STRESS-LAMINATED SCL BRIDGES WITH PRESTRESSING

Michael A. Ritter
USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

Matthew S. Smith
Laminated Concepts Inc, Big Flats, New York, USA

Terry J. Wipf
Iowa State University, Ames, Iowa, USA

SUMMARY

Growing interest in wood bridges over the past decade has led to the use of new wood products and innovative designs. One material that is becoming increasingly popular for bridges is structural composite lumber (SCL), which includes laminated veneer lumber and parallel lumber. SCL bridges are typically constructed of solid T-beams that are stress-laminated together with steel bars placed through the top flanges. As an option for improved performance and economy, a SCL bridge was recently constructed using steel prestressing strand as a replacement for steel bars. This paper describes the development and initial 2-year field evaluation of that bridge. Overall, bridge performance has been excellent; however, the grips on several strands slipped due to defective strand epoxy coating.

1 INTRODUCTION

The objective of the Timber Bridge Initiative (TBI), passed by the United States Congress in 1988, was to further develop and extend the use of wood as a bridge material [1]. As part of this objective, emphasis has been placed on the use of new engineered wood products and innovative bridge designs. One group of engineered wood products that has been adapted for bridge applications is structural composite lumber (SCL), which includes laminated veneer lumber (LVL) and parallel strand lumber (PSL). LVL is made from thin sheets of rotary-peeled wood veneer that are glued together with waterproof adhesive. PSL consists of narrow strips of veneer that are compressed and glued together with the wood grain direction parallel (Figure 1). There are several characteristics which make SCL well-suited for bridge applications. Because it is a manufactured product, SCL can be produced in a variety of sizes and shapes. The laminating process disperses the natural strength-reducing characteristics of wood, which reduces product variability and provides significantly improved design strength and stiffness compared to sawn lumber. SCL also provides excellent treatability with wood preservatives, and full preservative penetration is typically achieved [2].

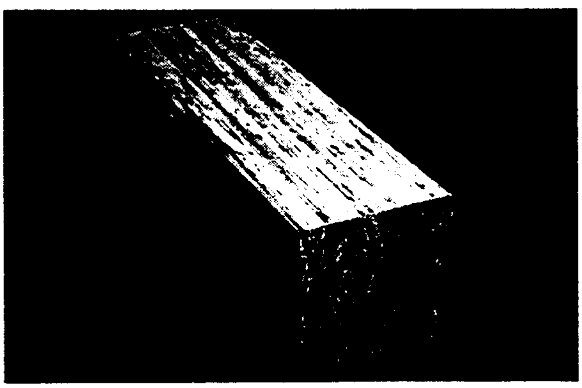


Figure 1 - Typical PSL beam

Although SCL has been used for several bridges in the United States since 1977, the first effort to develop and market a bridge system constructed entirely of SCL was initiated by Trus Joist MacMillan in 1989. These bridges consist of a series of fully laminated LVL T-beams with box sections along the outside bridge edges (Figure 2). The T-beams and box sections are stress-laminated together with steel bars placed through the top flanges. By 1993. approximately 20 bridges of this type were constructed with clear spans of 7.3 to 15.2 m and widths of 3.0 to 11.0 m. Beginning in 1993, LVL was replaced with PSL using the same design configuration. Since that time, approximately 19 PSL bridges have been built. One obstacle to acceptance of SCL for bridges was a lack of design values in the *Standard Specifications for Highway Bridges* published by the American Association of State Highway and Transportation Officials (AASHTO)[3]. This was subsequently resolved and design values for SCL were included in the 1995 interim specifications. As a result, SCL is becoming more popular as an alternative for new construction and bridge replacement.

During the development process for stress-laminated SCL T-beam bridges, a field evaluation program was considered necessary to fully evaluate bridge performance and

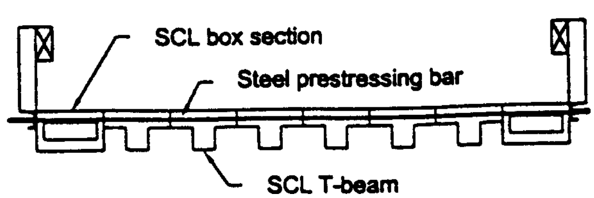


Figure 2 - Typical configuration for a stress-laminated SCL T-beam bridge (not to scale).

optimize design methodology. As a result, the Forest Products Laboratory (FPL) was asked to participate in the evaluation of 6 LVL bridges built between 1990-1991 [4]. With the introduction of PSL as a bridge material, further evaluation was considered benificial. Additionally, the development and evaluation of steel prestressing strand as a replacement for steel bars was initiated. This paper describes the design, construction and initial field evaluation of the Hornby Road bridge, which is the first PSL T-beam bridge to he stress-laminated with prestressing strand.

