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MaineDOT

Transportation Research Division

Technical Report 13-02

Post-Tensioned Carbon Fiber Composite Cable (CFCC), Little Pond Bridge, Route 302, Fryeburg, Maine

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Introduction

Corrosion of reinforcing steel in concrete has been a constant and expensive maintenance problem which is exacerbated by Maine's coastal environment, harsh winters, and the use of chlorides on the roads and bridges. Carbon fiber products are increasingly being used in many applications to replace steel in structures. Carbon fiber can be used as reinforcing in concrete slabs. Carbon reinforced polymer (CFRP) is non-corrosive and can be made into rigid bar and used as reinforcement. It is light in weight, strong, non-magnetic, and non-corrosive and also has a low thermal linear expansion coefficient. Carbon Fiber Composite Cable (CFCC) is a cable made with carbon fiber and polymer composite. As a pre-stressing or post tensioning strand it has relaxation properties very similar to that of steel. This material could prove to be a very good tool in our battle again corrosion in bridges.

The Maine DOT Bridge Program decided to utilize CFCC for the transverse post tensioning of the voided slabs on the Little Pond Bridge, in the town of Fryeburg Maine. The project was designed to utilize four galvanized steel tendons in a conventional pot-tensioned configuration. The opportunity to use CFCC arose after this bid process. At the there was only one company that had developed a suitable method for post tensioning pre-cast voided slab bridge beams using CFCC. That company, Tokyo Rope Mfg. Co., LTD is not the only manufacturer of CFCC, however their method for post-tensioning CFCC uses the same equipment that fabricators and contractors normally employ to tension conventional threaded bar. A proprietary method has been developed of tensioning the cable that requires minimal specialized equipment. The technique works by splicing a section of steel onto the CFFC. Post tensioning of voided slabs and box beams can be done with the same conventional tools normally used. This could enable contractors to bid projects using this material without renting or purchasing expensive specialized equipment. The change to CFCC tendons required some modifications to the project plans. In addition five tendons were used rather than four.

Carbon fiber reinforcing steel (CFRP) was not used in the concrete slabs on the project due to unavailability and cost; CFCC was only used as post-tensioned tendons. CFRP appears to have an advantage over some of the composite reinforcement materials available in today's market in its ability to be shaped into multidirectional stirrups. CFCC can be fabricated into the same shapes and stirrups that as conventional reinforcing steel. This could prove beneficial in highly corrosive areas on bridges such as curbs, transition barriers and pier columns. If CFRP were more available at a competitive price, the potential uses would be broadened.

Project Location

The bridge chosen for this installation is the Little Pond Bridge, on Route 302, in Fryeburg. The project location is shown on the map.

Figure 1. Location Map

Typical Sections

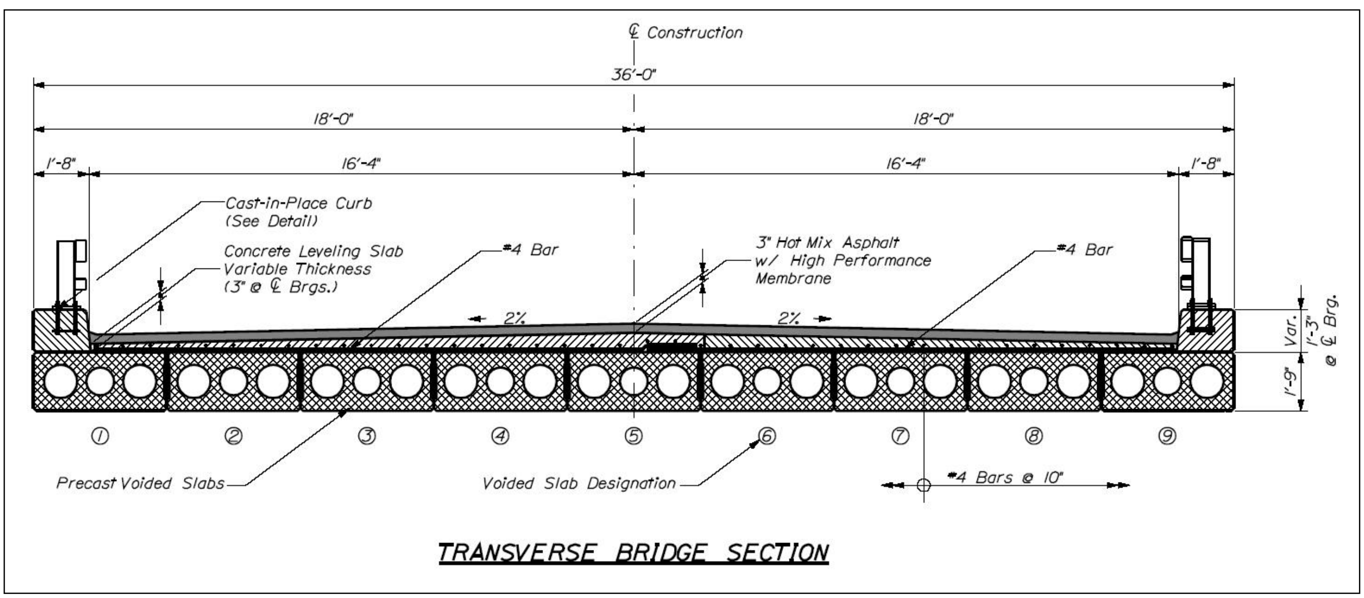


Figure 2.

