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Evaluation of Anchors for CFRP tendons

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UTC
R123

Technical Report Documentation Page

1. Report No. UTC R123	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Evaluation of Anchors for CFRP tendons	5. Report Date June 2005 6. Performing Organization Code
7. Author/s Khaled Soudki	8. Performing Organization Report No. **0000613 OTO133**
9. Performing Organization Name and Address Center for Infrastructure Engineering Studies/UTC program University of Missouri - Rolla 223 Engineering Research Lab Rolla, MO 65409	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTRS98-G-0021
12. Sponsoring Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration 400 7th Street, SW Washington, DC 20590-0001	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Carbon FRP (CFRP) reinforcement is a very promising alternative material in prestressed concrete structures. Acceptance of CFRP tendons in post-tensioned concrete applications is inhibited by the lack of a suitable anchor system to maintain the prestressing force in the reinforcement. The experimental data and experience on mechanical behavior of prestressing steel tendons and anchorages are abundant but cannot be used when developing FRP tendon-anchorage systems. A new anchor system was designed and developed at the University of Waterloo. In this project, anchors are fabricated based on the Waterloo design. The performance of the anchor system will be evaluated under short-term static loading to evaluate the anchorage efficiency for the CFRP tendons.

17. Key Words FRP tendons, Anchoring Systems	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. Of Pages	22. Price
unclassified	unclassified		

Form DOT F 1700.7 (8-72)

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ANCHOR SYSTEM FOR CFRP RODS

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ABSTRACT: An innovative wedge anchor system for different prestressing CFRP rods is developed. This anchor consists of an outer cylinder (barrel), a number of wedges, and a soft metal sleeve. Experimental and analytical studies of the system were conducted. It was found that the anchor was capable of carrying the ultimate tensile strength of the CFRP rods. Satisfactory testing using different presetting loads, geometric configurations, and rod sizes was then carried out. The anchor was tested with and without presetting load. No pre-setting was required. In addition, fatigue load tests were conducted on the anchor using different load ranges including the one recommended by the Post-Tensioning Institute (PTI).

INTRODUCTION

One of the challenging problems for the implementation of fiber reinforced polymer (FRP) reinforcements in prestressed concrete application is finding a suitable anchor (ACI 440, 2002). The conventional anchor system for prestressing steel cables cannot be used for FRP rod due to its weakness of in the lateral direction. Different failure modes of the rod-anchor system may occur before the ultimate tensile strength of the rod is reached. These modes include rod pull out, or low bond, and crushing of the rod inside the anchor (Al-Mayah et al. 2001).

Different anchor systems have been used for FRP rods including clamps, resin sleeves, resin potted, metal overlays, plugs and cones (spikes), and split wedges anchors (Erki and Rizkalla, 1993). The performance of some of these anchors was examined under monotonic (Nanni et al. 1996a) and short term sustained loads (Nanni et al. 1996b).

A novel wedge anchor system for CFRP rods has been developed at the University of Waterloo (Al-Mayah et al. 2003). The anchor consists of three components: copper sleeve, four stainless steel wedges, and stainless steel barrel, as shown in FIG. 1.

Anchor specifications are given in Table 1. The anchor was tested under monotonic and fatigue loading conditions.

Under monotonic loading, comprehensive test program has been carried out to measure the tensile load-displacement relationship of the anchor components. Two different carbon fiber reinforced polymer (CFRP) rod sizes were tested including Hughes No3 (9.4 mm diameter) and Hughes No2 (6.3 mm diameter). The anchor was capable of carrying the guaranteed tensile strength (300 ksi) of the rods. In addition, the fatigue life of the CFRP rod anchor system was measured for different tensile load ranges.

