PERFORMANCE OF BRIDGE TIMBER TIES
UNDER STATIC AND DYNAMIC LOADING

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ABSTRACT

A dramatic increase in railway car axle loads has occurred over the past 50 years. This paper presents the results of an experimental program undertaken at the University of Manitoba to evaluate the structural performance and durability of treated timber bridge ties under different load levels. A portion of a prototype bridge deck, consisting of eight prototype timber ties, was tested under various loading and support configurations using segmented railcar wheels, rails, and tie plates to determine the axle load distribution on the timber ties. Test results were compared to a theoretical model, based on energy principles, used to predict the axle load distribution on the ties for different bridge configurations. The shear strength of the timber ties was determined using nine large-size Z-shaped shear specimens with different shear cross sections machined from the same timber ties. Material properties of timber were obtained using bending tests of full-size treated bridge ties.

Serviceability of the treated timber bridge ties is also presented and discussed, based on fatigue testing of prototype timber bridge ties under different load levels.
INTRODUCTION

Treated timber ties are used extensively by railroads in the construction of open deck bridges in North America. The ties are supported on girders or stringers and the rails are seated onto bearing plates which are secured into the ties. It has been reported (CN Rail, 1989) that over the past 50 years, a dramatic increase in railway axle loads has occurred. Where a typical train normally consisted of 40 to 50 cars carrying 450 KN (50 tons) each, the trains of today are pulling 100-120 cars each carrying 890 KN (100 tons), and it is expected that the car capacities will increase up to 1112 KN (125 tons) or more in the future. In addition, some of the ties are showing signs of distress and failure in the form of longitudinal cracks. Hence, the behaviour and failure modes of the timber ties must be examined to verify the structural performance and durability of these ties under the increasing axle loads.

EXPERIMENTAL PROGRAM

A portion of an open deck bridge consisting of eight prototype treated timber bridge ties was constructed and tested to determine the axle load distribution to the ties (Soudki and Rizkalla, 1990). The ties were standard bridge ties, 255 mm × 304 mm (10 in × 12 in) in cross-section × 3.6 m (12 ft) long, creosote pressure treated Douglas fir. The different parameters investigated included the span of the ties, spacing between ties and the use of tie pads. In this program, tie spans of 2.44 m (8 ft) or 2.13 m (7 ft) were used, ties were spaced at 356 mm (14 in) or 406 mm (16 in) o/c, and tests were conducted with or without tie pads between the plate and the tie. Figure 1 shows the test setup used for the axle load distribution test. The ties were loaded through rail car wheels located halfway between ties #4 and #5 at the center of the 6 m rail segment, as shown in Figure 1. The load was applied in increments of 44.5 KN (10 kips) until a maximum specified load of 670 KN (150 kips) was reached. At each load increment, midspan deflection of each tie was recorded using linear variable differential transducers.

Material properties of timber were obtained through two-point load bending tests of full-size treated timber bridge ties. The bending tests were performed according to ASTM standard D198-84 (1989).

To determine the longitudinal shear strength of the treated timber ties, nine full-size Z-shape specimens, machined from typical timber bridge ties, with the same width and three different shear region lengths of 152 mm (6 in.), 304 mm (12 in.), and 452 mm (18 in.) were tested. The ends of the specimens were reinforced with a steel angle to induce pure shear loading condition, as shown in Figure 2.

To determine the fatigue life of the timber bridge ties, a total of six full-size bridge ties were tested under cyclic load levels ranging from 135 KN (30 kips) to 425 KN (95 kips), with the frequency varied between 0.5 to 2.0 Hz. The test setup is shown in Figure 3. One tie was tested at each load level. The load midspan deflection data were
recorded by an XY plotter during which the tie was cycled at a very low frequency. Each tie was tested up to failure. Failure of the tie was observed as material failure and/or excessive deflection and significant loss of stiffness of the tie.

TEST RESULTS AND DISCUSSION

Axle Load Distribution

Typical measured axle load distribution to the timber ties within the bridge test is shown in Figure 4. The slight skewness of the bell-shaped curves from the expected symmetrical shape could be attributed to possible uneven sizes or the bearing plates of the ties and/or variations of natural properties of timber used. Figure 4 is the axle load distribution curve for the case of a bridge with a tie span of 2.44 m (8 ft) and spacing of 356 mm (14 in), tested with no tie pads. In general, the measured load distribution indicates that the interior ties carry most of the axle load, whereas a small percentage of the load is distributed to the outer ties.

