Species, Grading, and Mechanical Properties of Locally Sourced Lumber in the Joyabaj Region of Guatemala

Summary Paper

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Keywords: Guatemala, locally sourced lumber, lumber grading, lumber mechanical properties

1 TARGET AUDIENCE

Individuals and organizations that design wood structures who are interested in evaluating locally sourced lumber provided by sawmills that do not identify lumber by species or grade.

2 BACKGROUND

The Milwaukee School of Engineering (MSOE) chapter of Engineers without Borders USA (EWB-USA) has been collaborating with the local government of Joyabaj, Guatemala for over a decade on the design and implementation of several vehicular and pedestrian bridges. The construction of these bridges requires a significant amount of locally sourced lumber for formwork from a small community sawmill. The lumber from this sawmill is not separated or identified by species or grade. It was known that the lumber was comprised of three species of pine, but the distribution of grades and mechanical properties were unknown.

3 PURPOSE

The objectives of this study were to investigate the species, evaluate the quality by assessing the distribution of lumber grades, and determine the mechanical properties of lumber purchased from an informal sawmill in the Joyabaj region of Guatemala for use on EWB projects.

4 METHOD

This research project included three components: species investigation, lumber grade distribution assessment, and mechanical properties determination. The species investigation
include interviews, material testing, and comparison to literature. The distribution of lumber grades was assessed by grading 509 pieces of lumber according to a visual grading guide created by the authors from standard grading rules used in industry. Clear wood testing was performed on 64 samples in MSOE’s structural laboratory to determine modulus of rupture, compression parallel to grain, modulus of elasticity, and specific gravity.

5 RESULTS

The lumber provided by the local sawmill in Joyabaj, Guatemala was not identified by species, but was determined to be a mixture of three species of pine grown in the region. The lumber quality was additionally not identified by grade but was determined that approximately 90% was No. 3 or better and approximately 50% to 80% was No. 2 or better depending on the size of lumber. Design properties of Eastern White Pine were adopted as conservative values for lumber sourced from this sawmill.

6 IMPLICATIONS FOR TARGET AUDIENCES

This paper outlines a strategy for other individuals or organizations to evaluate the species, distribution of grades, and mechanical properties of lumber from local sawmills where this specific information is unavailable.
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Abstract: The purpose of this project was to research the lumber used by Engineers without Borders (EWB) groups in the Joyabaj region of Guatemala. This project aimed to investigate the species of wood, evaluate the quality by assessing the distribution of lumber grades, and determine mechanical properties. The results will aid EWB groups in the design of wood structures in the Joyabaj region of Guatemala.

Samples were collected for species investigation and mechanical testing. Species investigation was triangulated from interviews with the sawmill owner, construction foreman, testing by the USDA Forest Products Laboratory, and comparisons to literature. The results were inconclusive and indicated multiple species were intermixed at the sawmill with no distinction made when purchased. Lumber quality was evaluated by using a visual grading guide developed by the authors to assess the distribution of grades within a large order of lumber. Static bending and compression parallel to grain tests were conducted to obtain modulus of rupture, compression parallel to grain, and modulus of elasticity. Specific gravity was also obtained.

The results indicate that three different species were collected. Ninety percent of the lumber was No. 3 or better and 50% to 80% was No. 2 or better depending on the size. Clear wood testing values were similar to those of Eastern White Pine. Structural design should be performed based on National Design Specification (NDS) design values for a No. 3 or No. 2 Eastern White Pine, depending on the degree of wood selection in the construction process.

Keywords: Guatemala, locally sourced lumber, lumber grading, lumber mechanical properties

1 INTRODUCTION

The municipality of Joyabaj is located in the Sierra de Chuacús Mountains of Guatemala. Several chapters of Engineering without Borders (EWB) partner with the municipal planning office and community development committees to address civil infrastructure needs. The Milwaukee School of Engineering (MSOE) chapter of EWB-USA has been working in Joyabaj
for over a decade on the design and implementation of several vehicular and pedestrian bridges. The construction of these bridges requires significant amounts of locally sourced lumber for formwork (Figure 1). While there is a well-established, responsibly regulated, professional lumber industry in Guatemala, the lumber used in these EWB projects is provided from a small community sawmill. The lumber from this sawmill is not separated or identified by species or grade.

Figure 1: Formwork for the Aguacate II Vehicular Bridge in Joyabaj, Guatemala using locally sourced lumber

The purpose of this study was to investigate the species of wood, evaluate the quality by assessing the distribution of lumber grades, and determine mechanical properties of the lumber provided by this local sawmill. The results will aid multiple EWB groups in the design of wood structures in the Joyabaj region. This paper also serves to outline a strategy for other EWB groups to evaluate the lumber used in their projects in any region of the world.