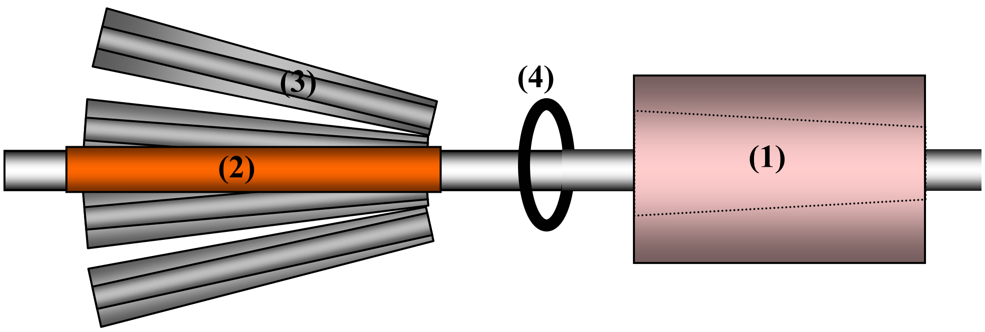
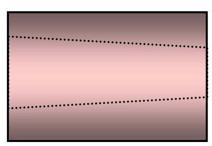
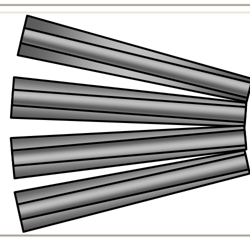
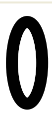


FIG. 1 Anchor Components

Table 1: Specification of Anchor Components

Part No. and Name	Shape	Material	Size (mm)
(1) Barrel		Stainless Steel	Length =70 Diameter = 45
(2) Sleeve		Copper	Length = 90 mm OD = 10.7 mm
3) Wedges		Stainless Steel	Length = 80 Largest OD = 24
4) Rubber Band		Rubber	

INSTALLATION PROCEDURE

After cleaning the wedges, sleeve, barrel and rod using acetone, a thin layer of lubricant (G-n Metal Assembly Paste) was applied to the outer surfaces of the wedges contacting the inner surface of the barrel to facilitate inserting the wedges into the barrel. To ensure a uniform distribution of the contact pressure on the rod, the wedges were arranged evenly around the sleeve.

Prior to tensile load application, the anchor was assembled by tapping the CFRP rod-sleeve-wedges combination into the barrel. In some tests where the effect of presetting was examined, a hydraulic jack was used to insert wedges into the barrel. FIG. 2 shows the presetting rig used to insert the wedges into the barrel. It was constructed from steel plates in a U-shape to facilitate installation and removal of the test anchor. At one end, a hydraulic jack was used to apply the presetting load with hardened steel fitting to ensure no load was applied to the sleeve or the rod. A pressure dial gage was used to monitor the applied load on the wedges.

The presetting rig was also used to disassemble the anchor for further use by pushing the wedges out of the barrel in a direction opposite to that for presetting.

