PHILIPPINE ENGINEERING JOURNAL
PEJ 2009; Vol. 30, No. 2: 21-34

MECHANICAL PROPERTIES ON FLEXURE AND SHEAR OF COMMERCIALLY AVAILABLE TIMBER BEAMS IN THE PHILIPPINES

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ABSTRACT

Commercially available wood used as structural members are commonly referred to as "good lumber." Good lumber consists mostly of imported wood, and those of lesser known or unknown local species. With the wood species not clearly specified, there is a need to determine the mechanical properties of good lumber. Standard laboratory tests were conducted to determine the range of values of good lumber properties including moisture content, specific gravity, modulus of elasticity and the bending and shear strength of timber beams. The mechanical properties of good lumber were obtained through a series of laboratory tests that simulated the conditions for the loading schemes specified in the ASTM manual on beams of nominal cross section 2"x4". With the information on the variation of strengths of good lumber, structural designers can be guided on appropriate allowable stresses in designing structural members such as purlins and joists made of commercially available wood with unknown species.

Keywords: good lumber, timber, flexure, shear, wood specie, Philippine lumber

1. INTRODUCTION

The most common types of lumbers used in the Philippines are coco lumber and good lumber. Coco lumber, or coconut timber, is more commonly used as formworks and scaffoldings during construction. On the other hand, good lumber is preferred for more permanent structural purposes such as trusses, rafting, floor decking and floor joists. A survey conducted by FPRDI – ITTO in 2003 showed that 23% of commercially available timber or good lumber consists of naturally grown timber species and plantation-grown species, while the other 77% accounts for imported logs from Malaysia, Brazil and Indonesia. A recent survey on good lumber conducted by the authors in Metro Manila showed that 44% of the 28 participating lumberyards have foreign sources of lumber, while 56% resort to local sources. Among those surveyed, 30% have lumber belonging to the Tangile species, 4% to the Miranthe species, 7% have lumber that are combinations of Tangile, Miranthe or Lauan, 11% use lumber from the Saba species imported from Malaysia, and the rest are of unknown or unidentified wood and mixed wood species.

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Received: September 30, 2011
Accepted: January 5, 2012

Harvest species of commercially available timber are not specified in the market, and are only referred to as “good lumber.” The NSCP provides the strength properties of the lumber species in the Philippines. However, this is no longer applicable in designing wood structures that use good lumber because the wood species used is unknown. Thus, there is a need to determine the mechanical properties of good lumber.

This study aims to determine the variation of strength properties of timber beams commonly referred to as good lumber. These strength properties can guide structural designers on the appropriate allowable stresses in designing structural members made of good lumber.

2. TESTING

Standard laboratory tests were conducted on beams of nominal cross section 2”x4” to determine the range of values of the properties of good lumber such as moisture content, specific gravity, modulus of elasticity, and the bending and shear strength of timber beams.

2.1 Sample Size Determination

The sample size was determined using the two-stage method found in ASTM D 2915, where an initial test was conducted and the sample size was determined based on the initial mean, standard deviation, percent estimate, and the t statistic for a desired confidence level. Equation (1) below shows the formula used in determining the sample size. This formula is based on the assumption that the samples are normally distributed.

$$\mathbf{n} = \left(\frac{\mathbf{ts}}{(\mathbf{pe})(\bar{\mathbf{X}})}\right)^2 = \left(\frac{t}{pe}CV\right)^2 \qquad (1)$$

where n = sample size
s = standard deviation of specimen values
X = specimen mean value
CV = coefficient of variation, s/$\bar{X}$
pe = percentage estimate
t = value of t statistic

For the purposes of this study, a percentage estimate of 0.25 was used to obtain the sample size for the flexure tests, and 0.30 for the sample size of the shear tests.