2 BACKGROUND

2.1 Species Investigation

There are more than 300 species of trees in Guatemala and pines are the most common for structural lumber with Pinus oocarpa being the primary species (Rosales et al., 1995). The many pine species have common names that vary regionally (CONCYT, 1999).
The Guatemalan sawmill owner and the Guatemalan construction foreman identified four species of pine grown and harvested in the Joyabaj region (De Leon Vielman, 2014; Ortega 2014). They referenced their common names (pino blanco, pino macho, pino hembra, and pino ocote) and did not know their botanical or scientific names.

The Forest Products Laboratory (FPL) of the United States Department of Agriculture (USDA) Forest Service identified three main species of hard pine that grow in Guatemala: *Pinus oocarpa*, *Pinus patula*, and *Pinus caribaea*.

### 2.2 Grading

Lumber is graded for quality by either visual inspection (visually graded lumber) or by a non-destructive test (machine stress rated). Visually graded lumber is by far the most common method of grading sawn lumber and is performed according to a set of grading rules applicable to a species group (Breyer et al., 2015). A species group contains species with similar strength properties that can therefore be evaluated by the same grading process.

Visual grading determines the structural quality of lumber based heavily on the presence and size of defects or “characteristics.” Many characteristics (e.g., knots, decay, warp, checks) are assessed during the visual grading process, and some are specific to a certain species or species group.

### 2.3 Mechanical Properties

Within a species, the mechanical properties (e.g., bending stress, compressive stress, modulus of elasticity) of wood vary due to its anisotropic nature, the presence of defects (e.g., knots, checks, splits), and other issues (e.g., growth rate, moisture content).

A species group reports mechanical properties that are conservative for all species within the species group. Generally, structural engineers do not design based on properties of a specific species but rather from a species group (Breyer et al., 2015).

Currently the US performs in-grade testing on full size specimens (e.g., a No. 2 2x4 by 12’ long (38mm x 89mm by 3658mm long)) to obtain mechanical properties. Historically, clear wood testing was the industry standard to obtain mechanical properties for dimension lumber in the US. Clear wood testing uses small, clear, straight-grained specimens free of defects to determine the clear wood strength. Full sized strength properties for each grade can then be determined by multiplying the clear wood strength by a series of factors to account for a 5% exclusion, seasoning, presence of defects, load duration, among others (Breyer et al., 2015).

A summary of the clear wood mechanical properties of the three common hard pine species in Guatemala identified by the FPL are listed in Table 1. The data was obtained for clear wood specimens at 12% moisture content from literature (Kretschmann, 2010; Chudnoff, 1984).

<table>
<thead>
<tr>
<th>Species</th>
<th>Botanical name</th>
<th>Modulus of Rupture</th>
<th>Modulus of Elasticity</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Compression parallel to grain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Summary of small clear wood mechanical properties for common species found in Joyabaj, Guatemala
Pinus oocarpa  103 (14,900)  53.0 (7,680)  15.5 (2.25)  0.55
Pinus patula  82.7 (12,000)  50.3 (7,300)  12.8 (1.86)  0.40
Pinus caribaea  115 (16,700)  58.9 (8,540)  15.4 (2.24)  0.68

3  METHODOLOGY

3.1 Sample Gathering

The samples obtained in this study were obtained from the Aserradero Movil De Leon sawmill (Figure 2) in Joyabaj, Guatemala. Numerous EWB chapters have obtained lumber from this sawmill for more than a decade. Samples were collected over three trips: Trip A (June 2014), Trip B (November 2014), and Trip C (March 2015). Clear-grained samples selected by the authors were cut oversized to 64mm x 64mm x 813mm (2.5” x 2.5” x 32”) to allow for shrinkage and warping during conditioning prior to final machining to the required testing specimen dimensions. The final specimen dimensions were 50mm x 50mm x 762mm (2” x 2” x 30”) for static bending testing and 50mm x 50mm x 205mm (2” x 2” x 8”) for compression parallel to grain and modulus of elasticity testing in accordance with ASTM D143-09.

Figure 2: Bogle-Boesiger and Davis obtaining samples at sawmill in Joyabaj, Guatemala

3.2 Species Investigation

The species investigation included personal interviews with the sawmill owner (De Leon
Vielman, 2014) and the construction foreman (Ortega, 2014), crosschecking with documented properties for clear grain samples (Kretschmann, 2010; Chudnoff, 1984), and through species identification testing performed by the USDA Forest Products Laboratory (FPL).