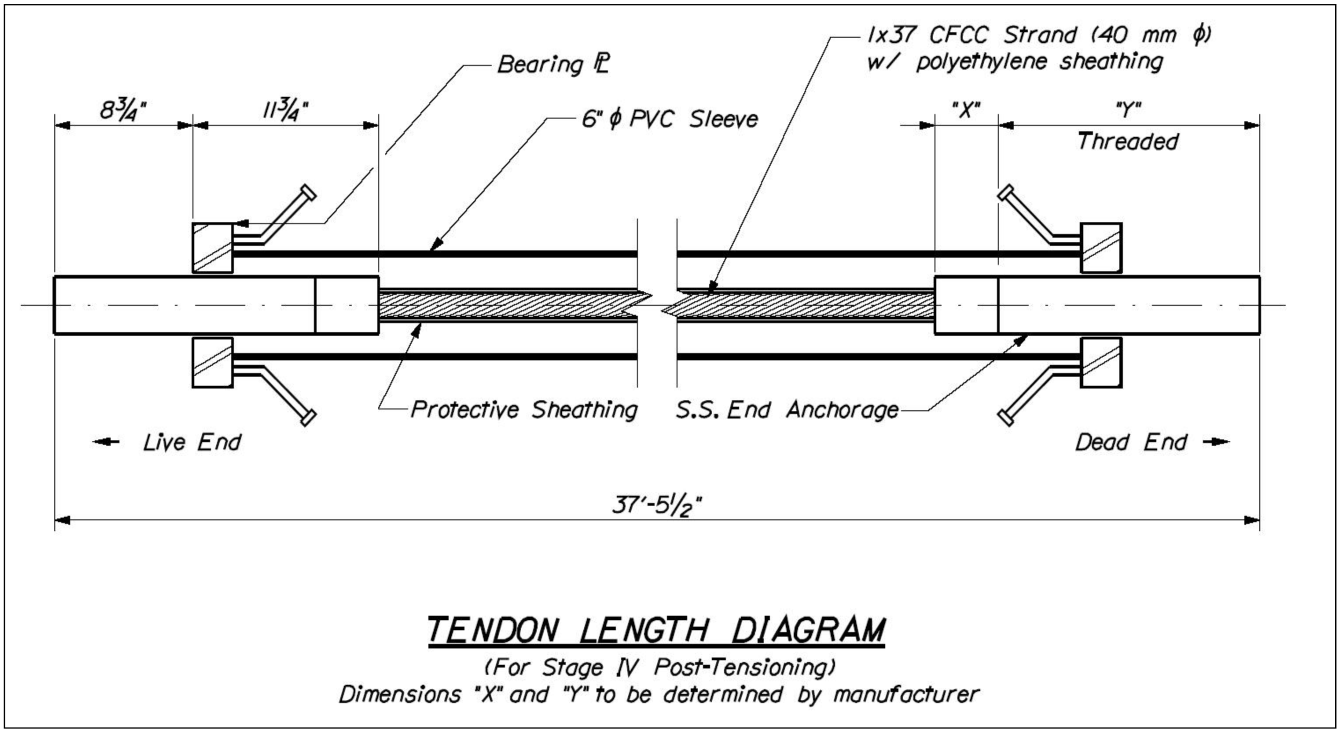


Figure 3.