2 BACKGROUND

The Hornby Road Bridge is located in the Town of Orange, in Schuyler County, New York. The bridge is on Schuyler County Route 16, a two-lane, paved road with an average daily traffic of approximately 500 vehicles. The previous bridge at the site was constructed in the mid-1970s and consisted of a 18.3-m long, three-span, nail-laminated deck fabricated from nominal 75-by 305-mm sawn lumber. The substructure consisted of nominal 305-mm-diameter timber piling abutments and bents. In 1994, the New York State Department of Transportation inspected the bridge and downgraded the structural capacity. The reasons for the reduced capacity were due in large part to accelerated deterioration of the substructure, inadequate bridge railing, and loosening of the nail-laminated deck.

In considering options for the Hornby Road bridge, Schuyler County determined that the bridge would be replaced. It was further determined that a replacement bridge should include a crashworthy bridge railing, a low design profile, and a minimum single clear span of 18.3 m to provide waterway and debris clearance. Several alternatives were evaluated for the replacement bridge, and a timber bridge was considered the best option for the site. Given the requirement for a low profile bridge, a design employing stress-laminated PSL T-teams was selected.

To assist with project funding, Schuyler County applied for and received a partial funding grant from the USDA Forest Service National Wood in Transportation Information Center. The bridge replacement was subsequently initiated as a cooperative effort involving the Schuyler County Highway Department, The Sullivan Trail Resource Conservation and Development Council, and the USDA Forest Service.

3 DESIGN, CONSTRUCTION, AND COST

Design and construction of the Hornby Road bridge involved a consulting engineering firm for site layout and abutment design Laminated Concepts Inc. for bridge superstructure design and a construction contractor. During superstructure design, Laminated Concepts Inc. worked extensively with the FPL to develop a design that met the required criteria. An overview of the bridge design construction, and cost follows.

3-1 Design

Design of the Hornby Road bridge was based on material technology and load distribution criteria developed by Trus Joist MacMillan. All other aspects of the design were based on the AASHTO *Standard Specifications for Highway Bridges* [3]. Design requirements specified a center-to-center bearing length of 18.29 m and a clear roadway width of 7.32 m. Loading was two lanes of AASHTO HS 25-44 truck loading, with a maximum live load deflection of 1/400 of the bridge span. To meet these requirements, the design employed tweleve T-beams with box sections along each of the bridge edges (Figure 3). All components were Southern Pine PSL with tabulated design values of 20.0 MPa for bending, 2.0 MPa for shear, and 290 MPa for modulus of elasticity. The individual T-beams measured 552 mm wide by 800 mm deep, and the box sections measured 457 mm wide by 800 mm deep (Figure 4). The interconnecting flanges of the T-beams and box sections were fabricated with a scalloped edge to interlock and prevent vertical movement. All PSL was specified to be treated after fabrication with pentachlorophenol in petroleum oil to American Wood Preservers' Association (AWPA) Standard C33 requirements [5].

The stressing system for the Hornby Road bridge was designed to provide an initial 0.69-MPa interlaminar compression between the T-beam flanges. Historically, bridges of this type have been stress-laminated with 16-mm-diameter high-strength steel bars. One feature of the Hornby Road bridge design was the inclusion of a stressing system that employed 13-mm-diameter epoxy coated steel prestressing which is commonly used for concrete [6]. The strand was designed to pass through the top flanges of the T-beams and box sections at 0.95 m on-center, with a design tension force of 102 kN. The use of strand was considered to offer several potential advantages over the bars, including an approximate 25% savings in material costs, easier installation, and more elongation to compensate for dimensional changes in the bridge deck. Laminated Concepts, Inc. had previously used strand on several stress-laminated decks. For these projects, the strand was anchored along each bridge edge with standard strand chucks that press against the steel and deform the strand surface. Over a relatively short period, the chucks become permanently fixed on the strand and cannot be removed if the strand must be retensioned. One design refinement for the Hornby Road bridge was to develop a means of retensioning the strand. To accomplish this, a special chuck was used that grips the strand and provides attachment for a 19-mm steel bar (Figure 5). This chuck is placed inside the deck near the edge and the bar extrends beyond the deck edge for anchorage and subsequent retensioning, if required. The other strand end is anchored with a standard chuck. Bearing at both strand ends was on 13- by 102- by 152-mm steel bearing plates that were placed on steel channels between the railing posts.