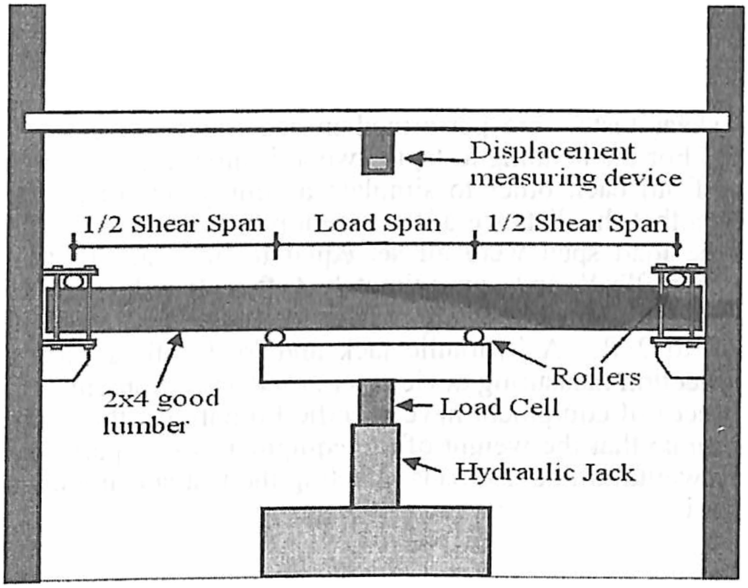

Fig. 1 Bending Test Set-up

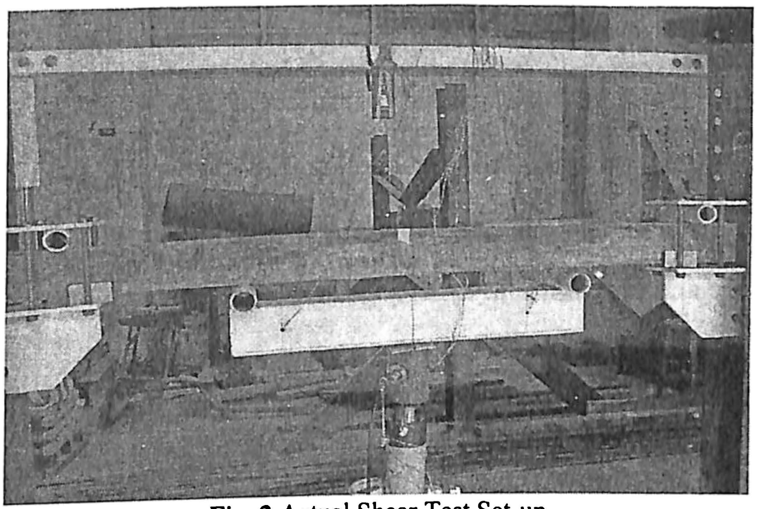

Fig. 2 Actual Shear Test Set-up

2.2 *Specific Gravity & Moisture Content*

The specific gravity and moisture content were determined in accordance with ASTM D2395-02, where the volume was obtained through measurement, and the moisture content through the oven-dry method.

2.3. Bending Tests

Bending and shear tests were performed in accordance with ASTM D198-02 and ASTM D4761-02a. For the bending tests, the wood beams were loaded edge-wise on two points equidistant from each other to simulate a simply-supported third point loading scheme. This means that the distance of the reaction to the nearest load point (half of the shear span) and the load span were all set equal to one-third of the span. Beams of nominal cross section 2"x4" and approximately 6 ft in length were used to satisfy the required span-depth ratio. Hence, in Fig. 1, the load span is 2 ft, and half of the shear span is also equal to 2 ft. A hydraulic jack and load cell, a rigid frame, fabricated supports, and a deflection measuring device were used as equipment.

Because the pieces of equipment have specific limitations, the beams were loaded in an upward direction so that the weight of the equipment used, particularly the hydraulic jack and load cell, would not act as loads affecting the test specimens. A typical test set-up is shown in Fig. 1.

2.4. Shear Tests

For the shear tests, a similar set up was used, but for the reaction at the supports to be larger and for the wood to fail in shear, the shear span was made relatively shorter and the beam was loaded at the outer quarter points of the span. The load span was made equal to half of the span, and the shear span was set to half of the total span. Hence, for the beams of nominal cross section 2"x4" with a length of about 4 ft, the load span is 2 ft while half of the shear span is 1 ft. An actual shear test set-up is shown in Fig. 2.

