GRP Prestressing of Wood Decks

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Abstract

This paper describes the results of an experimental program in which Glass Reinforced Plastic (GRP) tendons, rather than the commonly employed steel threaded bars, are used to post-tension a laminated wood deck. Initial results show that properly designed GRP tendons can significantly reduce prestress losses. While initial results are encouraging, long term concerns with GRP tendons include creep-rupture in the E-glass reinforcement and environmental attack on the glass fibers.

Introduction

In stress-laminated bridges, longitudinal wood laminations, consisting of either solid sawn lumber, glulam girders, LVL girders, or a combination of these are post-tensioned transverse to traffic (Ritter, 1992). The prestress force causes friction to develop between the wood laminations, enhancing the load sharing capacity of the system and causing the behavior of the individual laminations to approach that of a continuous orthotropic plate.

One of the biggest draw-backs of stress-laminated bridges is the need to periodically retention them in service. Creep in the wood laminations over time can cause significant losses of prestress. According to the AASHTO Guide Specification for Stress-Laminated Decks (AASHTO, 1991), the initial prestress p_i applied to the deck should be 2.5 times the minimum required value p to compensate for losses due to creep and relaxation. Also, the AASHTO Guide Specification calls for re-stressing the deck to the same initial level p_i during the second and again between the fifth and eighth weeks after the first laminating.

Even though the re-stressing operation is relatively easy to perform and requires less than one day on most bridges, DOT engineers and maintenance personnel are often not at ease with a bridge. design that needs periodic re-stressing.

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Stress-laminated systems would therefore gain more acceptance if re-stressing in Service can be avoided, The objective of this paper is to evaluate the effectiveness of Glass Reinforced Plastic (GRP) tendons in reducing prestress losses in stress-laminated wood decks thereby avoiding re-stressing in service.

Prestress Losses in Stress-Laminated Wood Decks

An early study on prestress losses in stress-laminated wood systems was conducted at Queen's University using small-scale laboratory models post-tensioned using 19 mm Grade 5 steel threadbars (Batchelor et al., 1981). The test results showed that long-term prestress losses may be as high as 65 % of the initial prestress. Restressing could however reduce the prestress losses to 45% of the initial prestress. Subsequent restressing did not show any further reduction of prestress loss. About 50% prestress loss was observed in the Herbert Creek Bridge, the first stress-laminated wood bridge deck, constructed in Ontario, Canada. Another laboratory study of prestress loss conducted on a 14 m x 3 m deck at the University of Wisconsin showed that the long-term prestress losses exceed 50% (Dimakis, 1987).

In order to reduce the magnitude of the long-term prestress losses, it is possible to install the bridge at a moisture content (MC) below the expected Equilibrium Moisture Content (EMC) for the site. The wood expansion in service will compensate in part for the loss of prestress in the deck. Another way to reduce the prestress losses may be to reduce the stiffness of the steel stressing system by using curved-washer type springs (Belleville springs) in series with the steel prestressing threadbars. Dagher et. al. (199 1) monitored a stress-laminated timber bridge in which one-half of the post-tensioning threadbars used Belleville springs. Results showed little difference in prestress between the half of the bridge with the Belleville springs and the other half of the bridge. The lack of effectiveness of the Belleville springs in this application was attributed at least in part to the corrosion of the spring stacks which caused them to partially "lock" in place.

GRP Stressing System: Advantages and Disadvantages

GRP tendons have a relatively low modulus, about one-fourth that of steel; they also have a relatively high strength, as much as twice that of Grade 50 steel. It is however the low stiffness of GRP tendons that makes them attractive in stresslam deck applications. The low stiffness of GRP tendons is expected to reduce prestress losses in stress-laminated decks. GRP tendons are also desirable because of their low cost compared to carbon or Kevlar composites.

While GRP tendons have the advantages stated above, there are some important concerns with regard to their use as prestressing elements in bridges. When the sustained load is above a minimum threshold, GRP exhibit creep-rupture failures. The creep-rupture problem in glass reinforced plastics has been known for a long time (Barker and Bott, 1967; Hofer and Olsen, 1967). Creep-rupture of GRP may be accelerated in aqueous and seawater environments (Phillips et. al., 1983; Hogg and Hull, 1983). As stress levels increase, cracks in the matrix accelerate water penetration into the GRP which may cause surface pitting and strength reduction of the glass fibers.

In dry samples, the minimum critical stress which may cause creep rupture in GRP has been reported as high as 50% of the ultimate tensile strength. However, because of environmental exposure in bridge applications, the prestress level in GRP tendons should be kept lower than 50%, possibly in the 20-30% range. Even lower stresses may be required if there is significant shear lag in the prestressing elements used. Shear lag will cause higher-than average stresses on the outer portions of the cross-section near the anchors and accelerate creep-rupture rates in those areas.

To verify the manufacturer’s claims with regard to the relaxation rates in the particular GRP tendons used in this study, a GRP tendon was placed in a laboratory steel reaction frame under an initial stress equal to approximately 50% of the ultimate strength of the tendon. The prestress force, temperature and humidity were monitored daily. As of this writing, the test has been on-going for nearly one year and there is no evidence of a relaxation loss in the GRP tendon.