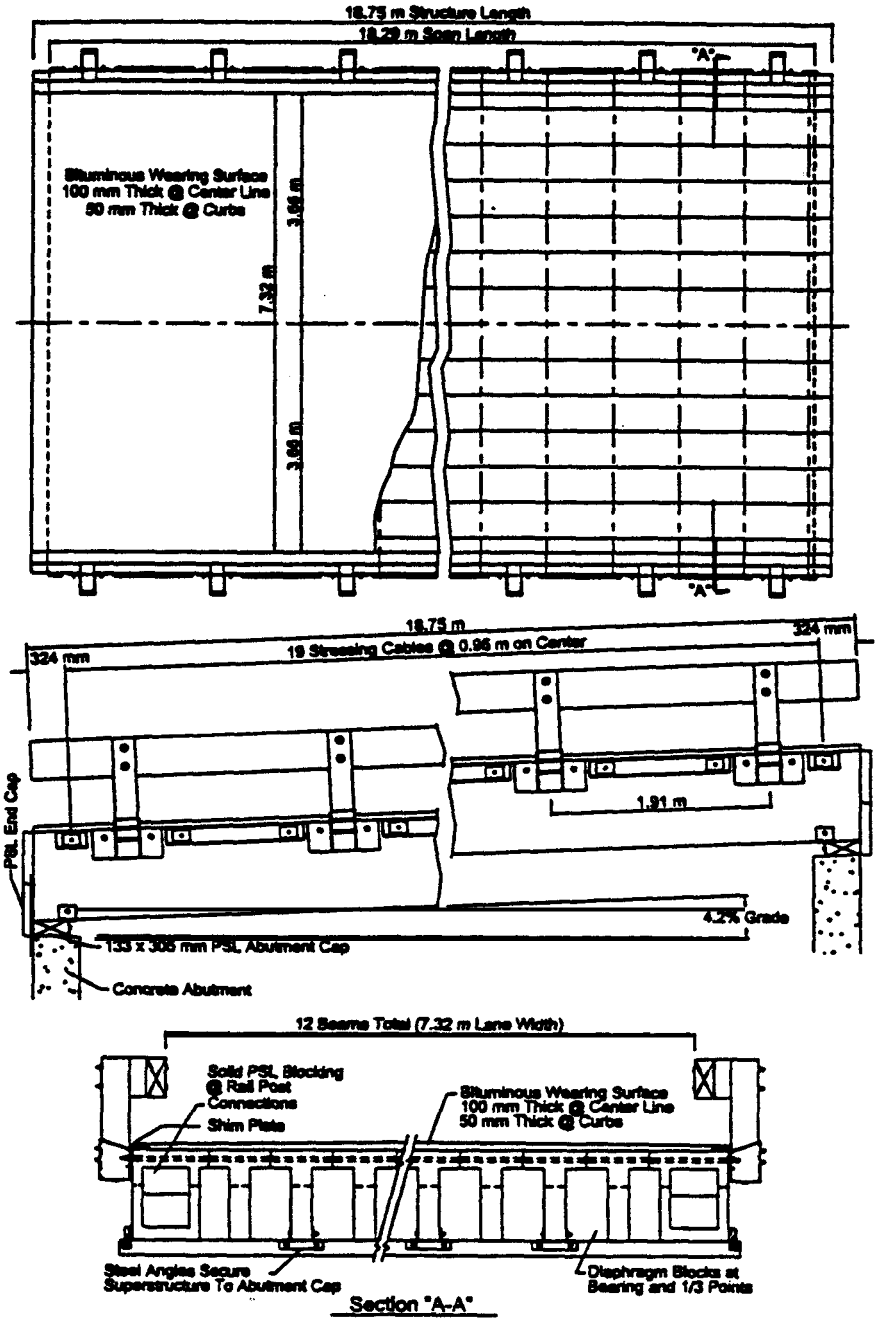


Figure 3 - Design details for the Hornby Road bridge.

To meet design requirements for a crashworthy railing system, a bridge railing that was previously crash tested end approved was selected. This railing consisted of a steel "shoe" configuration that supported a post and rail manufactured from PSL [7]. The shoe was connected to the bridge with two high-strength steel bars that extended through the top flange of the box sections. The steel attachment hardware was galvanized for corrosion protection.

3.2 Construction

Construction of the bridge was completed by contract and began with the construction of a bypass crossing and removal of the old bridge superstructure and substructure. New concrete abutments were then constructed, and the PSL bridge components were delivered to the site on two 15-m flatbed trucks. For bridge bearing, a 133- by 305-mm PSL cap was placed on the concrete abutments and attached with 19-mm diameter anchor bolts. The first two T-beams were then placed and aligned on each side of the roadway centerline and connected to the abutment cap with steel angle brackets and bolts (Figure 3). The remaining T-beams and box sections were placed within 3 hours. To facilitate construction, the bridge railing shoes were attached to the box sections prior to placement.

After placement of the T-beams and box sections, the steel strand was inserted through 51-mm-diameter holes predrilled through the top flanges. The oversized holes proved valuable for ease of strand installation and all 18 strands were placed within 1 hour. The special chucks

