Long Term Load Performance of FRP Reinforced Glulam Bridge Girders

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Abstract

The use of high-strength-fiber-reinforced plastic (FRP) as a reinforcement for glulam bridge girders is now a commercial reality. To assist in the assessment of in-service characteristics of these new girders, a 49.6 m HS-25 highway bridge constructed in August of 1995 was equipped with internal strain gauges for long-term load effects monitoring. This report represents the findings to-date from these tests. Further, the economic, environmental and maintenance advantages of reinforced glulams are presented.

Keywords: Reinforced glulams, glulam bridge girders

Background

A bridge composed of FiRP™ Reinforced glued laminated timber (glulam) girders and a transverse conventional glulam deck was constructed over the Clallam river near Sekiu, Washington. It consists of two simple spans, each 24.8 m, for a total span of 49.6 m with an HS-25 load rating. Six Douglas-fir (DF), L2 girders spaced at 1.60 m center-to-center are used for each span. A composite modulus of elasticity (E) of 14480 MPa was used to estimate deflections. The exterior girders are 222 mm wide by 1499 mm deep with four layers of 3.81 mm thick aramid reinforced plastic (ARP) FiRP™ Reinforcement. The interior girders are 171 mm wide by 1499 mm deep with seven layers of 1.78 mm thick carbon-m-amid reinforced plastic (CARP) FiRP™ Reinforcement. The bridge deck is constructed of 52 conventional glulam deck panels oriented transversely to the girders. Also, glulams were used for deck stiffeners and curbs. All the lumber was pressure treated with pentachlorophenol. Figures 1 and 2 show side and end views of the Clallam Bay bridge, respectively.

The bridge was designed by Western Wood Structures, Inc. of Tualatin, Oregon and manufactured by American Laminators, Inc. of Swisshome, Oregon. Monitoring of the bridge was undertaken in a joint effort by the Wood Science & Technology Institute (N.S.), Inc. and the Forest Products Laboratory at Oregon State University, both of Corvallis, Oregon.

The FiRP™ Reinforcement technology was implemented in the girders because of the significant cost and weight savings it provides as compared to conventional glulams. The reinforcement allows low grade lumber to be utilized throughout the depth of the beam. The reduced cross section, increased bending stiffness, and low grade lumber substitution often provide a substantial size and cost reduction compared to unreinforced glulam beams.

Another significant advantage of FiRP™ Reinforced glulam beams is the reduced variation in the modulus of elasticity and the strength. The reduced variation permits significantly increased design properties and a closer approximation of the deflections.