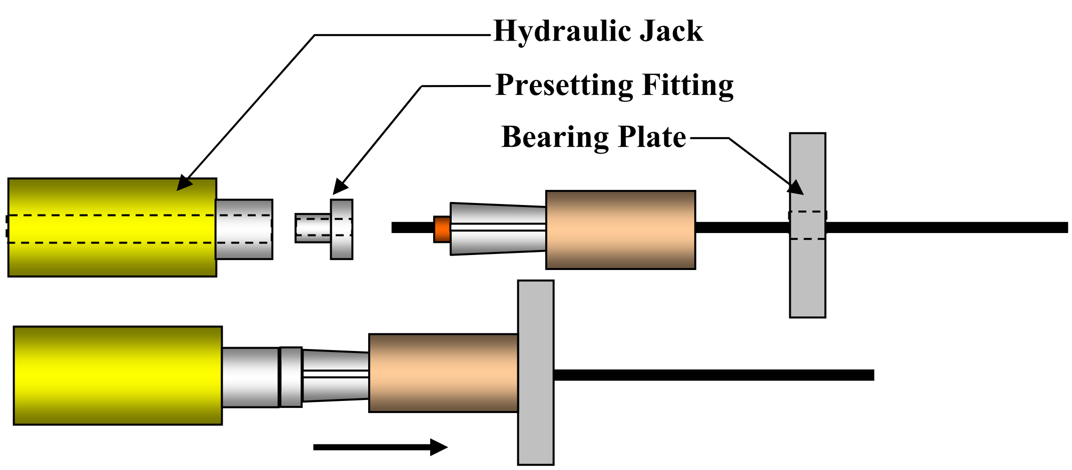


FIG. 2 a) Presetting of the anchor using hydraulic jack

At the other end of the rod, a clamp anchor was used. This anchor consisted of two grooved steel plates each 152 mm long x 51 mm wide x 25 mm thick. The clamping force was applied by tightening high strength 6x13 mm diameter bolts. An annealed aluminum sleeve 152 mm long was used to encase the rod. The inner diameter of the sleeve was drilled to fit the diameter of the rod (9.4 mm or 6.4 mm) and the outer diameter of the sleeve was 12.7 mm or 9.53 mm.

The assembly of the CFRP rod with its attached top and bottom anchors were mounted in the loading frame (FIG. 3) with an MTS servo controlled hydraulic system. A smaller housing (test rig) was built of two horizontal steel plates and four vertical steel bars to accommodate the test anchor together with the attached displacement transducer (LVDT). The test rig was attached to a load cell mounted to an MTS actuator. The test anchor was seated and centered between the two plates through a slit in the lower plate.

At the other end of the rod, the clamping anchor was supported by a steel bearing plate that was attached to the bottom cross head of the loading frame. This plate had a central hole at the end of a slot extending from the outer edge.

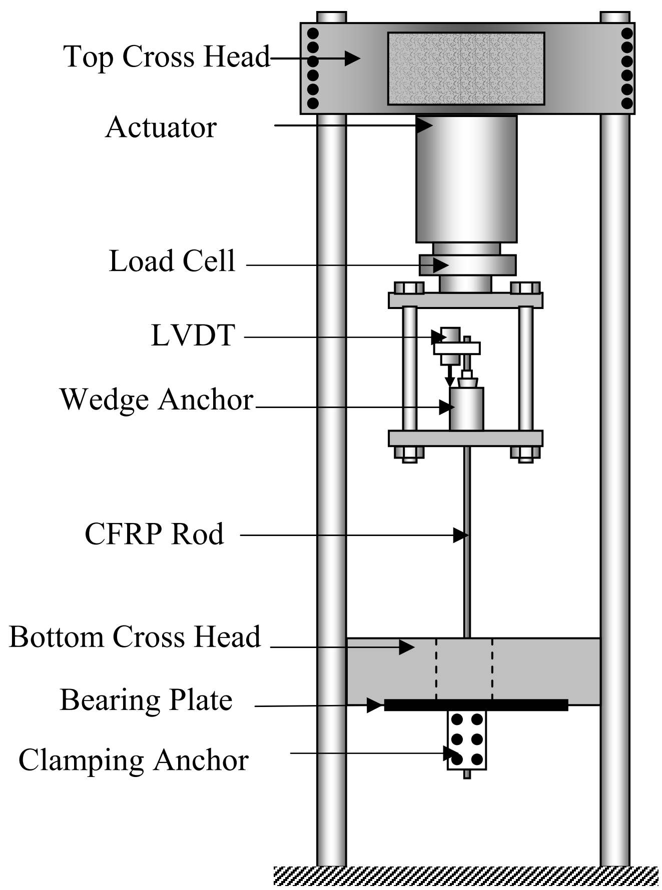


FIG. 3 Test Rig (Schematic)

One LVDT was attached to the rod to measure its slip relative to the barrel. Initially, a second LVDT was mounted on the sleeve to measure the displacement of the sleeve relative to the barrel. The latter was removed since rod, sleeve and wedges moved in unison. The load was monitored using a load cell (222.4 kN) attached to the top of the ram, between the jack and the test rig. The LVDT and the load cell were connected to a data acquisition system (Labview platform).