The measured maximum axle load distribution per tie for the eight tie open bridge configurations tested in this investigation is shown in Figure 5. Test results indicate that the maximum axle load distribution per tie is 25% and 30% for bridge with tie spans 2.44 m (8 ft) and 2.13 m (7 ft), respectively. It was found also that ties with spacing of 355 mm (14 in) produced a stiffer system in comparison to the 406 mm (16 in.) tie spacing. This conclusion is based on the fact that the measured values of the maximum axle load for the ties close to the applied load with tie spacing at 355 mm (14 in.) were less than those for the case with tie spacing of 406 mm (16 in.). The effect of using tie pads was insignificant in terms of load distribution. However, the results suggest that the presence of tie pads helps in distributing the load, as observed in the reduction of the skewness in the bell-shaped distribution.

Using prototype ties, it was found that the average modulus of elasticity for the treated 254 x 304 mm (10 in. x 12 in.) Douglas Fir ties is 9 MPa (1.3 ksi). This value is 13% lower than that for untreated Douglas Fir species given by the AREA Manual (1988) for Select Structural grade No. 1. This value could influence the load distribution, and should be used in predicting the axle load distribution.

Longitudinal Shear Strength

The measured ultimate shear stress, based on testing of full-size Z-shaped specimens, ranged from a minimum of 4.48 MPa (650 psi) to a maximum of 6.4 MPa (930 ksi) with a coefficient of variation of 13%. The average shear modulus was found to be 1.24 MPa (180 psi). Although the ultimate shear load was dependent upon the shear region, the ultimate shear stress was not significantly affected by the area of shear region. Failure of the shear specimens was characterized by radial and tangential splitting along the shear plane, as shown in Figure 6.
Using ASTM standard D245-88 (1989) and the ultimate measured shear strength, the minimum shear stress value for the treated Douglas Fir timber ties was calculated and found to be 0.85 MPa (120 psi). This value is higher than the allowable shear stress value for Douglas Fir given in the AREA Manual (1988) as 0.60 MPa (85 psi). It should be noted that the allowable shear stress values given in the AREA Manual (1988) are based on testing of small-size specimens of clear wood. In this program the results are based on tests of full-size Z-shaped shear specimens randomly chosen including all possible contributions of knots, checks, cracks and other defects in wood and therefore, the measured strength should be more reliable. The results based on this investigation indicate that the code value is conservative and should be modified to a more safe realistic value of 0.85 MPa (120 psi) in the design of treated bridge Douglas Fir timber ties.

Serviceability of Bridge Ties

Test results of six bridge ties tested under cyclic loading in this program are given in Table 1. Figure 7 shows typical mid span deflection-load curves at selected cycles for tie #4 tested at maximum load of 290 KN (65 kips). The relationship between the relative midspan deflection and the number of cycles for all specimens tested is shown in Figure 8. The relative deflection was calculated as the difference between the midspan deflection of the tie at maximum and minimum applied load. The test was terminated due to material failure of the tie and/or significant loss of stiffness as shown in Figures 7 and 8. The Strength-Number of cycles relationship, S-N, for the tested ties is shown in Figure 9. A parabolic regression model was used to quantify the variability of the data. Due to the limited number of specimens tested at this stage, the given curve mainly describes the trend of the behaviour at various load levels rather than qualitative conclusions in terms of the endurance limit. The research program includes testing of three additional ties at the lower load level.

Failure of the ties under cyclic loading was accompanied by significant cracking, large deflection and serious reduction in stiffness. The various modes of failure, for all tested specimens, are given in Table 1. The four failure patterns observed in this study are shown in Figure 10. The various failures were horizontal splitting of the ties at the corners of notches at the interface location with the supporting girders (Figure 10a), flexural tension cracks in the vicinity of the loading rail (Figure 10b), and/or crushing of the surface near or under the tie plate area (Figure 10c). For some cases, at low cyclic load level, brittle failure of the bearing plate occurred before failure of the tie (Figure 10d).

ANALYTICAL MODEL

The axle load distribution could be predicted with reasonable accuracy, using energy principles, by modelling the bridge deck as a beam on discrete elastic supports. The beam is the rail segment and the elastic supports are the timber ties. Tie pads
were also included as elastic springs in series with the elastic springs simulating the ties. The model is based on minimizing the total strain energy of the system with respect to the redundant forces carried by the springs. As a result, the solution reduces the system into simultaneous equations in terms of the redundant spring forces.