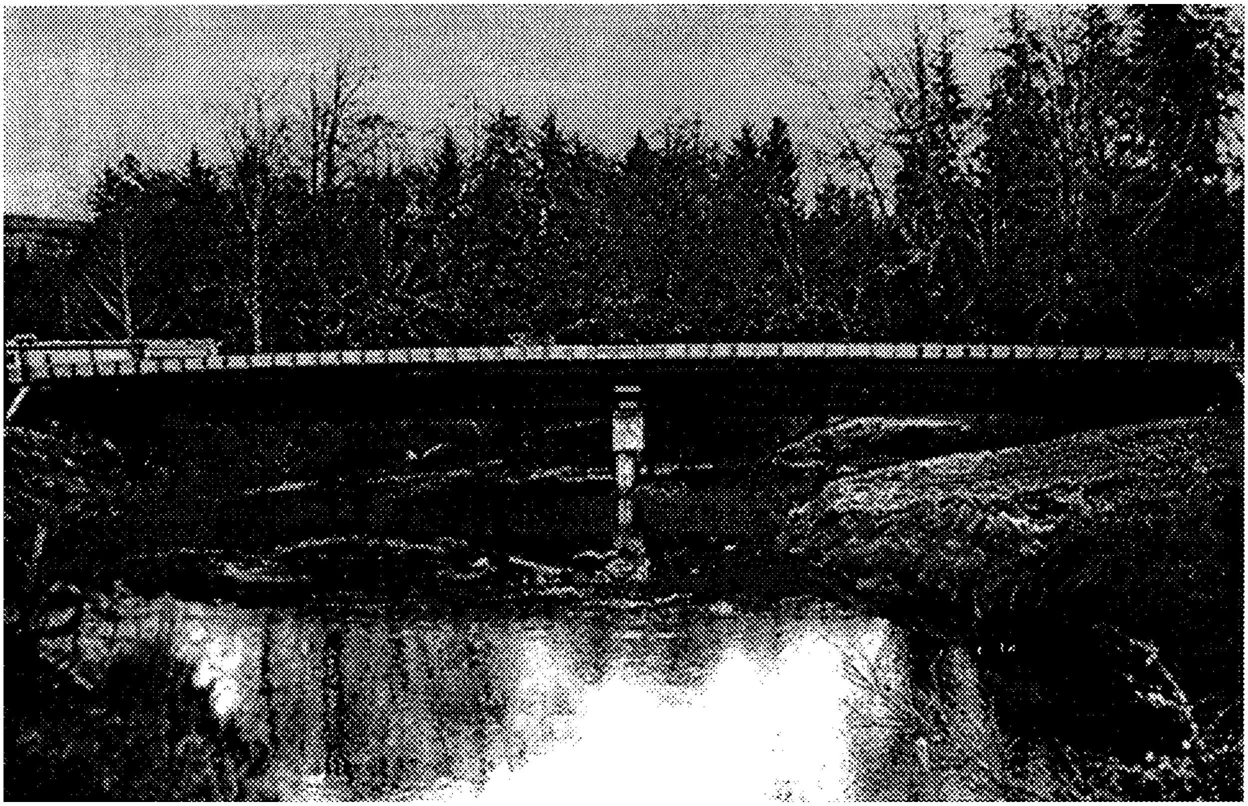

Figure 1-Side view of the Clallam Bay bridge.