TEST RESULT AND DISCUSSION

In monotonic load tests, the tensile load (*T*) vs. displacement (*D*) of the rod was measured and plotted. It was noticed that the rod, sleeve and wedges moved together inside the barrel. The new anchor design aimed to shift the displacement from the most critical, susceptible and least controllable surface (rod-sleeve), to the controllable surface (wedge-barrel). The wedge-barrel contact surface could be lubricated, and/or the wedge could be seized to move during loading by a stopper at the end of the anchor. This was observed in some tests where the wedge were prevented from any movement by the bearing plate that supported the barrel during loading whereas the rod continued to carry load until it reached its ultimate tensile capacity.

FIG. 4 shows the typical load–displacement behavior of the anchor used with Hughes No 3 rod (9.4 mm in diameter) without applying presetting except of light hammering of the wedges. The performance of the anchor was compared to that of the guaranteed tensile strength of the rod (300 ksi).

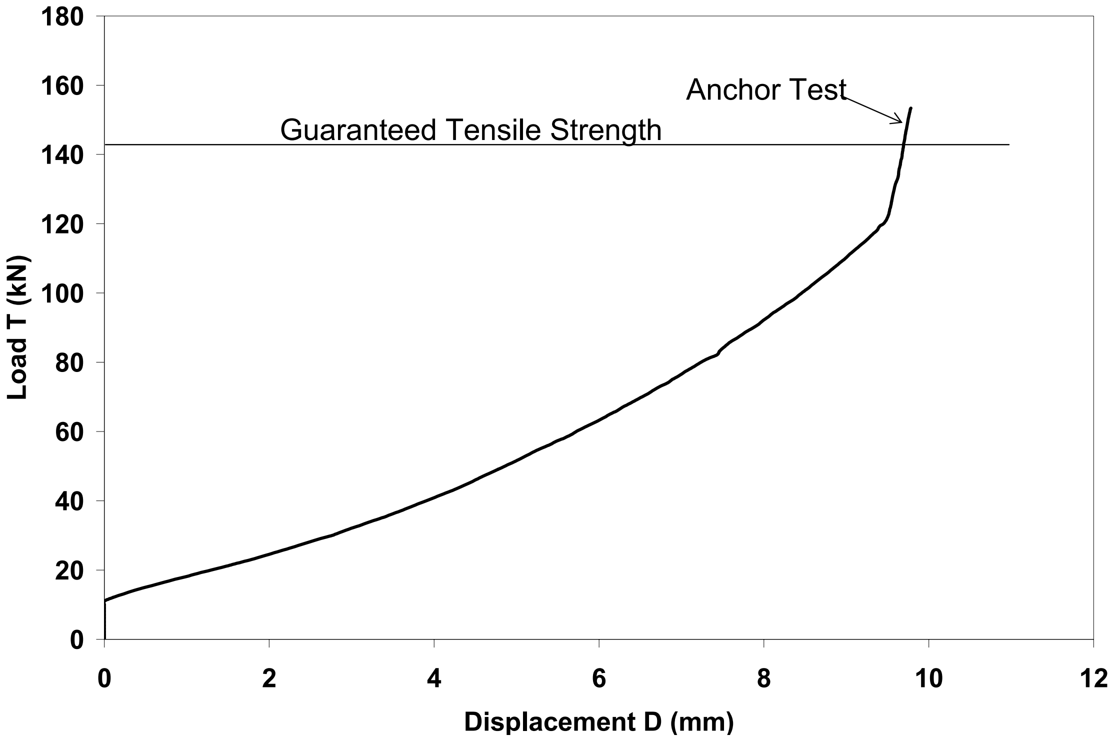


FIG. 4 Tensile Load-Displacement Relationship of Anchor with Hughes No3 Rod.