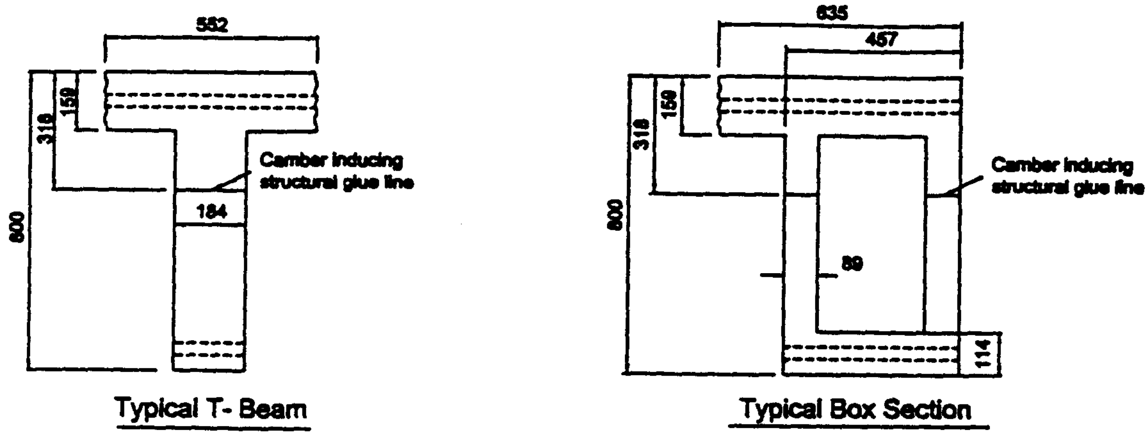


Figure 4 - Typical T-beam and box section details (all units are in mm).

with steel bars were placed on one end of each strand, and the chucks were inserted into the outside box section top flange. The steel channels and bearing plates were placed on the bars and double nuts were installed to secure the bar against the plate. Standard strand chucks were then placed on the opposite strand ends.

Strand tensioning was completed with a hollow core hydraulic jack using equipment and procedures common for stress-laminated deck construction [8]. To facilitate tensioning, a portable platform was constructed to support workers and equipment (Figure 6). The tensioning procedure employed a somewhat unconventional sequence in order to allow observation of the changes in strand force after tensioning. The first tensioning occurred on the strand ends with standard chucks and involved tensioning all 18 strands to approximately 60% of the 102 kN initial design force. Approximately 30 days later, half the strands were retensioned on the bar side to the full design force. Approximately 30 days after this, the remaining 9 strands were tensioned to the full design level. After strand tensioning was complete, an asphalt wearing surface was placed on the bridge deck The completed bridge is shown in Figure 7.

3.3 Cost

The cost for the bridge superstructure including design, railing, and material delivery was $81,400. Based on a deck area of 148 m^2, the unit cost was $550/$m^2$. This is slightly greater than the cost of a typical timber bridge but reflects the special requirement for a low-profile structure.

4 EVALUATION METHODOLOGY

Evaluation of the Hornby Road Bridge focused primarily on measurement of prestressing strand force, behavior of the bridge under static load testing, and condition evaluation. A brief description of the methods used follows.

4.1 Strand Force

Strand force was measured periodically using two load cells constructed by FPL. One load cell (#179) was installed at approximately the bridge midspan, and the other (#176) was located near the south abutment. Load cell strain measurements were obtained with a portable strain indicator and converted to units of tensile force by applying a laboratory calibration factor to the strain indicator reading.

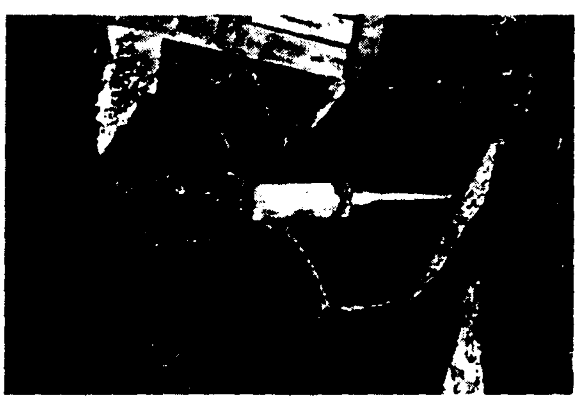


Figure 5 - Special strand chuck which transitions from strand to a 19-mm steel bar.

Figure 6 - Strand tensioning on a portable work platform.

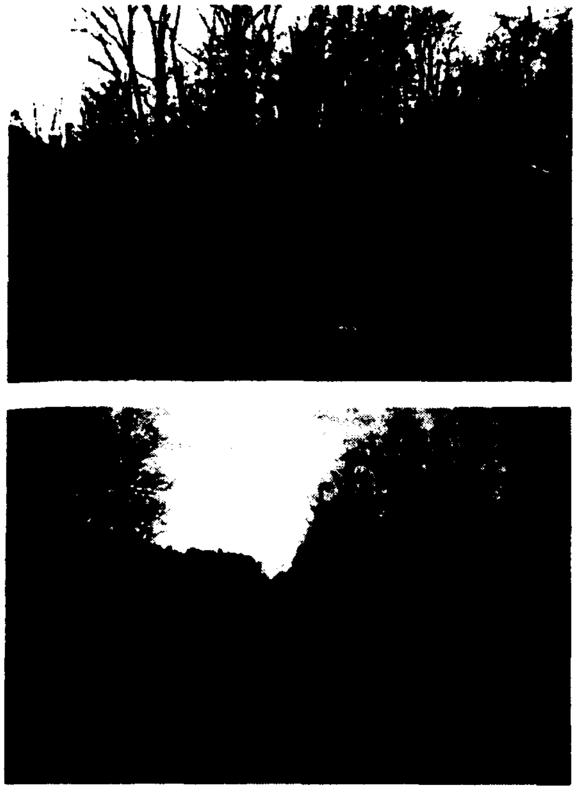


Figure 7 - Completed Hornby Road bridge.