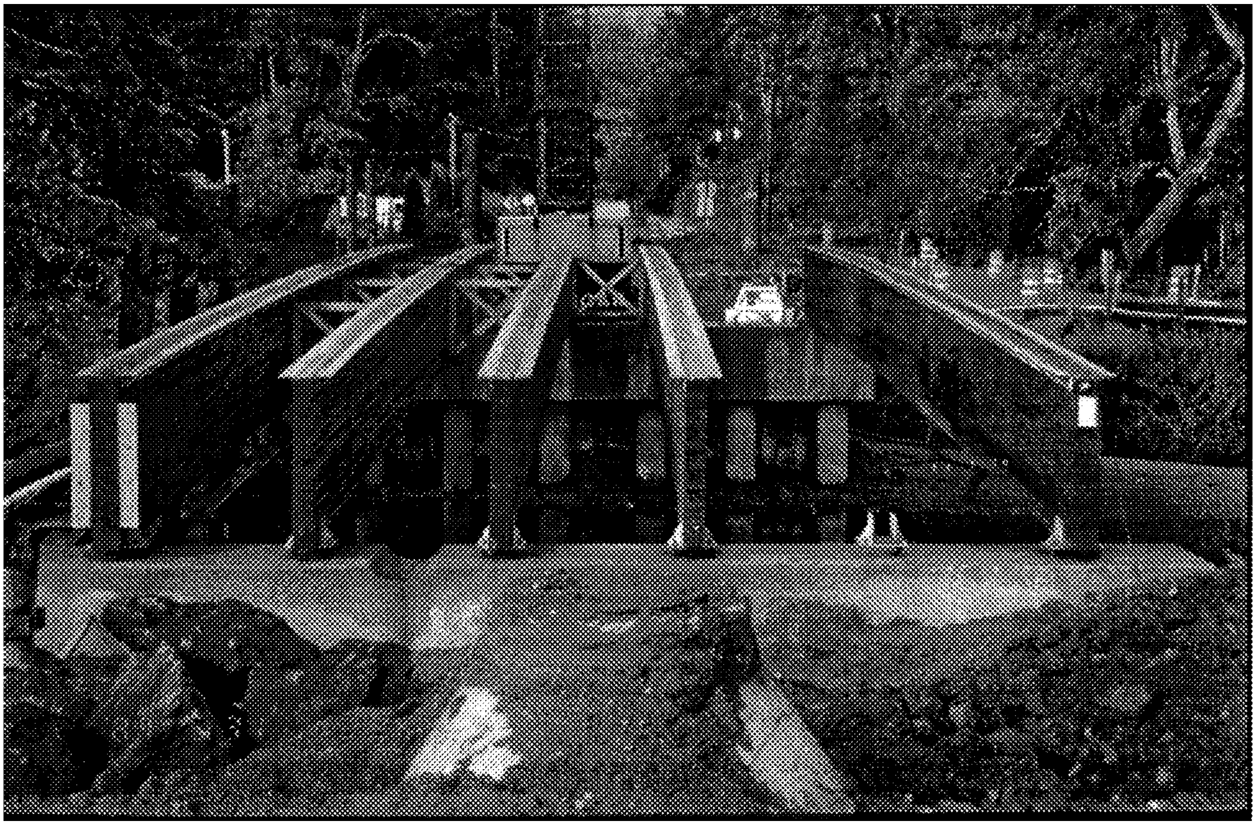

Figure 2-End view of the girders.

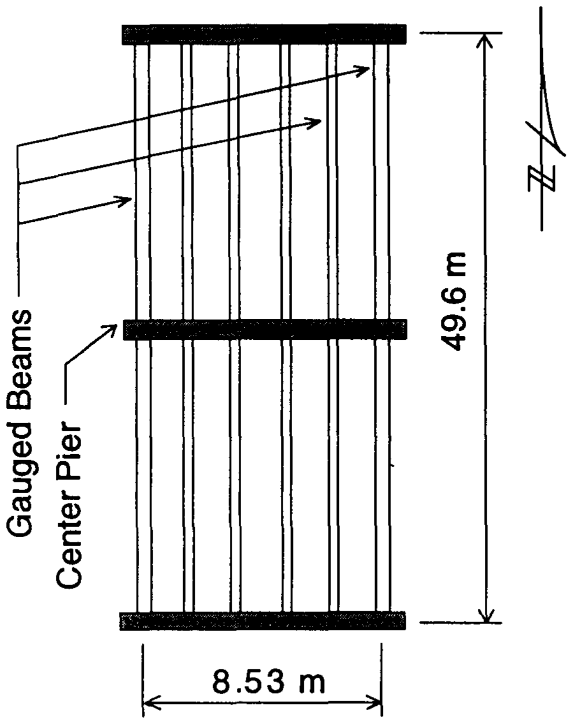

Figure 3-Plan view showing the location of gauged girders in the Clallam Bay bridge.

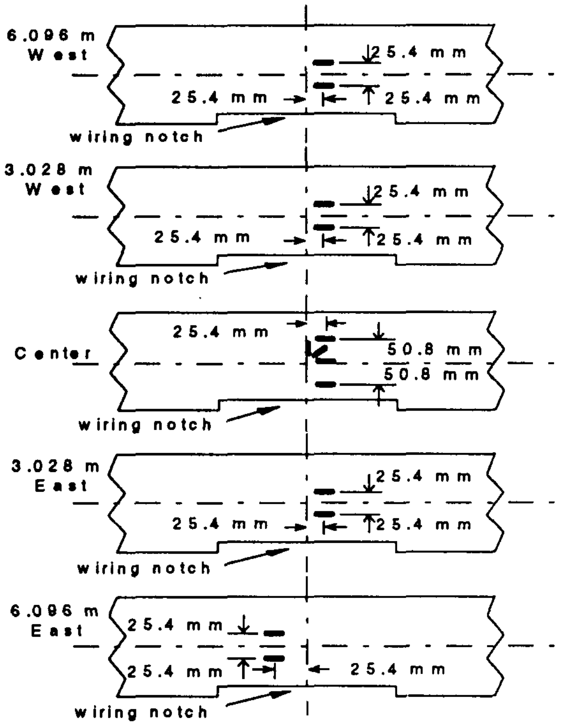

Figure 4-Plan view of strain gauge layout in the girders.

