Periodic Evaluation of Northeastern Spruce and Balsam Fir Lumber Properties

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PERIODIC EVALUATION OF NORTHEASTERN SPRUCE AND BALSAM FIR LUMBER PROPERTIES

By

Benjamin Farber

B.S. University of Maine, 2016.

A THESIS
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (In Forest Resources)

The Graduate School
The University of Maine
August 2018

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BALSAM FIR LUMBER PROPERTIES

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Advisors: Dr. Douglas Gardner

An Abstract of the Thesis Presented
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In the past two decades, proportions of juvenile wood have increased in lumber cut from intensively managed Southern yellow pine (Pinus spp.) plantation-based forests. Knowing that a decrease in rotation age can increase proportions of juvenile wood, which in turn negatively affects mechanical properties in lumber, the SYP grouping was evaluated to determine if the published design values in the National Design Specification (NDS) required a downward adjustment. In 2011, following extensive testing, the American Lumber Standards Committee (ALSC) required that design values for SYP be reduced by 30 percent. As a result of this, ASTM D1990-16 was revised to include required periodic monitoring of all lumber species groupings to detect possible downward shifts in mechanical properties. The Northeastern Lumber Manufacturing Association (NeLMA) conducts monitoring programs approximately every five years within the Northeast and Great Lakes regions, two of the three regions where SPF(s) lumber is produced (the third region is in the Western U.S. which is monitored by the Western Wood Products Association (WWPA)). The monitoring program described herein, as required by
ASTM D1990-16, evaluates bending properties of balsam fir (Abies balsamea) and the Eastern spruces (Picea rubens, Picea glauca, Picea mariana and Picea abies) for No.2 grade 2” x 4” lumber. In addition to the required 2” x 4” size this research program also evaluated 2” x 6” and 2” x 8”.

The monitoring program requires testing and subsequent analysis follows ASTM standards D1990-16 and D4761-13, the latter specifying testing procedures for static bending tests of lumber.

After lumber flexural failure, procedures outlined in ASTM D4761-13 were applied to each specimen to diagram and quantify the failure behavior and create a failure code. This failure code is used in the determination of the strength ratio which is then used to calculate Grade Quality Index (GQI), which is used to determine if further lumber mechanical property adjustments are required.

The 2” x 4” modulus of rupture (MOR) and modulus of elasticity (MOE) values derived from this testing program were statistically compared to the three separate testing programs. The 2” x 6” and 2” x 8” values from the 2017 monitoring program, were compared with the 1991 values and showed a decrease in MOR and MOE. Further testing of the 2” x 6” and 2” x 8” No. 2 nominal widths should be conducted in future testing programs to investigate any possible downward shift in mechanical property values.

A Wilcoxon test showed that the 2” x 4” samples of both species had similar MOE values when compared with the 1991 design values, but did show a downward shift in values when comparing the MOR values. A Tukey HSD reported similar results reporting the MOE as statistically the same as the 1991 values for both species, whereas the mean MOR was statistically lower. These
findings are still considered preliminary as this programs results will be pooled together with the
two future monitoring programs and combined with the remaining species within SPF(s). After
final submission to the ALSC, The SPF(s) pooled values will be re-evaluated.
DEDICATION

For my Father, Richard

A giant pine, magnificent and old
Stood staunch against the sky and all around
Shed beauty, grace and power.
Within its fold birds safely reared their young.
The velvet ground beneath was gentle,
and the cooling shade gave cheer to passersby.
Its towering arms a landmark stood, erect and unafraid,
As if to say, “Fear naught from life’s alarms”.

It fell one day.
Where it had dauntless stood was loneliness and void.
But men who passed paid tribute – and said,
“To know this life was good,
It left its mark on me. Its work stands fast”.
And so it lives. Such life no bonds can hold –
This giant pine, magnificent and old.

Georgia Harkness
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Chris Urquhart, Lab Operations Manager, Advanced Structures and Composite Center, University of Maine

Deborah Farber, my mother
Jon Hill, Advanced Structures and Composite Center Engineer

Aaron Weiskittel, Professor of Forest Biometrics and Modeling

Staff and friends at the Advanced Structures and Composite Center, University of Maine

*Disclaimers*

The analysis, discussion, conclusions drawn and recommendations given in this thesis are solely those of the author. As the test data generated from this program will be used in the actual 2018 SPF-S monitoring program, it is possible that the subsequent analysis, interpretation and conclusions drawn by the Wood Composites Manager at the Advanced Structures & Composites Center at the University of Maine, who will be responsible for the submission to NE LMA and the ALSC, will differ from those herein.

As this is not the first program to go through these testing standards, much of this report’s format and evaluation is similar to the “Proposed Design Values for Norway Spruce (Picea Abies) Grown in the United States for Potential Inclusion in the SPF-S Species Grouping Category” report.
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CHAPTER
1 INTRODUCTION

1.1 Objectives and Hypothesis

The objective of the lumber monitoring research program described herein was to (1) test and analyze samples of Eastern spruce and balsam fir as required by ASTM D1990-16, which will subsequently be grouped with data from other species and regions as part of the periodic monitoring of the spruce-pine-fir south (SPF(s)) lumber grouping, and (2) compare this data to that from earlier monitoring programs completed in 1991, 2006, 2012, and 2013 (CWC 2006). By using the currently accepted ASTM mechanical testing standards for structural lumber in flexure, the project reviews the modulus of elasticity (MOE) and the Modulus of Rupture (MOR) of this current testing with values from previous testing programs. This project evaluates these properties based on the procurement regions across the Northeast as well as the species groupings growth characteristics.

Objectives

1. Testing visually graded No. 2, 2” x 4”, 2” x 6” and 2” x 8” balsam fir and Eastern spruce lumber in edge-wise bending to determine MOE and MOR as outlined in ASTM D4761-13.

2. Analyze the mechanical property data per ASTM D1990-16

Hypothesis

H₀: There has been no change in the mechanical property design values for balsam fir and Eastern spruce within the current SPF(s) grouping.
H$_{A}$: There has been a change in the mechanical property design values for balsam fir and Eastern spruce within the current SPF(s) grouping.

1.2 Background and Literature

The implementation of a quinquennial monitoring program of published mechanical property values of lumber is an ongoing requirement of all grade-rule writing agencies in the U.S. and Canada. Monitoring of the Spruce-Pine-Fir south (SPF(s)) lumber grouping of species requires a regional approach since it incorporates three regions of the United States that produce SPF(s)-stamped lumber, the Western states, the Great Lakes, and the Northeastern regions. This lumber grouping includes, red, white, black, and Norway spruce, (*Picea rubens*, *Picea glauca*, *Picea mariana*, and *Picea Abies*), red pine (*Pinus resinosa*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*) in the Northeastern and Great Lakes regions, as well as lodgepole pine (*Pinus contorta*), Sitka spruce (*Picea sitchensis*), and Engelmann spruce (*Picea engelmannii*) in the West. The most recent testing of the full lumber grouping varied by region, with the Northeastern’s latest testing conducted in 2006, the Great Lakes in 2012, and the West Coast species in 2013 (Canadian Wood Council 2006, NE/LMA 2013, Natural Resource Research Institute 2013). The combined analysis of the first cycle of lumber monitoring programs, which was submitted in 2013, indicated that no further testing was necessary as the groupings’ strength values were similar or higher than the published SPF(s) values. These lumber testing results were approved by the ALSC Board of Review at their April 17, 2014 meeting.

During this current project, the Northeastern Lumber Manufacturers Association (NE/LMA), in close cooperation with the University of Maine’s Advanced Structures and Composite Center, sampled and tested the Northeastern SPF(s) lumber grouping in 2017 as part of the required monitoring of published design values. It has been 10 years since the last lumber testing in the
region for these species, as the 2006 testing was very extensive with over 5,000 samples so a
testing was not needed for 2012. This 2017 testing program is compared with the 1991, 2006,
and 2013 programs. These results will help determine if any further lumber testing should occur,
or if there has been a downward shift in values. Lumber testing data from this program will
subsequently be pooled with that from the other species and regions.

1.3 The Northeastern Lumber Monitoring Program

The selection of lumber samples for testing represented the Northeastern species procurement
range in addition to sawmill production levels within this geographic region. This program
follows ASTM D1990-16 and D4761-13 Standards, and tested No. 2 graded, 2” x 4”, 2” x 6”,
and 2” x 8” lumber that had lengths of 8’, 10’, and 12’. Monitoring only requires testing No. 2,
2” x 4” lumber, but as requested by NE-LMA (who were asked by FPL), this program included all
three lumber sizes to gather more information on the mechanical properties of these three widths.

With advancements in forestry practices over the past two decades that have pushed for
sustainable forestry and faster production of timber for forest products, the need to monitor
mechanical properties of structural lumber has become a necessity. With faster growth rates and
shorter rotation ages, the mechanical properties of the lumber itself can change attributable to the
increased amounts of juvenile wood. The cause for lower strength values in juvenile wood is
because of the high microfibril angle in the S2 layer of the cell wall within the tree. The S2 layer
makes up the largest portion of the cell wall and is 3 to 15 times thicker than the S1 and S3
layers combined (Forintek, 1994). For this reason, this layer dictates the physical properties of
the wood. (Barnett, 2004).

In the past 15 years, it was reported that Southern yellow pine plantation lumber had higher
percentages of juvenile wood, which contributed to statistically lower strength values. Southern
yellow pine is typically produced using plantation based forestry methods, which increases growth rate to allow for a 20-year rotation age. This causes the proportion of juvenile wood to increase drastically. This increase of juvenile wood in Southern yellow pine caused lower strength values than older growth Southern yellow pine.

With newer silvicultural practices, such as pre-commercial thinning, in the past few decades a concern rose that there could be an increase of juvenile wood within other lumber species groupings. The possible increase of juvenile wood and reduced mechanical properties resulted in the need for a periodic monitoring program for all lumber groupings, including SPF(s). The SPF(s) grouping is a structural lumber grouping that consists of red, white, black, and Norway spruce, red pine, jack pine and balsam fir species within the northern region of the United States. The existence of species groupings is for ease of production attributable to similar strength values, visual aspects, and growth characteristics.

For structural purposes, lumber must be graded by a licensed grader that is associated with a specific grading agency. This project required working in cooperation with one of the Northeastern grading agencies, the Northeastern Lumber Manufacturers Association (NELMA). NELMA, like all other grading agencies in North America, is under the jurisdiction of the American Lumber Standards Committee (ALSC). The ALSC approved the sampling and testing plan for this project (NELMA, 2017) and will receive the final testing results at the conclusion of this program.

When lumber is graded by a licensed inspector, the grader examines the lumbers visual aspects to determine its grade according to the National Grading Rule (NGR). The lumber grade is based on the visual aspects known as maximum strength reducing defects such as knots, shake, slope of grain, etc. Select structural (SS), No. 1’s, No. 2’s, are the most commonly used grades for
structural purposes. All grades of lumber that will be used structurally must have appropriately assigned strength values, as lower grades of lumber may not be safe to be used as a structural material. This is why since 2005, monitoring programs are required to be conducted every five years as wood construction materials are derived from dynamic forest systems and periodic testing is necessary to ensure the current lumber stock meets current published design values.

In a study done involving jack pine, it was shown that the bending properties of the lowest rotation age stand were significantly lower than those of later rotation aged stands, which related directly to the percentage of juvenile wood in the trees (Duchesne, 2005). In Southern yellow pine, the presence of higher proportions of juvenile wood also directly affects the modulus of elasticity and the modulus of rupture in structural lumber (Larson, 2001). This monitoring of visually graded structural lumber became the precursor to the development of the five-year monitoring program that was developed in 2005 by the ALSC (Kretschmann et al., 1999).

For timber to be used as structural lumber, design values must be developed using appropriate testing standards. A monitoring program was put into place to insure mechanic values of lumber being produced today are statistically the same to the design values and monitoring programs (ALSC, 1991). Testing of lumber must also be able to be reproduced across the globe, which is done by following ASTM standards. For this project, multiple American Society for Testing and Material (ASTM) standards were used. Since 2005 there have been three SPF(s) lumber monitoring programs conducted which were compiled into a final report and submitted to the ALSC for review and approval (Canadian Wood Council 2006, NEELMA 2013, Natural Resource Research Institute 2013). It was determined that all of the programs matched or exceeded values of the 1991 published design values. This current project is the first part of the second monitoring rotation for the Northeast, now being 10 years after the initial program in 2005.
The lumber was tested in four-point edge-bending, (Figure 1.1) at various loading rates, 0.5”/min, 0.6”/min, and 0.75”/min for 2” x 4”, 2” x 6” and 2” x 8” samples respectively. This was to target sample failure within 2-5 minutes.

Using a graph that plots a stress strain curve, the slope of the linear curve is the modulus of elasticity (MOE). In compression or tensile tests, this slope is sometime referred to as Young’s modulus to differentiate it from bending MOE. Bending MOE is a measure of the resistance to bending deflection, which is relative to the stiffness (Wood Handbook, 2010). The modulus of rupture (MOR) is the measurement of the samples strength, which is the maximum stress a sample can support before bending failure. The equations for MOR and MOE are shown below in equations 1 and 2.

\[
\text{Modulus of elasticity}_{app} = \frac{23PL^3}{108bd^3\Delta} \quad (1)
\]

\[
\text{Modulus of Rupture} = \frac{P_{max}L}{bd^2} \quad (2)
\]
MOEapp = Apparent modulus of elasticity (psi)
MOR = Modulus of rupture (psi)
Pmax = Maximum load (lbf)
L = Test span (in)
b = Thickness of board = breadth of bending member (in)
d = Width of board = depth of bending member (in)
Δ = Midspan deflection (in)

These mechanical property values are calculated from deformation data collected at the neutral axis at mid-span and is plotted vs. load to create a graph similar to Figure 1.2. The slope of the load vs. deflection curve in the linear range was calculated. A graph was created for every sample that was tested to help calculate for the MOEapp.

![Graph showing load vs. deflection](image)

**Figure 1.2.** Example of stress vs. strain curve used for calculating modulus of elasticity.

This lumber testing program will be the first testing of the second cycle of monitoring programs and will consist of five of the ten species within the SPF(s) grouping. A final summary report of all three regions will then be submitted for comparative analysis to the 1991 ALSC published values. The information gathered also helps to keep the public and the industry informed on current values as the previous three testing programs since 2005 have done.
1.4 Sampling Plan

The “Sampling and Testing Plan for the Monitoring of Northeastern Species within the SPF(s) Grouping”, dated December 5th, 2016 and revised on March 5th 2017, was submitted by NELMA and approved by the ALSC Board of Review.

1.4.1 Location of Species

The following map of the Northeastern region provides information critical to lumber sample selection:

![ArcGIS map of New England showing growth area of balsam fir and Eastern spruces and Maine mills producing SPF(s) lumber.](image)

The gray-colored areas (combination of blue and pink colors) indicate the growing region for both the Eastern spruces (red, white, black, and Norway) and balsam fir. All mills that use the SPF(s) stamp on lumber are indicated, U.S. mills as green squares and Canadian border mills as
orange triangles. All Canadian mill information was provided in an email by either the Maritime Lumber Bureau (MLB) or the Quebec Forest Industries Council (QFIC). This email can be found in Appendix C.

1.4.2 Excluded Mills

It is important to note that the Canadian border mills were strategically built near the border with the U.S. to utilize the vast forests of Eastern spruce and balsam fir located in Maine, New Hampshire and to lesser extent, Vermont. Northern New York is dominated by the Adirondack Park that severely limits timber harvesting. These Canadian mills are required to stamp lumber manufactured from logs procured in the U.S. with the SPF(s) stamp.

