Species, Grading, and Mechanical Properties of Locally Sourced Timber[1] in the Joyabaj Region of Guatemala

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ABSTRACT: *The purpose of this project was to research the timber 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 timber 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. Timber 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 per cent (90%) of the timber 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 timber, timber grading, timber 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 timber for formwork (Figure 1). While there is a well established, responsibly regulated, professional timber industry in Guatemala, the timber used in these EWB projects is provided from a small community sawmill. The timber from this sawmill is not separated or identified by species or grade.

The purpose of this study was to investigate the species of wood, evaluate the quality by assessing the distribution of timber grades, and determine mechanical properties of the timber 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 timber used in their projects in any region of the world.

[1] The word 'timber' refers to wood that is processed into beams and planks, otherwise known as 'lumber' to north American audiences.

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

2 BACKGROUND

2.1 Species Investigation

There are more than 300 species of trees in Guatemala and pines are the most common for structural timber 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 O 2014, personal communication, 22 November; Ortega, F 2014, personal communication, 22 November). 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

Timber is graded for quality by either visual inspection (visually graded timber) or by a non-destructive test (machine stress rated). Visually graded timber is by far the most common method of grading sawn timber 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 timber 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 United States (US) performs in-grade testing on full size specimens (e.g. a 38 mm x 89 mm by 3,658 mm long (no. 2 2" x 4" by 12' long)) to obtain mechanical properties. Historically, clear wood testing was the industry standard to obtain mechanical properties for dimension timber 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 (Glass & Zelinka 2010; Chudnoff 1984).

Table 1: *Summary of small clear wood mechanical properties for common species found in Joyabaj, Guatemala*

Species **Botanical name**	**Modulus of Rupture [MPa] (psi)**	**Compression parallel to grain [MPa] (psi)**	**Modulus of Elasticity [GPa] (106 psi)**	**Specific Gravity**
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 timber 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 64 mm x 64 mm x 813 mm (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 50 mm x 50 mm x 762 mm (2” x 2” x 30”) for static bending testing and 50 mm x 50 mm x 205 mm (2” x 2” x 8”) for compression parallel to grain and modulus of elasticity testing in accordance with ASTM D143-09.

3.2 Species Investigation

The species investigation included personal interviews with the sawmill owner (De Leon Vielman O 2014, personal communication, 22 November) and the construction foreman (Ortega, F 2014, personal communication, 22 November), cross checking 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 United States of America (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 timber provided by the sawmill, the Visual Grading Guide was field tested by one of the authors on 509 pieces of timber for use as forming for a vehicular bridge (Figure 3). Timber sizes are described in standard North American dimensional timber units that are nominal cross-section dimensions in inches. All the 2 x 4s, 2 x 6s, and 4 x 4s were evaluated, but only a portion of the 2 x 3s and 1 x 12s were evaluated due to time constraints. Timber 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 2 (top): Bogle-Boesiger and Davis obtaining samples at sawmill in Joyabaj, Guatemala

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

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 50 mm x 50 mm x 762 mm (2" x 2" x 30") specimens centre-loaded in bending by a bearing block with supports 710 mm (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 50 mm x 50 mm x 205 mm (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 (Fc) 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 50 mm x 50 mm x 205 mm (2" x 2" x 8") specimens were cut from undamaged portions of the 50 mm x 50 mm 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. Specific Gravity (G) was also determined on each test specimen.

4 EVALUATION

The following summarises 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 summarised 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 (Table 3 to Table 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 O 2014, personal communication, 22 November). The FPL provided no specific species information only that the samples were hard pine. The results from the mechanical testing (Table 3 to Table 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 to Table 6) compare well to values of *Pinus oocarpa* found in literature (Table 1).

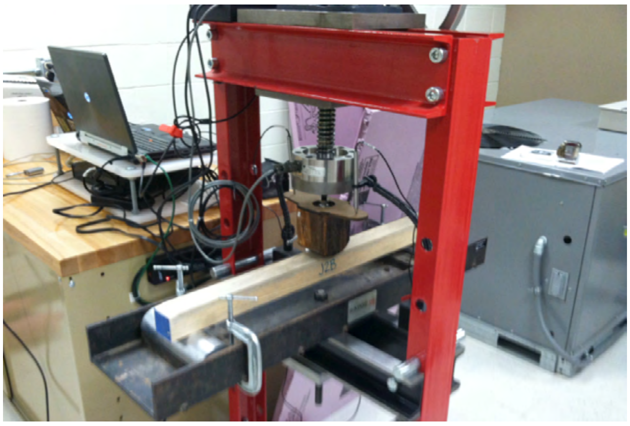


Figure 4 (top): Static bending test

Figure 5 (bottom): Compression parallel to grain test

These results highlight the fact that timber 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 wood 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.

