FLEXURAL RESPONSE OF GLUED LAMINATED (GLULAM) BEAMS SUBJECTED TO BLAST LOADS

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ABSTRACT: An extensive body of research is currently available on the behaviour of concrete and steel structures when subjected to blast threats, however, little to no details on how to address the design or retrofitting of wood structures are available. In this paper, preliminary results, both experimental and analytical, are presented on the flexural behaviour of glulam beams under high strain rates. A total of three 80 mm x 228 mm x 2,500 mm glulam beams with a clear span of 2,235 mm were subjected to simulated blast loads using a shock tube. The preliminary experimental results showed that a brash tension failure mode was observed on the tension laminate. It was also shown that a simplified SDOF model, using linear elastic resistance curves, was capable of predicting the failure displacement and level of damage with reasonable accuracy.

KEYWORDS: glued laminated timber, high strain rates, flexural response, blast loading, glulam beams, SDOF model.

1 BACKGROUND

The advancement in manufacturing technologies to produce engineered wood products has allowed for wood to be utilized beyond traditional low-rise light-frame structures and to become a viable material option for much larger structures. Such engineered products include, but are not limited to, glued laminated (Glulam) timber, cross laminated timber (CLT), parallel strand lumber (PSL) and laminated veneer lumber (LVL). Where glulam has been used for at least 100 years, new wood products are becoming increasingly economically viable compared to other construction materials, mainly due to sustainability considerations.

One area where there is little to no literature is available is on establishing the behaviour of glulam under high strain rates, similar to those experienced under blast loading. With the potential of the glulam structures to be high-risk high-profile structures, mitigation methodologies to deliberate attacks (i.e. World Trade Center 2001, Oklahoma City Bombing 1995) and accidental explosions (i.e. Lac Mégantic 2013, BP Texas 2005) need to be investigated. Whereas an extensive body of research is currently available on concrete and steel structures [1-3], limited research on how to address the design or retrofitting of wood structures subjected to a blast threat is available. The research has mainly been focused on typical North American light-frame trailers usually found in petro-chemical facilities or barracks used to house soldiers abroad [4-6].

This paper presents preliminary results on an investigation of the flexural response of glulam beams subjected to a shock wave simulating far-field blast loading. In addition to reporting on the experimental results and failure modes, the paper investigate whether an equivalent single-degree-of-freedom (SDOF) model can effectively describe the response of the beams under blast loading.

2 EXPERIMENTAL PROGRAM

The experimental research is being conducted in the Blast Research Laboratory at the University of Ottawa, which is a unique facility in Canada. So far, a total of three 80 mm x 228 mm x 2,500 mm Spruce-Pine (SP) 20F-E beams were subjected to simulated blast loading under four point bending and simply supported end conditions. The following sections describe the shock tube apparatus and the dynamic test setup as shown in Figure 1.

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The strain gauges, LVDTs, and pressure sensors were connected to the data acquisition system which recorded the experimental data at a sampling rate of 100,000 samples per second. The data acquisition system was triggered by the shock wave front as it passed the pressure sensors.

3 EXPERIMENTAL AND ANALYTICAL RESULTS

Table 1 shows a summary of the results completed so far. The table includes the reflected pressure, $P_r$, reflected impulse, $I_r$, displacement at mid-span, $\Delta L/2$, displacement at the load point, $\Delta L/3$, and the time to maximum displacement.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$P_r$ (kPa)</th>
<th>$I_r$ (kPa-ms)</th>
<th>$\Delta L/2$ (mm)</th>
<th>$\Delta L/3$ (mm)</th>
<th>$t_{\Delta \text{max}}$ (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1.1</td>
<td>52.4</td>
<td>407</td>
<td>26</td>
<td>26</td>
<td>11.8</td>
</tr>
<tr>
<td>B2.1</td>
<td>28.3</td>
<td>245</td>
<td>22</td>
<td>26</td>
<td>20.2</td>
</tr>
<tr>
<td>B2.2</td>
<td>44.7</td>
<td>337</td>
<td>35</td>
<td>34</td>
<td>16.6</td>
</tr>
<tr>
<td>B3.1</td>
<td>49.4</td>
<td>347</td>
<td>36</td>
<td>32</td>
<td>16.2</td>
</tr>
</tbody>
</table>

Equivalent SDOF analysis was performed and the predictions were compared to the experimental mid-span displacement as shown in Figure 2. It can be seen that the model accurately predicted the maximum displacement as well as time to maximum displacement. This demonstrates that the SDOF method, with appropriate input parameters and conversion factors, can be employed to predict the behaviour of the beam.

For the purpose of comparing the observed damage levels to what was predicted by the model, a P-I diagram was generated and showed conservative estimate of the expected damage.

4 CONCLUSIONS

An experimental program investigating the dynamic behaviour of glulam beams and columns under blast loading is underway. The paper presents the preliminary results of three 80 mm x 228 mm x 2,500 mm beams with a clear span of 2,235 mm subjected to shockwave loading causing high strain rates in the beams.

The preliminary analytical results showed that a SDOF approach can effectively be used to predict the maximum displacement time to maximum displacement but that the model is conservative in predicting the damage levels.

More research is underway by the authors to fully investigate the behaviour of glulam beams and columns under shock wave loading.

REFERENCES