Discussions were held with the Maritime Lumber Bureau (MLB) and the Quebec Forest Industry Council (QFIC) regarding the potential to procure lumber samples from these border mills, as was done in the 2006 jointly supported testing project with NELMA. As a result of these discussions, this monitoring plan proposed the selection of testing samples from the six U.S. sawmills ONLY. The rationale for this decision was as follows:

- The New Brunswick border sawmill is mixing U.S. and Canadian logs and stamping their production with the SPF(s) stamp. There would be no guarantee that lumber samples from this mill would be exclusively U.S. logs, as SPF lumber has higher design values than SPF(s).

- The Quebec border sawmills are procuring logs from exactly the same areas as the 6 U.S. mills. It was believed that in a monitoring type of program, this would be redundant in the selection process. In addition, there could also be instances of mills mixing U.S. and Canadian logs to produce lumber, but for simplification purposes just stamping all as SPF(s).
An email of the decision to exclude the Canadian border mills can be found in Appendix C.

1.5 Sample Quantity by Mill

A survey was sent to each of the six mills located in the Northeast that produce SPF(s) stamped lumber. The information regarding the mill’s total annual production of lumber in board feet, approximate percentage of each species in their output, and procurement of logs by state was requested. Table 1.1 presents a summary of the results

<table>
<thead>
<tr>
<th>Survey Results from NELMA Certified Mills in the Northeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species Utilized</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Balsam Fir</td>
</tr>
<tr>
<td>Eastern Spruces</td>
</tr>
<tr>
<td>Red Pine</td>
</tr>
<tr>
<td>Jack Pine</td>
</tr>
</tbody>
</table>

The predominant species being harvested in this region is divided between the Eastern spruces and balsam fir. The fact that there was no procurement of red pine and jack pine in this region was not a surprise. Jack pine is an incidental species in the Northeast that could show up in a mill’s log supply by accident since it grows in the same region, however it is not preferred and certainly not separated. Red pine is not procured by the mills attributable to its different manufacturing and drying characteristics that create problems at the mill. The surveys for each of the mills are included in Appendix B. The surveys have the mill names and signatures redacted as it is desirable to keep information of where the lumber is coming from confidential.

1.6 Sample Matrix

When first formulating the sample matrix and determining how many samples would be required for testing, it was originally based on the output of the two species being produced by each mill. Those with a higher production of balsam fir will have more samples procured from that mill.
than Eastern spruce, and vice versa. A total of 600 samples would be procured from all mills with 300 samples for each species. There was also the need to fill the minimum requirement of 15 samples of each species and width from each mill. As balsam fir had an average of 33% production output compared to Eastern spruce among all mills, it was decided a smaller sample size was needed. Discussions with NELMA led to the lower sample size of 240 pieces for balsam fir. In Table 1.2, the original sampling plan based on statistical output for species per mill was formed.

To keep all information confidential, unbiased, and randomized, each of the six mills samples is labeled A through F. This labeling is used throughout the monitoring program.

| Table 1.2. Original lumber sampling plan based on the statistical output of each species per mill. |
|-----------------------------------|-----|-----|-----|
| Mill | Eastern Spruce | Balsam Fir | Total by mill |
| A | 90 | 15 | 105 |
| B | 65 | 45 | 110 |
| C | 50 | 65 | 115 |
| D | 60 | 50 | 110 |
| E | 40 | 45 | 85 |
| F | 55 | 20 | 75 |
| Total | 360 | 240 | 600 |

After thorough discussion concerning the sampling plan and the sample sizes with NELMA, it was determined that the sampling plan of 600 samples was not necessary. It was suggested that there should be an equal amount of samples based on the geographical location of the lumber being harvested. A total of 13 pieces of each nominal width (2” x 4”, 2” x 6”, and 2” x 8”) all No. 2 grade were selected at each of the six mills for both Eastern spruce and balsam fir. The overall total sample size was 234 pieces for each species (468 test pieces). Two additional pieces for each width and species were collected at the time of sampling to be used in testing should any of the original samples become unusable. In Table 1.3, the revised sampling plan is shown. This is the sampling plan that was used for the program.
Table 1.3. Revised sampling plan for each mill based on geographical region.

<table>
<thead>
<tr>
<th>Mill</th>
<th>Eastern Spruce</th>
<th>Balsam Fir</th>
<th>Total by mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>39</td>
<td>39</td>
<td>78</td>
</tr>
<tr>
<td>B</td>
<td>39</td>
<td>39</td>
<td>78</td>
</tr>
<tr>
<td>C</td>
<td>39</td>
<td>39</td>
<td>78</td>
</tr>
<tr>
<td>D</td>
<td>39</td>
<td>39</td>
<td>78</td>
</tr>
<tr>
<td>E</td>
<td>39</td>
<td>39</td>
<td>78</td>
</tr>
<tr>
<td>F</td>
<td>39</td>
<td>39</td>
<td>78</td>
</tr>
<tr>
<td>Total</td>
<td>234</td>
<td>234</td>
<td>468</td>
</tr>
</tbody>
</table>
CHAPTER

2 LUMBER MONITORING TEST REPORT

2.1 Experimental Methods

This section covers all information for the experimental methods used in this project. This includes information pertaining to sample collection, testing procedures, and adjustment methods used on the data. The second section of this chapter provides the post analysis results.

2.1.1 Testing Location and Dates

Testing was conducted at the Advanced Structures and Composite Center at the University of Maine in Orono. The structural testing laboratory floor is shown in Figure 2.1. Shipments of the procured lumber were received by U-Haul trucks on three separate dates; lumber from mill A was received on March 31st, 2017, mills E and F on April 5th, 2017 and mill B, C, and D, on the May 4th, 2017. The testing of the lumber occurred between July 2017 and September 2017.

2.1.2 Lumber Sampling Procedures

Lumber was procured using a systematic procurement process at the mill sites. A single unit of No.2 or better lumber was selected and every fifth piece of graded No. 2 lumber was selected.
The samples that were procured for sampling were labeled with a unique identifier at the time of selection, written by a professional NE LMA inspector. Depending on the frequency of the species it took as little as one pile, or as many as 4 piles of lumber to obtain the desired number of samples.

The visual grade of each piece was confirmed by multiple senior NE LMA graders at each mill to ensure each sample was representative of the No. 2 grade. This confirmation grading process included NE LMA’s Lumber Inspection Program Coordinator, Director of Inspection Services, and regional Inspector for the mill.

2.1.2.1 Sample Labeling

A unique sample ID was assigned to every piece including: mill code, width, grade, sample number, species, grade controlling defect, and strength reducing defect. (Figure 2.2 and Table 2.1).

Figure 2.2. Labeling scheme for lumber sample F-4-2-7-BF.
Table 2.1. Description of lumber labeling scheme.

<table>
<thead>
<tr>
<th>Label interpretation</th>
<th>Label example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumber Mill (A-F)</td>
<td>F</td>
</tr>
<tr>
<td>Lumber Width (4, 6, or 8)</td>
<td>4</td>
</tr>
<tr>
<td>Grade of lumber</td>
<td>2</td>
</tr>
<tr>
<td>Sample number (1-15)</td>
<td>7</td>
</tr>
<tr>
<td>Species (BF or ES)</td>
<td>BF</td>
</tr>
<tr>
<td>Grade Controlling defect</td>
<td>20</td>
</tr>
<tr>
<td>Maximum strength reducing defect</td>
<td>20</td>
</tr>
</tbody>
</table>

2.1.2.2 Conditioning of Lumber

Lumber samples were stacked in covered, unheated storage and were then separated by mill, species, and width. The samples were checked for moisture content (MC) using a Delmhorst J2000 electrical resistance two-pin moisture meter to ensure they were within allowable parameters per ASTM D1990-16 (10% to 23%). The average MC for balsam fir was 16.4% with some samples above 23%. Because of concern from NELMA that some of the samples were over 30%, all balsam fir lumber samples were placed into a Nyle dehumidification dry kiln for conditioning (Figure 2.3).

A kiln sample was gravimetrically measured on a daily basis to predict MC. The lumber was conditioned for eleven days, with the kiln sample dropping from 19.4% to 16.5%. It was decided that the lumber samples had been properly conditioned after doing several spot checks with a moisture meter on random samples throughout the stack with no measurements above 20% MC. The lumber samples were then restacked by species and size.
2.1.3 **Pre-test Data Collection**

Prior to testing, the following information was recorded for each piece of lumber:

- Test order
- Lumber Specimen ID (Region, Width, Grade, ID#)
- Thickness (to 0.001”)
- Width (to 0.001”)
- Length (to the nearest 1/16”)
- Weight (to 0.001 lb)
- Moisture content using a pin meter
- Rings per inch (visually based average)
- Percent summerwood (visually based average)
- Presence or absence of pith on both samples ends
- Grade controlling defect (GCD) as identified by NELMA grader
- Maximum strength reducing defect (MSRD) as identified by NELMA grader
All of these data were recorded in an Excel spreadsheet.

2.1.4 Calibration of Instruments

As the Advanced Structures and Composite Center is an ISO 17025 accredited testing laboratory, all equipment is calibrated on an annual basis. Calibration stickers and certificates are located in Appendix E.

2.1.5 Bending Tests

For the lumber monitoring program only static bending tests are required. The static bending tests were done in accordance with ASTM D4761-13, Section 6.

2.1.5.1 Test Machine and Fixtures

Testing was conducted using a hydraulic actuator that is rated for 55 kips (55,000 lbf) which was mounted to a steel H-frame (Figure 2.4). A 20 kip Instron load cell was attached underneath a swiveling clevis that was attached to the end of the hydraulic cylinder. Underneath the load cell a 10” deep x 9’ long steel I-beam was installed with two maple load heads (Figure 2.5 and 2.6) having a radius of curvature of 13.2”. These load heads were placed equidistant from each other so that the center of the load head would be the same distance to the center of the I-beam as well as the same distance to the end of the testing span, (e.g. four-point edge-bending). For both the 2” x 8” and 2” x 6” boards, lateral supports were used (Figure 2.7 and 2.8) to prevent lateral buckling. Each end of the lateral supports had one or more HDPE strips applied depending on any warping of the board. Two concrete blocks were used with steel reactions bolted on the top of them which pivoted in two axes. On top of the steel reactions, a 6” x 6” plate with rollers built in sat, on top of which the specimens were placed. The rollers helped to prevent any axial forces from developing within the sample (Figure 2.9).
Figure 2.4. Hydraulic actuator attached to H-frame.

Figure 2.5. I-beam with two maple load heads attached.

Figure 2.6. Load head.
Figure 2.7. Lateral supports.

Figure 2.8. Concrete reaction block.

Figure 2.9. Reaction plate.
2.1.5.2 Test Controls and Data Collection

Tests were conducted using Instron controls and their data acquisition “Console” software. Using the control software allowed the testing rate to be controlled (Figure 2.10). Data were collected using the DAQ National Instrument software to record time, load, and displacement (Figure 2.11). The 20-kip Instron load cell was attached to the hydraulic actuator with the I beam underneath (Figure 2.12). Displacement was measured using an Omega LVDT at a rate of 2 Hz. The LVDT was mounted on a wooden stand, leveled, and positioned under an “L” bracket that was screwed into the specimen at the neutral axis at the exact midpoint which was measured using a laser level (Figure 2.14).

![Figure 2.10. Instron program.](image1)

![Figure 2.11. Labview program.](image2)
Figure 2.12. 20-kip load cell.

Figure 2.13. +/- 25mm LVDT on a stand.
2.1.5.3 Equipment List

Table 2.2. Equipment list.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Equipment #</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 kip hydraulic actuator</td>
<td>263</td>
</tr>
<tr>
<td>20 kip load cell</td>
<td>104</td>
</tr>
<tr>
<td>+/- 0. 25mm LVDT</td>
<td>1992</td>
</tr>
<tr>
<td>NI DAQ Chasis</td>
<td>763</td>
</tr>
<tr>
<td>DAQ cards</td>
<td>851, 855</td>
</tr>
<tr>
<td>12” calipers</td>
<td>433</td>
</tr>
<tr>
<td>Balance for boards and MC sample</td>
<td>2071</td>
</tr>
<tr>
<td>Ovens</td>
<td>131/132</td>
</tr>
<tr>
<td>Delmhorst J2000 electrical resistance 2-pin moisture meter</td>
<td>277</td>
</tr>
<tr>
<td>Instron Control software</td>
<td>1558</td>
</tr>
</tbody>
</table>

2.1.5.4 Sample Position

Each sample was placed vertically into the fixture so that the label was consistently facing the same way, thus assuring randomization of the maximum strength reducing defects in relation to the load heads. Each sample had a mark, placed by the NeLMA graders, indicating the strength reducing defect that was predicted to be the cause of failure. This mark was placed as close to mid-span as possible while still leaving 2” overhang on the reaction plates. Horizontal randomization was carried out using a randomization chart (Figure 2.15). The chart is a random
number table with numbers ranging from 0-30” in 3” increments. The mark was moved towards the same end in the amount indicated in the table, or until there was at least 2” of overhang.

2.1.5.5 Test Span and Testing Rates

Per ASTM D4761-13, a 17:1 span-to-depth ratio was used based on the actual width of the lumber; 3.5”, 5.5”, 7.25”, the test spans were calculated to be 59.5”, 93.5” and 123.25,” respectively.

Load rate also is dependent on specimen depth (lumber width). The target time to failure was 2-4 minutes. To achieve this for the 2” x 4”, 2” x 6”, and 2” x 8” the speed of testing was set to 0.5, 0.6 and 0.75 inches/minute, respectively.

2.1.5.6 Test Procedure

1. The sample number was entered into the DAQ Labview program as a filename.

2. The sample was placed into the fixture of the test machine and moved according to the randomization chart

3. For 2” x 8” and 2” x 6” samples if necessary, additional HDPE strips were placed over the face of the lateral supports to minimize, or prevent lateral buckling.
4. Using the hydraulic controls, a preload of 150 lbf was placed on the test sample to remove any slack in the testing fixture which also helps to keep the sample in firm contact with the load heads and the reactions.

5. The “L” bracket that is used with the LVDT was screwed in at the neutral axis.

6. The LVDT was placed under the center of the L bracket

7. Data acquisition was initiated.

8. At a load of 700 lbf the 2” x 4” samples were removed and at 1,000 lbf the 2” x 8” and 2” x 6” the LVDT was removed to prevent damage that might occur during ultimate failure.

The range of stress between 400-7000 psi is adequate to determine MOE of the samples as per ASTM D4761-13. The stress for each sample at 1,000 lbf is approximately 3,250, 2,050, and 1,550 psi for the 2” x 4”, 2” x 6” and 2” x 8” samples, respectively.

9. Upon ultimate failure, the testing was stopped and the fixture was set back to the original position.

10. The data was saved as a .csv file.

11. The sample was removed from the test fixture.

12. The label was copied near the point of failure and a photograph was taken of the sample at the point of failure.

13. Within an hour of testing, a moisture content sample was cut from each specimen (about 2-3” in width near the failure point). These are then weighed to the nearest 0.01g, labeled, and placed in an oven at 103˚C for up to 72 hours. After drying the samples were removed from the oven and weighed again to calculate oven-dry moisture content.
2.1.6 Calculation of MOE and MOR

Modulus of elasticity was calculated using the slope within the linear range of the load vs. deflection data.