Using the above mathematical model, the maximum axle load distribution per tie was found to be 27% and 32% for ties spaced at 2.44 m (8 ft) and 2.13 m (7 ft), respectively. The calculated values are slightly higher than those measured experimentally. The difference could be attributed to the inelastic behaviour of timber ties rather than elastic behaviour assumed in the model, the variation of material properties of timber ties, contact of the bearing area and/or other construction details.

The measured-predicted ratios of the axle load distribution per tie are shown in Figure 11 as a function of the maximum measured values for the different test configurations. All test results were within 80% to 93% of the predicted values. It should be noted that both the experimental and theoretical predictions are still within the range of 33% of the axle load specified by section 1.3.4.1, chapter 7 of the AREA Manual (1988).

**CONCLUSION**

Based on the test results of this study, the following conclusions can be drawn:

1. The maximum measured axle load distribution per tie was found to be 25% and 30% of the axle load for bridge girders spaced at 2.44 m (8 ft) and 2.13 m (7 ft), respectively. These values are lower than the predicted values as well as the 33% value specified by the AREA Manual (1988).

2. A 355 mm (14 in.) spacing of the ties produces a stiffer system than 406 mm (16 in.) tie spacing. Similarly a 2.13 m (7 ft) girder spacing produces a stiffer deck than a 2.44 (8 ft) spacing.

3. An allowable shear stress of 0.85 MPa (120 psi) for treated Douglas Fir timber ties could be used under service loading conditions. This would yield more economical and safe design of Douglas Fir timber ties used for open deck bridges.

4. Fatigue life of treated Douglas Fir timber ties at different levels of axle load was determined and used to construct the S-N curve for this type of ties. Additional tests are currently underway at the lower load levels. This information is useful in assessing the lifetime serviceability of these timber ties.

5. The proposed mathematical model is capable of predicting the axle load distribution per tie in the elastic range. Test results are in good agreement with the theoretical values.
ACKNOWLEDGEMENT

This experimental program was conducted at the Structures Laboratory at the University of Manitoba. The financial assistance of CN Rail is greatly appreciated. The experiments were conducted by K.A. Soudki and C. Algeo. The help of Messrs. M. McVey, M. Green and E. Lemke is greatly appreciated.

REFERENCES


Soudki K.A. and Rizkalla S.H. Performance of Bridge Timber Ties under Static and Dynamic Loading, Report 1, Civil Engineering Department, University of Manitoba, Winnipeg, Manitoba, June 1990.

Table 1. Summary of dynamic test results at failure.

<table>
<thead>
<tr>
<th>Load KN (Kips)</th>
<th>Specimen Mark</th>
<th>Cycles to Failure</th>
<th>Comments</th>
<th>Mode of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>135 (30)</td>
<td>Tie #8</td>
<td>2,140,000</td>
<td>no failure</td>
<td></td>
</tr>
<tr>
<td>200 (40)</td>
<td>Tie #7</td>
<td>1,934,000</td>
<td>failed</td>
<td>1,4</td>
</tr>
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<td>225 (45)</td>
<td>Tie #1</td>
<td>2,928,800</td>
<td>failed</td>
<td>1</td>
</tr>
<tr>
<td>290 (60)</td>
<td>Tie #4</td>
<td>411,430</td>
<td>failed</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>356 (80)</td>
<td>Tie #3</td>
<td>126,240</td>
<td>failed</td>
<td>1,3</td>
</tr>
<tr>
<td>425 (95)</td>
<td>Tie #6</td>
<td>675</td>
<td>failed</td>
<td>1,3</td>
</tr>
</tbody>
</table>

Notes - failure modes:
1. tension splitting along notches
2. flexural tension cracks
3. crushing of tie fibers under pad
4. fracture of tie pad
Figure 1. Test setup for axle load distribution test.

Figure 2. Shear test setup.

Figure 3. Dynamic test setup.
Figure 4. Typical measured axle load distribution per tie.

Figure 5. Maximum measured axle load distribution per tie.
Figure 6. Typical shear failure.

Figure 7. Typical load-midspan deflection behaviour under cyclic loading.

Figure 8. Relationship between midspan deflection and number of cycles.

Figure 9. Failure S-N curve for timber bridge ties.
Figure 10. Failure patterns under cyclic loading: a) tension splitting, b) flexural tension cracks, c) crushing of tie fibers under pad, and d) fracture of bearing plate.

Figure 11. Comparison of measured and predicted axle load distribution per tie.