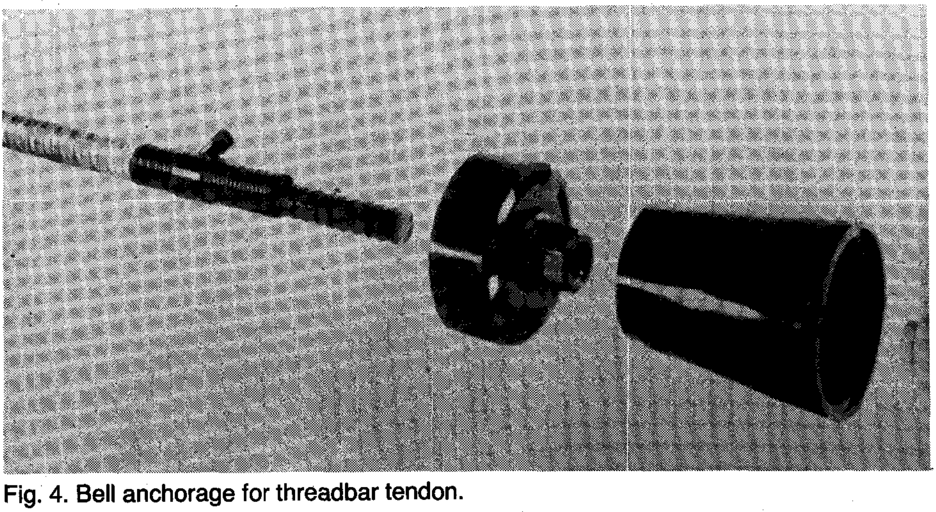


Fig. 4. Bell anchorage for threadbar tendon.

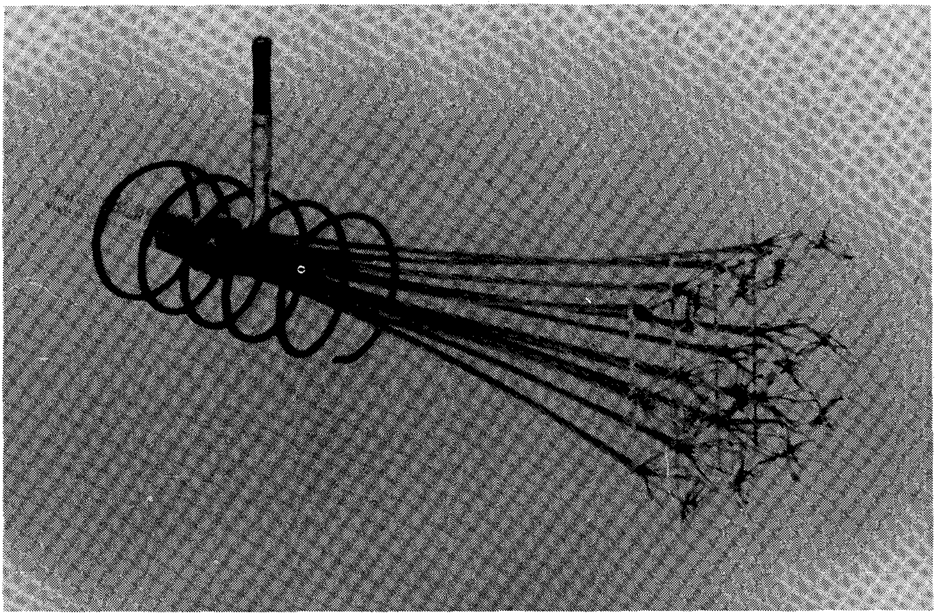


Fig. 5. Bond anchorage for multiple strand tendon.

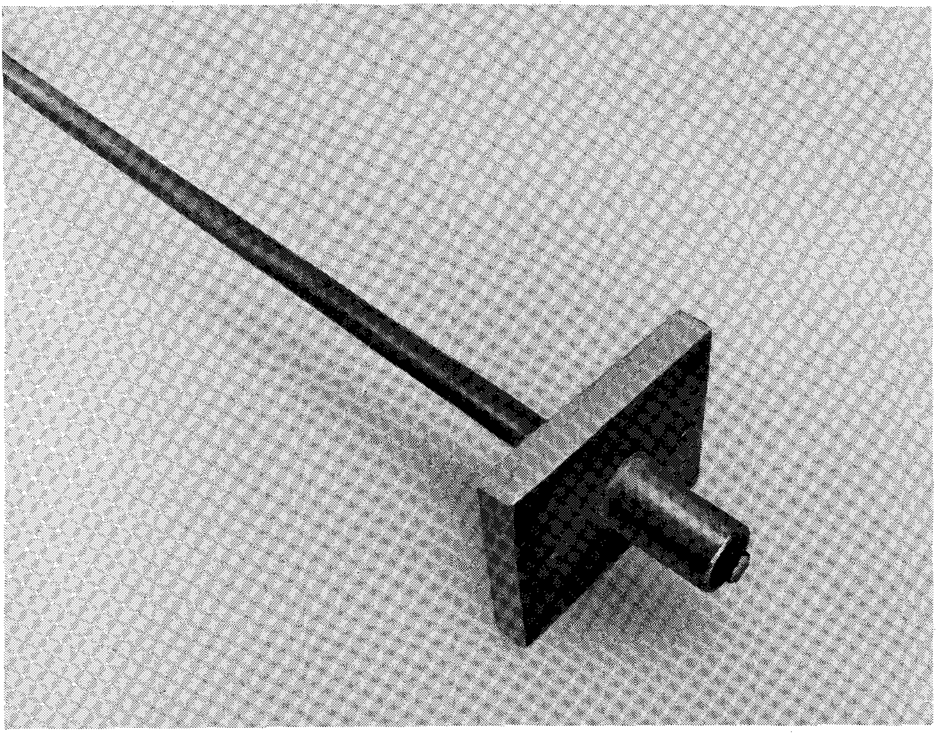


Fig. 6. Compression grip anchor for single strand tendon.