![Graph showing slope of a tested lumber sample used to determine the specimen's MOE.](image)

**Figure 2.16.** Slope of a tested lumber sample used to determine the specimen's MOE.

Using this slope derived from a graph similar to Figure 2.16 and the equation from ASTM D198-15 table X2.1 the MOE is calculated using equation 4.

\[
Modulus\ of\ elasticity_{app} = \left(\text{Slope of } \frac{P}{\Delta}\right) \frac{23L^3}{108bd^3} \tag{4}
\]

Where:

- \(L\) = Test span (in)
- \(b\) = Thickness of board = breadth of bending member (in)
- \(d\) = Width of board = depth of bending member (in)
- \(\Delta\) = Midspan deflection (in)
All of the data were processed through Matlab which was coded to find the following information:

- Maximum load
- Time to maximum load
- The slope of the least square regression line from the load vs deflection data. This was done at specific ranges for each of the widths. The ranges for determining the slope for each of these widths were 300-500 lbf, for 2” x 4”s and 400-700 lbf for 2” x 6”s and 2” x 8”s. Each sample provided a graph that was also visually checked individually to make sure the slopes were calculated within a linear range prior to the proportional limit. Any samples with abnormalities were recalculated individually with a new range that was chosen to be sure was within the linear range. These slopes were used in the equation above to find MOE_{app}.

Modulus of rupture (MOR) was calculated using the equation given in ASTM D198 table X2.1.

\[
Modulus\ of\ Rupture = \frac{P_{max}L}{b d^2}
\]  

(5)

Where:

- \( P_{max} \) = Maximum load (lbf)
- \( L \) = Test span (in)
- \( b \) = Thickness of board = breadth of bending member (in)
- \( d \) = Width of board = depth of bending member (in)

2.1.7 Failure Codes, Strength Ratios, and Grade Quality Index (GQI)

The grade quality index (GQI) is a scaling parameter which allows modeling of strength and modulus of elasticity with respect to grade. GQI is a method to compare the grade quality of the sample tested to the grade quality assigned for that grade (45% for a No. 2). Section X12 of
ASTM D1990-16 describes the objective: “…to provide data that helps to verify that the lumber samples (1) represented the quality range expected in production and, (2) included pieces with the maximum knot size and slope of grain described in the grading rules for a specified grade”. Diagrams of each of the failed lumber samples were drawn and calculated by expert NE LMA inspectors over three separate visits per ASTM D4761-13, Appendix X1. From these failure codes, strength ratios are calculated.

As required, strength ratios were only determined for samples that failed attributable to knots, slope of grain, or distorted grain (Codes 11-20, 34 and 51) using equations from D245-06 Appendix X1 (Table 2.3). For a given cell (e.g. balsam fir, 2” x 4”), the data were ranked from lowest strength ratio to largest. An order statistic determined the lower 5th percentile strength ratio, which defines GQI.
Table 2.3. Equations to calculate strength ratios.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cause: Extent</th>
<th>Extent calculation</th>
<th>2x4 or 2x6</th>
<th>2x8</th>
<th>If S &lt; 45%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow face or spike knot, intergrown</td>
<td>X = 11</td>
<td>% displacement</td>
<td>S = 100(1-(p-1/24)/(h+k(3/8)))*2</td>
<td>S = 100(1-(p-1/24)/(h+(1/2)*k))*2</td>
<td>S = 100(1-(p-1/24)/h)*2</td>
</tr>
<tr>
<td>Narrow face or spike knot, encased</td>
<td>X = 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrow face or spike knot, sound</td>
<td>X = 13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide face knot, center line, intergrown</td>
<td>X = 14</td>
<td>Knot size nearest 1/16&quot;</td>
<td>S = 100(1-(k-(1/24)/(h+(3/8)))*2</td>
<td>S = 100(1-(k-1/24)/(h-(1/2))*2</td>
<td>S = 100(1-(k-1/24)/h)*2</td>
</tr>
<tr>
<td>Wide face knot, center line, encased</td>
<td>X = 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide face knot, at edge, intergrown</td>
<td>X = 17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide face knot, at edge, encased</td>
<td>X = 18</td>
<td>Knot size nearest 1/16&quot;</td>
<td>S = 100(1-(k-(1/24)/(h+(3/8)))*2</td>
<td>S = 100(1-(k-1/24)/(h-(1/2))*2</td>
<td>S = 100(1-(k-1/24)/h)*2</td>
</tr>
<tr>
<td>Wide face knot, at edge, sound</td>
<td>X = 19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knots, not well spaced, or combinations</td>
<td>X = 20</td>
<td>% cross section</td>
<td>S = 100(1-(p-1/24)/(h+(3/8)))*2</td>
<td>S = 100(1-(p-1/24)/(h+(1/2))*2</td>
<td>S = 100(1-(p-1/24)/h)*2</td>
</tr>
<tr>
<td>Distorted grain, knot cluster or bulk</td>
<td>X = 34</td>
<td>% displacement</td>
<td>S = 100(1-(p-1/24)/(h+(3/8)))*2</td>
<td>S = 100(1-(p-1/24)/(h+(1/2))*2</td>
<td>S = 100(1-(p-1/24)/h)*2</td>
</tr>
<tr>
<td>Slope of grain</td>
<td>X = 51</td>
<td></td>
<td>S = (a<em>b)</em>(slope of grain)</td>
<td>S = (a<em>b)</em>(slope of grain)</td>
<td>S = (a<em>b)</em>(slope of grain)</td>
</tr>
</tbody>
</table>

X = Failure code
Y = Extent of failure (e.g. knot size in 1/16ths of an inch, % displacement, slope of grain)
b = Actual narrow face width (in)
h = Actual wide face width (in)
k = Knot size (in)
S = Strength ratio (%)
p = Percent displacement converted into equivalent knot size on wide face (in) = (width*Y/100)
a and b for slope of grain depend on the slope (slope <8:1, a=1.0, b=6.5; slope b/w 8:1-11:1, a=21, b=4); slope b/w 12:1-17:1, a=36.3, b=2.7; slope > 18:1, a=-50, b=7.5)

2.1.8 Raw and Adjusted Data

All test data, both raw and adjusted, are included in Appendix A. For MOE, the three adjustments are for loading condition, GQI, and to 15% moisture content at time of testing. For MOR the adjustments are for GQI, 15% moisture content at time of testing, and to 7.25” depth x 144” long. All derived test values were determined in accordance with ASTM D1990-16.

2.1.8.1 Abbreviations

Abbreviations used include:

MOE<sub>app</sub> – Apparent modulus of elasticity, unadjusted

MOE’<sub>app</sub> – Apparent modulus of elasticity adjusted for loading condition
MOE''\text{app} – Apparent modulus of elasticity adjusted for loading condition and GQI
MOE''\text{app} - Apparent modulus of elasticity adjusted for loading condition, GQI, and to 15% MC
MOR – Modulus of rupture, unadjusted
MOR’ – Modulus of rupture adjusted for GQI
MOR’’ – Modulus of rupture adjusted for GQI and to 15% MC
MOR’’’ – Modulus of rupture adjusted for GQI, to 15% MC and to 1.5” x 7.25” x 144”

2.1.8.2 Statistical Methods

Per ASTM D1990-16, non-parametric statistics are used to analyze the data. Order statistics are used to determine values including the non-parametric point estimates and lower 5\textsuperscript{th} percentile values. This is done by ranking values from weakest to strongest, and finding the value associated with the chosen order statistic. Order statistics are based on sample size at a content of 95\% with a confidence of 75\%. For this program, the NON-PAR program was used which can be found on the U.S. Forest Products Laboratory’s statistical analysis website to find point estimates, tolerance limits, and confidence intervals (NONPAR, 2018). For point estimates, which were not always an integer, linear interpolation was used between the two corresponding data points (ASTM D245-06, Section 4.2.2). Interpolation was used when determining GQI using the strength ratios. The example below uses a linear interpolation with a sample size of 71.

The order statistic for non-parametric point estimate (NPE) is 3.60. The NPE is calculated as value 6/10\textsuperscript{th} the distance from the third to fourth lowest data points.

\[
50.2\% = 49.7\% + (0.6 * (50.4\% - 49.7)) 
\]  

Conservative rounding was always used when determining the lowest 5\textsuperscript{th} percentile tolerance limits as well as the 75\textsuperscript{th} percentile confidence intervals.
2.1.8.3 **Size Adjustment to 15% MC**

Wood shrinks and swells causing changes to its dimensions depending on moisture content. Using the formula from ASTM D1990-16 in Appendix X1, all dimensions were adjusted to what they would be at 15% MC.

\[
d_2 = d_1 \frac{1 - \left(\frac{a - b \cdot MC_2}{100}\right)}{1 - \left(\frac{a - b \cdot MC_2}{100}\right)}
\]

\(d_1\) = Dimension at MC_1 (in)
\(d_2\) = Dimension at MC_2 (in)
MC_1 = MC at \(d_1\) (%)
MC_2 = MC at \(d_2\) = (15 %)
a = 6.031 for width, 5.062 for thickness
b = 0.215 for width, 0.181 for thickness

2.1.8.4 **Adjustment of MOE for Loading Conditions**

Adjustment from deflections measured at mid-span to those at the load-head was done using the equation in ASTM D2915-10, Section X4

\[
E_{ai2} = \frac{1 + K_1 \left(\frac{h}{L_1}\right)^2 \left(\frac{E}{G}\right)}{1 + K_2 \left(\frac{h}{L_1}\right)^2 \left(\frac{E}{G}\right)} E_{ai}
\]

\(E_{ai}\) = Original apparent modulus of elasticity (psi)
\(E_{ai2}\) = Adjusted apparent modulus of elasticity (psi)
\(K_1\) = 0.939 for third-point loading with \(\Delta\) measured at mid span
\(K_2\) = 1.080 for third-point loading with \(\Delta\) measured at load heads
\(h\) = Depth of beam
\(L\) = Test span (in)

For this testing program, the adjustment was found to be 0.9926:

\[
E_{ai2} = \frac{1 + 0.939 \left(\frac{1}{17}\right)^2 \left(\frac{16}{17}\right)}{1 + 1.080 \left(\frac{1}{17}\right)^2 \left(\frac{16}{17}\right)} E_{ai}
\]
\[ E_{ai2} = 0.9926 \times E_{ai} \]

MOE\textsubscript{app} adjusted for loading conditions and is now abbreviated MOE'\textsubscript{app}.

2.1.8.5 Moisture Content Adjustment

All adjustments in this report utilize the oven-dry moisture content. The average difference between the pin moisture meter reading and the oven-dry moisture content was (n=500) avg. = 0.4%.

2.1.8.6 Adjustment for Temperature

All testing was completed in a heated testing facility with average temperatures maintained at 70 +/- 3°F, where the samples had been stored for up to four days, and adjustment was deemed unnecessary as the wood had acclimated to the ambient temperature.

2.1.8.7 Adjustment of Properties for MC

All values in the data set were adjusted from the original moisture content at the time of the test, to 15% as described in ASTM D1990-16 Annex A1. The calculations used the following formula;

\[
\begin{align*}
For\{\text{MOR} \leq 2,415 \text{ psi}\} S_2 &= S_1 \quad (10) \\
For\{\text{MOR} > 2,415 \text{ psi}\} S_2 &= S_1 + \left\{ \frac{(S_1 - B_1)}{(B_2 - MC_1)} \right\} (MC_1 - MC_2) \quad (11)
\end{align*}
\]

\( S_1 \) = Property at \( MC_1 \) (psi)
\( S_2 \) = Property at \( MC_2 \) (psi)
\( MC_1 \) = Moisture content 1 – moisture content at the time of the test
\( MC_2 \) = Moisture content 2 – 15%MC
\( B_1 \) = 2,415 for MOR
\( B_2 \) = 40 for MOR

For MOR values that were found to be more than 2,415 psi the formula became the following:
\[ MOR_2 = MOR_1 + \left\{ \frac{(MOR_1 - 2415)}{(40 - MC_1)} \right\} (MC_1 - 15) \] (12)

The MOE values were adjusted with the formula below, which was re-formatted and became the equation 14.

\[ S_2 = S_1 + \frac{(B_1 - (B_2 \times MC_2))}{(B_1 - (B_2 \times MC_1))} \] (13)

\[ MOE_2 = MOE_1 + \frac{(1.857 - (0.0237 \times 15))}{(1.857 - (0.0237 \times MC_1))} \] (14)

Where:

- \( S_1 \): Property at MC\(_1\) (psi)
- \( S_2 \): Property at MC\(_2\) (psi)
- \( MC_1 \): Moisture content 1 – actual MC at time of test (%)
- \( MC_2 \): Moisture content 2 – (15 %)
- \( B_1 \): 1.857
- \( B_2 \): 0.0237

The MOE values now adjusted for loading condition, GQI, and to 15% MC is now abbreviated as MOE''''\_app. For MOR, the data was now adjusted for GQI and 15% MC and is abbreviated MOR''.

### 2.1.8.8 Adjustment of Properties to the Characteristic Size

As per ASTM D1990-16, section 8.3.4, all MOR data was adjusted to the characteristic size (7.25” wide by 144” long) using the following equation:

\[ F_2 = F_1 \left( \frac{W_1}{W_2} \right)^w \left( \frac{L_1}{L_2} \right)^l \left( \frac{T_1}{T_2} \right)^t \] (15)

Within this equation \( t=0 \), as thickness is not required in this adjustment. An example of this adjustment can be seen in equation 16 using a 2” x 6” and adjusting it to the characteristic size
after the 15% MC adjustment was done, with an adjusted width of 5.537” and a calculated
MOR’’ of 6,188 psi.

\[ 6,188 \left( \frac{5.537''}{7.25''} \right)^{0.29} \left( \frac{93.5}{144''} \right)^{0.14} \left( \frac{T_1}{T_2} \right)^0 = 5,387 \text{ psi} \] (16)

2.1.9 GQI Adjustment

ASTM D1990-16 Section 8.2 describes the process of adjusting values for GQI where the lower
5th percentile point estimate of strength ratios for each cell is determined and then compared on
the assigned GQI for No. 2 grade which is 45%. Only samples with failure codes 11-20, 34 and
51 were used. As required, all other samples were excluded from the GQI calculation including
those that failed in “clear wood” with a 100% strength ratio. The values for the observed GQI for
all cells is presented in Table 2.4.

<table>
<thead>
<tr>
<th>Species</th>
<th>Width</th>
<th>N</th>
<th>NPE Order</th>
<th>Statistic</th>
<th>GQI</th>
<th>GQI factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF</td>
<td>4</td>
<td>71</td>
<td>3.60</td>
<td></td>
<td>50.2</td>
<td>0.997</td>
</tr>
<tr>
<td>BF</td>
<td>6</td>
<td>71</td>
<td>3.60</td>
<td></td>
<td>53.0</td>
<td>0.943</td>
</tr>
<tr>
<td>BF</td>
<td>8</td>
<td>43</td>
<td>2.20</td>
<td></td>
<td>53.0</td>
<td>0.943</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td>52.1</td>
<td></td>
</tr>
<tr>
<td>ES</td>
<td>4</td>
<td>64</td>
<td>3.25</td>
<td></td>
<td>52.3</td>
<td>0.957</td>
</tr>
<tr>
<td>ES</td>
<td>6</td>
<td>60</td>
<td>3.05</td>
<td></td>
<td>55.0</td>
<td>0.908</td>
</tr>
<tr>
<td>ES</td>
<td>8</td>
<td>60</td>
<td>3.05</td>
<td></td>
<td>53.1</td>
<td>0.941</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td>53.5</td>
<td></td>
</tr>
</tbody>
</table>

As stated in ASTM D1990-16 Section 8.3.1.2 “If the average of all cell GQIs in one grade does
not exceed the grade GQI by more than 5 points (50%), reduce the property value for all
specimens in any cell whose GQI exceeds the grade GQI by more than 7 points using the
formula in 8.3.1.2 (repeated below as Equation 17). If the average of all individual cell GQIs in
the grade exceeds the grade GQI by more than 5 points, reduce the property value for all
specimens in each cell that exceeds the grade GQI by more than 5 points using the formula in
8.3.1.2. Cells adjusted, using this procedure, are assumed to be compliant and no further grade quality adjustment is required for the grade in question.”

\[ GQI \text{ Factor} = \frac{\text{assigned GQI} + 5\% \text{ points}}{\text{Observed GQI}} \]  
(17)

As the standard dictates no observed average GQI for a species is to be more than 5% points above the assigned GQI (45%). As the average GQI for both species is above the 50% all cells for both species must be adjusted for GQI using the above formula. An example of the GQI adjustment for balsam fir 2” x 6” No.2, which is applied to both MOE and MOR, is presented in the equation below.

\[ 0.943 = \frac{45\% \text{ points} + 5\% \text{ points}}{53.0\% \text{ points}} \]  
(18)

2.1.10 Order Statistics, Point Estimates, Tolerance Limits, and Confidence Intervals

Non-parametric order statistics, point estimates (NPE), the lower 5th percentile, tolerance limits (NTL), and the lower and upper 75% confidence intervals (LCI/UCI) were determined for MOR”, MOR’’, and MOE’’. Unrounded order statistics are tabulated below (Table 2.5).