Prior to testing, the researchers conducted visual inspection to note defects present on each beam. Testing at a constant rate to achieve maximum load within 10 minutes but not less than 10 seconds was conducted. The load and deflection were obtained at the beam's first signs of failure and at maximum load, if possible.

3. STATISTICAL TREATMENT OF DATA

3.1 Confidence Interval

The equation below was used to compute a confidence interval for the mean values of the property being estimated.

$$\mathbf{CI} = \bar{\mathbf{X}} \pm \left(\frac{\mathbf{ts}}{\sqrt{\mathbf{n}}}\right) \tag{2}$$

where CI = confidence interval
n = sample size
$\underline{s}$ = standard deviation of specimen values
$\bar{X}$ = specimen mean value
t = value of t statistic

This is based on the assumption that the samples are normally distributed. The value of t depends on a sample size and a confidence level desired for the estimated range. The confidence interval obtained from this formula may be expected to contain the true population mean.

3.2 Obtaining Allowable Properties

For allowable bending and shear stress properties, a near minimum value must be estimated. The researchers used the reduction factors found in ASTM D6570 for assigning allowable properties of mechanically graded lumber. The said reduction factors were obtained for the fifth percentile tolerance limit (95% content) and of 75% confidence.

For the MOE and specific gravity, the upper 95% confidence interval of the sample mean shall equal or exceed the assigned grade of MOE. Thus, the reduction factor in relating the test statistics to the allowable properties would simply be equal to 1, and the mean obtained from the laboratory test results would be acceptable.

For the evaluation of the extreme fiber stress in bending, and shear stress parallel to the grain, the fifth percentile tolerance limit with 75% confidence would be equal to or exceed 2.1 times the assigned allowable strength values. This is similar to the reduction factors used to reduce test statistics to the level of allowable properties found in ASTM D245, which include safety factor and a 10-year cumulative load effect. Thus, the bending and shear stress values obtained from laboratory tests may be reduced to the level of allowable properties by multiplying the test statistics with a factor of 1/2.1. This would give conservative results acceptable for use in design.

4. DATA ANALYSIS

4.1 Moisture Content

The values for the moisture content of the samples for the flexure tests ranged from about 13% to 82%, while that of the samples for the shear tests ranged from 12% to 34%. An average of 25.05% was obtained from all the samples.

For common wood species, the fiber saturation point was within 25% to 35% range for moisture content. As wood dries below the fiber saturation point, it increases in strength and stiffness. Thus, lumber is usually dried below fiber saturation point, having an optimum limit of 19%. Green wood or freshly cut lumber may have moisture content that varies from 30% to 200% (Aghayere & Vigil, 2007). It can be assumed that the samples with very high moisture content have not yet dried up to their fiber saturation point; thus, may still increase in stiffness as they dry further.

4.2 Specific Gravity

There is high correlation between the strength and specific gravity of timber, making this a good basis for the prediction of timber strength. The specific gravity of the samples tested in flexure ranged from 0.236 to 0.730, while that of samples tested in shear ranged from 0.254 to 0.743. The average specific gravity obtained from all the samples was 0.469.

4.3 Flexure

In determining the unit stress in the extreme fiber of the timber beam, the following flexure formula was used.

$$f_b = \frac{Mn}{I} \tag{3}$$

where f_b = unit stress in the extreme fiber in bending, MPa
M = maximum bending moment, kN-mm
n = distance from the neutral axis to extreme fiber, mm
I = moment of inertia about the neutral axis, mm^4

This is true assuming that the stress is proportional to strain, and that strain is directly proportional to its distance from the neutral axis. This fiber stress obtained using the flexure formula at failure is called the modulus of rupture.