Compression Grips

Another means of anchoring strand tendons is through the use of cylindrical compression grips as shown in Fig. 6, which are swedged (reduced in diameter and increased in length under high lateral pressure) onto the strand. An adaptation of this type of anchorage to multi-strand tendons was used for the anchorages of the vertical web tendons in the latter stages of construction of the Houston Ship Channel Bridge.

Loops

The use of loops for tendon anchorages in Europe also preceded their use in the United States by many years.[3] One of the first notable American applications of loops as anchorage for flexural reinforcement was at the San Francisco Airport Viaduct in the middle 1970's. Since that time, loops have been widely used in conventional cast-in-place post-tensioned bridge construction, as illustrated in Fig. 7, and in long-span segmental bridges.

The loops shown in Fig. 7 have been used for anchorage of both longitudinal tendons and vertical web tendons. In the vertical web tendon application, the loops require the use of vents or drains in colder climates to avoid potential damage due to water freezing in the loops. In both applications, both ends of the loop tendon shown in Fig. 7 are stressed simultaneously. The loops shown in Fig. 8 were used in the Kline Avenue Bridge in Indiana as dead end anchors for longitudinal tendons. This tendon requires only one jack for stressing. A similar detail was used for the longer web tendons on the Houston Ship Channel Bridge.

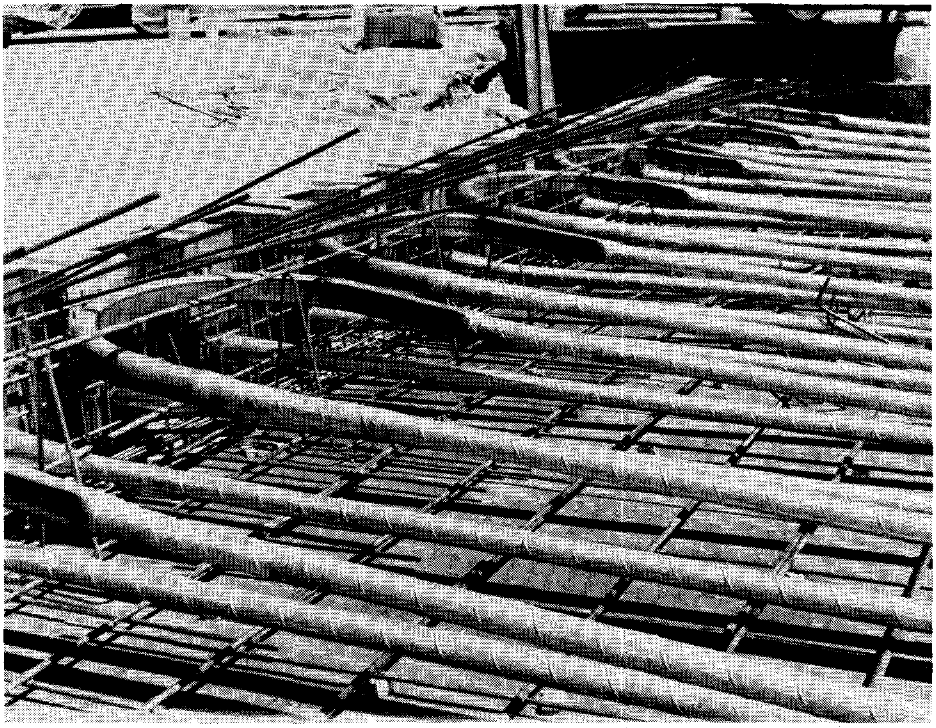


Fig. 7. Loop tendon anchorages for multiple strand tendons.

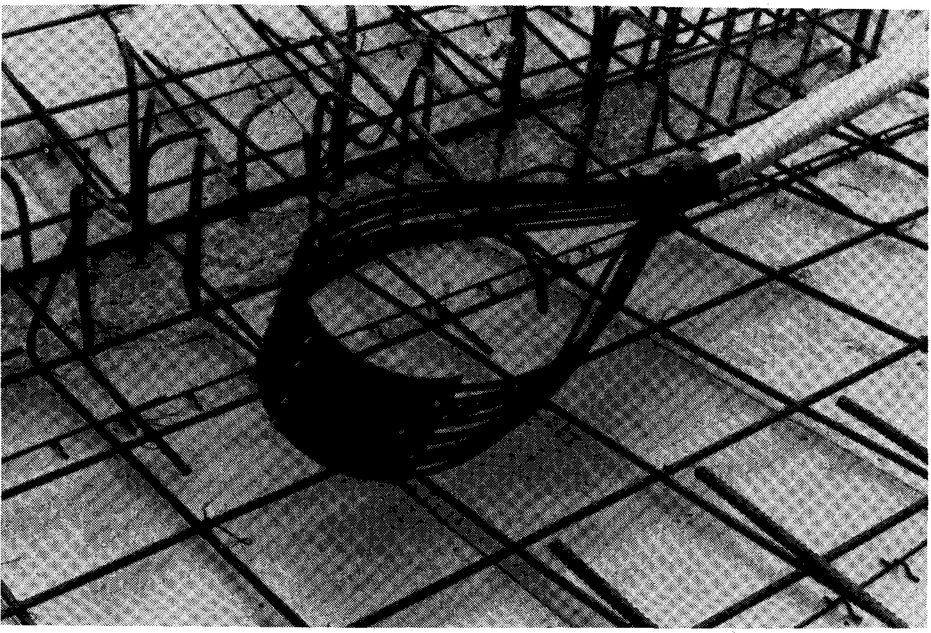


Fig. 8. Multiple strand tendon loop anchorage used in the Kline Avenue Bridge, Indiana, and Houston Ship Channel Bridge, Texas.