<table>
<thead>
<tr>
<th>Width</th>
<th>Species</th>
<th>n</th>
<th>NPE O.S.</th>
<th>Unrounded Order Statistics</th>
<th>NTL</th>
<th>LCI</th>
<th>UCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>BF</td>
<td>87</td>
<td>4.40</td>
<td>3.50</td>
<td>2.03</td>
<td>6.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>85</td>
<td>4.30</td>
<td>3.40</td>
<td>1.96</td>
<td>6.64</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>BF</td>
<td>85</td>
<td>4.30</td>
<td>3.40</td>
<td>1.96</td>
<td>6.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>84</td>
<td>4.25</td>
<td>3.30</td>
<td>1.92</td>
<td>6.58</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BF</td>
<td>79</td>
<td>4.00</td>
<td>3.10</td>
<td>1.74</td>
<td>6.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>79</td>
<td>4.00</td>
<td>3.10</td>
<td>1.74</td>
<td>6.26</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>BF</td>
<td>251</td>
<td>12.60</td>
<td>10.70</td>
<td>8.61</td>
<td>16.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>248</td>
<td>12.45</td>
<td>10.60</td>
<td>8.49</td>
<td>16.41</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.6 reports the rounded non-parametric order statistics, NPE, the lower 5\textsuperscript{th} percentile, NTL, LCI, and UCI for MOR’’, MOR’’’, and MOE’’’ of both balsam fir and Eastern spruce.
Table 2.6. Values derived using order statistics, NPE, NTL, 75% LCI and UCI.

<table>
<thead>
<tr>
<th>Width</th>
<th>Species</th>
<th>n</th>
<th>NPE</th>
<th>O.S.</th>
<th>MOR**</th>
<th>MOR*</th>
<th>MOE**</th>
<th>Rounded Order Statistics</th>
<th>NTL</th>
<th>LCI</th>
<th>UCI</th>
<th>NTL</th>
<th>LCI</th>
<th>UCI</th>
<th>NTL</th>
<th>LCI</th>
<th>UCI</th>
<th>NTL</th>
<th>LCI</th>
<th>UCI</th>
<th>NTL</th>
<th>LCI</th>
<th>UCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>BF</td>
<td>67</td>
<td>4.40</td>
<td>3.977</td>
<td>2.751</td>
<td>843.339</td>
<td>3.0</td>
<td>2.0</td>
<td>7.0</td>
<td>1.949</td>
<td>1.778</td>
<td>2.114</td>
<td>2.721</td>
<td>2.474</td>
<td>2.941</td>
<td>634.403</td>
<td>792.333</td>
<td>877.403</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>85</td>
<td>4.30</td>
<td>2.043</td>
<td>2.889</td>
<td>880.995</td>
<td>3.0</td>
<td>2.0</td>
<td>7.0</td>
<td>2.003</td>
<td>1.978</td>
<td>2.205</td>
<td>2.803</td>
<td>2.760</td>
<td>3.085</td>
<td>843.439</td>
<td>838.395</td>
<td>893.405</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>BF</td>
<td>65</td>
<td>4.30</td>
<td>7.748</td>
<td>2.005</td>
<td>754.875</td>
<td>3.0</td>
<td>2.0</td>
<td>7.0</td>
<td>1.320</td>
<td>1.295</td>
<td>2.017</td>
<td>1.511</td>
<td>1.485</td>
<td>2.313</td>
<td>706.951</td>
<td>689.183</td>
<td>819.184</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>84</td>
<td>4.25</td>
<td>1.637</td>
<td>1.883</td>
<td>728.827</td>
<td>3.0</td>
<td>2.0</td>
<td>7.0</td>
<td>1.554</td>
<td>1.494</td>
<td>1.769</td>
<td>1.792</td>
<td>1.718</td>
<td>2.049</td>
<td>725.727</td>
<td>712.928</td>
<td>752.454</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BF</td>
<td>79</td>
<td>4.00</td>
<td>2.059</td>
<td>2.096</td>
<td>739.020</td>
<td>3.0</td>
<td>1.0</td>
<td>7.0</td>
<td>2.047</td>
<td>1.584</td>
<td>2.165</td>
<td>2.094</td>
<td>1.616</td>
<td>2.228</td>
<td>731.223</td>
<td>665.693</td>
<td>871.614</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>79</td>
<td>4.00</td>
<td>3.171</td>
<td>1.344</td>
<td>585.537</td>
<td>3.0</td>
<td>1.0</td>
<td>7.0</td>
<td>1.317</td>
<td>0.649</td>
<td>1.624</td>
<td>1.344</td>
<td>0.861</td>
<td>1.665</td>
<td>449.845</td>
<td>421.515</td>
<td>630.087</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>BF</td>
<td>251</td>
<td>12.00</td>
<td>2.005</td>
<td>2.236</td>
<td>814.740</td>
<td>10.0</td>
<td>8.0</td>
<td>17.0</td>
<td>1.556</td>
<td>1.621</td>
<td>2.059</td>
<td>2.199</td>
<td>2.096</td>
<td>2.349</td>
<td>785.556</td>
<td>748.323</td>
<td>841.549</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.2 Summary Statistics and Analysis

Summary statistics for both species are presented in Table 2.7. For this table it is important to note that for 2” x 4”, 2” x 6”, and 2” x 8” MOE”’app and MOR”’ are used, where for the combined cell the adjustment to characteristic size reporting the MOR”’.
Table 2.7. Summary Statistics for MOR and MOE for balsam fir and Eastern spruce
*MOR'' and MOE'''
**MOR''' and MOE'''

<table>
<thead>
<tr>
<th>2017 Monitoring Program</th>
<th>Summary Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 x 4 *</td>
</tr>
<tr>
<td><strong>Balsam Fir</strong></td>
<td></td>
</tr>
<tr>
<td>Sample Size (n)</td>
<td>87</td>
</tr>
<tr>
<td>SG (OD Wt/Vol. at test MC) - Ave</td>
<td>0.37</td>
</tr>
<tr>
<td>MC at time of test (OD) (%) - Ave</td>
<td>11.9</td>
</tr>
<tr>
<td>GQI (Lower 5th% SR)</td>
<td>50.2</td>
</tr>
<tr>
<td>GQI (Reduction factor)</td>
<td>0.997</td>
</tr>
<tr>
<td>Mean MOE app</td>
<td>1.168</td>
</tr>
<tr>
<td>Mean MOE app (without GQI adj.)</td>
<td>1.171</td>
</tr>
<tr>
<td>Median MOE app</td>
<td>1.153</td>
</tr>
<tr>
<td>Standard Deviation MOE app</td>
<td>0.232</td>
</tr>
<tr>
<td>Lower 5th percentile MOE app (PE)</td>
<td>0.843</td>
</tr>
<tr>
<td>Lower 5th percentile MOE app (TL)</td>
<td>0.834</td>
</tr>
<tr>
<td>Upper 75% CI Limit for TL</td>
<td>0.877</td>
</tr>
<tr>
<td>Lower 75% CI Limit for TL</td>
<td>0.792</td>
</tr>
<tr>
<td><strong>Mean MOR</strong></td>
<td>4.679</td>
</tr>
<tr>
<td>Median MOR</td>
<td>4.542</td>
</tr>
<tr>
<td>Standard Deviation MOR</td>
<td>1.337</td>
</tr>
<tr>
<td>Lower 5th percentile MOR (PE)</td>
<td>2.761</td>
</tr>
<tr>
<td>Lower 5th percentile MOR (TL)</td>
<td>2.721</td>
</tr>
<tr>
<td>Upper 75% CI Limit for TL</td>
<td>2.728</td>
</tr>
<tr>
<td>Lower 75% CI Limit for TL</td>
<td>2.474</td>
</tr>
<tr>
<td><strong>Eastern Spruce</strong></td>
<td></td>
</tr>
<tr>
<td>Sample Size (n)</td>
<td>85</td>
</tr>
<tr>
<td>SG (OD Wt/Vol. at test MC) - Ave</td>
<td>0.42</td>
</tr>
<tr>
<td>MC at time of test (OD) (%) - Ave</td>
<td>12.7</td>
</tr>
<tr>
<td>GQI (Lower 5th% SR)</td>
<td>52.3</td>
</tr>
<tr>
<td>GQI (Reduction factor)</td>
<td>0.957</td>
</tr>
<tr>
<td>Mean MOE app</td>
<td>1.161</td>
</tr>
<tr>
<td>Mean MOE app (without GQI adj.)</td>
<td>1.213</td>
</tr>
<tr>
<td>Median MOE app</td>
<td>1.083</td>
</tr>
<tr>
<td>Standard Deviation MOE app</td>
<td>0.202</td>
</tr>
<tr>
<td>Lower 5th percentile MOE app (PE)</td>
<td>0.861</td>
</tr>
<tr>
<td>Lower 5th percentile MOE app (TL)</td>
<td>0.843</td>
</tr>
<tr>
<td>Upper 75% CI Limit for TL</td>
<td>0.893</td>
</tr>
<tr>
<td>Lower 75% CI Limit for TL</td>
<td>0.838</td>
</tr>
<tr>
<td><strong>Mean MOR</strong></td>
<td>4.972</td>
</tr>
<tr>
<td>Median MOR</td>
<td>4.806</td>
</tr>
<tr>
<td>Standard Deviation MOR</td>
<td>1.388</td>
</tr>
<tr>
<td>Lower 5th percentile MOR (PE)</td>
<td>2.869</td>
</tr>
<tr>
<td>Lower 5th percentile MOR (TL)</td>
<td>2.803</td>
</tr>
<tr>
<td>Lower 5th percentile MOR (TL) (without GQI adj.)</td>
<td>2.917</td>
</tr>
<tr>
<td>Upper 75% CI Limit for TL</td>
<td>3.085</td>
</tr>
<tr>
<td>Lower 75% CI Limit for TL</td>
<td>2.760</td>
</tr>
</tbody>
</table>
2.2.1 Test Cell Data Checks

Per ASTM D1990-16 Section 9.3.1 describes the purpose of data checks: “The purpose of the test cell data check is to minimize the probability of developing non-conservative property estimates by comparing the model generated property values against the confidence interval for each cell in the test matrix. This test ensures that the individual matrix cell estimates generated with the volume adjustment procedures of Section 8.4.3 (Adjustment to the characteristic size) and the tolerance limit of the combined data do not lay above the upper limit of the confidence interval for the fifth percentile of any tested cell.”

2.2.1.1 Test Cell Data Check 9.3

This data check was conducted on data from both species with characteristic MOR values of 1,956 for balsam fir and 1,554 for the Eastern spruces (Table 2.8). These values are then compared against the upper 75% confidence interval. The cell passes a data check as long as the volume adjusted values generated are lower than the 75% confidence interval. For this testing all values passed and no further changes were needed.

<table>
<thead>
<tr>
<th>Width</th>
<th>Species</th>
<th>Upper 75% CI for NTL MOR (psi)</th>
<th>Characteristic MOR Value (psi)</th>
<th>MOR (psi) adjusted to width of (in)</th>
<th>Passes Check?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Combined</td>
<td>BF</td>
<td>2,059</td>
<td>1,956</td>
<td>2,734</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>1,751</td>
<td>1,554</td>
<td>2,172</td>
<td>Pass</td>
</tr>
<tr>
<td>4</td>
<td>BF</td>
<td>2,941</td>
<td></td>
<td>2,251</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>3,085</td>
<td></td>
<td>1,789</td>
<td>Pass</td>
</tr>
<tr>
<td>6</td>
<td>BF</td>
<td>2,313</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>2,049</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BF</td>
<td>2,228</td>
<td></td>
<td>1,999</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>1,665</td>
<td></td>
<td>1,588</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Table 2.8. Section 9.3 Data check.
2.2.1.2 Test Cell Data Check 12.6

Similar to the previous data check the volume adjusted MOR values are compared against the non-parametric 5\(^\text{th}\) percentile point estimate (NPE).

Table 2.9. 12.6 Data check for all cells for both species.

<table>
<thead>
<tr>
<th>Width</th>
<th>Grade</th>
<th>5th% MOR PE (psi)</th>
<th>5th% MOR NPE + 100 (psi)</th>
<th>5th% MOR NPE + 5% (psi)</th>
<th>Characteristic MOR Value</th>
<th>MOR (psi) adjusted to width of (in)</th>
<th>Pass/Fail Check?</th>
<th>If fail, value needed to pass (psi)</th>
<th>If fail, new Characteristic Value (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.5</td>
<td>5.5</td>
<td>7.25</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>BF</td>
<td>2.005</td>
<td>1.956</td>
<td></td>
<td></td>
<td></td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>1.643</td>
<td></td>
<td></td>
<td></td>
<td>Pass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>BF</td>
<td>2.761</td>
<td>2.661</td>
<td>2.699</td>
<td></td>
<td>2.734</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>2.869</td>
<td>2.969</td>
<td>3.012</td>
<td></td>
<td>2.712</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>BF</td>
<td>2.005</td>
<td>2.105</td>
<td>2.105</td>
<td></td>
<td>2.261</td>
<td>Fail</td>
<td>2.104</td>
<td>1,829</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>1.833</td>
<td>1.833</td>
<td>1.977</td>
<td></td>
<td>1.709</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BF</td>
<td>2.096</td>
<td>2.196</td>
<td>2.201</td>
<td></td>
<td>1.999</td>
<td>Pass</td>
<td>1,410</td>
<td>1,379</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>1.344</td>
<td>1.444</td>
<td>1.411</td>
<td></td>
<td>1.588</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To pass this data check, the volume adjusted MOR cannot be higher than 5% of 5\(^\text{th}\) percentile NPE, or 100 psi more than the 5\(^\text{th}\) percentile NPE. Two cells failed the check and thus the characteristic value must be lowered until this the cell passes. In this case the values for balsam fir were lowered from 1,956 psi to 1,829 psi and the values for Eastern spruce were lowered from 1,554 psi to 1,380 psi.
CHAPTER

3 DISCUSSION

3.1 Grade Quality Index (GQI): Summary, Problems, Calculations, and Proposed Solutions

3.1.1 GQI Introduction

In this section, GQI is examined comprehensively to better understand the procedures involved. GQI is somewhat ambiguous and the procedures for deriving GQI can be interpreted differently by different people. The procedures for carrying out GQI span three separate testing standards as well as the national grading rule (NGR). Because of this lack of clarity on GQI, this section will discuss its history, provide a detailed description, and offer suggestions on how GQI could be applied in a more uniform manner. Through the comprehensive analysis of GQI, it was surprising to learn how sensitive this data adjustment can be and that a minor misinterpretation or incorrect value during the analysis of failure codes during post-test procedures can have a significant impact on the final adjusted mechanical properties values.