4.2 Load Test Behavior

Static bad testing was completed in December 1998, approximately 2 years after bridge construction. The load testing consisted of positioning loaded test trucks on the bridge deck and measuring the resulting deflections at a series of transverse locations at midspan. Measurement of bridge deflections were taken prior to testing (unloaded), for each load position (loaded), and at the conclusion of testing (unloaded). Deflection measurements from an unloaded to loaded condition were obtained by placing

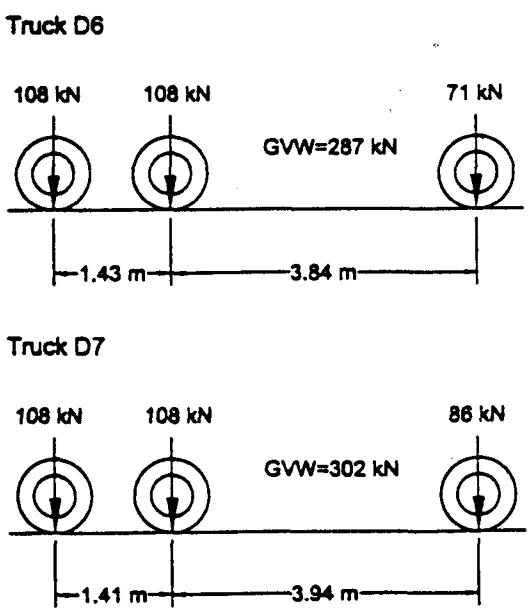


Figure 8 - Load test truck configurations and axle loads.

calibrated rules at the bottom center of each web and at the box corners and reading values with a surveyor's level to the nearest 0.5 mm. The load test vehicles were fully-loaded 3-axle dump trucks (Figure 8). The trucks were positioned longitudinally on the bridge so that the two rear axles were centered at midspan. Transversely, six different load positions were used with the trucks 0.61 m from centerline for load positions 1 through 3, and 1.17 m from centerline for load positions 4 through 6 (Figure 9).

4.3 Condition Assessment

The general condition of the bridge was assessed shortly after construction and at the time of load testing. The assessment involved visual inspections, measurements, and

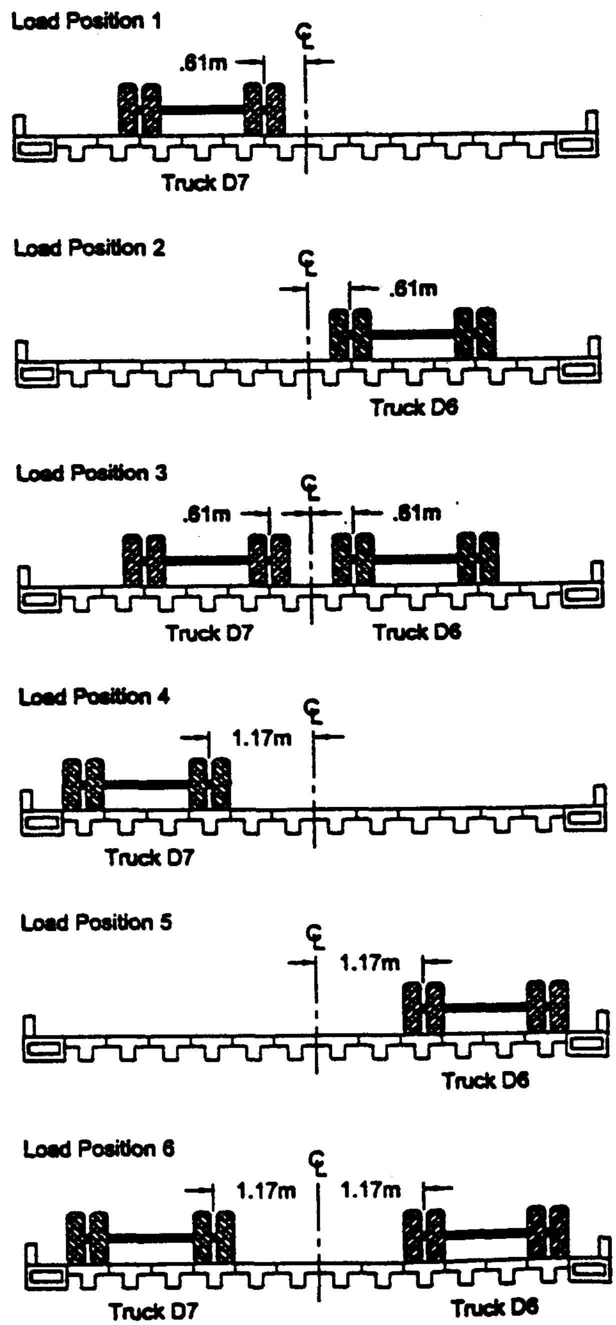


Figure 9 - Load test vehicle positions (looking north). Truck rear axles were centered at midspan (not to scale).

photographic documentation of the bridge condition. Items of specific interest included the condition of the strands and anchorages, bridge geometry, and condition of the PSL components.