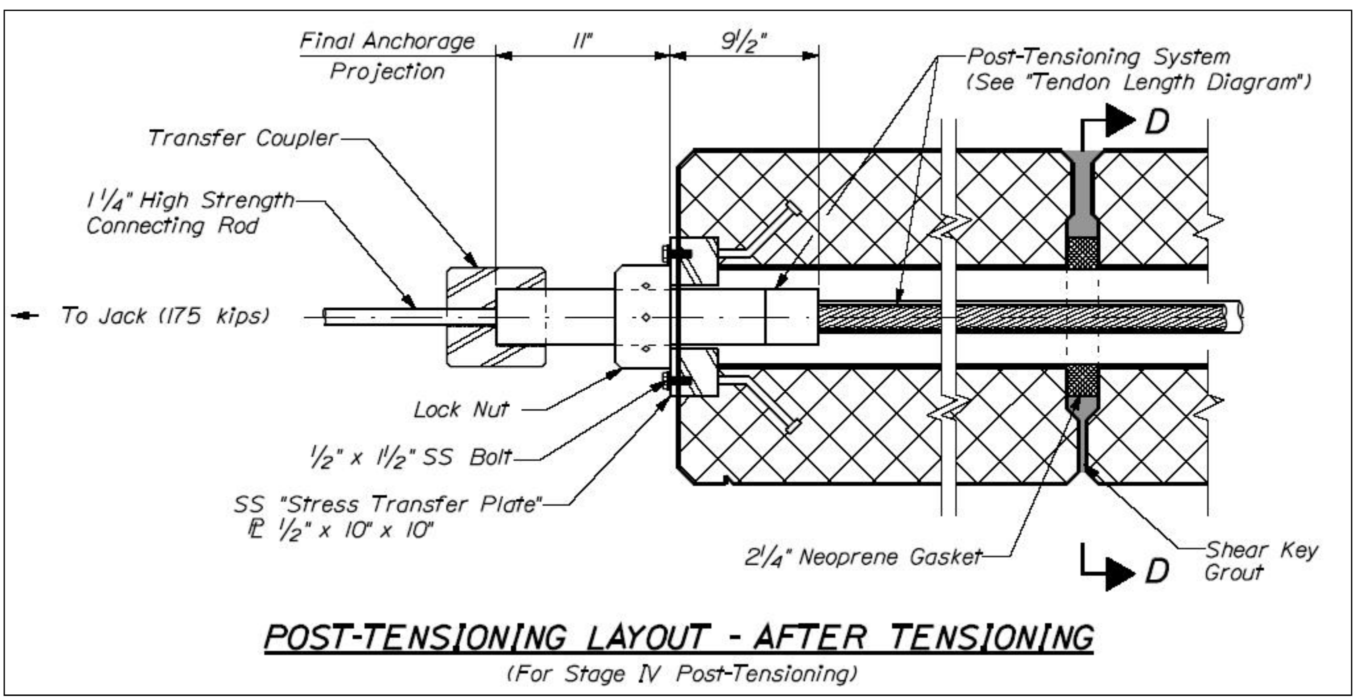


Figure 4.

Construction

The CFCC cable was 40 mm in diameter which is considerably larger that the largest steel cable normally available. Research done at the Lawrence Technological University indicates that much higher post-tensioning forces are needed to eliminate differential movements between slabs and joint crack formation. [1] It was decided to change the post-tensioning design for this bridge based on the higher forces. The design change called for increased jacking pressure as compared to conventional steel post-tensioning slab systems, from 44 kips to 175 kips. Again this is due to the particular design for the between slab pressures, which is intended to reduce future pavement cracking between the precast slabs, that has been observed in some states. The design change also increased the number of post-tensioning strands from 4 to 5. Nevertheless, the MaineDOT uses a bridge design that incorporates a reinforced deck slab to eliminate between-slab cracking.

There were no significant problems with construction of this project. It proceeded in a comparable fashion to conventional post-tensioning systems, The CFCC did, however, require additional labor in placing the protective sheathing. In addition, extra care was required during cable handling, in order to prevent damage to the carbon strands, which can be subject to abrasion. A plastic sheet was laid down whenever the cable was laid out on the concrete deck, Special precautions also were taken whenever the coils of CFCC were lifted or moved. This extra care leads to increased risk during construction. Extra care needs to be observed by the contractor.

Costs

The final cost of this demonstration project was roughly $860,300. The use of 40 mm diameter CFCC cables combined with the re-design of post-tensioning forces increased the cost of the bridge by about 12% over the original design, which called for conventional 0.6 inch diameter greased & sheathed steel tendons. As noted above. there are some differences that were considered when doing a cost comparison. The CFCC tendons were larger than the steel cables that MaineDOT normally uses on post-tensioned slab bridges. Another difference is that the tensioning force was 175 kips rather than the 44 kips that would have been used on steel tendons. The increased tendon size and tensioning force also caused an increase in anchorage hardware costs. Additional costs were incurred to redesign anchorage details, slab voids, and pre-casting changes, as well as contractor training. These differences, in addition to the increased material cost for CFCC, help explain the increased final in-place cost of the structure. Presumably if CFCC were used more frequently in the market, then cost efficiencies would reduce the cost for using it. This analysis cannot project the future of CFCC costs or utilization. The analysis is based on actual price quotes from the manufacturer. For this project the CFCC costs 24 times more than galvanized steel.

This leads to several questions: If smaller CFCC tendons and the original post-tensioning design had been used on the Fryeburg bridge what would be the estimated cost of the bridge? What would be the one-for-one replacement cost for the same size structure? What is the cost increase on a square foot basis? In order to answer these questions it is necessary to develop an alternate construction scenario using the Fryeburg bridge structural dimensions including the deck dimensions of 45.4 feet by 36 feet.

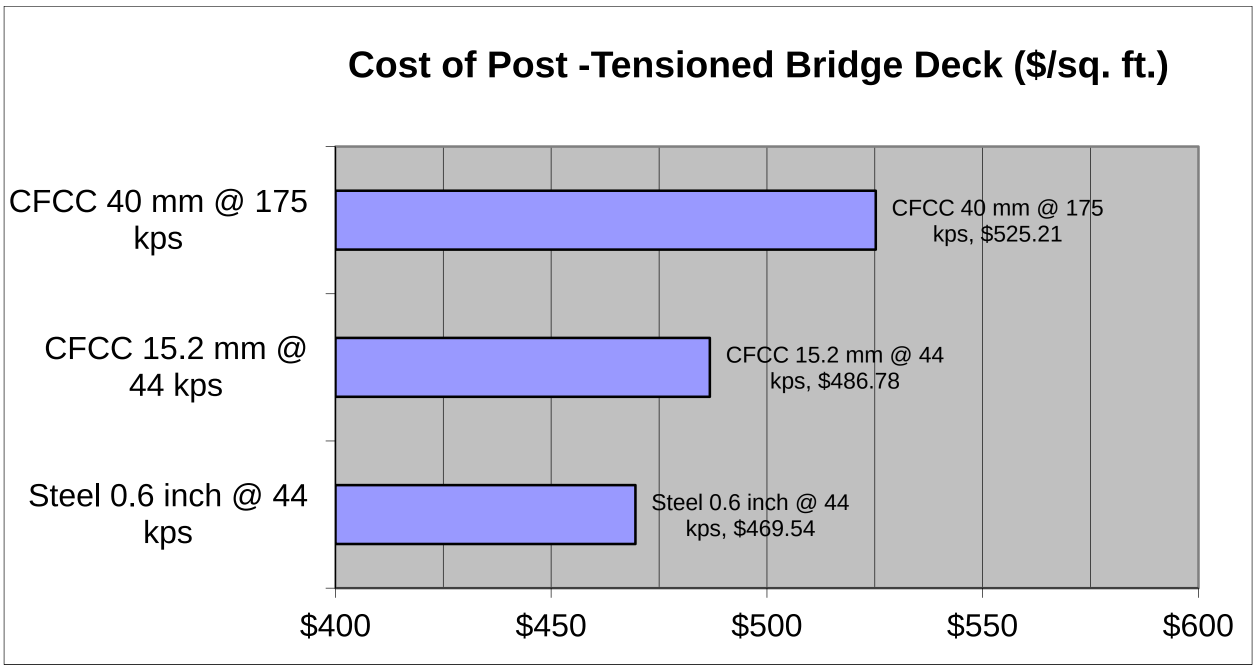
This analysis shows that smaller (15.2 mm) CFCC tendons would result in a cost of about $797,000 for a comparable bridge. The cost for specialized stainless steel hardware was prorated on a size basis. The post-tensioning and specialized engineering costs were prorated as well for the alternative scenarios.