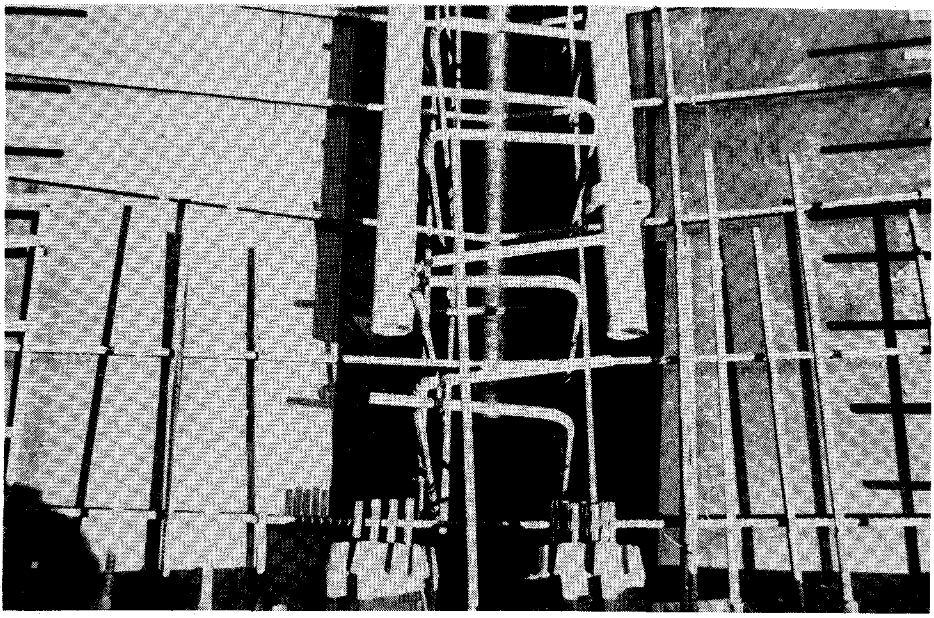


Fig. 9. Coupler used at the ends of each segment for tendons of twelve ½-in. (13 mm) diameter 270 K (1863 MPa) strand for the incrementally launched Wabash River Bridge, Indiana.

Couplers

The use of couplers such as the one shown in Fig. 2 is an integral part of the threadbar system. Since couplers are compact in dimension, they are easy to install. It is important that couplers develop the full strength of the threadbar tendon. Couplers are also required for some strand tendon applications.

The uniform prestress of the incrementally launched Wabash River Bridge in Indiana provides a good example of a strand tendon application. Couplers in this bridge were used as illustrated in Fig. 9 at the ends of each segment for tendons of twelve ½-in. (13 mm) diameter 270 K (1863 MPa) strand. To extend the tendon for the next segment, each strand is anchored to the coupler casting in this detail by use of a field-applied cylindrical compression grip similar to the one shown in Fig. 6.

CABLE STAYS

Possibly the most demanding anchorage requirements in bridges relate to cable stays. Anchorages and stay material for the Pasco-Kennewick and Luling Bridges (see Fig. 10) were successfully supplied to very stringent, yet manageable, specifications. However, the specifications for the cable stays for the Huntington Bridge introduced a number of more stringent requirements.

Specifically, the limitations on permissible variation in modulus of elasticity (±3 percent variation), fatigue testing of a 307-wire specimen to 2,000,000 cycles of fatigue loading in the stress range of 0.30 to 0.40 of the guaranteed ultimate strength of the tendons without any wire failures (previously a 5 percent fractile allowance was permitted, and this reflects international practice), and addition of a

Fig. 10. Cable stay for Luling Bridge, Louisiana, comprised of 307 ¼-in. (6.4 mm) diameter 240 K (1656 MPa) wires. Stay is approximately 630 ft (192 m) long and weighs approximately 38,000 lb (171,000 N).

500,000 cycle fatigue test to a stress range of 0.25 to 0.40 percent of the guaranteed ultimate strength of the test specimen without wire breakage, are all substantially more stringent than previous international requirements for cable stays.

Those requirements may also be incompatible with the "Buy American" requirements of the construction special provisions. Specifications for cable stays that are compatible with international standards would seem more appropriate, even at the expense of some modifications in other aspects of the design of cable stayed bridges.

TRANSVERSE DECK POST-TENSIONING

Transverse deck post-tensioning is considered to be desirable from the standpoints of crack control and durability for all major bridges. For precast construction, transverse post-tensioning of the deck also provides desirable toughness for handling of segments during erection. In many, or even most, applications, the use of post-tensioning for the deck slab contributes significantly to the economy of the bridges. A variety of anchorages have been used successfully for post-tensioning of deck slabs, including those of the bearing plate, confinement, and bond types described above. Fig. 11 illustrates tendon installation in a deck slab with use of confinement anchors.

The use of plastic conduits for deck tendons, as specified for the Wiscasset Bridge in Maine, would appear to raise questions about the bond characteristics for the tendons; the use of epoxy coated metal conduit may be preferable. It also seems appropriate to use conservative cover dimensions and the best available protective systems in the design of post-tensioned deck slabs. Nonetheless, it seems reasonable to question the extrapolation of the durability experience with unprotected conventionally reinforced bridge decks, many with inadequate amount and quality of concrete cover, to performance of decks prestressed in two directions, with conservative cover, epoxy coated reinforcement, and, in some cases, additional surface protective systems.