The modulus of elasticity was obtained by relating the deflection of the beam and the loads applied. For a simply supported beam with two concentrated loads at each point a third of the beam length away from the supports, the maximum deflection may be computed using the following formula:

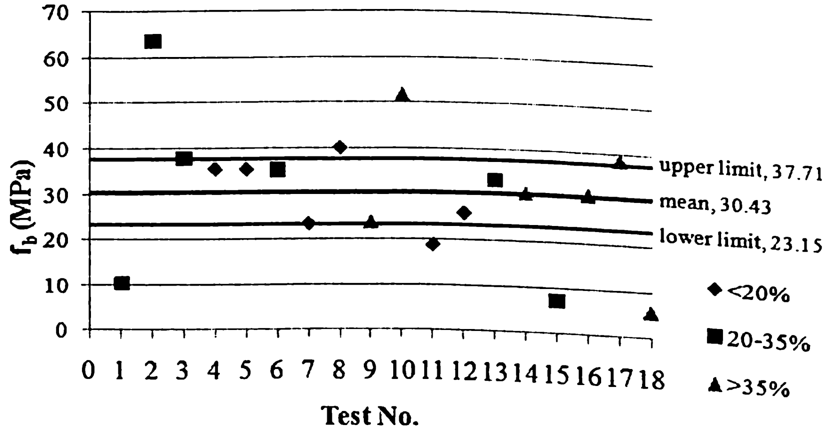

Fig. 3 Flexural Stress classified by the Moisture Content

$$\Delta = \frac{23Pl^3}{648EI} \tag{4}$$

where Δ = maximum deflection at middle of beam span, mm
P = equal concentrated loads, kN
l = span, mm
E = modulus of elasticity, MPa
I = moment of inertia about the neutral axis, mm^4

4.3.1. Confidence Interval

Since the researchers tested only few samples (n<30) in this experiment, a good approximation for the confidence interval would be the Student's t-distribution, with the assumption that the population is normally distributed. Using Eq. (2), the 95% confidence interval obtained for the modulus of rupture is 30.43 ±7.28 MPa. In other words, with 95% confidence, the modulus of rupture of good lumber is within the limits of 23.15 to 37.71MPa.

4.3.2. Moisture Content and Specific Gravity

The values for moisture content obtained from the flexure tests vary. Fig. 3 shows a graph of the flexural strengths of the specimens with moisture content below 20%, between 20% to 35% and above 35%.

The samples with moisture content less than 20% had values mostly within the ranges for the confidence interval of the flexural stress. These samples can be assumed to have been dried below the fiber saturation point. For the samples with moisture content ranging from 20% to35%, their flexural strength reached high values. These samples may or may not have reached their fiber saturation point. Some other samples had flexural stresses of lower values, which may be explained by the moisture content or perhaps by the presence of strength-reducing defects. The samples with moisture content higher than 35% may be assumed to still have the potential of reaching higher strengths should the specimens be dried further below the fiber saturation point.

The specimens with lower MOE also had lower specific gravity values, while those with high MOE exhibited higher specific gravity. The specimen with the highest flexural stress did not necessarily have the largest value of MOE. However, the value of the MOE obtained for this test was close to the upper limit of the confidence interval for the MOE.