3.1.2 History of the Grade Quality Index

ASTM D1990-16, Section X12.1 states that the GQI is meant to ensure that lumber samples: (1) represent the quality range expected in production; and (2) include pieces representing the maximum knot size and slope of grain described in the grading rules for a specified grade. GQI is in effect a scaling parameter which is used as a reduction factor for bending strength and modulus of elasticity if a sample is deemed by GQI to be above grade. This is done by calculating a strength ratio for each lumber sample based on the type and extent of failure. A strength ratio is “the hypothetical ratio of the strength property being considered compared to that for the material with no strength reducing characteristic. Thus, a piece of stress-graded lumber with a strength ratio of 75% in bending would be expected to have 75% of the bending
strength of the clear piece” (ASTM D-245-06, Section 3.2). Each failure type has an associated code (In Table 3.1, “Cause” or “X”), the extent of that cause is calculated, and formulas in ASTM D245-06 are used to calculate the strength ratio. The GQI for each of the six test cells is calculated as the nonparametric lower 5th percentile point estimate of the calculated strength ratios for each cell. Samples that fail in clear wood or have a strength ratio of 100% are excluded from the GQI calculation.

Table 3.1. Strength ratio calculations.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cause</th>
<th>Extent</th>
<th>Extent calculation</th>
<th>Equations if S &gt; 45%</th>
<th>Equations if S &lt; 45%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow face or spike knot, intergrown</td>
<td>X</td>
<td>Y</td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Narrow face or spike knot, encased</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrow face or spike knot, sound</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide face knot, center line, intergrow</td>
<td>14</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Wide face knot, center line, encased</td>
<td>15</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Wide face knot, center line, sound</td>
<td>16</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Wide face knot, at edge, intergrow</td>
<td>17</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Wide face knot, at edge, encased</td>
<td>18</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Wide face knot, at edge, sound</td>
<td>19</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Knots, not well spaced, or combinations</td>
<td>20</td>
<td></td>
<td>% cross section</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Distorted grain, knot cluster or burl</td>
<td>34</td>
<td></td>
<td>% displacement</td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
<tr>
<td>Slope of grain</td>
<td>51</td>
<td></td>
<td></td>
<td>2x4 or 2x8</td>
<td>2x8</td>
</tr>
</tbody>
</table>

GQI was first established to deal with lumber imported into the U.S. from abroad that were suspected to be of a higher grade than that assigned (i.e. some lumber designated No.2 was suspected to be of a higher grade, thus assigning inappropriately high values to No. 2). GQI was found to be a necessity to ensure that samples being tested are representative of their given grade (ASTM D1990, Section X12.5).

During the 1990s GQI evolved further because of new initiatives related to importing lumber from outside of North America. Three main factors were considered:

1. Lumber production from new regions or sources
2. Size of knots in relation to grade requirements
3. Calculated GQI in excess of target grade-defined GQI ranges
Problems with GQI are discussed in ASTM D1990-06, section X12.5.5 and X12.6.1. The first problem relates to sample size. Section X12.5.5 cautions “Calculation of point estimates from a small number of samples will increase the variability of the GQI estimate.”

3.1.3 Standards Involving GQI

ASTM D1990-16 goes over GQI and how to implement it within a testing program. The extent of information in this standard is based on applying GQI using the strength ratio for each of the samples. Sections 8.2 and 8.3 of this standard specify how to apply GQI using the assigned grade GQI and comparing it to the observed GQI.

The National Grading Rule (NGR) references several of the other standards that deal with GQI and strength ratio calculations (ASTM D1990-16, D245-06, D4761-13). Many of the informative images and figures come from ASTM D245-06, which are shown in the knot measurement section of the standard. Many images in this section are placed pages ahead of where they are mentioned and have insufficient description of what each image is and how to calculate percent displacement. When the images in this standard are referenced in Section 5.3.4.1 (Figure 3.1), there are no equations to verify the use of this method as well as little description on the three images displayed. These images are shown again in the NGR with better descriptions and equations for both center line and spike knots in the NGR Section 1.7.
The rest of the descriptions in ASTM D245-06, Section 5.3.4 reference only two images which have within them up to four examples. Within the description in the standard it is difficult to interpret which illustration is being described within the example. (Figure 3.2).

Figure 3.1. Measurement of knots in dimension lumber using the displacement method.

Figure 3.2. Figure identifying different types of knots from ASTM D245-06.
The standard that specifies the coding for each of the failure code diagrams is found in ASTM D4761-13. These codes can be seen in Table 3.1. In the appendix of ASTM D4761-13 Table X1.1 it shows several examples of drawn diagrams with letters as the variables for the measurements, but again there are no equations to help standardize this method.

The NGR is the best resource when trying to calculate displacement during the failure code diagraming/calculation process. An updated version of this would be recommended to help reduce the already ambiguous nature of this process. There have been a few attempts to re-evaluate the methods used to calculate knot displacement. The Southern Pine Inspection Bureau (SPIB) has a small step-by-step example that attempts to help people calculate and grade knots (SPIB, 2018), but this method is not applicable to all failure codes. The West Coast Lumber Inspection Bureau’s (WCLIB) standard grading rules from 2015 (WCLIB, 2015) has some newer figures which attempt to define how certain knots should be measured. This is found in Section 8 of their grading rules (figures reproduced below).

![Figure 3.3](image.png)

Figure 3.3. Figure from WCLIB grading rules book for measurement of a wide face knot.
Figure 3.4. Figure from WCLIB grading rules book showing different measurements needed for different types of knots.

Even with these newer diagrams depicting how knots should be measured, there are still no examples using the equations given in the NGR. The goal and challenge is to have all grading agencies conform to one way of calculating failure codes and extents.

3.1.4 The Challenges with Implementing GQI

Review of the failure code diagrams that were hand drawn at the point of failure revealed possible inaccurate values. During previous testing programs a chart was made for each width to help determine the displacement of both narrow face and wide face knots without the use of calculations given from the NGR. This chart known as the wide/narrow face chart, which has been used in past testing programs since it was created. The wide face portion is quite accurate when compared to the NGR method calculations, but there seems to be problems when trying to use the narrow face chart. The one problem with this chart when determining displacement for narrow face knots is that not everyone understands how to interpret this chart properly or what
would be fully considered a narrow face knot, which can result in incorrect reports of displacements and failure codes.

Figure 3.5 demonstrates how measurements were recorded in the failure code diagrams using the chart for narrow face knots and NGR calculations. This example shows how using this method may result in different displacement measurements when compared to NGR calculations and how there is a difference between them. When matching up the two measurements of the knots using the 2” x 4” narrow face chart, it shows that the diagram has only 11% displacement, where if the NGR calculations are used the displacement would equate to 32%.

![Lumber cross section diagram](image)

**Figure 3.5.** Lumber cross section diagram that results in two different displacements depending on calculation method

\[
\frac{1.5'' + 0.75''}{2} \times 1.5 = \frac{5.25}{2} = 32\% \text{ displacement}
\]

Throughout the process of analyzing the cross sectional diagrams at the point of failure, there were nine examples of inconsistencies with the use of the narrow/wide face chart (images of all questionable samples are presented in Appendix D). An example of this occurred in sample E-4-2-13-BF (Appendix D) where using the chart results in 17% displacement, but when done properly the displacement was found to be 30%, almost twice that of the original calculated displacement.

Further analysis of the data brought up several issues that were correlated with the four problems discussed in ASTM D1990-16 X12.1. Before recommending ways to solve some of these issues,
the problems need to be defined to demonstrate how uncertain this process is and show the undesired variables that come with GQI.

Defining the problem

- Ambiguous percent displacement definition in ASTM D245-06
- Uncertainty of percent displacement versus percent cross section
- Deciding on when narrow/wide face chart should be used for spike knots
- Variation depending on who is calculating the knot/grain displacement

3.1.5 GQI Sensitivity

It is noteworthy that a single miscalculation in the interpretation and calculation of the failure diagrams could have a large impact on the GQI reduction factor. For example, say the strength ratio of a sample was calculated and found to be 59.3%. When finding the lowest 5th percentile strength ratio, where the order statistic is 3.5 and the two samples being interpolated are 51.2% and the sample with 59.3% mentioned above, it creates an inaccurate GQI of 55.3%. This is well above the allowable 52% resulting in an almost 10% reduction in mechanical values.

When the error is found for the strength ratio with 59.3 and is corrected, a new strength ratio is found to be 52.7%. This would change the GQI to 51.95%, just under the allowable limit and the cell involved no longer needs an adjustment, which would otherwise reduce the strength values by almost 10% if the miscalculation was not addressed.

Knowing how sensitive the GQI adjustment can be attributable to even one incorrect diagram, and knowing that there has been testing done with thousands of samples, there is bound to be a few interpretation mistakes that could affect the entire evaluation process. By understanding the
sensitivity of GQI and the effect strength ratio has on it, a robust data checking system should be developed to make sure that the failure diagrams are being interpreted correctly.

3.1.6 Strength Ratio Effect on GQI

By recalculating the strength ratios of the diagrams that impacted the GQI within this program, a new GQI and GQI factor was determined after thorough reassessment of suspect samples.

Using all re-calculated values of the failure code diagrams that were adjusted, several changes occurred attributable to the new GQI factor. Four cells between the two species had further adjustments needed after the initial analysis. The most noticeable difference was with the balsam fir 2” x 4” that resulted in a change from a 11.4% reduction to a 0.03% reduction with a GQI factor changing from 0.886 to 0.997, respectively. The one cell that had an increased reduction was the 2” x 6” Eastern spruce, which went from a 0.27% reduction to a 9.2% reduction. The two other cells that required the application of GQI were the 2” x 6” balsam fir and the 2” x 8” Eastern spruce, both had a final reduction of 5.7% and 5.9%, respectively.

To see that four of the six cells had significant changes to GQI was surprising and shows how large of an impact this process can have during the implementation of ASTM D4761-13. Out of 499 samples that were part of the testing program, 27 samples needed to be re-evaluated, meaning that 5.4% of the samples were effected by misinterpreted failure code process.

There was a question that was consistently brought up during the drawing of the failure code diagrams by the NE-LMA professionals, “Does the code I use have any effect on the strength ratio calculations?” A report done by the Southern Pine Inspection Bureau (SPIB) showed that the type of failure reported does have an affect on the calculations (SPIB, 2012).
The problem concerning if the different codes and equations used to calculate strength ratios was found in a paper from the SPIB about the creation of design values for Southern yellow pine. They found there was an issue when calculating the strength ratios and the difference between the equations.

It was reported that “a complication arises if a cross section contains a reasonably large edge knot in combination with other center-of-the-wide-face or edge knots. For example, if a piece of #2 2” x 10” contained an edge knot, that occupies 28.4% of the cross section, then using the edge-of-wide face equation we see that the strength ratio associated with this single edge knot is 54.03, but if the same cross section had additional knots which would change the equation, this displacement would go from 28.4% to 33%. When this occurs you would typically expect the strength ratio of 54.03 to go down. But, in fact, when the center-of-wide-face knot equation is used for combination knots, the calculated strength ratio becomes 69.12 compared to the 54.03 from the edge-of-wide face equation” (SPIB, 2012)

Slight differences in displacement calculations when using different codes is attributable to the different formulas being used for the equations from ASTM D245-06 and also because of the subjective nature of choosing certain codes depending what the grader sees as the cause of failure. One way to be certain of where the failure occurred would be to visually record each lumber sample test to failure with a high speed camera. With visual confirmation, the location of failure would be easy to pinpoint and could be used as a second check if needed. If this is an issue that we have no control over, the best we can do is narrow the remaining undesired variables to make this process more accurate.
3.1.7 Correlation of Strength and Strength Ratio

One issue that was found in previous literature was the relationship between the strength properties of the samples and the strength ratio that is derived from the equations in ASTM D245-06. As previously mentioned in D1990-16 X12.1 it was discovered that there is actually little correlation between the strength properties and the strength ratio. This brings into question, why use it if this is the case? In Figure 3.6, the relationship between the strength ratio and the modulus of rupture are graphed and shown to have an \( R^2 \) value of 0.2085. This brings one large question into consideration, if no GQI adjustment was made for the original data set and there is no correlation between strength ratio and strength properties, should the adjustment only be used for specific data sets where grade quality is in question? This is not something that can be easily reviewed or decided on, but this is an issue that should be solved to create a more standardized process that would be considered more robust and could be reproduced easily.

Figure 3.6. Correlation between all lumber strength ratios and modulus of rupture.
3.1.8 Rings per inch correlation to MOR

By also investigating the relationship between rings per inch and the modulus of rupture, the results may show a correlation between the two. Two important aspects of a sample that can help be determined by rings per inch is the density of the sample and presence of any juvenile wood. With lower amounts of rings per inch, this could signify that the sample has lower density and may contain more juvenile wood, which has been shown to decrease the strength property of lumber.

Figure 3.7. Log transformation of balsam fir RPI vs MOR.
By using a log transformation of the regression between both rings per inch and MOR, the relationship between the two can be seen in Figures 3.7 and 3.8. For both species there appears to be very little correlation between the two variables. For balsam fir there appears to be about a 20% relationship between the two variables with the Eastern spruce falling below that at 12.8%. Looking at both figures, from 0.4 RPI to about 1.1, there is a large variation among the samples, yet when the RPI increases to about 1.2, the results lie much closer to the regression line. The correlation to physical properties and MOR should be investigated further as there are most likely other factors to consider when determining the causes contributing to lower strength values.

3.1.9 Narrowing the undesired variation of GQI diagrams

One of the easiest ways to decrease the amount of variability in these types of lumber testing programs is to define the problems occurring in regards to GQI. Doing this can help determine ways to either remove the problem or find ways to address the amount of variability concerning the individual problem. One thing that should be considered first is the definition regarding the
difference between percent cross section and percent displacement. Through all the standards there is no single definition that defines percent cross section and percent displacement. They are both calculated the same and typically mean the same as far as ASTM D4761-13 describes them. The best definition that can be put into place to define a difference is that displacement is a one dimensional term, where cross section is a two dimensional term.

A second issue that creates confusion when defining equations based on ASTM D245-06 images is the lack of description among examples. Figure 3.2 is an image that is referenced in ASTM D245-06 multiple times with no equations to determine how to accurately calculate displacement and does not easily depict which example is being described in the image. Updated and more descriptive figures are needed for this type of standard that is already suffering from variables that can be completely subjective.

The only document that attempts to compile all of the information from the standards that discuss GQI (ASTM D1990-16, D245-06, D4761-13) and have any form of equations given to help the average worker decipher all of this information is the NGR handbook. Many images were taken from these standards and an attempt was made to compile equations that could help calculate the displacement of a strength reducing defects. Much of this information is not well organized with few equations to help find percent displacement other than a few basic examples that only helps with a small portion of the diagrams presented.

One of the larger issues that raised many questions in this study was when to use the narrow/wide face charts for displacement. The wide face chart appears to be accurate when comparing them to the NGR calculations, but a problem consistently occurs when a spike knot is measured with this chart resulting in much lower % displacement. Defining when to use this chart for spike knots is necessary to estimate the correct amount of displacement as accurately as
possible. As seen in this testing program it can easily cause problems later in calculations of the strength ratios, which have a strong impact on the GQI factor. This narrow/wide face chart as of now is just a guideline to help calculate certain diagrams, but without a standard on when to implement this it can easily and consistently cause an undesired variable.

