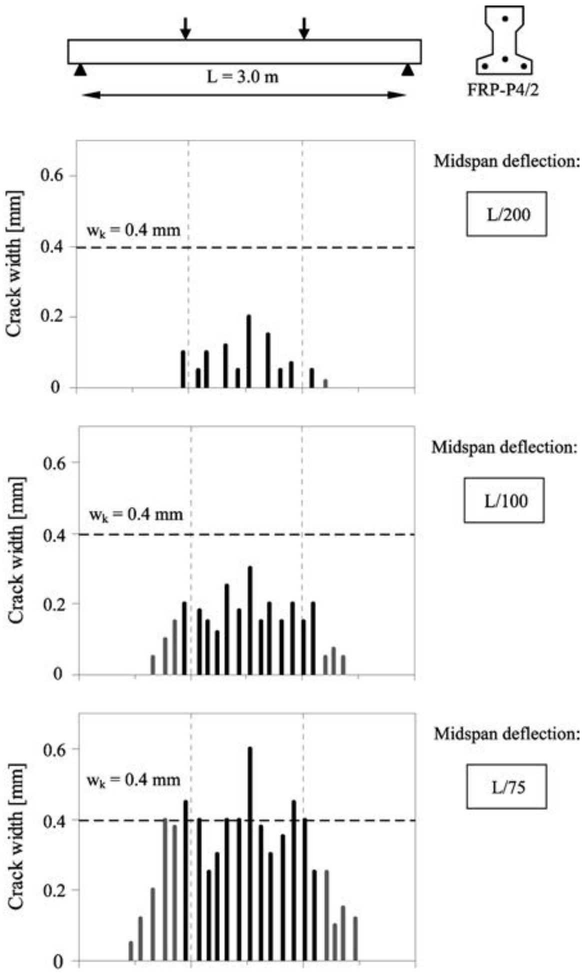

Figure 7—Crack pattern of test beam prestressed with four FRP wires to various mid-span deflections L/200, L/100, and L/75. Note: Designation of beam is given in Table 2. Columns in diagrams represent observed cracks, height of columns represent measured crack widths.

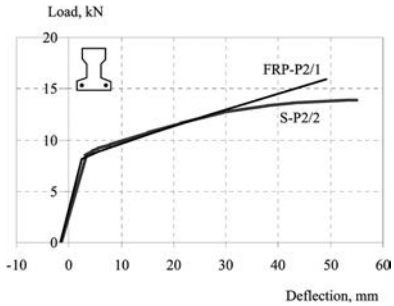

Figure 8—Comparative load versus deflection responses. FRP-P2/1: test beam prestressed with CFRP. S-P2/2: test beam prestressed with steel. Note: Designation is given in Table 2.

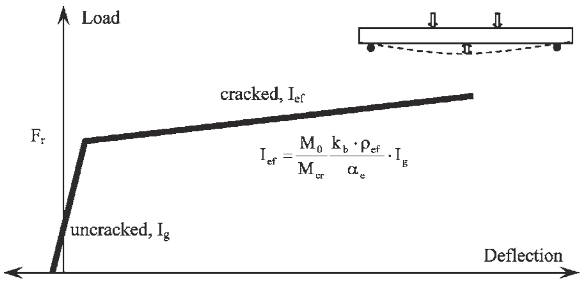

Figure 9—Illustration for the developed bilinear formula.