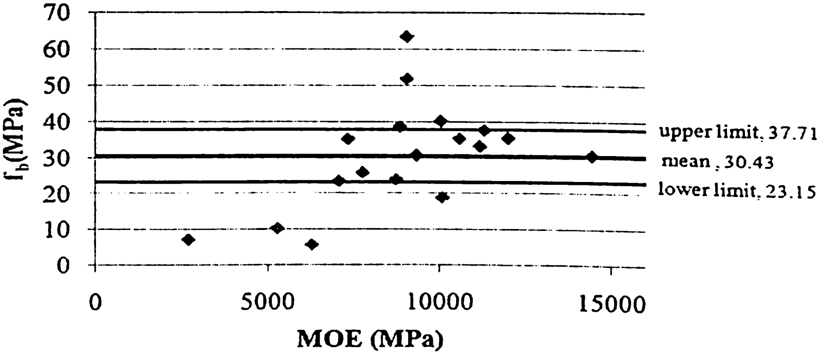

Fig. 4 f_b vs. MOE

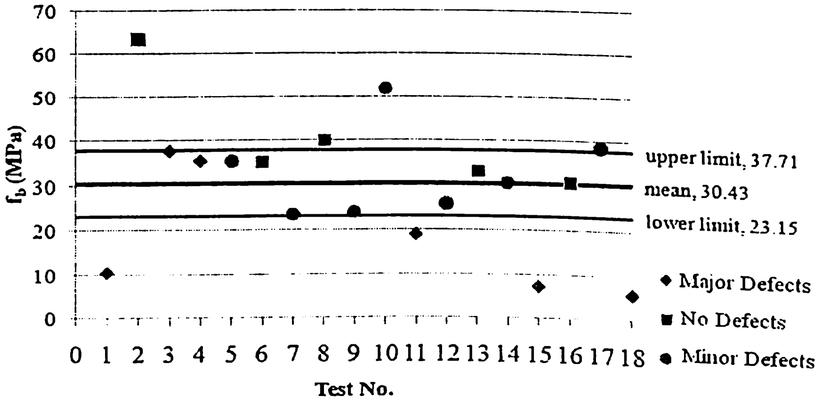

Fig. 5 Flexural strength in relation to defects

Fig. 4 shows the graph of the fb vs. the MOE, which reveals a consistency where the MOE can be a good estimate of the capacity of the wood for stiffness. As can be seen, the samples with low values of flexural stress also had lower values for the MOE.

4.3.3. Wood Defects

The researchers also recorded the defects present in the test specimens. Defects present in the specimen may greatly affect its strength. These include knots, splits, checks, insect holes and spots which are noted to affect the bending strength of the specimen. Cases where beams had a knot present at the point of loading, exhibited immediate failure or a weakness at that point.

There were cases of varying changes in color throughout the beam that might have been due to surface peeling or to the handling of the specimen. Checks or splits located at the supports may also have contributed to low flexural capacity. Some beams with several knots at different points throughout their length— at the points of loading, at the tension side, etc.— coupled with high moisture content also exhibited early cracking or lower flexural strength.

The researchers used the following classifications for the tests: specimens with major, minor or no defects present. Beams with defects that may have reduced their moment carrying capacity were classified as major defects. Those bearing fewer defects such as tiny insect holes and wanes, considered permissible in establishing grades of bending members as far as strength properties are concerned, were classified as minor defects.

Fig. 5 shows the bending strength obtained for each test sample and their corresponding classifications of defects. Most of the test specimens with no defects had strength values lying above the mean value, while those with minor defects were mostly within the range of the upper and lower limits of the confidence interval.

Most of the test specimens with major defects had bending strength values below the lower limit of the confidence interval. The average of the bending stresses of these test specimens is 19.21MPa. And the ratio of the bending strength of the members with major defects to that of the samples with no major defects was found to be 53%.

4.3.4. Allowable Properties

In establishing the allowable properties, the mean value of the MOE may be used as an acceptable estimate. However, for obtaining allowable stresses, a near minimum value for the property is desirable.

The value of the lower limit of the flexural strength with 95% confidence interval, which is 23.15 MPa, may be used. The adjustment factor for reducing test statistics according to ASTM D 6570 was applied to the value of the lower limit of the confidence interval. The lower limit was divided by a factor of 2.1, for a fifth percentile tolerance limit with 75% confidence. The researchers obtained 11.02 MPa as the allowable fb value, in accordance with the said reduction factor of 2.1 for bending strength. Given that the lower limit of the confidence interval was obtained with 95% confidence, and the reduction factor with 75% confidence, the allowable value obtained would be a conservative estimate of the design value for bending strength.

4.4. Shear

Shear strength is critical on relatively short, heavily loaded spans. The theoretical expression for unit horizontal shear stress in a beam of homogeneous material is

$$f_v = \frac{VQ}{It} \tag{5}$$

where
fv = unit horizontal shear stress, MPa
V = total shear at the section, kN
Q = static moment of area above or below the plane, about the neutral axis of the beam, mm^3
I = moment of inertia about the neutral axis, mm^4
t = width of the beam, mm

For a simply supported beam with two concentrated loads at the outer quarter points from the support, the maximum deflection at mid span can be taken as:

$$\Delta = \frac{Pl^3}{12EI}\left(\frac{3a}{4l} - \left(\frac{a}{l}\right)^3\right) \qquad (6)$$