3.3 Grading

While the exact species was unknown at the onset of this study, it was certain that they were Pines. Various grading rules were consulted in the preparation of a Visual Grading Guide. The grading rules from the Southern Pine Inspection Bureau (SPIB, 2014) were the primary source due to the likelihood that the lumber was a hard pine similar to the southern pines of the USA and that the Guatemala timber industry has used southern pine design properties (Rosales et al., 1995). The Visual Grading Guide included basic terminology and the characteristics that would affect the grade. Each characteristic included a graphic, a description, and the conditions for each grade. The possible grades were Select Structural, No. 1, No. 2, No. 3, and below No. 3.

To evaluate the distribution of grades in the lumber provided by the sawmill, the Visual Grading Guide was field tested by one of the authors on 509 pieces of lumber for use as forming for a vehicular bridge (Figure 3). Lumber sizes are described by their nominal cross-section dimensions in inches. All the 2x4s, 2x6s, and 4x4s were evaluated, but only a portion of the 2x3s and 1x12s were evaluated due to time constraints. Lumber was taken from various parts of each pile to ensure randomness. Each piece was numbered, photographed, and measured. All four sides were inspected. The size and soundness of knots were recorded, the presence of decay, warp, wane, split, shake, compression, and checks were also noted for evaluation. Some defects such as sloping grain, compression failure, and checks were not assessed due to the roughness of the cut and the dirt that covered them. Warp was measured on obviously warped pieces by comparing to a flat surface.

Figure 3: Portion of the lumber graded in this research project

The Visual Grading Guide developed by the authors was intended to be used as a tool to ensure
that the lumber used for structural applications would meet design assumptions. Following the field test, it was determined that it was not necessary to separate the lumber into discrete grades, but rather to identify those that were of a No. 2 or better quality. Therefore, a simplified Pass/Fail Visual Grading Guide (included in the appendix) was developed with pass/fail criteria including several main characteristics. Those that passed (i.e., No. 2 or better) would be used for structural applications, and those that failed would be used for lesser applications.

3.4 Mechanical Properties

The samples for mechanical testing were conditioned to an equilibrium moisture content (EMC) of 12% in a humidity and temperature chamber prior to testing. Once conditioned, the samples were milled at a local cabinetry shop to final dimensions per ASTM D143-09. The moisture content was verified by performing moisture content tests in accordance with ASTM D4442-07 method A (oven-drying) on small specimens cut from the samples before and after testing. Static bending and compression parallel to grain testing was performed in accordance with the testing procedures in ASTM D143-09.

The static bending tests (Figure 4) were performed on sixteen 50mm x 50mm x 762mm (2” x 2” x 30”) specimens centre-loaded in bending by a bearing block with supports 710mm (28”) apart. The specimens were loaded until failure and the test results used to determine the modulus of rupture (MOR).

The compression parallel to grain tests (Figure 5) were performed on twenty-four 50mm x 50mm x 205mm (2” x 2” x 8”) specimens loaded axially in compression along the long axis. The specimens were loaded until failure and the test results used to determine the compression parallel to grain ($F_c$) and modulus of elasticity (E). The equipment measuring axial strain...
malfunctioned such that modulus of elasticity (E) was not able to be obtained.

To increase the sample size for compression parallel to grain and obtain modulus of elasticity (E) data, twenty-four 50mm x 50mm x 205mm (2” x 2” x 8) specimens were cut from undamaged portions of the 50mm x 50mm x 762mm (2” x 2” x 30”) specimens used in the static bending tests. These specimens were loaded in a second round of compression testing. Their undamaged condition was verified by comparing the compression test results between the original and second round of testing.

![Figure 5: Compression parallel to grain test](image)

Specific Gravity (G) was also determined on each test specimen.

### 4 EVALUATION

The following summarizes the main findings of the study. A more complete discussion can be found in the original graduate research report (Bogle-Boesiger, 2016).
4.1 Species Investigation

Samples obtained from the three trips were sent to the Forest Products Laboratory (FPL) for species identification. Their results as well as discussions from the sawmill owner and the construction foreman are summarized below:

- Trip A: The FPL indicated that the samples had a specific gravity of 0.43 and the species was most likely *Pinus oocarpa* or *Pinus caribaea*. The results from the mechanical testing (Tables 3-6) compare well to values of *Pinus patula* found in literature (Table 1).