[1] Grace – PCI Journal Summer 2011

The table below shows the results of the analysis.

Component	Cross-section Diameter	Tensioning Force	Cost per Sq. ft. of Deck Area	Percentage increase
4 - Galvanized, Greased Sheathed Steel Strands	0.6 inch (15.2 mm)	44 kps	$469.54	
4 - Sheathed CFCC Strands	15.2 mm	44 kps	$486.78	3.7%
5 - Sheathed CFCC Strands	40 mm	175 kps	$525.21	11.9%

The chart below shows the same data in graphical form.



Conclusions

Post-tensioning re-design to higher forces and utilization of CFCC strands increased the bridge cost by 12%.

A one-to-one comparison of steel strand and CFCC strand for this bridge increased the cost by 4%.

The use of CFCC in this type of bridge application may have limited application for MaineDOT for the following reasons. One of the problems that bridge designers are seeking to solve by using larger diameter CFCC strands that are tensioned to higher limits, has partially been addressed by other design changes already in use by MaineDOT. That is, the problem of deck pavement cracking at the longitudinal slab joints has been addressed relatively recently in a different way by design changes to the joint shear key. In addition to that design change, MaineDOT has adopted the practice of placing a reinforced concrete leveling slab on top of the deck slabs. This has minimized our risk of long term issues at the joints.

The other problem that CFCC seeks to solve, that of corrosion of cables remains a potential risk. The magnitude of that problem cannot be known until the deck shows signs of deterioration. The durability and future performance of the CFCC system will determine if the increased cost of CFCC justifies the additional cost. Some studies in the U.S. research literature have indicated that CFCC is a favorable alternative when compared on a life cycle cost basis. It is beyond the scope of this demonstration project to do a life cycle cost analysis. The future maintenance costs are not known with certainty. If CFCC were more widely used it might reduce the costs. The project furthered the Department's understanding of carbon fiber applications. The experience gained from using CFCC for slab tendons, and advancing our familiarity with the product, could aid towards further use CFCC as a tool against corrosion. It is hoped that through gaining this experience and developing the technology, the public will benefit from longer lasting bridges, requiring less maintenance and favorable life cycle cost. The bridge will be periodically inspected to observe future performance.

Recommendations

MaineDOT needs to continue to closely monitor these types of bridges to determine if our current design and construction methods are adequate in minimizing or eliminating longitudinal joint failures. The use of CFCC strands on a one-to-one comparison for this bridge resulted in a 4% cost increase. The majority of this cost increase in the CFCC strand. However, changes in details/methods at the anchorage should be investigated to minimize the cost. The use of CFCC strands for post-tensioning is a viable option and should be considered for those bridges that may require a lower risk in regards to potential joint failures.

Photos

Figure 5. Protective Sheathing and Proprietary Steel End Anchorage System (See Figure 3. for Details)

Figure 6. Section of CFCC

Figure 7. Sliding Sheathed CFCC into Ducts in Precast Slabs

Figure 8. Center-hole Hydraulic Jack & Jack Chair

Figure 9. End Anchorage System with Lock Nut

Figure 10. End Anchorage System with Transfer Coupler (See Figure 4. for Details)

Figure 11. Upstream End Appurtenances

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SPECIAL PROVISION
FOR
CFCC TRANSVERSE POST-TENSIONING

a. Description. Furnish and fabricate post-tensioning accessories. Store and install the CFCC post-tensioning tendons as detailed on the plans and specified Here in.

b. Materials. The Contractor is responsible for furnishing all items in section 2 below.

1. CFCC post-tensioning tendons. The Maine DOT will provide the Carbon Fiber Composite Cables (CFCC) detailed in the plans to the Contractor for installation.

2. Post-tensioning accessories.

   A. <u>Polyethylene Sheathing</u>: Provide thin tube split polyethylene sheathing conforming to ASTM D 4313.

   B. <u>Sheathing Wrap</u>: Provide 2 inch diameter 1/2 inch thick wrap outside diameter spiral wrapping model T50R by Panduit Inc, or approved equal.

