On Experimental Study of Steel Stiffened Wooden Beams

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ABSTRACT

This paper reports the experimental results of steel stiffened laminated lumber beams. All laminated lumber beams used in this experiment were 10.8m long and had cross sections of 40cm by 80cm. Specimen No. 1 was not stiffened with steel. Specimen No. 2 was stiffened with two steel plates: one was inserted in the top of the wooden beam and the other was inserted in the bottom. Specimen No. 3 was stiffened with steel plate and orthotropic steel deck. The steel plate was inserted in the bottom of the wooden beam and the orthotropic steel deck was put on top of the beam by connecting mutually with shear connectors. All specimens were measured stress-strain and central deflection of the beam using 100-ton and 600-ton capacity compression testing machines.

INTRODUCTION

Steel stiffened wooden continuous beam bridge, namely SW Continuous Beam Bridge, is stiffened with steel plate and orthotropic steel deck as shown in Fig. 1. The steel plate is inserted in the bottom of the wooden beam and the orthotropic steel deck is put on top of the beam by connecting mutually with shear connectors. Laminated lumber and steel plates are united with adhesive epoxy glue. Merits of SW Continuous Beam Bridge are as follows:

(1) The SW Continuous Beam Bridge, compared to prestressed concrete bridge and previous wooden bridge, proves to be the most economical structure.

(2) Utilizing orthotropic steel deck, the SW Continuous Beam Bridge is designed to accommodate the burden of full 25-ton trucks and can be expected to have a lifespan of greater than one hundred years.
(3) The laminated wooden beams are protected from corrosion by the steel deck which provides an impervious surface to rain. As this protection eliminates the need for an artificial preservative to be applied to the wood, the SW Continuous Beam Bridge is not harmful to the environment.

(4) Because the pre-tensioned concrete bridge does not allow for a continuous beam, the number of joints is inherently large. The SW Bridge, on the other hand, takes advantage of the steel deck to provide for a continuous beam, resulting in a strong to negative bending moment.

(5) The lightness of the SW Bridge (the specific gravity of wood is 0.6 and that of concrete is 2.4) is influenced less by earthquakes and allow for foundations which, economically, compare favorably to those of the concrete bridge.

(6) The speed of construction is much quicker than that of the post-tensioned concrete bridge whose construction must be done by hand on site where, additionally, quality control is difficult.

(7) The cost of changes or dismantlement in the future are economical compared to those of the concrete bridge. Horyu-ji temple in Nara demonstrates the durability of wooden structures, and both the wood and steel used for the SW Bridge are recyclable.

(8) The main beam of the SW Bridge is wood which, if the handrail is also of wood, gives the entire bridge the appearance of a wooden structure, therefore the SW Bridge gives soft and warm image.
TEST SPECIMENS

All laminated lumber beams used in this experiment were 10.8m long and had cross sections of 40cm by 80cm. Specimen No.1 was not stiffened with steel. Specimen No.2 was stiffened with two steel plates: one was inserted in the top of the wooden beam and the other was inserted in the bottom. The steel plates were 10.8m long and had cross-section of 2cm x 30cm. Specimen No.3 was stiffened with steel plate and orthotropic steel deck. The steel plate was inserted in the bottom of wooden beam and the orthotropic steel deck was put on top of the beam by connecting mutually with shear connectors. Laminated lumber and steel plates are united with adhesive epoxy glue. The tests were performed with simple support conditions. Strain gauges were placed at suitable locations to measure stress-strain in each specimen. All specimens were tested using 100-ton and 600-ton capacity compression testing machines. The central deflection of the beam was measured using dial gauges.

Fig. 2 Test specimens
COMPARISON OF ANALYSIS AND EXPERIMENTS

Analytical stress distribution of the specimen No.3 applied P=115 tf are shown in Fig.3. When young's modulus of steel $E_s=2.1 \times 10^5$ kgf/cm², young's modulus of laminated lumber $E_w=1.05 \times 10^5$ kgf/cm², and the ratio $E_w/E_s=1/20$, the bending stress of wood is 1/20 times as much as steel at the border with steel as shown by point a or point b in Fig.3.