Creating a large table of examples on how to calculate the main codes used in the application of GQI (codes 11-20, 34, and 51) as well as difficult failure code diagrams could help resolve problems that relate to: 1) separate teams drawing diagrams, 2) different people calculating diagrams, and 3) the amount of calculation errors.

![Figure 3.9 SPIB image of growth of knots.](image1)

![Figure 3.10. SPIB image of knot growth through lumber.](image2)
When examining how a cross section diagram is drawn, the three images above from the SPIB shows how knots form from the pith of the tree can be seen through lumber. It depicts how the knots can create a strength reducing defect depending on the cut of the lumber. The Figure 3.11 shows what a cross section diagram depicts when it is drawn. The diagram attempts to accurately measure the full displacement of any strength reducing defect within the point of failure.

### 3.1.10 Conclusions on GQI

There are always issues that arise from variability during these types of testing programs, but being able to lower the amount of undesired variables is an important aspect of creating standards. There are four main issues that are depicted in ASTM D1990-16 X12.1 that pertain to GQI;

1. Measurements
2. Calculations
3. Strength relationships
4. Resource differences
Besides creating an updated standard or compilation book similar to the NeLMA NGR, there are two other solutions to issues. One way would be trying to apply failure code diagrams immediately after each sample is tested, although this can take time and if this is needed to be done by certified lumber inspectors, they may not be available to do this during the testing.

The second solution is after each day of drawing the failure code diagrams, double check all calculations to be sure they have been properly calculated and that the right equation is used for each defect being measured.

Delving into GQI which is spread out over several standards and takes time to fully understand, there is still a major question that needs to be addressed. The idea of GQI is that it should be able to determine the quality of lumber being produced, tested, and should match how professional graders are grading the lumber. So the question must be asked, if the samples were taken from graded No. 2 lumber and the samples were then graded a second time by two certified NeLMA inspectors who confirmed the grade of the lumber, how is it that all six cells still require GQI adjustments? This indicates that after three evaluations of the lumber by professional inspectors, the lumber is not the quality it should be according to GQI. The chances are that the sample is unequivocally on-grade, and that GQI does not accurately determine if a sample is on grade or not.

It is surprising that failure evaluation process has been implemented for this long and still has these issues, regardless of the fact that the GQI relies on strength ratios which aren’t even correlated to actual strength properties. A final solution should be discussed by taking into account all of these problems that come from the ambiguous nature of the GQI process.
3.1.11 GQI Drawings and Examples

When creating the failure code diagrams for ASTM D4761-13 specific codes from the standard are used, which determines if the strength ratio of the sample will be included in the GQI evaluation. As stated before, codes 11-20, 34, and 51 are used in GQI and the formulas that are used to calculate these specific strength ratios can also be found in Table 3.2.

The first part of this section is used to depict the six typical codes used for failure code diagrams in ASTM D4761-13 and show examples of how to calculate the displacement of the maximum strength reducing defect. The examples given show the point of failure where the diagram is drawn from marked in the photograph. The second image given is the drawn failure code diagram with measurements in accordance with the NGR. The final figure is a digitalized version of the drawn diagram with both measurements and examples of how the displacement was calculated. These equations are derived from the multiple standards that were discussed in this section.

The second portion of this section is to show more complicated versions of the failure code diagrams that may come up during the ASTM D4761-13 post-test analysis.

Figure 3.12. Picture and diagram example of code 34, grain distortion.
The example of a code 34 (grain distortion) is a fairly simple diagram to draw and involves the simplest equation. This type of failure is typically caused on the tension side of the sample attributable to high amounts of grain distortion around certain areas. This is not a very common failure code, but it will be observed in most post-testing evaluations.

The failure code 51, slope of grain, is the simplest diagram found in the post testing analysis when calculating failure code diagrams. Other than what the slope has been designated as the only number that will be used for this equation will be the 8 in the 1 in 8 slope, as can be seen in the failure code.
The failure code for narrow face spike knots are 11, 12, and 13 depending on what type they are. This type of diagram is not difficult if the proper equation is used from NGR. By knowing that these calculations for this type of failure code are based on finding the area of a triangle, the same type of equation is used depending on the extent of the knot. The three typical equations used on narrow face knots can be seen in Figure 3.17 below and in the NGR handbook.
Figure 3.17. Equations used to calculate narrow face spike knots (NGR handbook).

Figure 3.18. Picture and diagram for failure codes 14, 15, and 16, center line wide face knot.

Figure 3.19. Digitalized diagram and example for failure codes 14, 15, and 16, centerline wide-face knots.
Failure codes 14, 15, and 16 represent centerline wide-face knots. These failure code equations are very similar to the grain distortion equation; however, the final code is reported in 16ths of an inch. By measuring each side of the knot and converting the measurement to $1/16^{th}$ of an inch and then averaging these two sides, the final measurement is found. So in the example above the top knot has 1.25” knot which converts to $20/16^{th}$ and the bottom knot has 2” which equals $32/16^{th}$. The average of these two knots is $26/16^{th}$ which is what is reported for the failure code.

Figure 3.20. Picture and diagram for failure codes 17, 18, and 19, at edge wide-face knot.
Figure 3.21. Digitalized diagram and example for failure codes 17, 18 and 19, at edge wide-face knot.

The failure codes 17, 18, and 19 for edge wide-face knots, use the same measurements as used for the centerline wide-face knots. The one thing that can differ from the previous failure code is that sometimes there are edge wide-face knots that can occupy a total of three faces, called a three-face knot. In this case, which will be covered in the more difficult diagram example section, the knots are adjusted to strictly the wide face. For the example above, it is calculated in the same way as the previous wide-face knot equation and is reported in $1/16^{th}$ of an inch.

Figure 3.22. Picture and diagram for failure code 20, combination knots.
Failure code 20, combination knot, is the most common failure code found in the testing program. A combination knot failure can have any of the previously mentioned knot failures combined, which creates a failure code 20. The calculations for this type of knot failure combine all final displacement values together. Starting from one side of the sample and going across is easiest to be sure all knots are calculated and accounted for. The final code that is reported is the sum of all displacement within the cross section, for this case it is 30%.

### 3.1.11.1 Complicated Examples of ASTM D4761-13 Diagrams

This section addresses any complicated diagrams that can arise during post-testing analysis. This is to assist in performing calculations for a large number of knots and also how to use the adjustment method for three-faced knots.
This example is part of the failure code 20, in this case two narrow face spike knots and two centerline wide-face knots. The individual calculations for each knot displacement should be done and summed up to equal the full amount of displacement within the sample. This summed displacement is what is reported in the failure code, for this sample it is 45% displacement.

Example: 
\[
\frac{\frac{1}{2} \times 1 \times 1.25 \times 1.5}{8.25} \approx 0.1136 \approx 11\%
\]

Example: 
\[
\frac{\frac{1}{2} \times 1 \times 2.825 \times 2.825}{8.25} \approx 0.1712 \approx 17\%
\]

Example: 
\[
\frac{\frac{1}{2} \times 1 \times 1.25 \times 1.5}{8.25} \approx 0.0909 \approx 9\%
\]

Equation: 
\[
\frac{\text{Area of board}}{2 \times \text{base} \times \text{height}} = \% \text{displacement}
\]

Example: 
\[
\frac{\frac{1}{2} \times 1 \times 2.825 \times 2.825}{8.25} \approx 0.1712 \approx 17\%
\]

Example: 
\[
\frac{\frac{1}{2} \times 1 \times 1.25 \times 1.5}{8.25} \approx 0.1136 \approx 11\%
\]

Example: 
\[
\frac{\frac{1}{2} \times 1 \times 1.25 \times 1.5}{8.25} \approx 0.0909 \approx 9\%
\]

Equation: 
\[
\frac{(AB) \times (BC)}{2(1) \times BD} = \% \text{displacement}
\]

Example: 
\[
\frac{(2.75) \times (1.5)}{8.25} \approx 0.0833 = 8\%
\]
With samples that require adjustments, which are described in the NGR handbook section 1.7.2, find the narrow face that has the two-faced knot in question, in this case it would be the left side of the sample in figure 3.25. The reasoning for this adjustment is to find what knot percentage is being displaced on the left narrow face edge and to adjust the upper wide face knot accordingly so all displacement is still taken into account. For the sample in Figure 3.25 the 0.5” on the left narrow face edge accounts for 33% of that narrow face, as 1.5” would be considered 100%. Now take 33% of the remaining open area on the upper wide face, for this sample 33% of that area, which is 0.7”, and add the adjusted displacement to the existing wide face knot. This will change the upper wide face knot measurement from 0.625” to 1.375”. After this, a new diagram is created, shown in Figure 3.26, calculations for full displacement can now be made similar to the basic six examples on the fully adjusted new diagram.

Figure 3.26. Complex diagram for displacement adjustment, post-adjustment.

Equation: \[
\frac{(AB+CD) \times \text{Thickness}}{\text{area of board}} \times \% \text{dis. For each}
\]

\[
\frac{(.875”+1.375”) \times 1.5”}{10.875”} = .1552 \approx 16%
\]

\[
\frac{(1.25”+.375”) \times 1.5”}{10.875”} = .1120 \approx 11%
\]

\[
\frac{(.25”+.25”) \times 1.5”}{10.875”} = .0344 \approx 3%
\]

11% + 14% +3% = 28% displacement
Very similar to the previous example, an adjustment is made for easy calculation while also taking into account all displacement within the sample. In this case, the two-faced knot on the right narrow face side is \(\frac{3}{4}\)", which is 50\% of the narrow face, as 1.5" would be 100\%. Using the remainder of the wide face area closest to the narrow face, 50\% of that area should be added to the wide face knot, which would be 0.5". The adjusted diagram (Figure 3.28) added the 0.5" to the wide face knot going from 0.5" to a full 1" and can now be calculated as a basic code failure 20.
3.2 Comparison to Older Tests

3.2.1 Wilcoxon Discussion

As described in ASTM D1990-16 Section 14.2.3, a Wilcoxon test is used to compare the data from the current monitoring program against the 1991 data set. A Wilcoxon test is a ranked, non-parametric two sample test that pools the two data sets being compared together and ranks them from lowest to highest. The test then determines if there has been a downward shift in values over time based on which data set has more values ranked lowest.

As this is a non-parametric test, meaning the data does not have an equal distribution, the test is not very powerful. The following are the hypothesis for this type of statistical test.

$H_0$: There is no shift in data when comparing the two program values

$H_A$: There is a shift in data when compared to the older program
This analysis compared the 2017 data to datasets from 1991, 2006, and 2012 for 2” x 4”. For 2” x 6” and 2” x 8”, only 1991 data was compared against 2017. As a non-parametric test, only two datasets can be compared at once resulting in 2 responses for each comparison (MOE’’’ and MOR’’). The outputs for the Wilcoxon test for balsam fir and Eastern spruce can be found in the two Tables below. The R program outputs can be found in Appendix A.

Table 3.2 Wilcoxon test for all BF samples, all comparisons done for 2” x 4”, and only with 1991 data for 2” x 6” and 2” x 8”, α 0.05.

<table>
<thead>
<tr>
<th>Comparison being done</th>
<th>MOE’’’</th>
<th>MOR’’</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x4 BF 2017 vs. 2006</td>
<td>α &gt; 2.431e-09</td>
<td>α &gt; 6.655e-06</td>
</tr>
<tr>
<td>2x4 BF 2017 vs. 2012</td>
<td>α &gt; 0.01321</td>
<td>α &gt; 0.009594</td>
</tr>
<tr>
<td>2x4 BF 2017 vs. 1991</td>
<td>α &lt; 0.7751</td>
<td>α &gt; 0.0004622</td>
</tr>
<tr>
<td>2x6 BF 2017 vs. 1991</td>
<td>α &gt; 8.585e-06</td>
<td>α &gt; 0.0003841</td>
</tr>
<tr>
<td>2x8 BF 2017 vs. 1991</td>
<td>α &gt; 0.002775</td>
<td>α &lt; 0.1998</td>
</tr>
</tbody>
</table>

Table 3.3 Wilcoxon test for all ES samples, all comparisons done for 2” x 4”, and only with 1991 data for 2” x 6” and 2” x 8”.

<table>
<thead>
<tr>
<th>Comparison being done</th>
<th>MOE’’’</th>
<th>MOR’’</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x4 ES 2017 vs. 2006</td>
<td>α &gt; 3.603e-14</td>
<td>α &gt; 1.11e-06</td>
</tr>
<tr>
<td>2x4 ES 2017 vs. 2012</td>
<td>α &gt; 1.311e-06</td>
<td>α &gt; 9.965e-06</td>
</tr>
<tr>
<td>2x4 ES 2017 vs. 1991</td>
<td>α &lt; 0.2588</td>
<td>α &gt; 0.01262</td>
</tr>
<tr>
<td>2x6 ES 2017 vs. 1991</td>
<td>α &gt; 0.01928</td>
<td>α &gt; 0.0007645</td>
</tr>
<tr>
<td>2x8 ES 2017 vs. 1991</td>
<td>α &gt; 1.321e-08</td>
<td>α &gt; 2.112e-08</td>
</tr>
</tbody>
</table>

When interpreting the results of the Wilcoxon test it is important to remember that the sample sizes of all of these tests are different. Because this is a ranked test comparing data sets with different sample sizes, the test favors the larger sample sized data set attributable to those programs having more samples to rank and having a much larger statistical distribution. For example, 2” x 4” values from the 2017 program are higher than the 1991 values, yet the Wilcoxon test still indicates a downward shift. The reason for this is because the downward shift in the Wilcoxon test is detected by the lowest ranked values from the two programs being compared. So even if the final values of MOE in 2017 are higher than the values from 1991, there can still be a downward shift detected if more values from 2017 are ranked lower. In this
test, working at an alpha level of 0.05 anything over the \( \alpha=0.05 \) will accept the null hypothesis, which says that there has been no shift in data. If the \( \alpha \) is lower than 0.05 the alternative hypothesis is accepted indicating that there has been a shift in the data. In Tables 3.2 and 3.3, all cells with bold font have an alpha level above 0.05, and show that there has been no shift in values.

Looking at the summarized \( \alpha \) values from the two tables, there is a downward shift detected in the 2017 data when compared to almost all other tests. The Wilcoxon test creates one response as it is only checking to see which test has the lowest ranked values. Although this may show that there is a downward shift in values, it is not necessarily true.

Although the basis of the test can show a downward shift of data, it would only be reliable when comparing data sets with close to equal sample sizes, and with tests that have similar data. It would be advised to find a new way to fully compare these data sets and also start by using as close to the same amount of samples as possible for all monitoring programs.

### 3.2.2 General Comparison of Mean MOE and Lowest 5th Percentile MOR Based on Summary Statistics

This section examined the summary statistics of all previous SPF(s) bending test data and attempted to compare the data as a whole. For the summary statistics, only the 2017, 1991, and 2006 data has information for all widths, so comparison of the 2” x 6” and 2” x 8” samples will be done at the end of this section.

For monitoring, the width that is tested and analyzed is typically 2”x4” lumber. These values can all be seen on Table 3.9 when comparing all 2” x 4” values.
Table 3.4. Comparison of MOE" and MOR" for 2" x 4" samples from all testing programs.