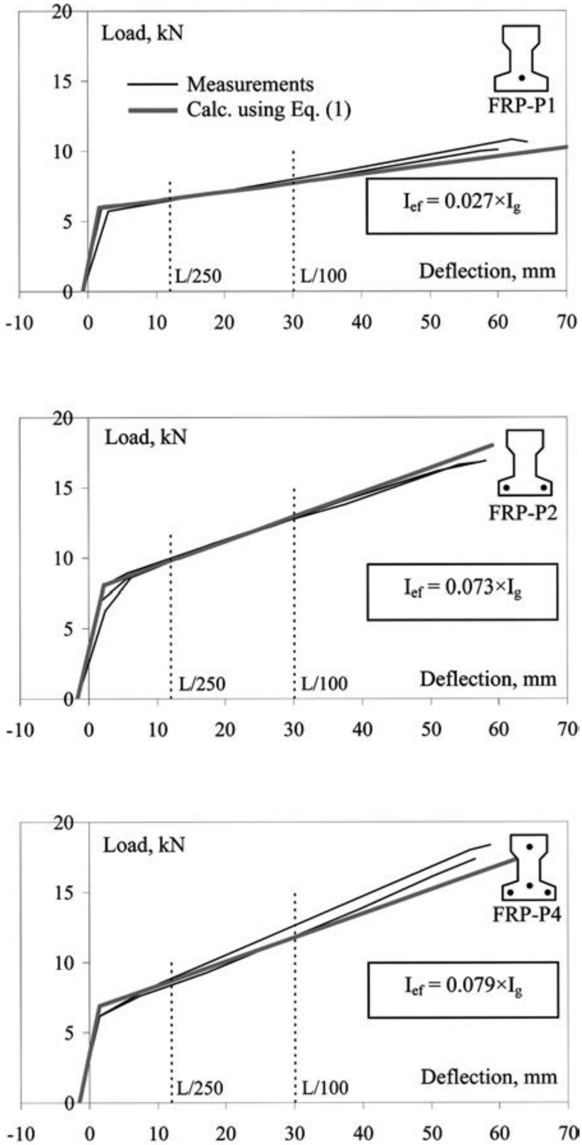

Figure 10—Evaluation of load versus deflection responses for members tested using the developed bilinear formula Eq. (1).

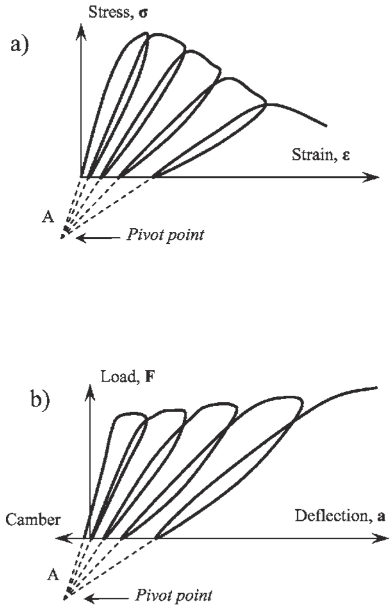

Figure 11—Pivot hysteresis behavior under repeated loads: (a) stress versus strain response of plain concrete in compression; and (b) load-versus-deflection response of a prestressed beam in flexure.

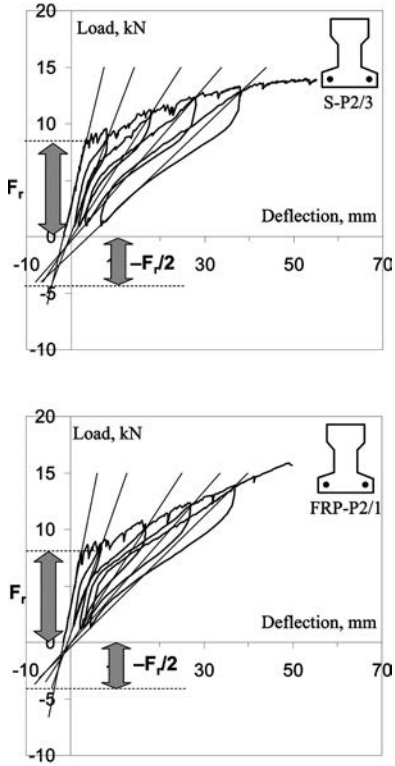

Figure 12—Pivot hysteresis behavior under repeated loads, low reinforcement ratio.
Note: Designation is given in Table 2.

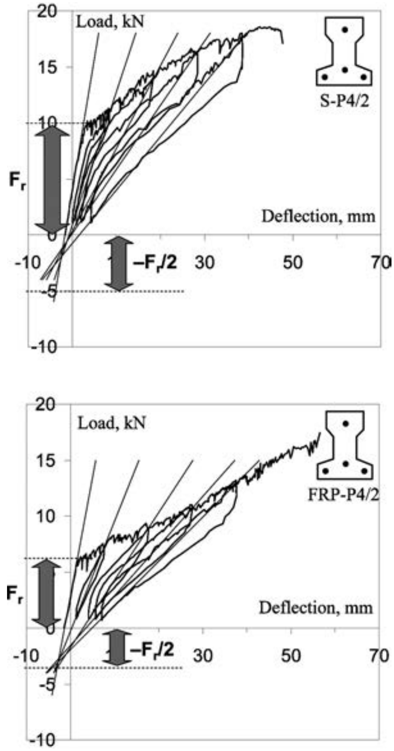

Figure 13—Pivot hysteresis behavior under repeated loads, higher reinforcement ratio. Note: Designation is given in Table 2.