The estimated unreinforced glulam beam size is 273 mm x 1524 mm for the interior and exterior girders. Based on an estimated wood cost of $775/MBF for reinforced Douglas-fir L2 and $850/MBF for unreinforced Douglas-fir 24F-V4, the overall cost savings for the bridge girders is approximately 24% (compared to the unreinforced option) which includes $250/MBF for treatment costs. FiRP™ Reinforced girders also provide an estimated 10% cost savings and less than 10% of the weight compared to precast concrete.

Objective

The purpose of this study is to investigate the long term performance of FiRP™ Reinforced glulam bridge girders subjected to in-service conditions such as dead loads, live loads, and environmental factors such as moisture content and temperature fluctuations.

Procedure

Both electronic data acquisition of strain gauges and direct surveying using precision optical levels are used to assess the response of the Clallam Bay bridge to applied loads and environmental conditions.

Strain Gauge Data Acquisition

Three of the main girders, two exterior and one interior, were fitted with internal strain gauges internally on the reinforcement and on the wood. Figure 3 shows the location of the gauged girders in the bridge. Figures 4 and 5 show the location of the internal gauges. The strain gauges are located at the center span point and at 3.05 m and 6.10 m toward each end from the centerline.

General purpose strain gauges (Measurements Group, Inc., Raleigh, North Carolina), type EA-06-10CBE-120) with a 25.4 mm effective gauge length and 120.0 ± 0.15% ohms resistance at 24° C are used for the long term monitoring. This type of strain gauge has a working temperature range from -75° C to 175° C and a maximum of 5% strain.

The wires from each gauge are connected to the monitoring apparatus in a central instrument panel located near the centerline bridge pier. For the first portion of this study, battery power was provided in a separate enclosure to power the instrumentation. Strain gauge data is collected at 108 min. intervals and is routed to a 32 channel multiplexer for each girder then stored in the memory of a Campbell datalogger.