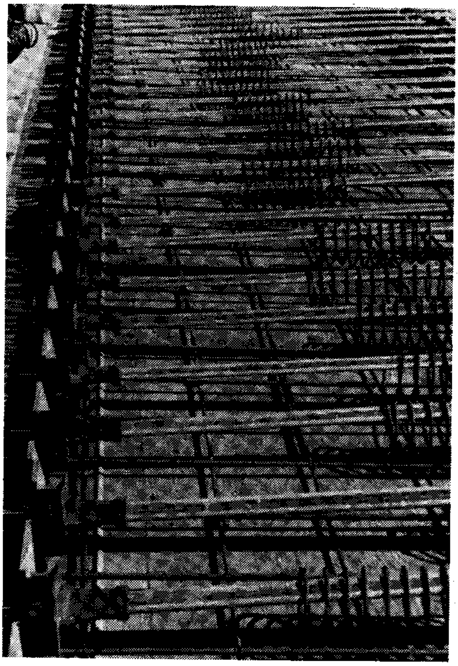


Fig. 11. Confinement anchorages for transverse deck post-tensioning installed in deck slab.

WEB POST-TENSIONING

Web post-tensioning for the Parrots Ferry Bridge in California using threadbar tendons is illustrated in Fig. 12. As noted above, various loop details and compression grips have also been used for anchorage of multiple strand vertical web tendons. With the exception of diagonal tendons at hinge joint details such as shown in Fig. 13, web tendons are now generally installed vertically.

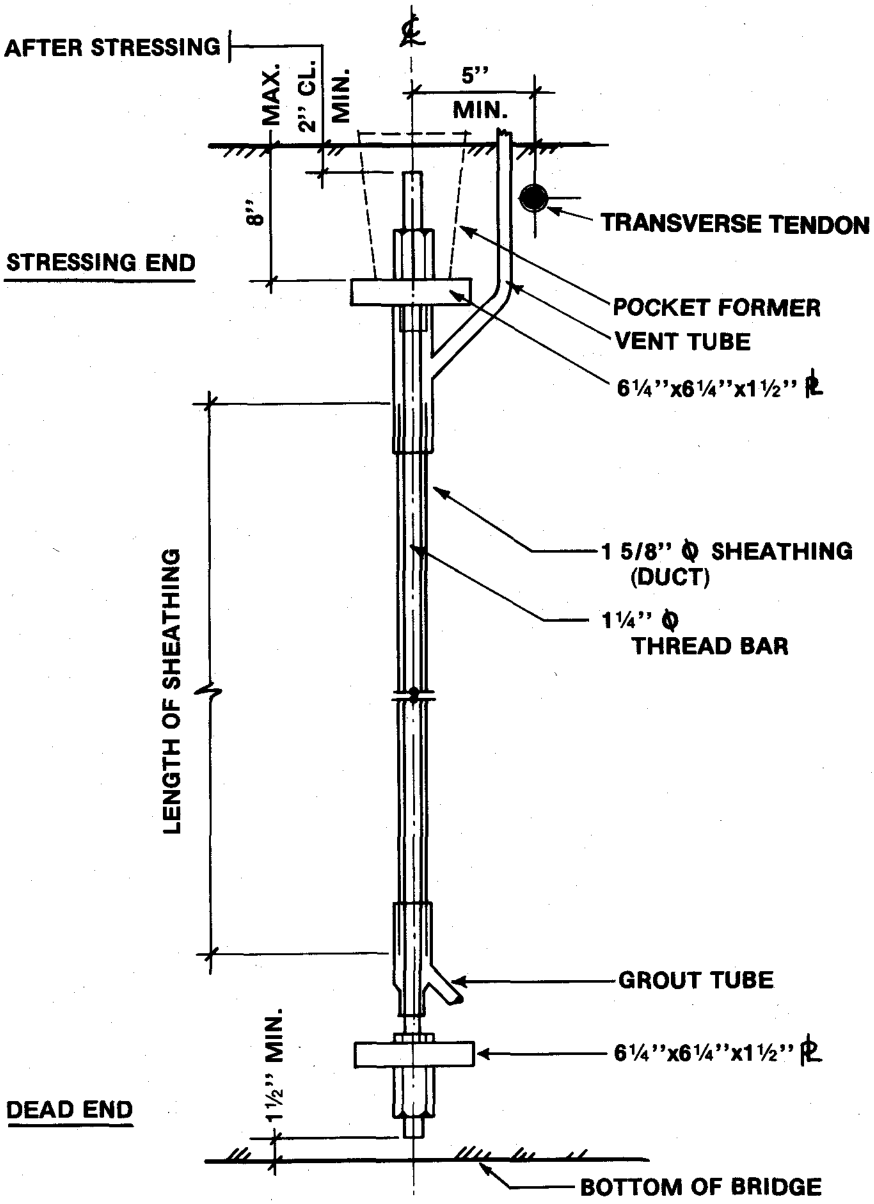


Fig. 12. Web post-tensioning, Parrots Ferry Bridge, California.