- Trip B: The sawmill owner indicated that there were two species identified by their common name (pino blanco and pino hembra) intermixed within his sawmill (De Leon Vielman, 2014). The FPL provided no specific species information only that the samples were hard pine. The results from the mechanical testing (Table 3-6) do not compare well to values found in literature (Table 1).

- Trip C: The FPL provided no specific species information only that the samples were hard pine. The results from the mechanical testing (Table 3-6) compare well to values of *Pinus oocarpa* found in literature (Table 1).

These results highlight the fact that lumber purchased from the sawmill is variable and can be of any of the three common species used in construction. This is partly due to variable supply of timber received at the sawmill and the nature of the local construction industry. While the owner is willing to provide any particular species requested, this is not typical and therefore steps are generally not taken to separate out species at the sawmill.

An attempt to correlate the common names with the botanical names proved difficult as several botanical species use the same common name. Furthermore, it was unclear whether the sawmill owner and the foreman were referring to the lumber by a species name or species group.

4.2 Grading

The results from the grading investigation are presented in Table 2 as the percentage of sample per grade. Cumulative percentages for lumber at a particular grade or better are also presented.

Table 2: Visual grading results of field test listed by grade. Column labels in this table refer to the lumber sizes by their nominal cross-section dimensions in inches. Numbers in parentheses are cumulative percentages for lumber at that grade or better.

<table>
<thead>
<tr>
<th>Grade</th>
<th>1x12</th>
<th>2x6</th>
<th>4x4</th>
<th>2x4</th>
<th>2x3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Structural</td>
<td>3% (3%)</td>
<td>8% (8%)</td>
<td>13% (13%)</td>
<td>13% (13%)</td>
<td>18% (18%)</td>
</tr>
<tr>
<td>No. 1</td>
<td>19% (22%)</td>
<td>44% (52%)</td>
<td>35% (48%)</td>
<td>16% (29%)</td>
<td>37% (55%)</td>
</tr>
<tr>
<td>No. 2</td>
<td>35% (57%)</td>
<td>28% (80%)</td>
<td>30% (78%)</td>
<td>21% (50%)</td>
<td>27% (82%)</td>
</tr>
<tr>
<td>No. 3</td>
<td>31% (88%)</td>
<td>12% (92%)</td>
<td>20% (98%)</td>
<td>42% (92%)</td>
<td>13% (95%)</td>
</tr>
<tr>
<td>Below No. 3</td>
<td>12% (100%)</td>
<td>8% (100%)</td>
<td>2% (100%)</td>
<td>8% (100%)</td>
<td>5% (100%)</td>
</tr>
<tr>
<td>Sample size</td>
<td>150</td>
<td>25</td>
<td>40</td>
<td>94</td>
<td>200</td>
</tr>
</tbody>
</table>
The grading results show that, on average, 80% of the 2x6s, 4x4s, and 2x3s were No. 2 or better, whereas approximately half of the 1x12s and 2x4s were No. 2 or better. Roughly, over 90% of all lumber was No. 3 or better. Knots were the predominate characteristic controlling the grading process. Approximately 75% of the grading was controlled based on the size, frequency and soundness of knots. Of the lumber that was determined to be below No. 3, 84% was due to large knots (over 3” in size in many cases) and decay.

4.3 Mechanical Properties

The test results for each sample set are presented in Tables 3-6. The load versus displacement graphs for the static bending tests for Trips A to C are presented in Figures 6-8 respectively. The load versus displacement graphs for the compression parallel to grain tests for Trips A to C are presented in Figures 9-11 respectively. The results exhibited a good degree of variability, and each sample set was tested for normality, but no outliers were identified. A two-tailed 95% confidence t-test demonstrated that the three sample sets were significantly different and could not be combined indicating that three distinct species were tested.

Table 3: Summary of modulus of rupture results

<table>
<thead>
<tr>
<th>Sample Set</th>
<th>Average [MPa] (psi)</th>
<th>Standard Deviation [MPa] (psi)</th>
<th>Coefficient of Variation [%]</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip A</td>
<td>83.7 (12,200)</td>
<td>11.8 (1,720)</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Trip B</td>
<td>65.8 (9,600)</td>
<td>5.4 (780)</td>
<td>8</td>
<td>2*</td>
</tr>
<tr>
<td>Trip C</td>
<td>103 (14,900)</td>
<td>12.1 (1,760)</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

Notes:
* After machining the Trip B samples to final dimensions, hidden defects were revealed such that only two static bending test samples could be obtained.