   C. <u>Gasket:</u> Provide 10 inch diameter with 7 inch diameter hole, and 2-1/4 inch thick closed cell neoprene gasket Everlastic Type 1060, NN3 by Williams Products Inc, or approved equal.

   D. <u>Stress Transfer Plate:</u> Provide a 1/2 inch x 10 inch x 10 inch stainless steel plate with 1/2 inch diameter high-strength stainless steel bolts and lock washers conforming to ASTM A 276, Type 304, hot finished, condition S.

   D. <u>Protective Cover</u>: Use a seamless 8 inch inner diameter, stainless steel pipe and 1/8” end plate Schedule 40S conforming to ASTM A 312, Grade TP304.

   F. <u>Connecting Rod:</u> Provide a high-strength (minimum 150 ksi) 1-1/4 inch diameter connecting rod conforming to ASTM A 722, Type 1 with extra fine threads to match transfer couplers provided by Tokyo Rope

   G. <u>Stressing Chair</u>: Use a stressing chair compatible with the CFCC post-tensioning system capable of pulling the tendon to the force shown on the plans.

c. Construction. Pick up the CFCC post-tensioning tendons, Lock nuts, and reusable transfer couplers from Maine DOT. Contact Don McKenna at (207) 462-4474 for pick up.

See the Notes on plans for “Carbon Fiber Composite Cable” for general handling and care instructions. In addition, store the CFCC post-tensioning cable indoors, free from dust and protected from damage, deformation, or deterioration. Avoid dropping tools and other hard objects on the CFCC. Prevent the CFCC from coming into contact with hot objects and avoid applying shearing forces to the cables during installation.

Do not hoist CFCC cables by holding the base of the socket alone. Always support the CFCC by the anchorage system so that the CFCC will not be broken or experience damaging forces. See Figure 1 for the proper way to support the CFCC.

Avoid pulling the cable against steel edges during installation as that may cause damage to the cable. Do not step on the cables at any time during storage and installation. If necessary to bend the CFCC during work other than tensioning, do not go below the minimum bending radius specified by the manufacturer.

1. Unpacking the CFCC (Figure 2). Lift and carry the package containing the cables using slings and crane or a fork-lift. Remove the top panel of the wooden box. Remove the side panels of the wooden box. Using the slings and crane, pick up the frame of the wooden lattice on which the cables are wound. Take caution not to damage the CFCC when removing the panels of the wooden box.

2. Spreading/uncoiling the CFCC (Figure 3). Spread CFCC just before cable insertion. Before spreading/uncoiling and dragging CFCC, spread a vinyl sheet on the ground to avoid scratches and stains to the CFCC. Ensure that the vinyl sheet is long enough to protect the entire length of the cable. Put the frame on the turn-table using the slings and crane. Spread the CFCC using the following sequence:

A. Grip the anchoring socket (Operator A).

B. Unfasten or cut off the strings (Operator B) that tighten the anchoring socket, while holding the frame from rotating (Operator C).

C. Slowly uncoil the transverse cables (Operator A and B), while controlling the rotating of the frame and the tension in the unwinding (Operator C).

D. Use as many operators as necessary (Operator D + others as necessary) to support the middle of the cable at the maximum spacing recommended by the manufacturer.

E. Unfasten or cut the strings that tighten the other socket (Operator C.)

The anchoring socket marked as #1 with an arrow should be unfastened at first and that cable spread out. After spreading out the first cable, cable #2 should be unfastened and spread out. Follow this sequence for the remainder of the cables.

3. Arranging the CFCC. Cover the threaded sections of the sockets that are used to secure the transverse cables during the pulling operation. Place the cables in an easy to reach place.

4. Inserting the CFCC (Figure 4). Insert the CFCC using the following sequence:

A. Install a winch at the outlet side of the bridge deck, take out the wire, and pass it through the duct.

B. Attach the insertion coupler to the socket at end of the transverse cable.

C. Connect the point end of the winch wire to the end of the insertion coupler.

D. Slowly pull the transverse cable through the beams by winding the wire rope with the winch.

E. When the transverse cable is inserted up to the specified position shown in the plans, screw the supplied locknut to the specified position at the insertion side of the bridge deck and tighten it to the bearing plate.

F. When the cable is pulled out, remove the insertion couple from the end of the cable and tighten the locknut to the bearing plate.

Pay attention so that the CFCC or thread of the socket will not be damaged by the bearing plates or edges of the conduit during insertion.

5. Tensioning the transverse cables (Figure 5). Pull the cables from one end of the CFCC. Lock the nut tight on the dead end to the stress transfer plate. Pull the cables from the live end using a jack equipped with a whirl-stop to prevent the untwisting of the cables during tensioning. Check that the axes of the bearing plate, socket, and jack are aligned. Exercise care so that the thread of the anchorages will not be rubbed by the inside of the duct or bearing plate. Measure the elongation on the live end and insure that the required initial post tensioning force has been achieved. Lock the nut on the live end tight to the stress transfer plate and measure the elongation again to insure that the losses do not exceed that of

what is specified on the plans. Apply lithium grease to the exposed threads to prevent rusting and install the protective cover plate as detailed on the plans. Locally coat welded areas with two coats of color matching zinc rich primer.

d. Measurement and Payment. The completed work as described will be measured and paid for at the contract price using the following contract item (pay item):

Contract Item (Pay Item)	Pay Unit
Post Tensioning, CFCC (Structure No.)	Lump Sum

Post Tensioning, CFCC includes all of the transverse CFCC post-tensioning cables grouped and measured as a unit. Payment for **Post Tensioning, CFCC** constitutes full compensation for completing the work as described herein.