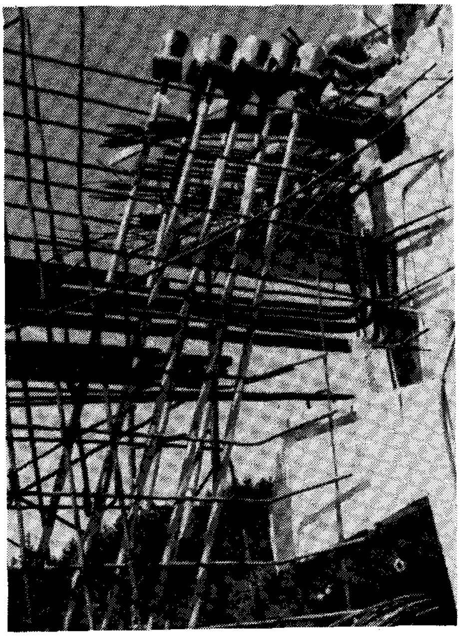


Fig. 13. Diagonal web tendons at interior hinge joint.

LONGITUDINAL POST-TENSIONING

Parrots Ferry Bridge

The Parrots Ferry Bridge, shown during construction in Fig. 14, utilized 0.6-in. (15 mm) diameter strand tendons for the main longitudinal post-tensioning.

Threadbar tendons were used for temporary longitudinal post-tensioning and for the longitudinal positive moment tendons.

Houston Ship Channel Bridge

The redesign for the Houston Ship Channel Bridge used 12 and 19-strand 0.6-in. (15 mm) diameter strand tendons in place of the 12-strand 0.5-in. (13 mm) diameter tendons, thus reducing the number of cantilever tendons over the pier from 217 to 92. Fig. 15 illustrates

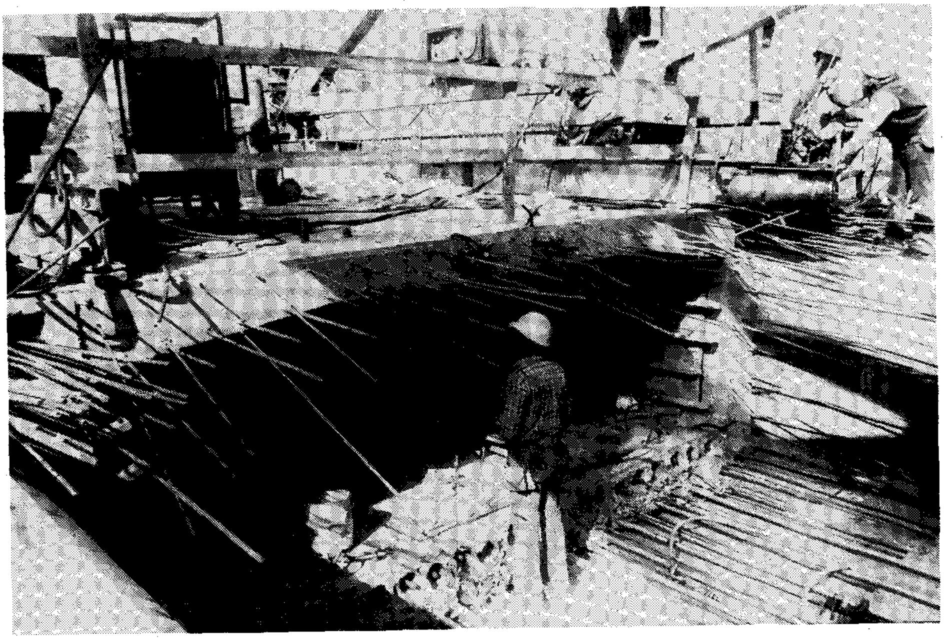


Fig. 14. Construction of the Parrots Ferry Bridge in California, using 0.6-in. (15 mm) diameter strand tendons and threadbar tendons.

tendon installation in the top slab of the Houston Ship Channel Bridge.

San Diego River Bridge

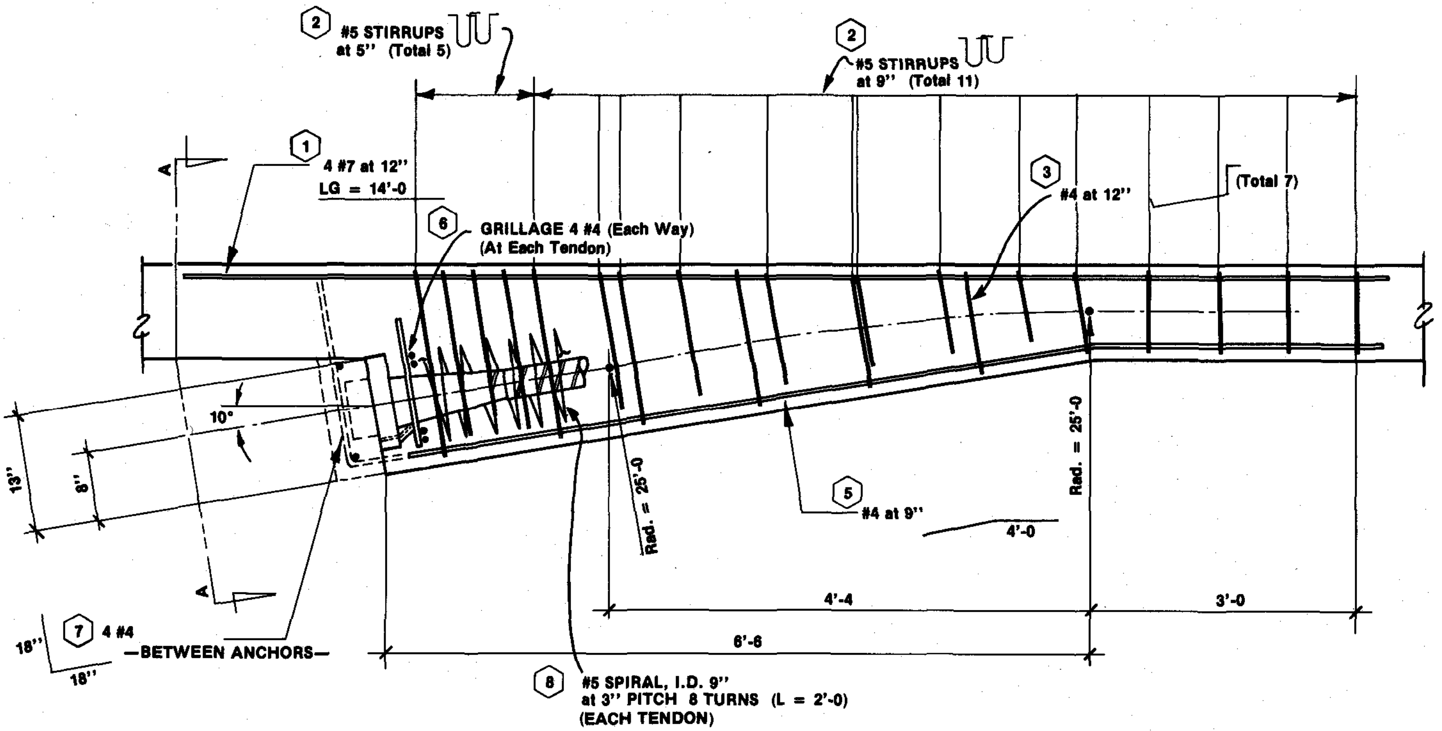
The San Diego River Bridge is a structure of 6 spans ranging from 157 ft 6 in. to 185 ft (48 to 56 m). The bridge was cast in place on falsework in segments of 2¼ spans, 2 spans, and 1¾ spans. Continuous web tendons of sufficient capacity were used to carry the bridge dead load and to permit movement of forms and falsework to the following segment. The remainder of the longitudinal post-tensioning was installed as shown in Fig. 17.