Table 2: Visual grading results of field test listed by grade. Column labels in this table refer to the timber sizes in standard North American dimensional timber units, i.e. cross-sectional dimensions in inches with a representive conversion in metric units. Numbers in parentheses are cumulative percentages for lumber at that grade or better.

Grade (in.) [mm]	**1 x 12 [25.4 x 304.8]**	**2 x 6 [50.8 x 152.4]**	**4 x 4 [101.6 x 101.6]**	**2 x 4 [50.8 x 101.6]**	**2 x 3 [50.8 x 76.2]**
Select structural	3% (3%)	8% (8%)	13% (13%)	13% (13%)	18% (18%)
No. 1	19% (22%)	44% (52%)	35% (48%)	16% (29%)	37% (55%)
No. 2	35% (57%)	28% (80%)	30% (78%)	21% (50%)	27% (82%)
No. 3	31% (88%)	12% (92%)	20% (98%)	42% (92%)	13% (95%)
Below no. 3	12% (100%)	8% (100%)	2% (100%)	8% (100%)	5% (100%)
Sample size	150	25	40	94	200

Table 3: Summary of modulus of rupture results

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

Notes:
1. *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

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

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 timber 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 timber at a particular grade or better are also presented.

The grading results show that, on average, 80% of the 2 x 6s, 4 x 4s, and 2 x 3s were no. 2 or better, whereas approximately half of the 1 x 12s and 2 x 4s were no. 2 or better. Roughly, over 90% of all timber 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 timber that was determined to be below no. 3, 84% was due to large knots (over 3" (76.2 mm) in size in many cases) and decay.

4.3 Mechanical Properties

The test results for each sample set are presented in Table 3 to Table 6. The load versus displacement graphs for the static bending tests for Trips A to C are presented in

Table 5: Summary of modulus of elasticity results

Sample Set	**Average [GPa] (103 psi)**	**Standard Deviation [GPa] (103 psi)**	**Coefficient of Variation [%]**	**Sample Size**
Trip A	12.6 (1,800)	4.7 (680)	37	9
Trip B	7.1 (1,000)	1.5 (220)	21	7
Trip C	14.4 (2,100)	4.6 (660)	32	7

Table 6: Summary of specific gravity results

Sample Set	**Average**	**Standard Deviation**	**Coefficient of Variation [%]**	**Sample Size**
Trip A	0.44	0.03	7	30
Trip B	0.40	0.03	8	13
Trip C	0.52	0.07	13	21

Figure 6 to Figure 8 respectively. The load versus displacement graphs for the compression parallel to grain tests for Trips A to C are presented in Figure 9 to Figure 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.

5 CONCLUSIONS & RECOMMENDATIONS

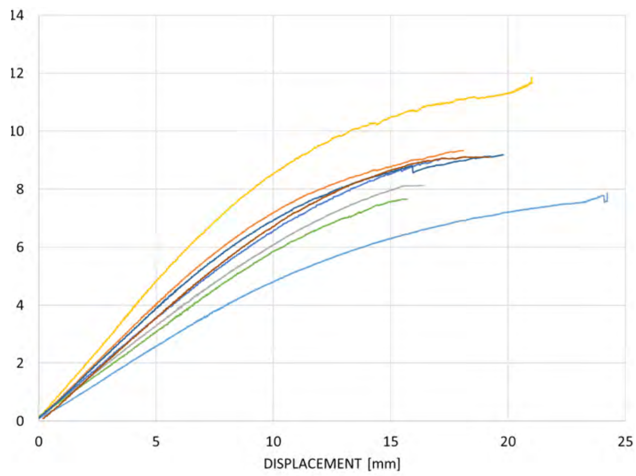
5.1 Species

Realising that knowing the exact species was not important, the authors view the timber 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 timber 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 timber are no. 2 or better, design may