5 RESULTS AND DISCUSSION

Results of the initial performance evaluation of the Hornby Road bridge follow. These results reflect the bridge behavior during the first 2 years of service. Field monitoring will continue to obtain a more representative evaluation of long-term performance.

5.1 Strand Force

The strand force after the first tensioning is shown in Figure 10 for load cells 176 and 179. Note that half the strands were retensioned to the full design level in February 1997 (cell 176), and the remaining strands were retensioned approximately 30 days later in March 1997 (cell 179). After retensioning, the strand force decreased slightly due to stress relaxation in the PSL. This was followed by an increasing trend in strand force to 112 and 102 kN in November 1998 for cells 176 and 179, respectively. The increase was likely due to slight swelling of the PSL resulting from a gradual increase in moisture content. It is expected that this will eventually stabilize, but may fluctuate with seasonal climatic changes that affected the moisture content and dimensional stability of the PSL

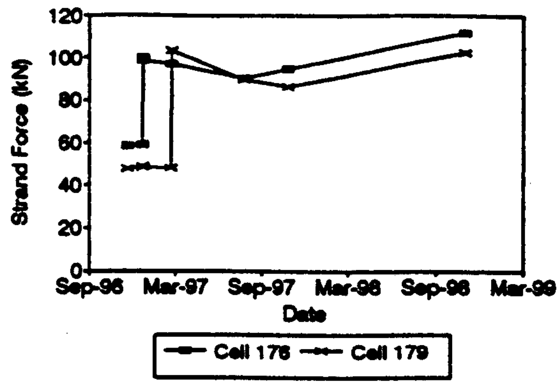


Figure 10 - Strand force plot

5.2 Load Test Behavior

Load test transverse deflection plots are presented in Figure 11. The interlaminar compression at the time of the testing was approximately 106 MPa. For all load