Laboratory Creep Test of Wood Deck Stressed with GRP Tendons

A laboratory test was conducted to study prestress losses in a wood deck post-tensioned with GRP tendons. The stress-laminated wood deck was approximately 5 m x 3 m, in which rough-sawn 5 mm x 25.4 mm (2 inch x10 inch) eastern hemlock wood laminations ran in the 5 m direction and the GRP tendons ran in the 3 m direction. There were ten GRP tendons in the deck and six of them were instrumented using load cells. The load cells were calibrated using a hydraulic universal testing machine before they were mounted on the deck. The creep test was conducted in a relatively constant indoor environment with temperatures ranging from 24°C to 27°C (75 to 80°F). Although there was a larger fluctuation of the relative humidity inside the lab (21%-54%), the moisture content of the wood remained below 6 percent throughout the creep test.

The initial prestress introduced between the wood laminations was 520 kPa (75 psi). The corresponding prestressing force in each GRP tendon was 62 kN (14 kips). The GRP tendons have an ultimate tensile strength of 116 kN (26 kips). The 63 kN (14 kips) initial tendon stressing force is 54% of the tendon’s ultimate strength. This high value (54%) was used in the laboratory to simulate a worse-case scenario for creep-rupture of the GRP. As stated earlier field applications should use lower stresses in the GRP, in the order of 20%-30% of ultimate.

The 520 kPa (75 psi) initial prestress introduced between the wood laminations is intentionally lower than the 860 kPa (125 psi) commonly used with steel stressing systems. The reason for the lower initial prestress is to take advantage of the lower anticipated prestress losses with the GRP system. The prestress was applied using an ENERPAC center-hole hydraulic jack. Tensile forces in each tendon were brought up to 63 kN (14 kips) sequentially from one end of the deck to the other. Only two passes were required before the desired prestress force in the first tendon (that was stressed in the second pass) was within 5% of the target value of 63 kN (14 kips). This is a significant development because comparable steel stressing systems may require as many as five or more passes before the target forces in the prestressing bars are reached.

Test Results and Conclusions

In Figure 1, the average prestress loss in the GRP tendons is compared with the results obtained in the Queen's University study discussed earlier (Batchelor et. al., 1981). It is clear that the GRP tendons appear to significantly reduce the prestress losses over steel threadbars. The following is concluded:

1. After 110 days, the GRP prestress loss appears to have nearly stabilized at 20% of the initial prestress. The corresponding value for the steel threaded bars used in the Queen's University study was about 60% of the initial prestress.

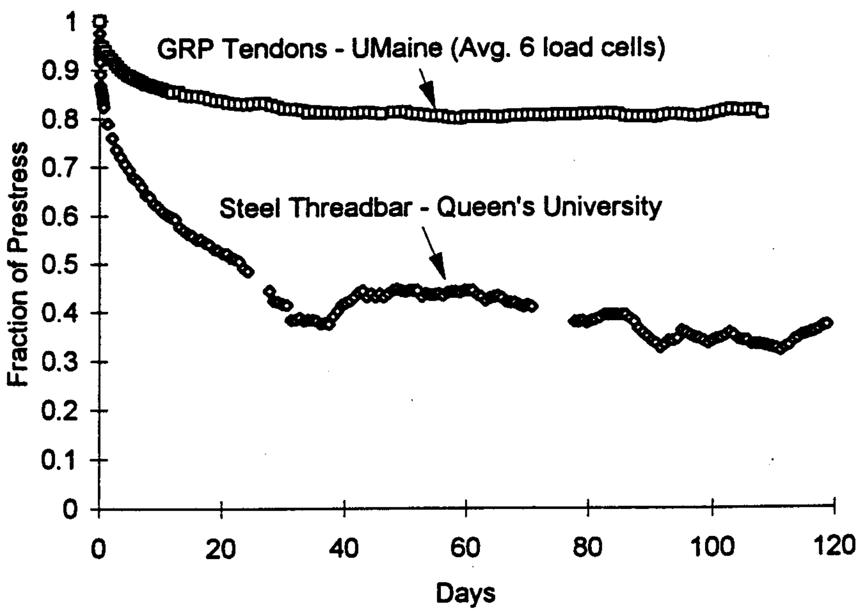

Figure 1. Prestress Loss: GRP vs Steel

2. Since prestress losses are reduced, the initial prestress in the GRP-wood deck does not need to be as high as is in the steel threadbar-wood deck, i.e. 860 kPa (125 psi). For the configuration tested, with an initial wood prestress of 520 kPa (75 psi), the residual prestress after 110 days is nearly 0.8x520 kPa = 416 kPa (60 psi). With a steel threadbar deck at an initial prestress of 860 kPa (125 psi), the remaining prestress after 110 days would be nearly 0.40 x 860 kPa = 344 kPa (56 psi).

3. The GRP system significantly reduces the number of passes required to complete the initial prestress. For the tested configuration, only two passes were required.
4. The prestress in the GRP in this laboratory study was near 54% of the ultimate strength of the GRP. This high stress level in the GRP was used to simulate a worse-case scenario in the laboratory and is not recommended in field applications. To avoid creep-rupture failures which may be accelerated by environmental attack, it is recommended to keep the prestress level in the GRP at 20-30% of the ultimate strength.

Initial results are encouraging and it may be possible to significantly reduce or even avoid re-stressing in service. However, more laboratory and field testing are necessary to further verify the results described in this paper.

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