This work includes storage of the CFCC, furnishing and fabricating all post-tensioning accessories necessary for installation, and all labor, equipment, and materials necessary to complete the work as described.

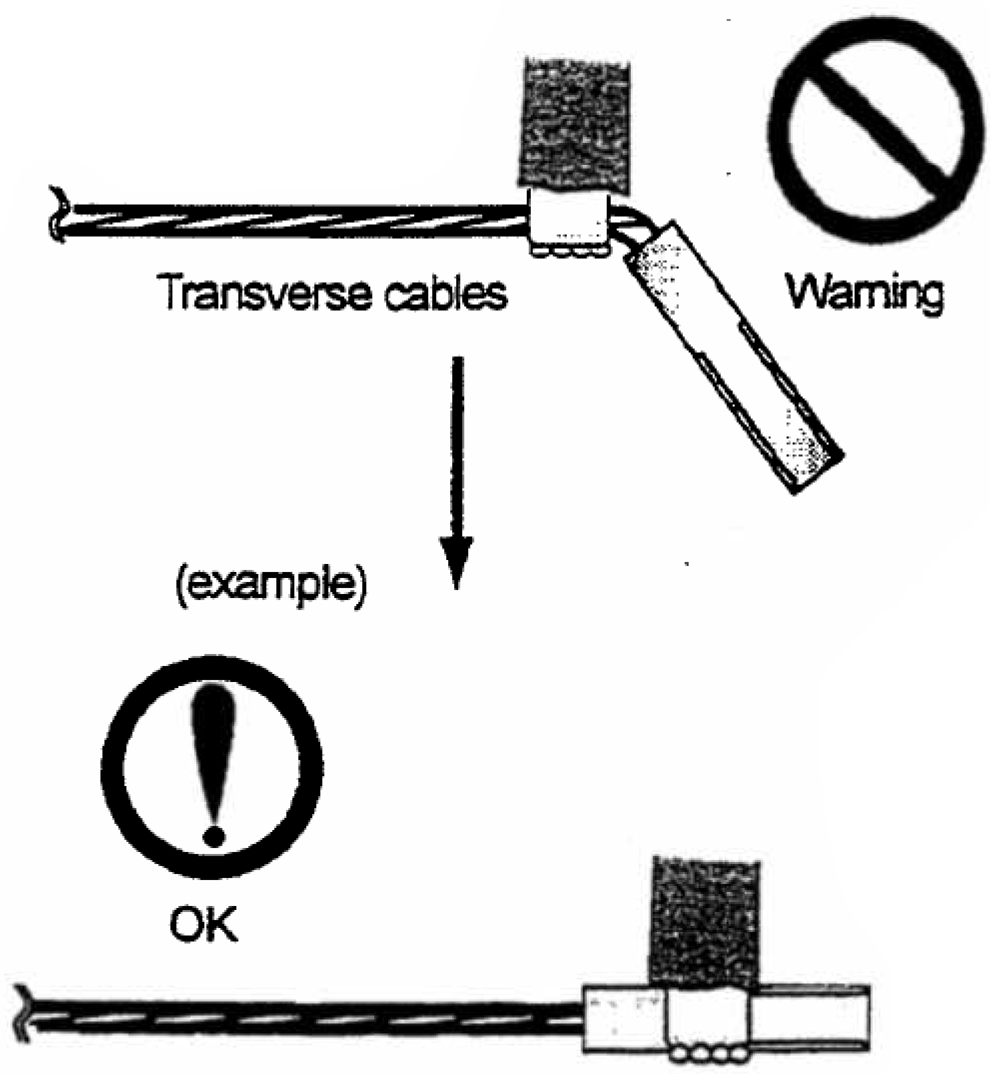