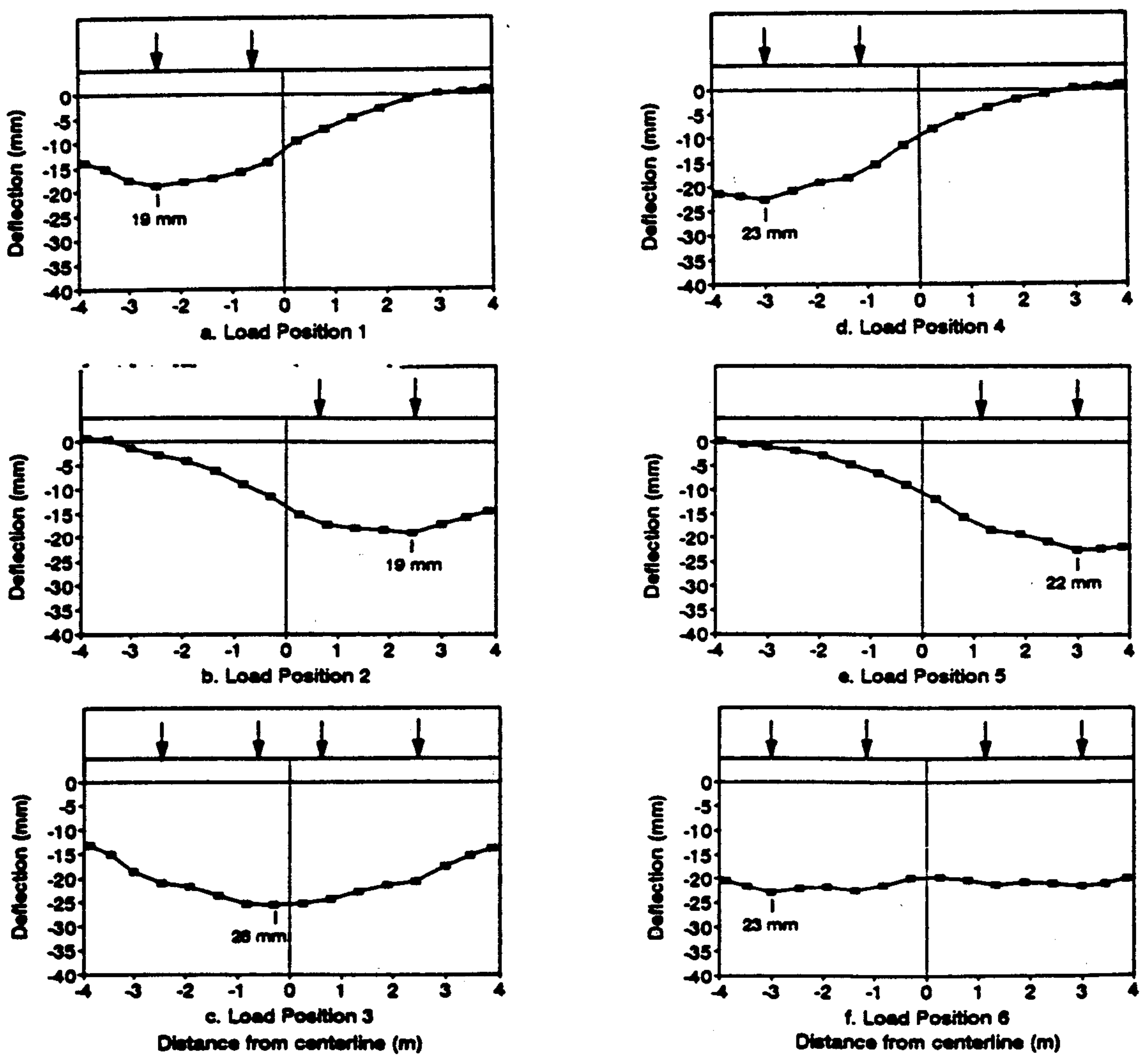


Figure 11 - Load test deflection plots (looking north).

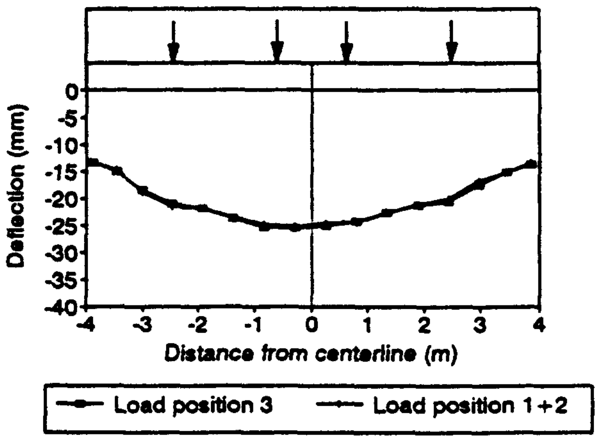
positions, the deflection plots are similar to the orthotropic plate behavior of stress-laminated LVL T-beam bridges and deck bridges constructed of sawn lumber [4,9]. The maximum deflections for load postitions 1 and 2 measured 19 mm and occured at the T-beam under the outside wheel line. With both vehicles on the bridge for load position 3, the maximum load test deflection of 26 mm was adjacent to the interior wheel line in the east lane. For load positions 4 and 5, maximum deflections measured 23 and 2 mm, respectively, and occurred under the outside wheel line. The maximum deflection for load position 6 was in the same relative position and measured 23 mm.

Assuming linear elastic behavior, the sum of the bridge deflections for load 1 and 2 and load positions 4 and 5 should equal the deflections of load position 3 and 6, respectively. Using superposition, comparative plots of these deflections are shown in Figure 12. As shown in the figure, the plots are almost identical, with only minor differences that are within the accuracy of the measurements.

5.3 Condition Assessment

A bridge condition assessment prior to load testing indicated that the standard chucks on 5 of the strands had slipped and the strands were no longer tensioned. These 5 strands were replaced with strand remaining from the initial construction and were retensioned with new chucks. During the retensioning, one standard chuck failed to grip the strand and slipped. Examination of strand indicated that all in all cases of slip, the chuck grip had not fully penetrated the epoxy coating to the underlying strand (Figure 13). Further, the pliable epoxy coating had become brittle. An evaluation by the strand supplier indicated that the epoxy coating was defective. The remaining 13 strands are performing as intended, and no slip is evident.

Inspection of the PSL components along the sides and underside of the bridge indicated that the material was in excellent condition However, exposed PSL rail and post members showed evidence of minor checking and separation The post ends were coated with an unknown sealer at the time of construction, hut at the time of load testing the coating was deteriorated and the underlying PSL was separating (Figure 14). For future bridges, improved coatings or alternate materials should be considered for exposed applications. Inspection of the bridge deck showed that the asphalt wearing surface was in excellent condition and no cracks or other evidence of deterioration was observed.