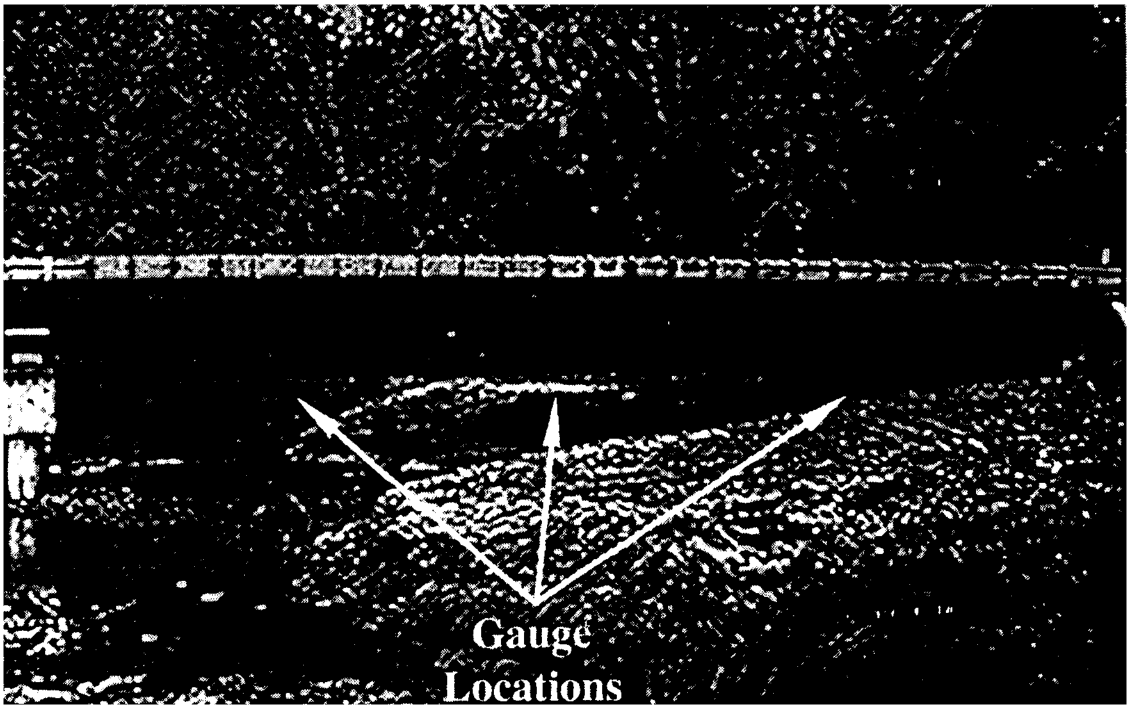

Figure 5-Photogragh of the northwest exterior girder showing location of the strain gauges.

Sensors for temperature, relative humidity and wood moisture content, a modem interface to allow remote user access to the data, and power line from a utility pole to provide electricity to the instrumentation will be installed in the summer of 1996.

Strain Gauge Data Processing

Strain gauge data down loaded from the Campbell datalogger was processed in Microsoft Excel 5.0 (1994). The voltage output from the gauges was converted to microstrain through a calibration constant of 1904 $^{\text{microstrain}}/_{\text{Volt}}$. The strain was subsequently zeroed-out based on the first recorded strain reading.

Survey of the Northwest Exterior Girder

Additional deflection measurements are taken by direct surveying. Locations on the bottom of the northwest exterior girder corresponding to the internal strain gauge locations are marked to allow consistent level measurements to be made. Benchmarks are located at the supports and the center pier. The initial survey took place on September 21, 1995 and the elevation of the deflected shape of the northwest exterior girder was established. During this time, only the dead load of the girder and the bridge deck contributed to the deflection. Upon returning to the bridge on January 26, 1996 (after the construction was complete), another survey was conducted to measure the deflected shape of the northwest exterior girder.

Results

Strain Gauge Analysis

Figure 6 displays the axial strain on the wood of the northwest exterior girder at the centerline, 3.05 m from the centerline and 6.10 m from the centerline. As shown in Figure 6, the axial strain in the northwest exterior reinforced glulam beam in the extreme tension zone shows an initial increase due to application of the asphalt concrete wearing surface. However, after the initial strain increase, no significant creep can be seen. A significant amount of variation in the strain is apparent.

A Fourier analysis was conducted to transform the time-domain to the frequency-domain using a fast Fourier transform algorithm to check for the influence of cyclic events. Figure 7 displays the Fourier amplitude spectrum of a strain gauge mounted on the wood between the bottom lamination and the reinforcement on the northwest exterior girder. Perhaps the most important result from the Fourier analysis is the presence of a spike at the one-per-day frequency indicating that there is significant cyclic