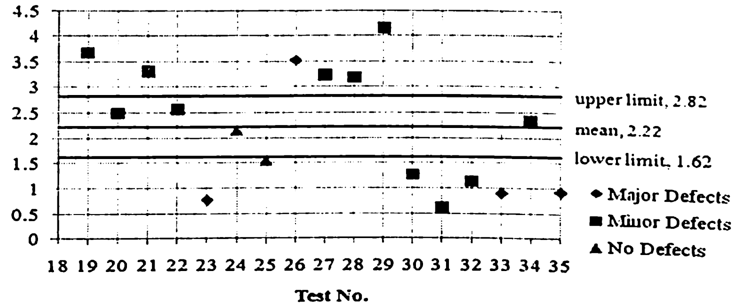

Fig. 6 Shear Strength in relation to Defects

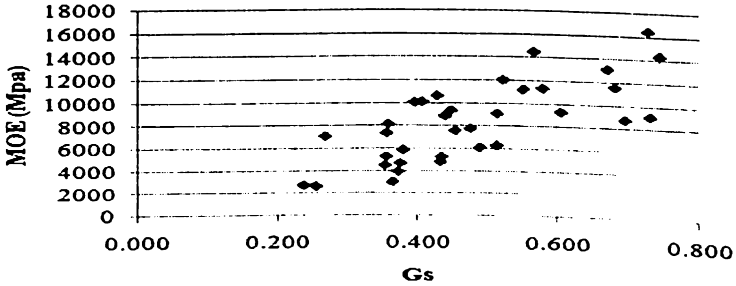

Fig. 7 MOE vs. Gs of all samples in flexure and shear

4.4.1. Confidence Interval

The Student's t-distribution was also used in obtaining the confidence interval for the shear tests. Similar to the flexure tests, Eq. (2) was used to determine the confidence interval for the MOE and shear stress. With 95% confidence, the shear strength of good lumber was found to be within the range of 1.6MPa to 2.8MPa.

4.4.2. Moisture Content and Specific Gravity

The values obtained for the moisture content of the shear specimens ranged from 12% to 34%, with majority of the values ranging below 20% moisture. This shows that most of the acquired specimens have probably already dried below the fiber saturation point. Similar to the flexure tests, the specimens with lower MOE also had lower specific gravity values, while those with high MOE values exhibited higher specific gravity.

4.4.3. Wood Defects

Although some specimens had major defects such as knots, so long as these were not located at any critical sections, such as the extreme tension side, the beams exhibited strength and stiffness.

The average value of the shear stress obtained from the tests with major defects was 1.52MPa. The specimens with minor defects had an average shear strength of 2.5MPa, while those with no defects had an average shear strength of 1.86MPa. The ratio of the shear strength of the beams with major defects to that of the beams without major defects was approximately 63%. Fig. 6 shows the shear strengths and their classifications of defects. Most of the values obtained from the tests had shear stresses higher than the average shear stress. Knowing that the samples were tested only until the first signs of cracking were imminent, it would be safe to say that the beams would be able to carry even greater loads than what they were subjected to during the testing. Thus, the lower limit of the shear stress, having a value of 1.62MPa, would be a good basis for estimating the allowable shear stress. For more reliable results, the defects of good lumber for which this shear stress value is applicable may be limited to those with minor ones only, such as knots located in the compression side having a sum of all diameters approximately less than 3", checks with lengths less than 3", wanes, dark spots and surface cracks.

4.4.4. Allowable Properties

In establishing the allowable properties for the shear strength of good lumber, a near minimum value of the property is also desired. Again, the lower limit of the 95% confidence interval of the shear strength, having a value of 1.62MPa may be reduced using the reduction factors found in ASTM D6570 and D2915. For the shear stress parallel to the grain, the reduction factor is 2.1 for a 95% content and a 75% confidence. The adjusted F_v value would then be 0.77MPa.

4.5. Modulus of Elasticity

Equation (2) was applied to the values obtained from the tests in order to estimate a confidence interval for specific gravity and MOE. With 95% confidence interval, and with the use of a t-statistic of 2.034, the values for the MOE of good lumber is within the limits of 6916 MPa to 9385 MPa, having an average of 8150MPa. Similarly, the specific gravity obtained for good lumber was within the limits 0.420 to 0.518, having an average value of 0.469. As can be seen in the MOE vs. Gs in Fig. 7, an almost linear relationship can be observed for the MOE and specific gravity. This shows that the higher the specific gravity, the greater its capacity for stiffness.