Prestressed Carbon Strands Utilized in Repair of Football Stadium Ramp

by C.R. Alburn and C.W. Dolan

Synopsis: Prestressed concrete planks using CFRP tendons were used to replace badly deteriorated hollow core planks for the access ramp to the University of Wyoming football stadium. The test program for the planks is described followed by the issues associated with the construction and installation of the replacement planks. The planks have been in service for five years and no signs of deterioration have been observed.

Keywords: CFRP; concrete; construction; prestressed; tendons

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BACKGROUND AND PROBLEM STATEMENT

The War Memorial Stadium in Laramie, Wyoming is home to the University of Wyoming Cowboys football team. This NCAA Division I facility was originally built in 1950 and additions built during the 1970s significantly enlarged the stadium. In 1970, the first of two concrete upper stands were constructed and aptly named Stage One Expansion. By the time Stage Two Expansion was being designed, Stage One Expansion had already shown significant structural deterioration.

This paper focuses on one aspect of the Stage One Expansion structure. Several years ago, the maintenance staff for the athletic facilities noticed cracks on the undersides of several of the prestressed hollow core planks used in the ramps leading to the upper stands (Figure 1). Water entered the ends of the hollow cores of the plank, collected and froze. Once frozen, the water would exert an outward force of varying intensity dependant upon how much of the hollow core was filled. If a significant portion of the cell was filled or entirely filled, the outward force would be relieved through the weakest area, which in this case would be toward the bottom of the plank. When the tensile strength of the concrete was exceeded, the concrete would crack horizontally along the length of the cell (Figure 2). Once the planks had cracked it was decided that the water would drain and no action was needed, but this changed when the lower half of one of the planks fell away.

The position of the deteriorated planks varied. Some were located at the top of the ramp, while others were located mid ramp, but most of the deteriorated planks were located toward the bottom of the ramp. The only explanation for the varying locations of the deteriorated planks is that construction debris could be blocking the space in between the planks' ends and the supporting structure would effectively create a dam that diverts water into the cells of the hollow core planks instead of continuing down the ramp. This would explain how individual planks were deteriorating but not the neighboring planks. This theory is further justified with the most deteriorated hollow core planks are located at the bottom of each ramp. There is no evidence of any past attempt to seal the open ends of the hollow core planks.

RESEARCH SIGNIFICANCE

This paper presents a methodology for field testing of CFRP prestressed planks for specialized rehabilitation of concrete structures. The process required approval by the building owner and their construction staff. The test program provided the assurance needed for the CFRP planks to be installed in the public facility.

REPLACEMENT OPTIONS

Several different solutions were considered. Most ideas were dismissed without further research, but two possible solutions were evaluated. The first consideration was to purchase new replacement planks. Inquiries were made to two prestressed precast manufacturers in the region as to the availability of six-inch deep by two feet wide hollow core planks. Neither manufacturer produced hollow core planks of those dimensions. Eight-inch deep by four feet wide hollow core planks were available but this would imply either a two-inch bump in the deck, chiseling away a portion of the existing structure or leaving the planks without a wearing surface. None of these solutions were appealing or economically reasonable.

The second option was to custom build new planks. If the full deterioration mechanism included factors not previously described, then a more durable solution would be beneficial. This situation lends itself to the use of prestressed carbon fiber reinforced polymer (CFRP) tendons. Using the prestressed CFRP tendons in the replacement planks could achieve the same characteristics of the original hollow core planks but with the added benefit that the carbon strand would be more resistant than steel in corrosive conditions should deicing salt ever be used on the ramp. The replacement planks could also be tailor made to the required six-inch depth. The use of new materials required approval of the University facilities department and a full testing program was proposed. Design criteria called for the new planks to have approximately the same performance as a 2 ft (610 mm) wide hollow core plank with 3-3/8 in. (9.5 mm) diameter 250 ksi (1.72 GPa) tendons. The design methodology for the planks came from Burke and Dolan (2001).