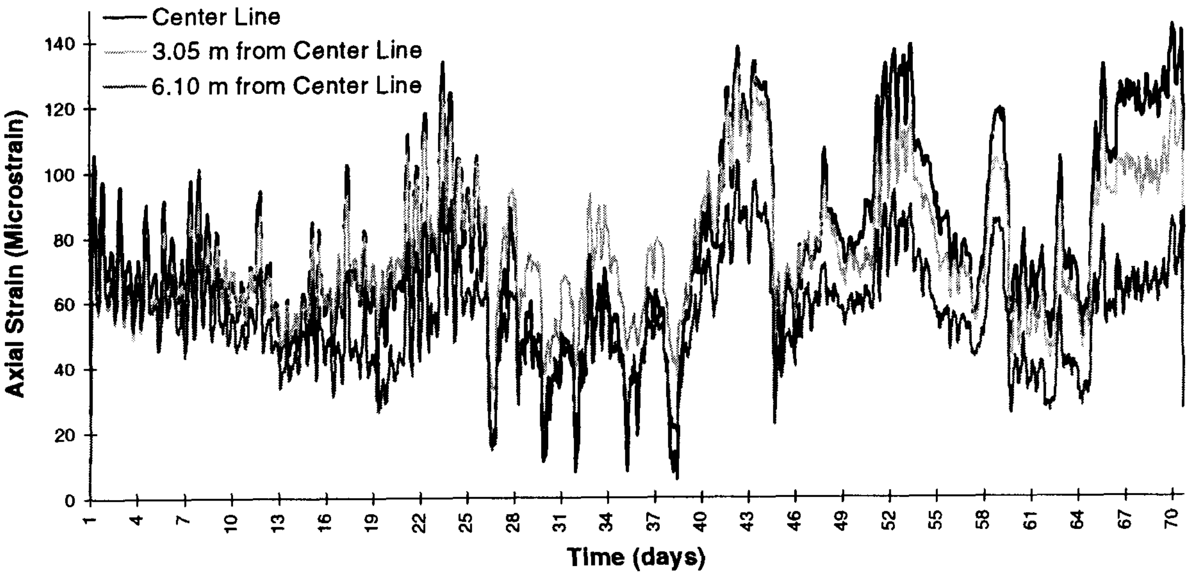

Figure 6-Response of strain gauges located at the centerline of each of the three gauged girders in the tension zone.

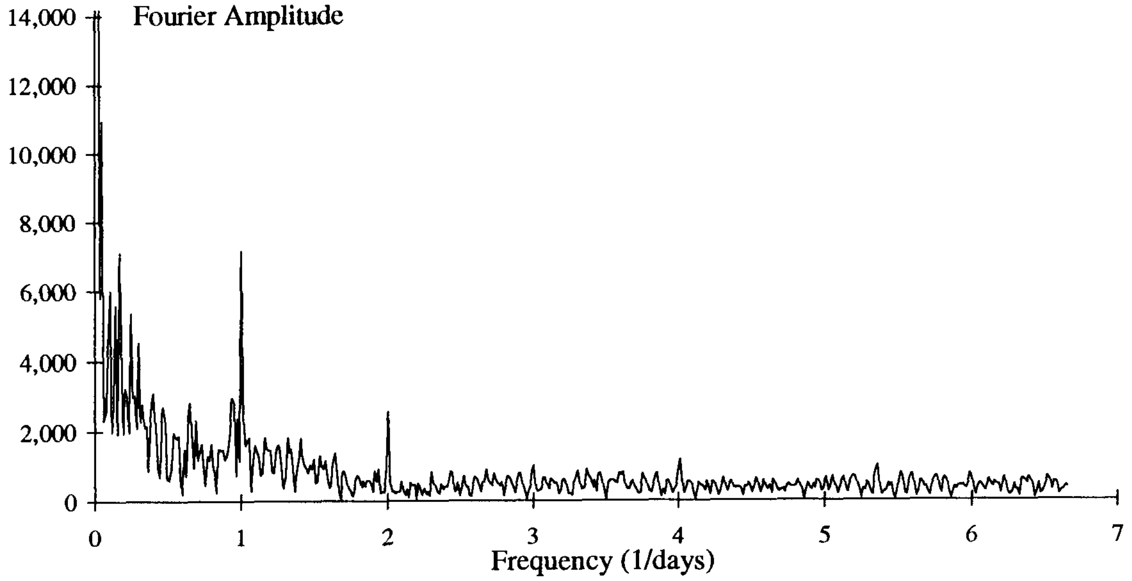

Figure 7-Fourier amplitude spectrum of a typical strain gauge response.

behavior at one-day intervals (the corresponding harmonics can be seen at higher frequencies). All of the strain gauges experienced the cyclic behavior. The most reasonable explanation of this response is day-to-day temperature fluctuations.