The dead ends utilized bond type anchorages and the stressing ends were anchored with confinement anchorages in build-outs using the details shown in Fig. 16. Fig. 18 presents a view of the completed build-outs after stressing of the tendons. This type of tendon installation takes most of the longitudinal post-tensioning operation (the part in the top and bottom slabs) off of the critical construction path.

Keys Bridges

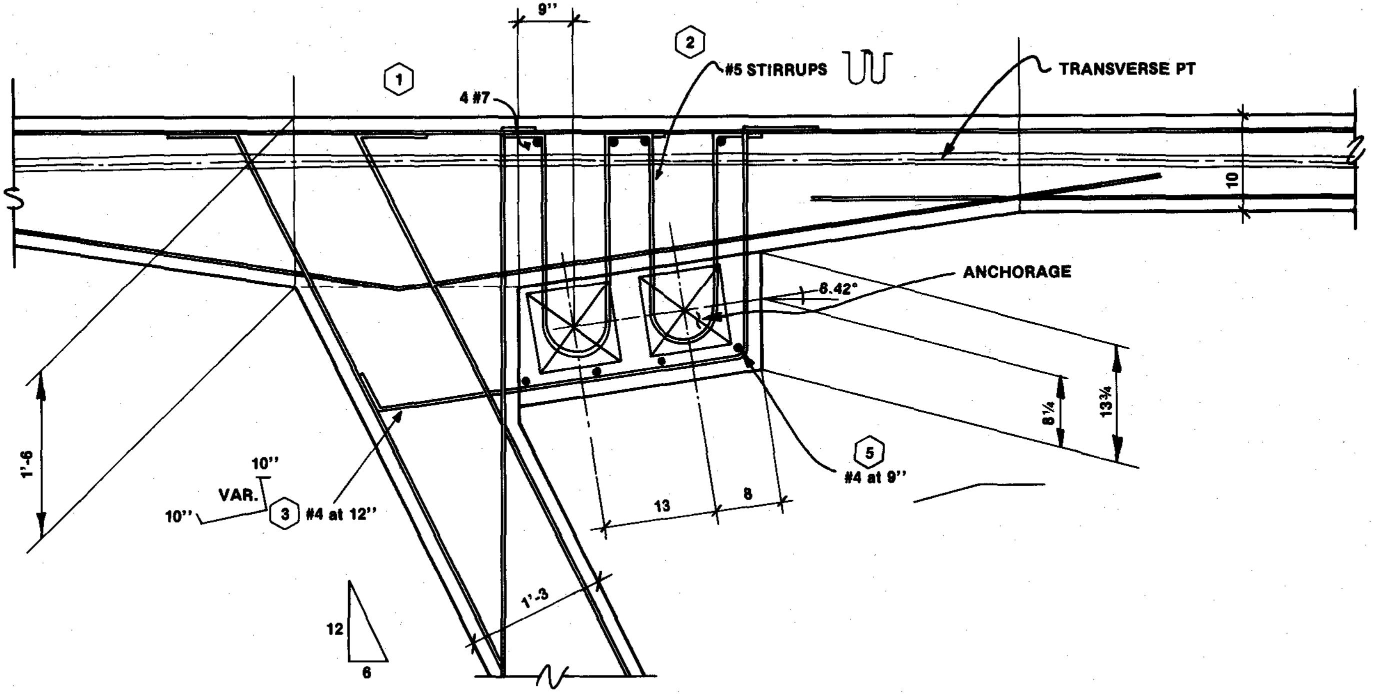
The so-called "unbonded tendons" used for the Keys Bridges in Florida (shown in Fig. 19) are actually grouted or bonded to the protective plastic pipe along their full length. For this reason, the behavior of these tendons at very high loadings would be somewhat different than the unbonded greased and plastic sheathed tendons that are widely used in buildings. The reduced web thickness permitted by the use of tendons in the inside of the box contributed significantly to the economy of these shorter span bridges. Low relaxation steel was specified for the Keys Bridges with economic benefits as discussed in the following section.