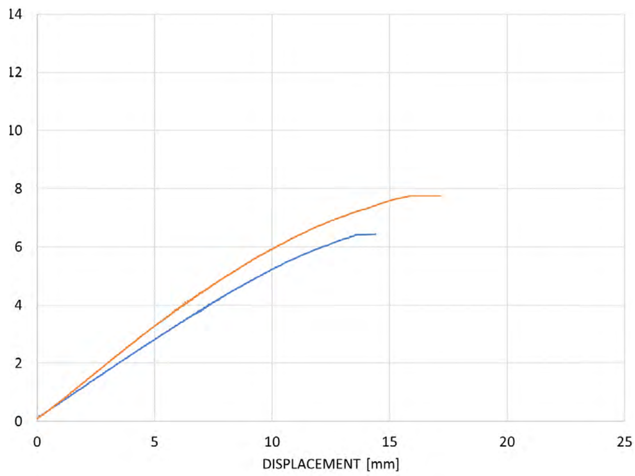
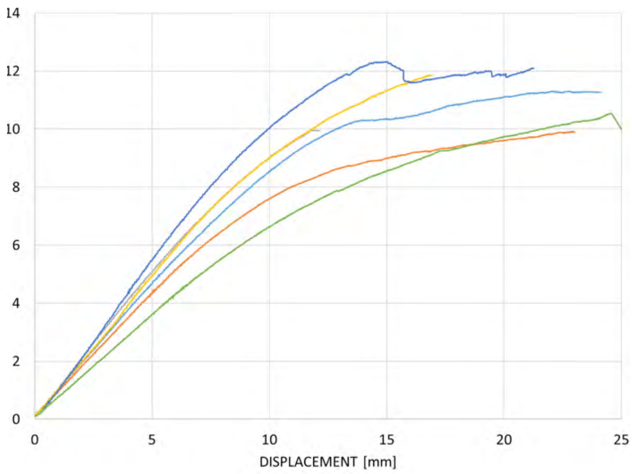
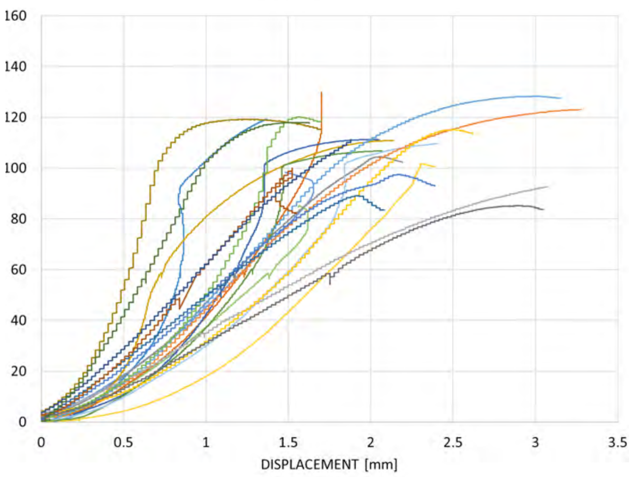
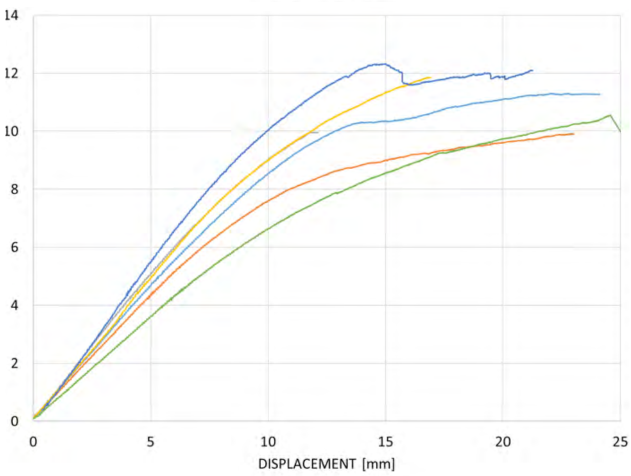


Figure 6 (top): Load versus displacement results for static bending tests for Trip A samples

Figure 7 (bottom): Load versus displacement results for static bending tests for Trip B samples







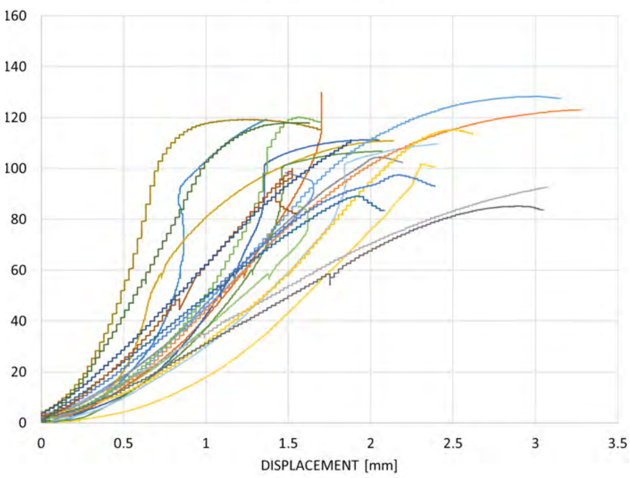


Figure 8 (top): Load versus displacement results for static bending tests for Trip C samples