PREPRODUCTION TESTING

Prior to constructing the planks to replace the deteriorating planks, two test programs were required. The first determined the properties of the tendons. The second load tested full sized planks to failure. The CFRP tendons were supplied by the Glasforms Inc., San Jose, California. They are 0.31 in (8 mm) in diameter with a tensile capacity of 420 ksi (2.89 GPa) and have a roughened surface. The details of the tendons can be found in the draft final research report (Dolan et al., 1999).

The development of the anchorage system required several iterations. An overall project requirement was to be able to use standard strand chucks for prestressing and anchorage. Initially copper tubing was epoxied to the end of the strands. The teeth in the strand chucks cut the copper tubing and the anchorage failed during stressing. Next, electrical tubing was used with epoxy adhesive. Improper centering of the tendon in the tube led to anchor failures due to the eccentric loads bending the anchors as much as 30 degrees when stress. Expansive Bristar™ cement and ½ in. (17.9 mm) electrical conduit was eventually used to anchor tendons. Rubber stoppers centered the tendon in the tube to give a concentric loading and thereby eliminating the eccentricity effects. The electrical conduit is larger than ½ in, (12.5 mm) in diameter; however; standard 0.6 in. (15.2 mm) strand anchors (barrel and wedge anchors with three-part wedge) could be used to grip the conduit (Gilstrap 1997). Test results of the strand properties are given in Table 1. The anchor specification using the expansive cement has been widely used since this work and is particularly reliable with stronger wall tubing.

The planks are 20'-6" (6.25 m) long with the cross section shown in Figure 3. The carpenters at the Physical Plant constructed the form used for both the replacement and test planks. This form rested on two concrete bulkheads separated by twin steel large wide flange beams. Just beyond each end of the plank form is a steel grate served as the stressing bulkheads (Figure 4). The first author and several students constructed the planks. One test plank was broken in half to allow two tests for shear, bond and flexural capacity. The second test plank was tested full length to validate strength and stiffness.

The initial prestressing force for the planks is shown in Table 2. These values are the pump force minus approximately 3/8 of an inch of initial seating of the CFRP tendons and grips. The 3-day concrete compressive strength was tested to be 2400 psi. This strength was adequate to remove the planks from the forms. The planks were tested in four-point loading. The overhang at each support assured full bond development and removed any damaged areas from the test. A schematic of the test is given in Figure 5 and a photo of the test is given in Figure 6. The 28 day concrete strength was 6200 psi (43 MPa) and the strength at the time of testing was 9500 psi (65.6 MPa).

The test planks were tested with a slight overhang rather than the small bearing seat that occurs in the field. Previous tests on the particular CFRP tendons indicated that there was no end slip of strand so bond is not affected by the shorter bearing in the field. The overhang provided the opportunity to set load cells and dial gages at the end of the test specimen for data collection. The load deflection data (Figure 7) indicated that the planks had sufficient strength and stiffness to satisfy the Physical Plant requirements for stadium replacement elements. At approximately 0.5 in. (12 mm) the dial gage slipped on the final loading cycle. The data is presented as recorded although a continuous extrapolation of the data is a more reasonable interpretation of the behavior.

Figure 8 indicates an excessive deflection of the long plank at full capacity. In order to better match the existing hollow-core panel camber, additional prestress was added to the CFRP tendon to increase the initial camber. The level of initial prestress has an effect on the strength of the plank. The total strain in the shallow plank does not allow for sufficient strain increase to rupture the tendon. The initial failure mode was concrete compression failure. After the anchorage issues were resolved and the prestress level raised, the full tensile capacity of the tendon could be developed and failure was by tendon rupture.

PRODUCTION MODIFICATIONS AND CONSTRUCTION

There were changes made in the course of constructing the planks as each plank constructed had improvements over its predecessor. Some of these improved the production of the planks by addressing problems as they arose, while others fall under the heading of just being conservative. General construction techniques improved with the