The effect of presetting on the load-displacement of the anchor was examined using a 110 kN presetting load and no presetting, as shown in FIG. 5. The displacement was not monitored for the whole test since the LVDT was removed to prevent its damage at failure as presented by doted lines. With presetting, slip was reduced significantly and only started when the tensile load reached around 85 kN. The rod continued to carry load until it fractured at a load level higher the guaranteed tensile strength. In this case, as the wedge moved inside the barrel, the contact pressure increased resulting in a higher grip. When no no-presetting load was applied, slip started at a load of 5 kN. As the wedge slipped into the barrel, the contact pressure and consequently shear stress increased at the rod-sleeve, and sleeve-wedges interfaces.

It is worth noting that although the wedges were slightly deformed along their length after tests, the anchor continued to function successfully indicating a good tolerance in the anchor design.

Eliminating presetting would be one of the attractions of using this anchor in the field, since it would be awkward to insert the wedges using the jack. However, self-seating of the anchor would result in lower prestressing load which is mainly dependent of the length of the CFRP rod between anchor points and becomes insignificant in case of beam lengths of 5 m or longer. Normally, to overcome the anchor seating loss, the rod is slightly overstressed beyond the desired load.

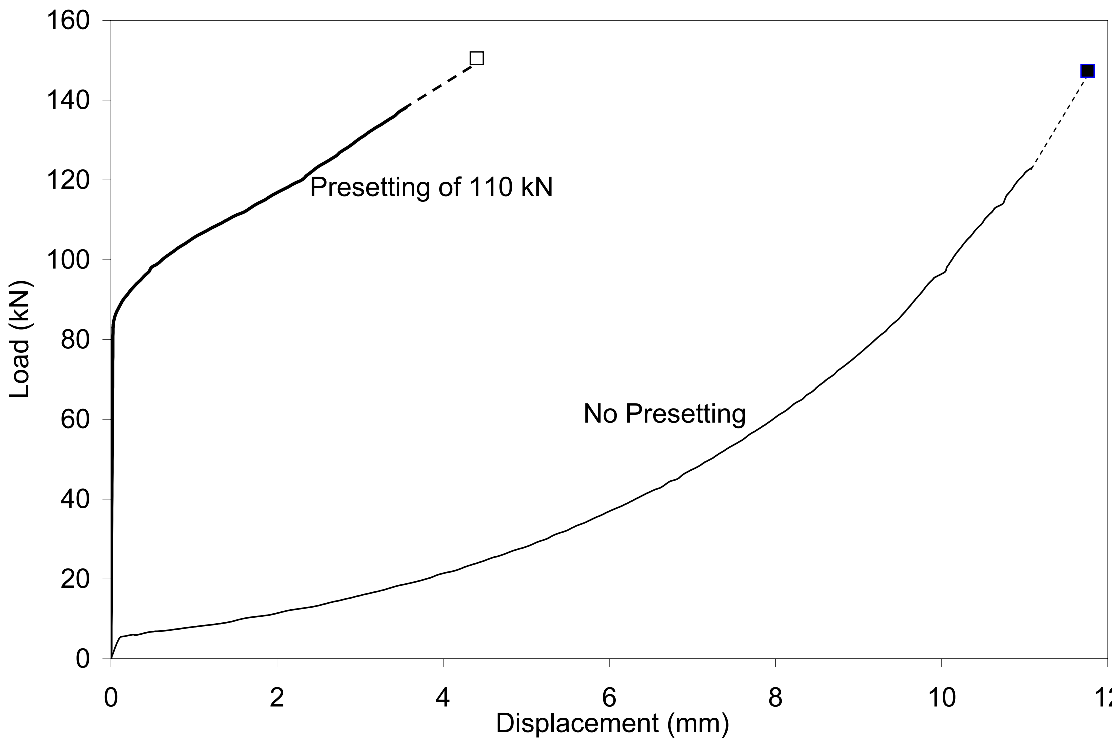


FIG. 5 Effect of Presetting Load on Load-Displacement of the CFRP Rod

Anchor was also used with Hughes No2 rod (6.4 mm diameter). Two different presetting loads of 0 and 80 kN were applied. All specimens failed at a load higher than the guaranteed tensile strength of the rod (300 ksi), as shown in FIG. 6.