<table>
<thead>
<tr>
<th>Testing program for 2” x 4” lumber</th>
<th>1991</th>
<th>2006</th>
<th>2012</th>
<th>2013</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Balsam Fir</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Size</td>
<td>60</td>
<td>193</td>
<td>44</td>
<td>237</td>
<td>87</td>
</tr>
<tr>
<td>Mean MOE***</td>
<td>1.106</td>
<td>1.335</td>
<td>1.257</td>
<td>1.246</td>
<td>1.168</td>
</tr>
<tr>
<td>Lower 5th %ile MOR</td>
<td>2,489</td>
<td>2,969</td>
<td>2,336</td>
<td>2,829</td>
<td>2,721</td>
</tr>
<tr>
<td><strong>Eastern Spruce</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Size</td>
<td>59</td>
<td>160</td>
<td>154</td>
<td>314</td>
<td>85</td>
</tr>
<tr>
<td>Mean MOE***</td>
<td>1.190</td>
<td>1.435</td>
<td>1.368</td>
<td>1.422</td>
<td>1.161</td>
</tr>
<tr>
<td>Lower 5th %ile MOR</td>
<td>2,298</td>
<td>2,851</td>
<td>2,676</td>
<td>2,851</td>
<td>2,803</td>
</tr>
</tbody>
</table>

When looking at the Table above, the one thing that stands out the most is the difference in sample sizes. There are several factors accounting for the different sample sizes which are as follows:

- 1991 original sample size for the creation of design values of SPF(s)
- 2006 had over 3,000 samples total and this test was done to see if balsam fir and Eastern spruce could be removed from the SPF(s) grouping, which explains the high sample size for both species
- The 2012 Great lakes test was one of the three parts of the first monitoring program and had a small sample size for balsam fir and then a sample size similar to the 2006 testing for Eastern spruces. The reasoning for the vastly different sample sizes between these two species is that balsam fir is a low percentage of production in the Great Lakes region.
- The 2013 data are a combined analysis that incorporates the first cycle of monitoring which includes the samples tested in the Great Lakes (which is shown above), the west coast monitoring program, and the Northeastern program, hence the large sample size.

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When comparing these data, it is difficult to reconcile the large variability among sample populations for these test programs. Such large variability makes it very difficult to rely on quantitative comparisons as none of the sample sizes are similar and there is a non-normal distribution of responses. For this reason, the Wilcoxon test was used to attempt to compare these programs, although the test itself is not very powerful.

Now attempting to compare these values of MOE and MOR, there are two things that can be observed. The values from the 2017 program are all slightly higher than the original 1991 values, besides MOE’’’ of Eastern spruce, and appear to be close to matching the original results. When looking at the other testing programs, 2006, 2012 and the 2013, the values appear to be significantly larger than both the current test and the 1991 values. It is interesting to observe that the 1991 and the 2017 data have similar values while the 2006, and 2012 testing had higher values. Although these programs were performed properly and followed all procedures according to the ASTM standards, there could still be several reasons that might explain the results obtained, and potential reasons that could possibly contribute to biased values;

1. Difference in testing methods
2. Difference in testing equipment
3. Difference in recording devices
4. Interpretation of the ASTM standards
5. Use of randomization
6. Exclusion of bad samples

The ones that are most concerning are the last three, which could be a possible explanation for the three aforementioned testing programs having much higher physical property values.
As discussed in the GQI section, the interpretation of the applied standards could cause large problems when deriving strength values from test samples. If there are multiple people working on the post-test diagrams, miscalculations can possibly occur attributable to the misinterpretation of failure code diagrams.

When performing lumber testing in edge-wise bending, the need for random placement of a sample is an absolute necessity. Within the ASTM D1990-16, the randomization of a sample is needed, but again it could be interpreted in different ways. If someone who is performing the test placed a specimen within the fixture only using a randomization chart, there would still be an option to which narrow face of the board would be placed in the test fixture on the tension or compression side. This would result in a bias to which way the maximum strength reducing defect would face. Having any type of choice in the placement of the sample within the fixture can lead to a bias of the test results, which could explain the drastically higher values obtained for in the three testing programs.

One final way that could explain the large difference in values between the 2017/1991 values and the 2006/2012/2013 could be the exclusion or non-exclusion of suspect samples. Although this should not occur in grade testing, in some cases because of off-grade material, the need to remove samples meeting the grade during post testing analysis may occur. The reasoning for this is because the testing is done on graded No. 2 lumber, and if a sample is considered off-grade during the post-test analysis, it may be removed as it was never on grade to begin with. On the contrary, in the real world it is possible that a piece of off grade material could be included within on-grade material. If a test uses either of these two methods, it can result in different lumber mechanical property values. This is something that should be considered in the standards and should be examined in future testing to create a more standardized sampling practice.
The 2” x 4”, 2” x 6”, and the 2” x 8” data from this monitoring program was compared with the 1991 design values as the two data sets matched well. A typical monitoring plan only tests 2” x 4” nominal width lumber, but through this testing program a thorough look at 2” x 6” and 2” x 8” nominal widths as well.

The mechanical property data of the 2” x 6” and 2” x 8” widths were available from the 2006 study, but because of the large sample size and that its purpose was to remove balsam fir and Eastern spruce from the SPF(s) grouping and was not a monitoring program, it will only be used in the comparison of the 2” x 4” samples seen above.

When comparing the values from this monitoring program to that of the 1991 values, there are several things to take into consideration;

- The 1991 values do not have a GQI adjustment applied to the data
- It says it follows ASTM D4761-13 and an adjustment was made, but does not signify what type of adjustment.
- It was said that a method of moisture content measurement was used but does not signify if it was done with an electronic moisture meter or based on oven-dry gravimetric calculations.

Knowing this, another row is added to the tables that show what the comparison would be if no GQI adjustment was made to the current monitoring programs data.
Table 3.5. Summary comparison of 2017 data and 1991 Design Values.

<table>
<thead>
<tr>
<th></th>
<th>1991 2x4</th>
<th>2 x 4 *</th>
<th>1991 2x6</th>
<th>2 x 6 *</th>
<th>1991 2x8</th>
<th>2 x 8 *</th>
<th>1991 Comb.</th>
<th>Comb. **</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Balsam Fir</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Size (n)</td>
<td>60</td>
<td>87</td>
<td>60</td>
<td>85</td>
<td>60</td>
<td>79</td>
<td>180</td>
<td>251</td>
</tr>
<tr>
<td>GQI (Lower 5th% SR)</td>
<td>50.2</td>
<td>53.0</td>
<td>53.0</td>
<td>53.0</td>
<td>52.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GQI (Reduction factor)</td>
<td>0.997</td>
<td>0.943</td>
<td>0.943</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean MOE&lt;sub&gt;app&lt;/sub&gt;</td>
<td>1.106</td>
<td><strong>1.168</strong></td>
<td>1.150</td>
<td><strong>1.051</strong></td>
<td>1.168</td>
<td><strong>1.125</strong></td>
<td>1.141</td>
<td><strong>1.115</strong></td>
</tr>
<tr>
<td>Mean MOE&lt;sub&gt;app&lt;/sub&gt; (without GQI adj.)</td>
<td>1.106</td>
<td><strong>1.171</strong></td>
<td>1.150</td>
<td><strong>1.114</strong></td>
<td>1.168</td>
<td><strong>1.192</strong></td>
<td>1.141</td>
<td><strong>1.159</strong></td>
</tr>
<tr>
<td>Lower 5th percentile MOR (TL)</td>
<td>2,489</td>
<td><strong>2,721</strong></td>
<td>2,163</td>
<td><strong>1,511</strong></td>
<td>2,067</td>
<td><strong>2,094</strong></td>
<td>1,896</td>
<td><strong>1,956</strong></td>
</tr>
<tr>
<td>Lower 5th %tile MOR (TL) (without GQI adj.)</td>
<td>2,489</td>
<td><strong>2,728</strong></td>
<td>2,163</td>
<td>1,602</td>
<td>2,067</td>
<td><strong>2,220</strong></td>
<td>1,896</td>
<td><strong>1,962</strong></td>
</tr>
<tr>
<td><strong>Eastern Spruce</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Size (n)</td>
<td>59</td>
<td>85</td>
<td>60</td>
<td>84</td>
<td>60</td>
<td>79</td>
<td>179</td>
<td>248</td>
</tr>
<tr>
<td>GQI (Lower 5th% SR)</td>
<td>52.3</td>
<td>55.0</td>
<td>53.1</td>
<td>53.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GQI (Reduction factor)</td>
<td>0.957</td>
<td>0.908</td>
<td>0.941</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean MOE&lt;sub&gt;app&lt;/sub&gt;</td>
<td>1.190</td>
<td><strong>1.161</strong></td>
<td>1.148</td>
<td><strong>1.087</strong></td>
<td>1.226</td>
<td><strong>0.995</strong></td>
<td>1.188</td>
<td><strong>1.083</strong></td>
</tr>
<tr>
<td>Mean MOE&lt;sub&gt;app&lt;/sub&gt; (without GQI adj.)</td>
<td>1.190</td>
<td><strong>1.213</strong></td>
<td>1.148</td>
<td><strong>1.196</strong></td>
<td>1.226</td>
<td><strong>1.058</strong></td>
<td>1.188</td>
<td><strong>1.158</strong></td>
</tr>
<tr>
<td>Lower 5th percentile MOR (TL)</td>
<td>2,298</td>
<td><strong>2,803</strong></td>
<td>2,363</td>
<td><strong>1,792</strong></td>
<td>1,923</td>
<td><strong>1,344</strong></td>
<td>2,045</td>
<td><strong>1,554</strong></td>
</tr>
<tr>
<td>Lower 5th %tile MOR (TL) (without GQI adj.)</td>
<td>2,298</td>
<td><strong>2,917</strong></td>
<td>2,363</td>
<td><strong>1,972</strong></td>
<td>1,923</td>
<td><strong>1,428</strong></td>
<td>2,045</td>
<td><strong>1,711</strong></td>
</tr>
</tbody>
</table>

*all **Bold** values are greater than 1991 values all *Bold italic* values are lower than 1991 values
Table 3.10 shows the comparison of all important values between the 2017 monitoring program and the 1991 design values. In the column for the 2017 data, all values that are in **bold** font are values that are higher than the 1991 properties, where the **bold italic** font depicts a decrease in value. Focusing first on the comparison between the 2” x 4” values there is a slight increase in almost all properties but the Eastern spruce MOR. Looking at the MOR for the same property that isn’t adjusted to GQI it exceeds the original 1991 value. This is occurring throughout the statistical summary to the 2” x 6”, 2” x 8” and combined cell as well in some cases. One cell in the combined column has *italic underline* font, this value is drastically increased with the removal of GQI which as stated before does not actually correlate with the strength properties of a sample.

### 3.2.3 One-way ANOVA

A one-way analysis of variance (ANOVA) was done on the 2” x 4” samples from both species. The primary data that were accumulated was for the 2” x 4” samples which are also the main focus of the monitoring portion of this testing program. The lumber testing programs compared in the one-way ANOVA are the 1991 design values, 2006 testing program, 2012 Great Lakes program, and the 2017 monitoring program. A post-hoc Tukey HSD test was done to compare all mean MOE’’ and MOR’’ values. Although the mean MOR’’ is not as crucial to this program as the lower 5th percentile MOR’’ values, it still shows the vast difference in strength properties among the different testing programs, which have similar differences in the lower 5th percentiles that can be seen in the general comparison in the previous section.
For the first Tukey HSD test, the mean MOE of 2” x 4” balsam fir was compared among all testing programs. The results for this show that this monitoring program has similar means to those from the 1991 values and one of the previous monitoring programs. It is understandable that it was not closely related to the 2006 testing as that was a very large sample set that was used to attempt to remove balsam fir and Eastern spruces from the SPF(s) grouping and was not a monitoring plan. The 2006 testing had over 180 samples, where the 2017 program had 80 samples. The Tukey HSD mean comparison for the MOR in for balsam fir in Figure 3.30 shows that that there is a similarity to the monitoring program from the Great lakes. Compared to the other testing programs it is slightly lower, but still significant to be classed differently.
Both figures for Eastern spruce Tukey HSD mean comparison test (Figure 3.31 and 3.32) show similar findings to the summarized comparison. The MOE”’ of both the 1991 values and the 2017 testing have similar values where the 2006 and 2012 programs are higher. The results of the Tukey HSD comparison for Eastern spruce MOR” shows that the 2017 values were significantly lower than the other testing programs. Although the mean MOR” is lower than the
other programs, the lower 5\textsuperscript{th} percentile is significantly higher than the 1991 values when looking at the comparison in Table 3.5. This is important, as the mean MOR does not show the conservative values of strength properties that the lower 5\textsuperscript{th} percentile does, which is what is reported.

![Eastern Spruce 2" x 4" Tukey HSD for Mean MOR”](image)

Figure 3.32 Eastern spruce 2" x 4" Tukey HSD for mean MOR”.

The findings from the Tukey HSD mean comparison tests shows that there is a relationship between the 1991 values as well as the previous monitoring program when comparing MOE”’ and MOR”’. The one value that does not match up well is the Eastern spruce MOR”’, which even though it is significantly lower in the Tukey test, it has a much higher values compared to the 1991 values. Besides this one value, these results help support the findings from the general comparison of the summary statistics by showing similar relationships between the 2017 monitoring program and the 1991 values. This comparison will be done again when the final compiled results from all three of monitoring programs are complete.
CHAPTER

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Review of Objectives

The two main objectives were:

1. Test visually graded No. 2, 2” x 4”, 2” x 6” and 2” x 8” balsam fir and Eastern spruce lumber in edge-wise bending per ASTM D4761-13.

2. Statistically analyze the mechanical property data per D1990-16

Both objectives were completed and the results compared to those from 1991 using the Wilcoxon test. The results of this testing program are solely preliminary, as this data will subsequently be combined with that from the remaining species and regions for the SPF(s) grouping. The focus of the monitoring program is on the 2” x 4” samples and the data from the Northeastern, Great Lakes, and West coast regions will be compared with the 1991 design values.

4.2 Future Programs

As discussed in Chapter one, this program is part of the second cycle of lumber monitoring programs for the SPF(s) grouping. As this is the first program in the second cycle, the other two regions, Great Lakes and West coast, will come within the next few years.

After all three lumber testing programs are completed a summary report will be compiled and submitted to the American Lumber Standards Committee. At that time the board of review will determine if any further monitoring will be needed for a third cycle of monitoring tests.

4.3 Recommendations for Future Work

While this is the fourth lumber grade monitoring program to be implemented since the first concerns of juvenile wood became apparent, there are still several aspects to the testing process
that can be improved. One of the best documents to turn to when starting the project is the FPL GTR-126. This report dictates how to follow ASTM D1990-16 in the correct steps as well as showing examples and reasoning for each part of the desired program that is being performed. Following along with this document helps the project manager understand what task needs to be completed and in the correct sequential order. Using this report along with the standards that need to be used for the monitoring program can help tremendously.

The suggestion on focusing more on the application of GQI is very important as discussed in the earlier section it can have a large impact on the testing data and its results. The suggestions made in the GQI section should be done for the next monitoring test which include the following:

- Updating the standards or NGR to depict equations and more descriptions on how to create and calculate failure code diagrams and failure coding.
- It is sometimes difficult to determine the actual point of failure, but if the sample is recorded during testing, the video can be used a confirmation of where failure occurred.
- At the end of each day when diagrams are drawn to create failure codes, go through all equations and double check all diagrams to be sure they are correct.
- Using diagrams with equations and examples

By fixing the process with the solutions above, it would take less time to conduct the post-test analysis as there would be fewer problems with the data set. As seen in this monitoring program much time was used in creating just a final data set attributable to problems with GQI, strength ratios, and failure codes. If these errors were to be corrected there would be a much smoother post testing process that could help create more accurate data.
4.4 Conclusions

The purpose of this monitoring program was to evaluate the physical properties of 2” x 4” lumber from the SPF(s) grouping. Here in the Northeast the two most prevalent species that are harvested for structural lumber are balsam fir and Eastern spruces. These species were procured, labeled, tested, and analyzed for their mechanical properties in flexural testing to be sure there has not been a downward shift in values since the previous testing program. This program for the Northeast is the first of three testing programs that will be combined into a final report that will re-analyze the data once combined for a final submission to the ALSC. Although for the monitoring program the main focus was the testing and analysis of only the 2” x 4” lumber, this thesis goes farther by testing the 2” x 6” and 2” x 8” widths to give a check on where the values are today.