5. RESULTS

5.1. Results from Lumberyard Survey

From the researchers' lumberyard survey, majority of the species of good lumber could not be found in the NSCP Table 6.1. It was also established that commercially available timber in Metro Manila may be composed of various local species mixed together, or of Tangile, which is the most popular species among the local lumber. At the same time, foreign lumber from different countries were used, with Malaysia being the most common source. This proves that there is uncertainty in terms of defining the characteristics of good lumber due to its many different species and sources.

5.2. Classification of Strength Values According to Defects

5.2.1. Flexure

By comparing the strength values obtained with those found in the NSCP 2010, the researchers determined that most of the bending strength values under the 80% and 63% stress grade medium strength group and low strength group fall within the range of allowable bending stress. Specimens with minor defects have bending stresses ranging from 11.2MPa to 24.7MPa, and can be classified as lumber of 80% stress grade in bending, belonging to the medium strength group. This shows that the samples tested for commercially available timber provide high allowable stresses based on the estimated modulus of rupture even with the presence of minor defects. Specimens with major defects have bending stresses that are beyond the range of values for the allowable bending stresses under 50% stress grade. This shows that the major defects present in the specimens would give allowable stresses that are not recommended for use in design.

5.2.2. Shear

Similarly, most of the beams found to have no defects and minor defects had allowable shear stresses that fall under the medium strength and low strength group for 80% and 63% stress grade. Shear specimens with major defects had allowable shear stresses that fall within the moderately high strength group for a 63% stress grade.

5.2.3. Flexure and Shear

Considering both flexure and shear, it can be noted that good lumber with minor or no defects have allowable flexural strength, shear strength and MOE values falling mostly within the 80% stress grade medium and moderately low strength groups based on the strengths found in NSCP Table 6.1. However, considering all the samples that were tested, a conservative classification of good lumber is the medium and moderately low strength group for a 63% stress grade.

5.3. Classification According to Source/Specie

Comparing the stresses of good lumber from local sources to the strength values in the NSCP Table 6.1, the range of the strength of this group were mostly within the values of the medium strength and moderately low strength group for 80% stress grades, and the moderately high strength group for 63% stress grades. Meanwhile, the group of imported lumber had strength that fall within the 80% stress grade medium and moderately low strength group.

6. CONCLUSION

Commercially available wood in the Philippines used as structural members are commonly referred to as "good lumber." Good lumber consists mostly of imported wood, and those of lesser known or unknown local species. A survey of lumberyards in Metro Manila showed that 56% have locally produced good lumber, while 44% import lumber from other countries. In most cases the wood species and properties are not clearly specified.

Standard laboratory tests on 2" x 4 " beams were conducted to determine the range of values of good lumber properties such as moisture content, specific gravity, modulus of elasticity and the bending and shear strength of timber beams. The laboratory results showed that good lumber has a moisture content ranging from 12% to 82% with 25% as average value, a relative density ranging from 0.236 to 0.743, with 0.47 as average, and an average modulus of elasticity of 8.15GPa. The modulus of rupture ranged from 5.7MPa to 63.5MPa, while the shear stress at failure ranged from 0.60MPa to 4.15MPa. For structural design purposes, a reduction factor of 2.1 based on ASTM Standards was applied and the allowable flexural strength obtained falls within the range 11.0MPa to 18.0MPa, while the allowable shear strength is within 0.77MPa to 1.34MPa. Comparing the strength properties to the timber species in the NSCP 2001/2010, the researchers determined that good lumber in general would have values within the ranges for medium and moderately low strength group for 63% stress grades, while good lumber with minor or no defects at all would have allowable flexural and shear strength values mostly within the 80% stress grade medium and moderately low strength groups. With the information on the variation of strengths of good lumber obtained from the study, structural designers can be guided on appropriate allowable stresses to be used in the design of structural members like joists and purlins made of good lumber.

ACKNOWLEDGMENT

We would like to give our whole-hearted thanks to the Civil Engineering Department, our friends and family who all helped and contributed to the fulfillment of this study.

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