**TABLE 1. Allowable stress (kgf/cm²)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Allowable Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminated lumber: Tension</td>
<td>65 - 110</td>
</tr>
<tr>
<td>Laminated lumber: Shear</td>
<td>9 - 12</td>
</tr>
<tr>
<td>Steel: Tension</td>
<td>1400 (SM400) - 2100 (SM620)</td>
</tr>
<tr>
<td>Steel: Shear</td>
<td>800 (SM400) - 1200 (SM620)</td>
</tr>
</tbody>
</table>

Fig. 3 Analytical stress distribution of specimen No.3
Steel equivalent Moment of Inertia: \( I_e = 1471769 - 47.3^2 \times 308.6 = 647104 \text{ cm}^4 \)

Flexural Rigidity: \( E I = E I_e = 2.1 \times 10^6 \times 647104 = 1.35 \times 10^{12} \text{ kgf} \cdot \text{cm}^2 \)

\( P = 115 \text{ tf}, \ P/2 = 57.5 \text{ tf}, Q = 57.5 \text{ tf}, M = 67.5 \times 4.0 = 230 \text{ tf} \cdot \text{m} = 2.3 \times 10^7 \text{ kgf} \cdot \text{cm} \)

\( C_a = M \cdot e_1 / I_e = 2.3 \times 10^7 \times 47.3 / 647104 = 35.54 \times 47.3 = 1681 \text{ kgf/cm}^2 \)

\( C_b = M \cdot y_2 / I_e = 35.54 \times 20.1 = 715 \text{ kgf/cm}^2, \quad (a_1 = 715/20 = 36 \text{ kgf/cm}^2) \)

\( C_{cb} = M \cdot y_9 / I_e = 35.54 \times 56.5 = 2009 \text{ kgf/cm}^2, \quad (a_{20} = 2009/20 = 100 \text{ kgf/cm}^2) \)

\( \sigma_N = (0/1_e) (S_N/t) = (67500/647104) (100 \times 1.2 \times 46.7 \times 1.2 \times 26 \times 33.14 \times 40 \times 20.1 / 20.1 / 20.1 / 20.1 / 20.1 / 20.1) / 40 \)

= 16 \text{ kgf/cm}^2

Strains at span center of specimen No. 3 are shown in Fig. 4. Analytical values are in good agreement with the experimental results.

\[\text{Dimension: mm}\]

\[\text{Fig. 4 Strains of specimen No. 3}\]
Load-deflection curves of three test specimens are shown in Fig. 5 and Fig. 6. Fig. 5 is experimental, and Fig. 6 is analytical. Specimen No. 3 with elastic shear connectors in Fig. 5 is more flexible than specimen No. 3 in Fig. 6. Allowable loads of three specimens are \( P_{a1} = 22.4 \text{tf} \), \( P_{a2} = 64.8 \text{tf} \), and \( P_{a3} = 115.0 \text{tf} \).

**Fig. 5 Load-deflection curves**

**Fig. 6 Analytical load-deflection relationship**

**CONCLUSION**

The results of experimental study are as follows:

1. Steel stiffened wooden beam has high flexural rigidity in comparison with previous wooden beam.
2. When young's modulus of steel \( E_s = 2.1 \times 10^4 \text{kgf/cm}^2 \), young's modulus of laminated lumber \( E_w = 1.05 \times 10^4 \text{kgf/cm}^2 \), and the ratio \( E_w/E_s = 1/20 \), the bending stress of wood is 1/20 times as much as steel at the border with steel as shown by point a or point b in Fig. 3.
3. Allowable load of the steel stiffened wooden beam is determined by bending- and shearing stress of wood at point b shown in Fig. 3 comparing with the allowable stress of TABLE I.