Figure 1 – Properly Supporting the CFCC

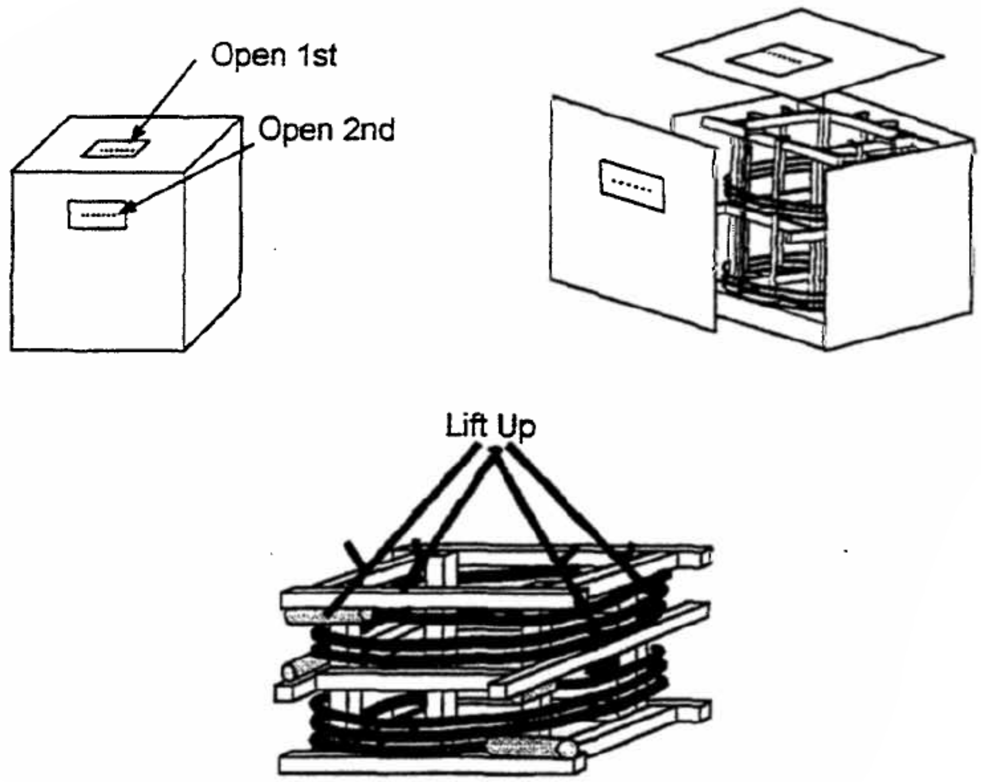


Figure 2 – Unpacking the CFCC

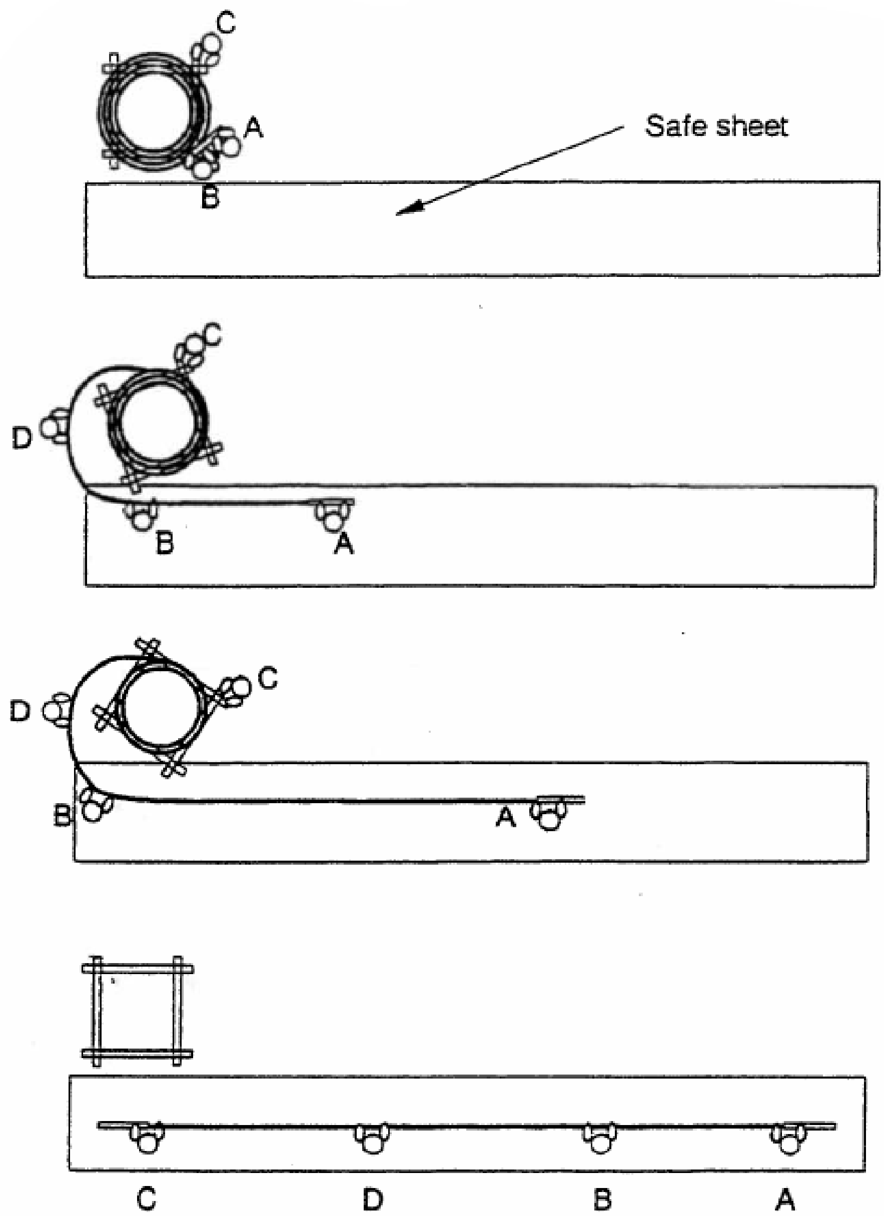


Figure 3 – Spreading/uncoiling the CFCC

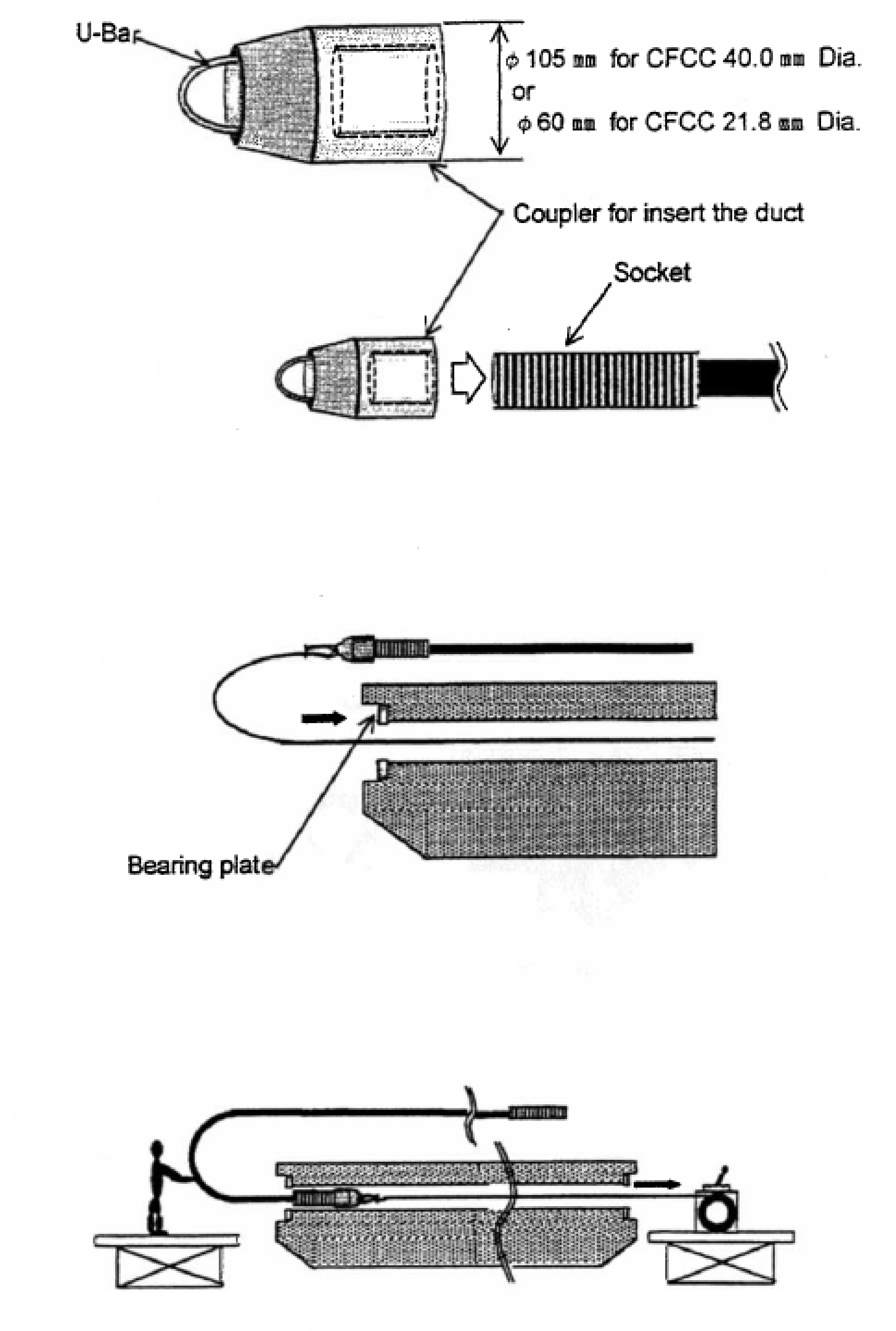