Fig. 15. Tendon installation in the top slab of the Houston Ship Channel Bridge near Houston, Texas.



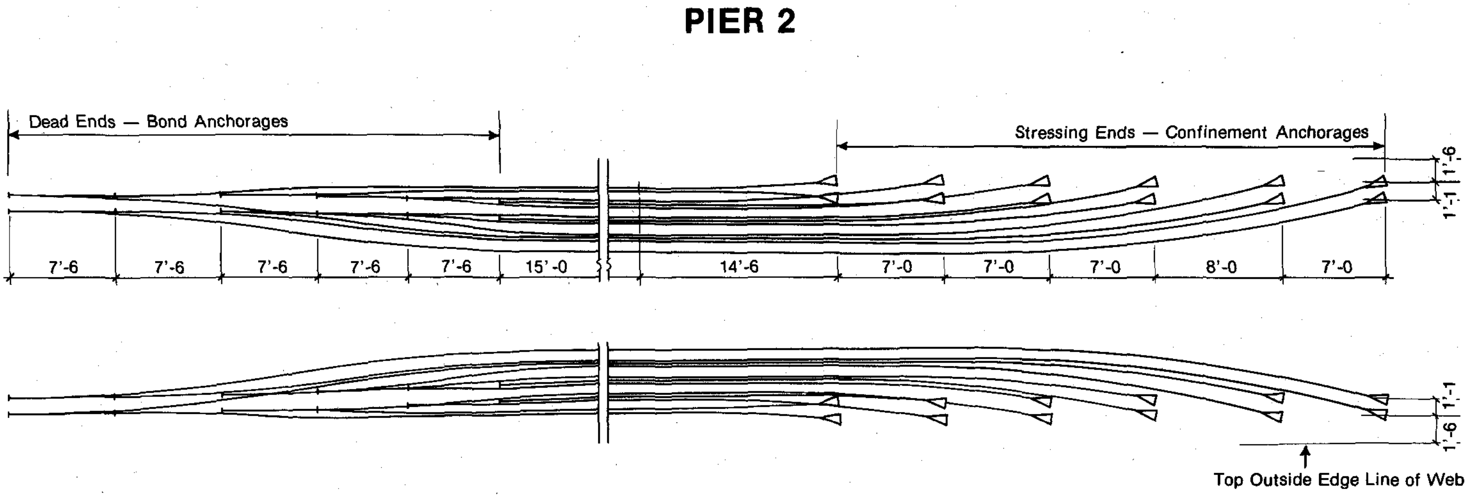
TOP SLAB BLOCKOUT

Fig. 16. Build-out details for stressing ends of longitudinal slab tendons in San Diego River Bridge, California. See Fig. 17 for longitudinal view of top slab tendons.



SECTION A—A

Fig. 16 (cont.). Build-out details for stressing ends of longitudinal slab tendons in San Diego River Bridge, California. See Fig. 17 for longitudinal view of top slab tendons.



LONGITUDINAL TOP SLAB TENDONS
SAN DIEGO RIVER BRIDGE

Fig. 17. Longitudinal post-tensioning installaton in top slab of San Diego River Bridge, California. See Fig. 16 *for detailed view of the top slab blockout and cross section.*

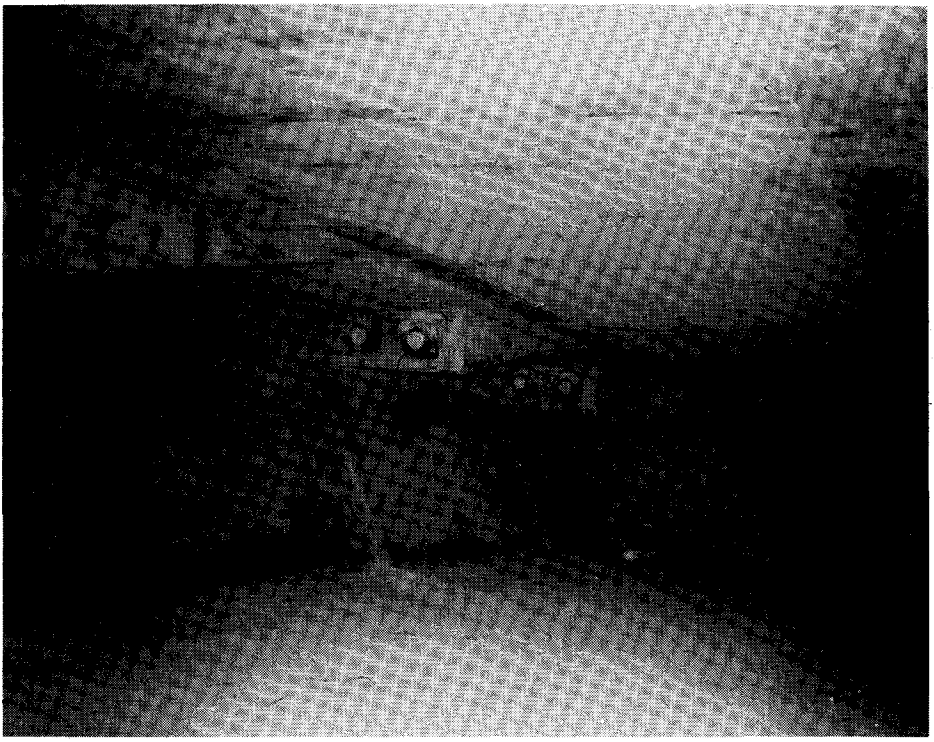


Fig. 18. Build-outs at stressing ends of longitudinal deck slab tendons, San Diego River Bridge, California.