Figure 9 (upper middle): Load versus displacement results for compression parallel to grain tests for Trip A samples

Figure 10 (lower middle): Load versus displacement results for compression parallel to grain tests for Trip B samples

Figure 11 (bottom): Load versus displacement results for compression parallel to grain tests for Trip C samples

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 timber 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.

Whilst there are many other mechanical properties for timber (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 summarised in Table 7. Test results from Trip B samples are included in Table 7 for comparison. 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.

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

Species	**Modulus of Rupture [MPa] (psi)**	**Compression parallel to grain [MPa] (psi)**	**Modulus of Elasticity [GPa] (106 psi)**	**Specific Gravity**
Eastern White Pine	59.3 (8,600)	33.1 (4,800)	8.50 (1.24)	0.35
Trip B	66.1 (9,600)	33.1 (4,800)	7.10 (1.03)	0.40

7 REFERENCES

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8 APPENDICES

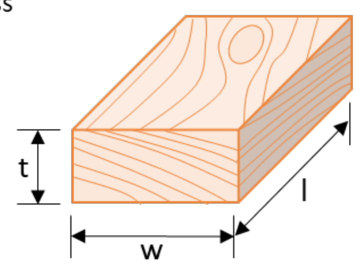
Pass/fail Visual Grading Guide

Please note: all references to the word 'lumber' in the 'Pass/Fail Visual Grading Guide' are the North American term for 'timber', all measurements are reported in the imperial dimensions where one inches is equal to 25.4 mm.

Pass/Fail Visual Grading Guide
No. 2 or Better

DIMENSIONS

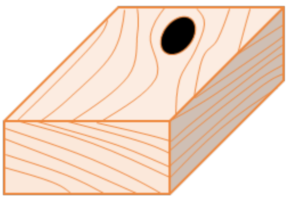
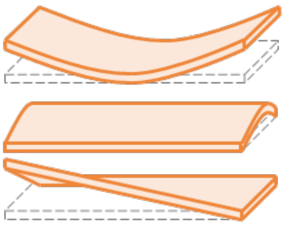
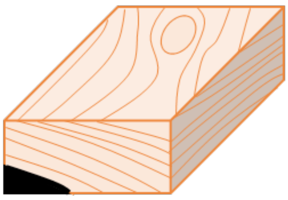
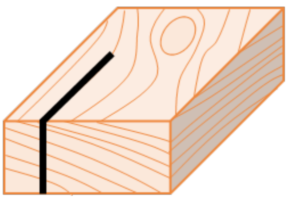
- t = thickness
- w = width
- l = length



HOW TO USE THIS GUIDE

This simplified pass/fail visual grading guide is intended for use on projects where a formal lumber grading process does not exist. Lumber is graded as meeting or not meeting the requirements for No. 2 lumber.

This simplified guide is based on the four characteristics identified below. If any piece of lumber meets **all** the criteria below it is graded as No. 2 or better.

CHARACTERISTIC (DEFECT)		DESCRIPTION	CRITERIA
KNOTS		Portions of the board with cross grain growth from where a branch is formed.	Maximum of 1 knot every 2 linear feet. Knots must be less than 1-¼" in diameter.
WARP		Bowing, cupping, or twisting of the board.	If the board appears to be warped it is not allowed.
WANE, WANT, or DECAY		Missing wood from face or edge due to fungus or pest or error in machining	Must be less than ⅔ thickness by ½ width for up to ¼ length
SPLITS		Separation from face to face (through the full thickness of the board)	Length of split must be less than 1.5 times the width

This guide was developed by Larissa Bogle-Boesiger for a graduate research project at the Milwaukee School of Engineering for use by Engineers without Borders USA (EWB-USA) chapters working in the Joyabaj region of Guatemala. It was based on the visual grading rules developed by the Southern Pine Inspection Bureau (SPIB). This guide is not intended to replace a formal lumber grading process, but rather to be used in locations where a formal lumber grading process does not exist.