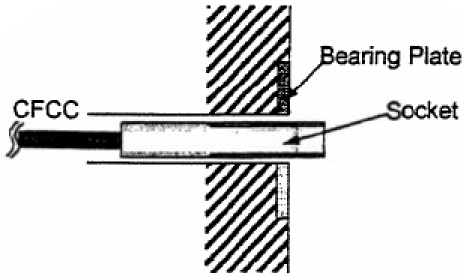
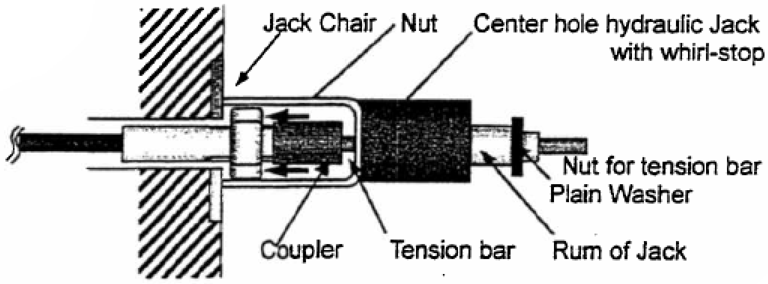


Figure 4 – Inserting the CFCC

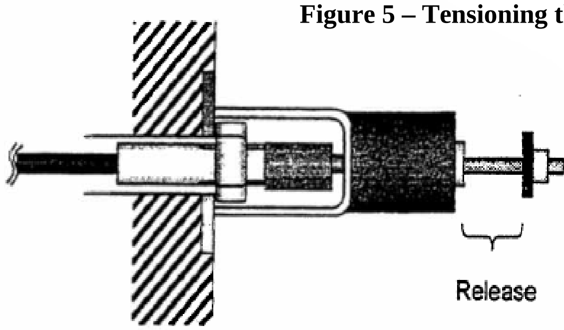


Tensioning



Releasing jack (Anchoring)

Figure 5 – Tensioning the CFCC



Remove the Jack