Table 4: Summary of compression parallel to grain results

<table>
<thead>
<tr>
<th>Sample Set</th>
<th>Average [MPa] (psi)</th>
<th>Standard Deviation [MPa] (psi)</th>
<th>Coefficient of Variation [%]</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip A</td>
<td>42.2 (6,100)</td>
<td>4.7 (680)</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Trip B</td>
<td>33.2 (4,800)</td>
<td>3.2 (460)</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Trip C</td>
<td>49.5 (7,200)</td>
<td>5.8 (850)</td>
<td>12</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 5: Summary of modulus of elasticity results
Table 6: Summary of specific gravity results

<table>
<thead>
<tr>
<th>Sample Set</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[GPa] (10^3 psi)</td>
<td>[GPa] (10^3 psi)</td>
<td>[%]</td>
<td></td>
</tr>
<tr>
<td>Trip A</td>
<td>0.44</td>
<td>0.03</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Trip B</td>
<td>0.40</td>
<td>0.03</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>Trip C</td>
<td>0.52</td>
<td>0.07</td>
<td>13</td>
<td>21</td>
</tr>
</tbody>
</table>

Figure 6: Load versus displacement results for static bending tests for Trip A samples.
Figure 7: Load versus displacement results for static bending tests for Trip B samples.

Figure 8: Load versus displacement results for static bending tests for Trip C samples.
Figure 9: Load versus displacement results for compression parallel to grain tests for Trip A samples.

Figure 10: Load versus displacement results for compression parallel to grain tests for Trip B samples.
5 CONCLUSIONS & RECOMMENDATIONS

5.1 Species

Realizing that knowing the exact species was not important, the authors view the lumber received from this sawmill as its own unique local species group. As shown above, the authors believe all three of the common species in the area were captured. Viewing the lumber from this sawmill as a unique local species group, conservative design properties based on samples obtained from Trip B were chosen.

5.2 Grading

Based on the visual grading data, EWB teams in Joyabaj, Guatemala would be safe to assume a No. 3 grade during design. If a typical 10% contingency is added to the materials estimate, it is safe to assume that there will be sufficient material of No. 3 or better quality available for construction.

If a selection process is employed at the construction site, such as the use of the simplified Pass-Fail Visual Grading Guide for identifying lumber are No. 2 or better, design may assume a No. 2 grade. In addition to the on-site selection, appropriate adjustments should be made to the purchased quantities to account for only 50% to 80% of the lumber being No. 2 or better.

5.3 Design Properties

The formwork used in these projects are designed per the National Design Specification (NDS) for Wood Construction (American Wood Council, 2016). The design properties from the
accompanying NDS Supplement (American Wood Council, 2014) are based on in-grade testing and not clear wood testing. As the unique local species group is obviously not found within literature (Kretschmann, 2010; American Wood Council, 2014), a species group that had similar clear wood values to the samples from Trip B was chosen to serve as a “bridge” between the two documents.

While there are many other mechanical properties for lumber (e.g., tension, shear, compression perpendicular to grain, etc.) compression parallel to grain and modulus of rupture were deemed more important properties to match due to their significance in formwork design. Eastern White Pine (EWP) was selected whose clear wood values are summarized in Table 7. Test results from Trip B samples are included in Table 7 for comparison.

Table 7: Summary of small clear wood values for Eastern White Pine (Kretschmann, 2010) and Trip B samples for comparison.

<table>
<thead>
<tr>
<th>Species</th>
<th>Modulus of Rupture [MPa] (psi)</th>
<th>Compression parallel to grain [MPa] (psi)</th>
<th>Modulus of Elasticity [GPa] (10^6 psi)</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern White Pine</td>
<td>59.3 (8,600)</td>
<td>33.1 (4,800)</td>
<td>8.50 (1.24)</td>
<td>0.35</td>
</tr>
<tr>
<td>Trip B</td>
<td>66.1 (9,600)</td>
<td>33.1 (4,800)</td>
<td>7.10 (1.03)</td>
<td>0.40</td>
</tr>
</tbody>
</table>

For calculation of dead weight, a higher specific gravity (G = 0.50) than that reported for EWP in the NDS Supplement is used in design.

6 ACKNOWLEDGEMENTS

The researchers would like to thank Michael Wiemann from the USDA Forest Products Laboratory (FPL) for his assistance in investigating the species of the wood samples used in this research study and Sr. Otto de Leon Vielman of the Aserradero Movil de Leon for his service to EWB groups working in Joyabaj.

7 REFERENCES


8 APPENDICES

Pass/Fail Visual Grading Guide