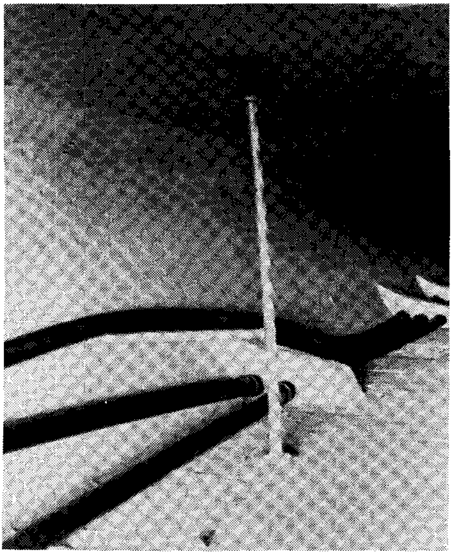


Fig. 19. Longitudinal tendons within box girder cells, Keys Bridges, Florida.

LOW RELAXATION STEEL

Post-tensioning tendons for segmental bridges require the use of very substantial amounts of 0.5-in. (13 mm) or 0.6-in. (15 mm) diameter strand. The specification of low relaxation steel for major bridges is becoming widespread due to the related economic and detailing advantages. Prestress losses due to steel relaxation in low relaxation tendons are typically about 20 to 25 percent of the steel relaxation losses for stress relieved tendons. This translates into a final stress advantage of 10,000 to 15,000 psi (69 to 103 MPa) for low relaxation tendons (5 to 8 percent).

In addition, the higher minimum yield stress of low relaxation material ($0.90 f_s'$ as opposed to $0.85 f_s'$ for stress relieved steel) has caused some agen-

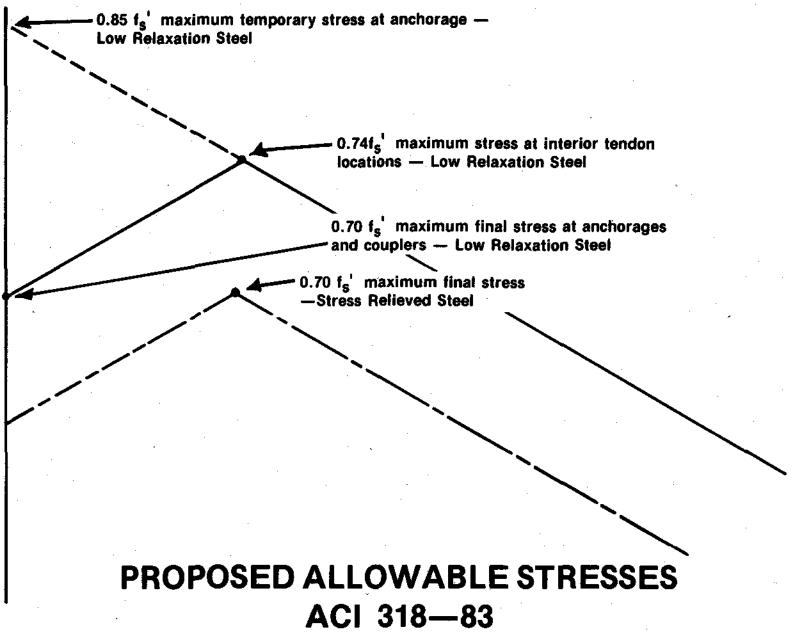


Fig. 20. Proposed ACI 318-83 code stress limitations for stress-relieved and low relaxation tendon material.

cies to permit higher initial tendon stresses for low relaxation steel. For example, as illustrated in Fig. 20, the 1983 ACI 318 Building Code will permit a maximum stress after anchorage of 0.74 f_s' with stress at anchorages and couplers limited to 0.70 f_s'. Although this type of initial stress diagram has been permitted for stress relieved tendons by many states for some time, use of a higher initial stress level for low relaxation material further increases the economic advantage.

The combination of reduced losses and higher initial stress level for low relaxation tendons could result in a reduction of 10 percent or more in the amount of tendon material and/or the number of tendons. In addition to the economic advantage, this reduction is obviously helpful in reducing the congestion of reinforcement in segmental bridges.

CLOSING COMMENTS

Over the past 10 years, the detailing and installation of post-tensioning materials in bridges has evolved from a relatively simple procedure based on bearing plate anchorages and full length pull-through tendons in webs to a much more complex mix of types, tendon materials, and anchorage types. The AASHTO Specifications for anchorage bearing stresses are obviously no longer sufficient to cover the anchorage details that have been developed in North America during this period. Each of the post-tensioning companies that have been involved in segmental bridge work offers a somewhat different mix of anchorage details to utilize their systems to the fullest advantage. In view of this, it would appear to be prudent to develop design drawings and special construction provisions with enough flexibility to permit the post-tensioning subcontractor to finalize detailing with optimum use of his system.

The post-tensioning industry has had a major role in the development of long-span concrete bridge construction in North America. Continued development in this field appears to be linked to the continued growth and development of the entire prestressed concrete industry. Contractual arrangements which, at the same time, minimize the financial involvement of post-tensioning companies in a project and involve substantial liability exposure (for example providing anchorage hardware only for a project) are not attractive and do not permit investment in development of improvements in post-tensioning technology. If reasonable economic incentives are available, the next 10 years should see continued development of the construction technology and economy of long-span post-tensioned concrete bridges.

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3. Leonhardt, F., *Prestressed Concrete Design and Construction,* Second Edition, Wilhelm Ernst & Son, Berlin-Munich, 1964.

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NOTE: Discussion of this paper is invited. Please submit your discussion to PCI Headquarters by July 1, 1983.