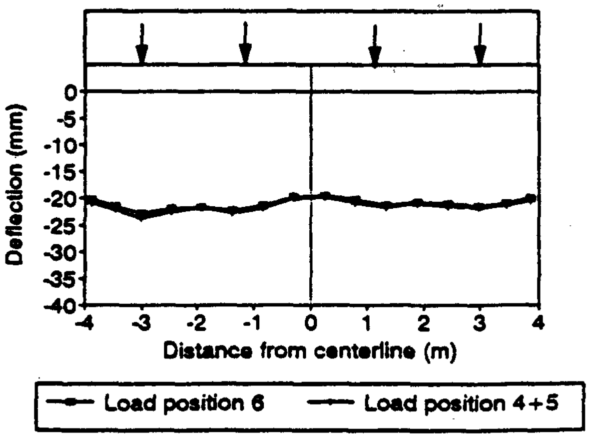


Figure 12 - Load test deflection comparisons showing load positions 1 and 2 compared to load position 3 and load positions 4 and 5 compared to load position 6.

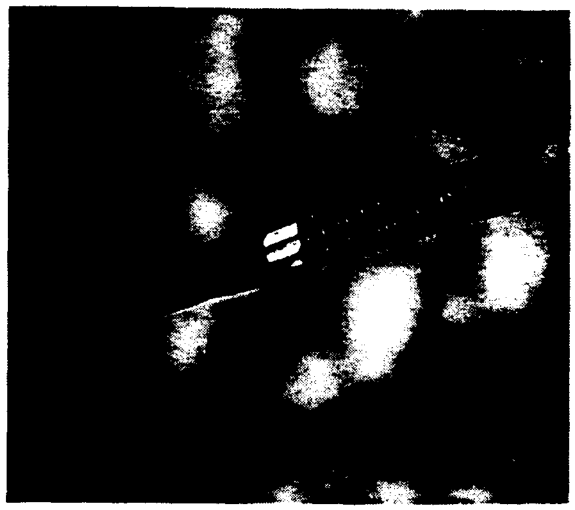


Figure 13 - Failure of the chuck to grip through the strand epoxy caused the chuck to slip along the strand.

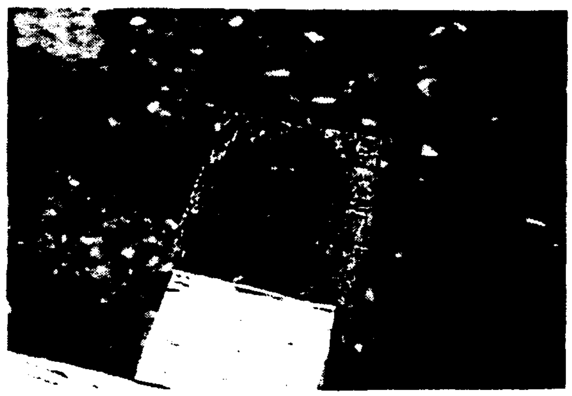


Figure 14 - Deteriorated coating on top of PSL railing post.

6 CONCLUDING REMARKS

Initial field evaluation of the Hornby Road bridge indicates that structural and serviceability performance are good, and the bridge should provide many years of acceptable service. The project demonstrates that it is both feasible and practical to construct PSL bridges using prestressing strand as an economical alternative to steel bars. Monitoring of this bridge will continue into the future to complete a more long-term evaluation. At the conclusion of this monitoring, final recommendations will be formulated for the design and construction of future bridges of this type.

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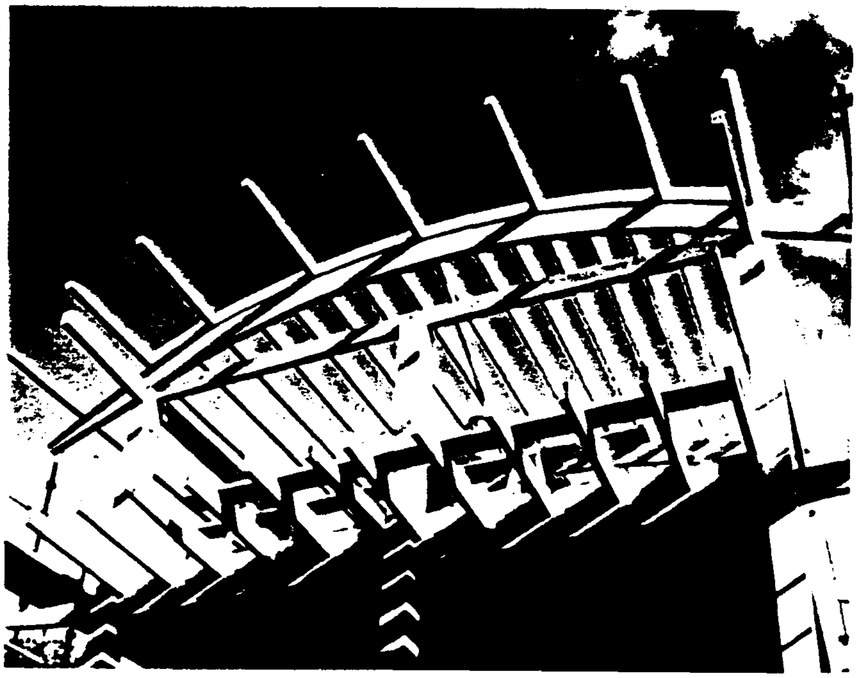

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