Generally, the strain gauges placed on the two exterior girders exhibited a larger degree of sensitivity to temperature than the interior girder due to the more direct exposure to the environment.

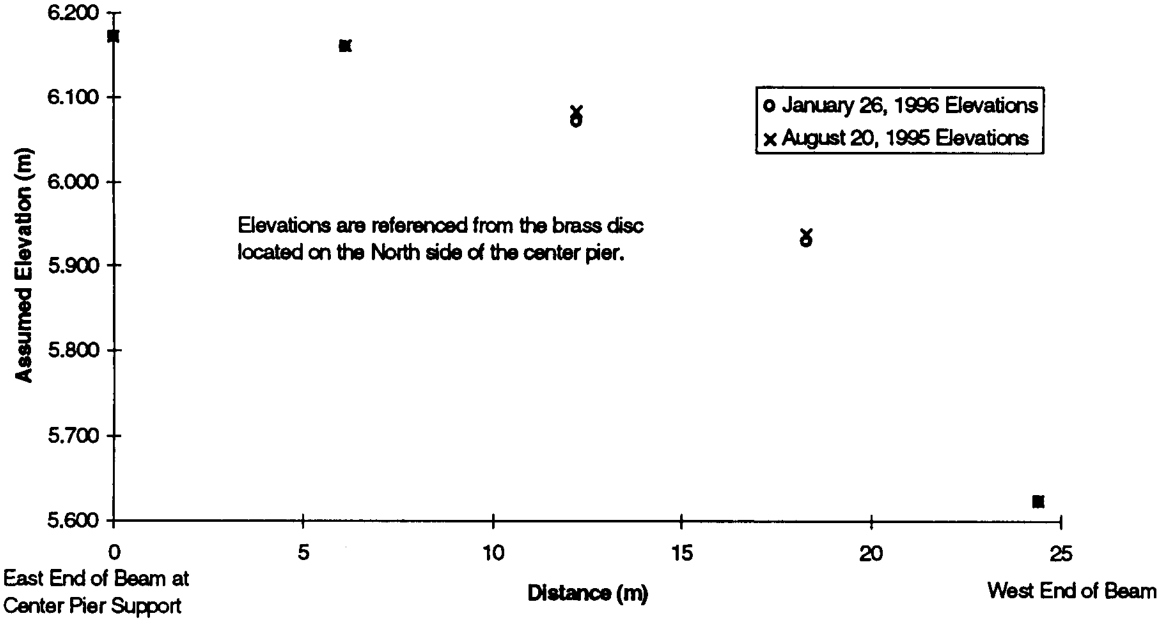

Figure 8-Survey results of the northwest exterior girder.

Survey of the Northwest Exterior Girder

Using a precision automatic level, the elevation of the bottom of the northwest exterior girder was measured in reference to a brass benchmark located on the north side of the center pier (assumed elevation of 6.096 m). Figure 8 displays the results of the two surveys. A difference in the centerline deflection of 1.016 mm can be seen from Figure 8 as a result of the increased dead load from the asphalt wearing surface.

Conclusions

The advantages of using FiRP™ Reinforced glulams were found to be

- Reduced cost due to low grade wood substitution
- Small cross section
- Substantially lower treatment costs
- Lower transportation weight
- Decreased coefficient of variation of the modulus of elasticity and strength
- Deadweight reduction allowing for simplified erection
- Utilization of low grade wood

The data collected to-date shows no appreciable creep in the reinforced girders. The slight increase in strain can be attributed to temperature effects.

The strain gauge output from the datalogger is heavily influenced by environmental conditions. It is apparent that modifications need to be implemented to the strain gauge acquisition system to account for the influence of environmental conditions. Planed modifications to be implemented during the summer of 1996 are:

- Control strain gauge, subject only to thermal stress to account for temperature variations.
- Thermometer
- Relative humidity indicator
- Modem for periodic downloading of data
- Electrical outlet for the data acquisition system

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