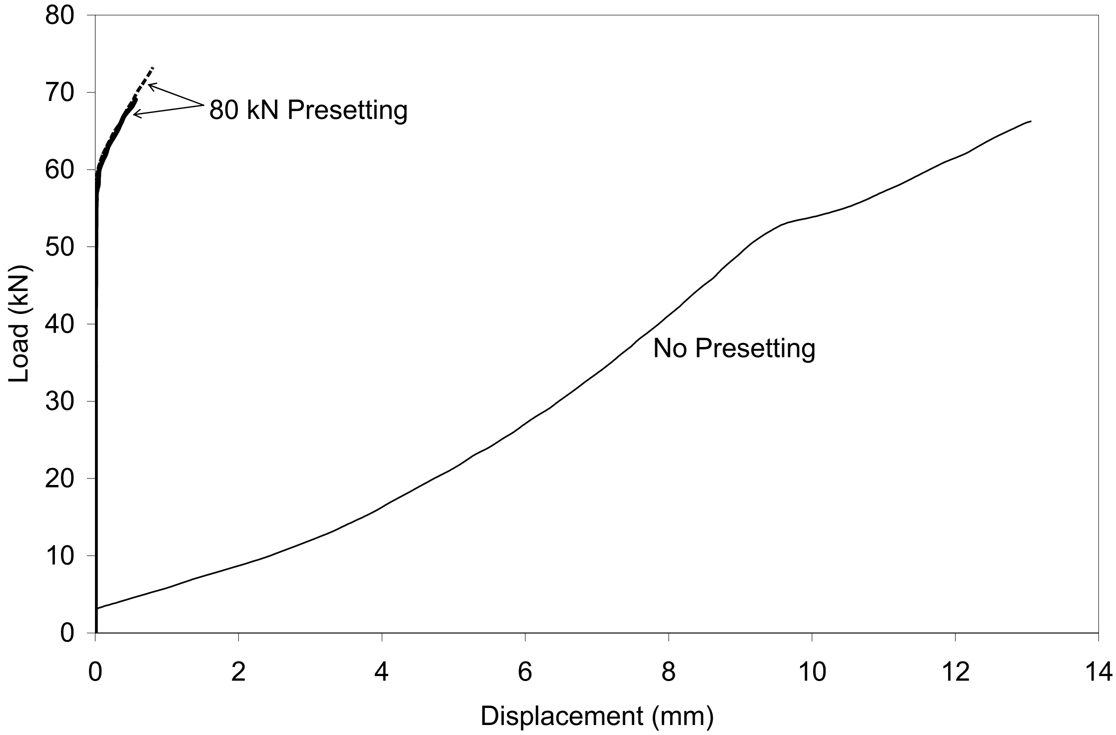


FIG. 6 Tensile Load-Displacement Relationship of Anchor with Hughes No2 Rod.

The anchor was also tested under fatigue loading condition. It passed the prove tests that were recommended by Post Tensioned Institute (PTI, 1985) for anchor with steel cables. Other fatigue tests were conducted using different load ranges.

SUMMARY

A new wedge anchor system has been developed for CFRP rods of different sizes. The system consists of a copper sleeve, a number of steel wedges, and a steel barrel. The anchor was capable of carrying the guaranteed tensile strength of the rods. In addition, no presetting was required to insert the wedges into the barrel before applying the tensile load to the rod. This is one of the main attraction of using this system in prestressed concrete applications.

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