The results of the 2” x 4” mechanical property values for both species went exactly as hypothesized and compared well to the other testing programs. When incorporated with the final data that will be submitted to the ALSC, there should be no concern about these values and should warrant no further investigation.

When looking at the 2” x 6” and 2” x 8” data, there are 7 of the 8 values lower than 1991, some by a significant amount. While these aren’t considered in the monitoring program, it warrants a deeper look. In this case it may be suggested that NE LMA re-sample and retest these cells. Possible resampling of these two widths would help look into what the reasons for these low values are. It was concerning that these values were much lower than all other testing programs and should be incorporated into the monitoring program. As lumber is a natural material no matter how many times a test is repeated the values will always be different. Conclusions can’t be drawn until further testing programs occur as it takes years for a trend to develop. It may be
wise for the next testing program within this cycle of monitoring, the Great Lakes, to look into the 2” x 6” and 2” x 8” widths as well.

From this testing program it was found that one of the largest adjustments done to the data set, as described by ASTM D1990-16, may not be necessary. The GQI and failure codes cause consistent ambiguity that could have a potential impact on the finalized data set, which could cause issues in future programs. This application of GQI should be thoroughly investigated as it only reduces mechanical properties for native species, when the original use for GQI was for outsourced lumber and may not necessarily be the best tool to check for grade quality. Either removing this adjustment or finding a new tool to check for quality would be advised.

Re-stating the above, it is very important to know that final conclusions from this monitoring program cannot be made. This data set is still technically preliminary data as the Eastern spruce and balsam fir data will be combined with the data from all other species and regions from within the SPF(s) grouping. After the completion of all three regions monitoring programs from this cycle, the full data set of the SPF(s) grouping will be re-evaluated with the 1991 values. When evaluating the entire grouping there will be a species that has the lowest values which is deemed the controlling subgroup. This controlling subgroup will have the largest impact on the finalized data when comparing it to the 1991 values. The impact of the controlling subgroup will have the most effect on the complete data set values.

With newer forestry practices and shorter biological rotation ages, the possibility of juvenile wood affecting the properties of lumber needs to be investigated. With increased proportions of juvenile wood to mature wood in second-growth forests it has shown that there are quality implications (Jozsa, 1994). This higher proportion of juvenile wood can cause lower strength properties in saw mill timber and will take time to create truly reliable data. Looking into these
implications in all three nominal widths can help tremendously for future research and testing programs.
BIBLIOGRAPHY

Reports

   Available at:


27. US Forest Service. 2018. NONPAR. Nonparametric Estimation Program. Forest Products Laboratory, Madison, WI.

APPENDIX A- STATISTICS
Table A.1. Balsam Fir 2" x 4" bending data.

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* SG: Specific Gravity * MC: Moisture Content * MOE: Modulus of Elasticity * (psi) : Pounds per Square Inch * (ksi) : Kilopounds per Square Inch
Table A.2. Balsam Fir 2” x 6” bending data.

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<td>1,077,522</td>
<td>D-4-2-6-ES</td>
<td>0.44</td>
<td>13.2</td>
<td>11</td>
<td>100.0</td>
<td>1,516,031</td>
<td>3.478</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-E-2-9-E</td>
<td>1.45</td>
<td>1.44</td>
<td>1.43</td>
<td>1.42</td>
<td>1.41</td>
<td>1.40</td>
<td>1.40</td>
<td>B-4-2-5-ES</td>
<td>0.80</td>
<td>93</td>
<td>12</td>
<td>13</td>
<td>0</td>
<td>20</td>
<td>1,077,522</td>
<td>D-4-2-6-ES</td>
<td>0.44</td>
<td>13.2</td>
<td>11</td>
<td>100.0</td>
<td>1,516,031</td>
<td>3.478</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>A-E-2-10-E</td>
<td>1.44</td>
<td>1.43</td>
<td>1.42</td>
<td>1.41</td>
<td>1.40</td>
<td>1.40</td>
<td>1.40</td>
<td>B-4-2-5-ES</td>
<td>0.80</td>
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<td>12</td>
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<td>D-4-2-6-ES</td>
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<td>13.2</td>
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<td>30.3</td>
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</tbody>
</table>

**Table A.4. Eastern Spruce 2" x 4" bending data.**
### Table A.5: Eastern Spruce 2" x 6" bending data.

<table>
<thead>
<tr>
<th>Combined</th>
<th>ID Thickness</th>
<th>Y Thickness</th>
<th>B Thickness</th>
<th>MC adj. Thickness</th>
<th>Density (lbf/in³)</th>
<th>Grade Strength</th>
<th>MOR (psi)</th>
<th>Defect Reducing MOR (psi)</th>
<th>Adj. to 7.25&quot;</th>
<th>Location</th>
<th>Volume (cu ft)</th>
<th>MID</th>
<th>Bounding Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-0-0-10</td>
<td>2.25</td>
<td>7.25</td>
<td>11.25</td>
<td>20</td>
<td>0.20</td>
<td>10</td>
<td>7.25</td>
<td>1,019,0004</td>
<td>183.2</td>
<td>1,504,094</td>
<td>350.62</td>
<td>215</td>
<td>A-6-2-8-ES</td>
</tr>
<tr>
<td>A-0-0-10</td>
<td>2.25</td>
<td>7.25</td>
<td>11.25</td>
<td>20</td>
<td>0.20</td>
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<td>A-6-2-8-ES</td>
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<td>183.2</td>
<td>1,504,094</td>
<td>350.62</td>
<td>215</td>
<td>A-6-2-8-ES</td>
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Note: The table continues with similar entries for other combinations and thicknesses.
<table>
<thead>
<tr>
<th>Combined</th>
<th>Thickness</th>
<th>Density</th>
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<tr>
<td>1.50</td>
<td>1000</td>
<td>123.25</td>
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</table>

Table A.6. Eastern Spruce 2" x 8" bending data.
R statistical Coding for balsam fir all widths Wilcoxon tests

getwd()
setwd("C:/Users/ben.farber/Desktop/Comparison")
BF2x4<-(read.csv("2x4BF.csv"))
year06<-(BF2x4$Year06)
MOE06<-(BF2x4$MOE06)
MOR06..<-(BF2x4$MOR06..)
MOR06...<-(BF2x4$MOR06.)
wilcox.test(MOE06 ~ year06, data=BF2x4)
wilcox.test(MOR06.. ~ year06, data=BF2x4)
wilcox.test(MOR06... ~ year06, data=BF2x4)
year12<-(BF2x4$Year12)
MOE12<-(BF2x4$MOE12)
MOR12..<-(BF2x4$MOR12..)
MOR12...<-(BF2x4$MOR12.)
wilcox.test(MOE12 ~ year12, data=BF2x4)
wilcox.test(MOR12.. ~ year12, data=BF2x4)
wilcox.test(MOR12... ~ year12, data=BF2x4)
year91<-(BF2x4$Year91)
MOE91<-(BF2x4$MOE91)
MOR91..<-(BF2x4$MOR91..)
MOR91...<-(BF2x4$MOR91.)
wilcox.test(MOE91 ~ year91, data=BF2x4)
wilcox.test(MOR91.. ~ year91, data=BF2x4)
wilcox.test(MOR91... ~ year91, data=BF2x4)
BF2x6.2x8<-(read.csv("BF2x6.2x8.csv"))
year2x6<-(BF2x6.2x8$Year2x6)
MOE2x6<-(BF2x6.2x8$MOE2x6)
MOR2x6..<-(BF2x6.2x8$MOR2x6..)
MOR2x6...<-(BF2x6.2x8$MOR2x6.)
wilcox.test(MOE2x6 ~ year2x6, data=BF2x6.2x8)
wilcox.test(MOR2x6.. ~ year2x6, data=BF2x6.2x8)
wilcox.test(MOR2x6... ~ year2x6, data=BF2x6.2x8)
year2x8<-(BF2x6.2x8$Year2x8)
MOE2x8<-(BF2x6.2x8$MOE2x8)
MOR2x8..<-(BF2x6.2x8$MOR2x8..)
MOR2x8...<-(BF2x6.2x8$MOR2x8.)
wilcox.test(MOE2x8 ~ year2x8, data=BF2x6.2x8)
wilcox.test(MOR2x8.. ~ year2x8, data=BF2x6.2x8)
wilcox.test(MOR2x8... ~ year2x8, data=BF2x6.2x8)
Code for Eastern Spruce all widths Wilcoxon tests

getwd()
setwd("C:/Users/ben.farber/Desktop/Comparison")
ES2x4<-read.csv("2x4ES.csv")
year06<-ES2x4$Year06
MOE06<-ES2x4$MOE06
MOR06..<-ES2x4$MOR06..
MOR06...<-ES2x4$MOR06.
wilcox.test(MOE06 ~ year06, data=ES2x4)
wilcox.test(MOR06.. ~ year06, data=ES2x4)
wilcox.test(MOR06... ~ year06, data=ES2x4)
year12<-ES2x4$Year12
MOE12<-ES2x4$MOE12
MOR12..<-ES2x4$MOR12..
MOR12...<-ES2x4$MOR12.
wilcox.test(MOE12 ~ year12, data=ES2x4)
wilcox.test(MOR12.. ~ year12, data=ES2x4)
wilcox.test(MOR12... ~ year12, data=ES2x4)
year91<-ES2x4$Year91
MOE91<-ES2x4$MOE91
MOR91..<-ES2x4$MOR91..
MOR91...<-ES2x4$MOR91.
wilcox.test(MOE91 ~ year91, data=ES2x4)
wilcox.test(MOR91.. ~ year91, data=ES2x4)
wilcox.test(MOR91... ~ year91, data=ES2x4)
ES2x6.2x8<-read.csv("ES2x6.2x8.csv")
year2x6<-ES2x6.2x8$Year2x6
MOE2x6<-ES2x6.2x8$MOE2x6
MOR2x6..<-ES2x6.2x8$MOR2x6..
MOR2x6...<-ES2x6.2x8$MOR2x6.
wilcox.test(MOE2x6 ~ year2x6, data=ES2x6.2x8)
wilcox.test(MOR2x6.. ~ year2x6, data=ES2x6.2x8)
wilcox.test(MOR2x6... ~ year2x6, data=ES2x6.2x8)
year2x8<-ES2x6.2x8$Year2x8
MOE2x8<-ES2x6.2x8$MOE2x8
MOR2x8..<-ES2x6.2x8$MOR2x8..
MOR2x8...<-ES2x6.2x8$MOR2x8.
wilcox.test(MOE2x8 ~ year2x8, data=ES2x6.2x8)
wilcox.test(MOR2x8.. ~ year2x8, data=ES2x6.2x8)
wilcox.test(MOR2x8... ~ year2x8, data=ES2x6.2x8)
R Statistical Program output for Wilcoxon tests both ES and BF

> wilcoxon.test(MOE91 ~ year91, data=BF2x4)

wilcoxon rank sum test with continuity correction
data:  MOE91 by year91
W = 2537, p-value = 0.7751
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR91. ~ year91, data=BF2x4)

wilcoxon rank sum test with continuity correction
data:  MOR91. by year91
W = 3499, p-value = 0.0004622
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR91... ~ year91, data=BF2x4)

wilcoxon rank sum test with continuity correction
data:  MOR91... by year91
W = 3485.5, p-value = 0.0005636
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOE06 ~ year06, data=BF2x4)

wilcoxon rank sum test with continuity correction
data:  MOE06 by year06
W = 12137, p-value = 2.431e-09
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR06. ~ year06, data=BF2x4)

wilcoxon rank sum test with continuity correction
data:  MOR06. by year06
W = 11220, p-value = 6.655e-06
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR06... ~ year06, data=BF2x4)

wilcoxon rank sum test with continuity correction
data:  MOR06... by year06
W = 11209, p-value = 7.254e-06
alternative hypothesis: true location shift is not equal to 0
> wilcox.test(MOE12 ~ year12, data=BF2x4)
  wilcoxon rank sum test with continuity correction
data:  MOE12 by year12
W = 2423, p-value = 0.01321
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR12.. ~ year12, data=BF2x4)
  wilcoxon rank sum test with continuity correction
data:  MOR12.. by year12
W = 2446, p-value = 0.009594
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR12... ~ year12, data=BF2x4)
  wilcoxon rank sum test with continuity correction
data:  MOR12... by year12
W = 1638.5, p-value = 0.1802
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOE2x6 ~ year2x6, data=BF2x6.2x8)
  wilcoxon rank sum test with continuity correction
data:  MOE2x6 by year2x6
W = 3659, p-value = 8.585e-06
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x6.. ~ year2x6, data=BF2x6.2x8)
  wilcoxon rank sum test with continuity correction
data:  MOR2x6.. by year2x6
W = 3435, p-value = 0.0003841
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x6... ~ year2x6, data=BF2x6.2x8)
  wilcoxon rank sum test with continuity correction
data:  MOR2x6... by year2x6
W = 3426, p-value = 0.0004403
alternative hypothesis: true location shift is not equal to 0
> wilcox.test(MOE2x8 ~ year2x8, data=BF2x6.2x8)
  
  Wilcoxon rank sum test with continuity correction
  
data:  MOE2x8 by year2x8
  W = 3074, p-value = 0.002775
  alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x8.. ~ year2x8, data=BF2x6.2x8)
  
  Wilcoxon rank sum test with continuity correction
  
data:  MOR2x8.. by year2x8
  W = 2672, p-value = 0.1998
  alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x8... ~ year2x8, data=BF2x6.2x8)
  
  Wilcoxon rank sum test with continuity correction
  
data:  MOR2x8... by year2x8
  W = 2671, p-value = 0.2013
  alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOE06 ~ year06, data=ES2x4)
  
  Wilcoxon rank sum test with continuity correction
  
data:  MOE06 by year06
  W = 10800, p-value = 3.603e-14
  alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR06.. ~ year06, data=ES2x4)
  
  Wilcoxon rank sum test with continuity correction
  
data:  MOR06.. by year06
  W = 9372.5, p-value = 1.11e-06
  alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR06... ~ year06, data=ES2x4)
  
  Wilcoxon rank sum test with continuity correction
  
data:  MOR06... by year06
  W = 9359.5, p-value = 1.257e-06
  alternative hypothesis: true location shift is not equal to 0
> wilcoxon.test(MOE12 ~ year12, data=ES2x4)

Wilcoxon rank sum test with continuity correction

data:  MOE12 by year12
W = 9021, p-value = 1.311e-06
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR12.. ~ year12, data=ES2x4)

Wilcoxon rank sum test with continuity correction

data:  MOR12.. by year12
W = 8806, p-value = 9.965e-06
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR12... ~ year12, data=ES2x4)

Wilcoxon rank sum test with continuity correction

data:  MOR12... by year12
W = 6230.5, p-value = 0.5394
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOE91 ~ year91, data=ES2x4)

Wilcoxon rank sum test with continuity correction

data:  MOE91 by year91
W = 2786, p-value = 0.2588
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR91.. ~ year91, data=ES2x4)

Wilcoxon rank sum test with continuity correction

data:  MOR91.. by year91
W = 3122, p-value = 0.01262
alternative hypothesis: true location shift is not equal to 0

> wilcoxon.test(MOR91... ~ year91, data=ES2x4)

Wilcoxon rank sum test with continuity correction

data:  MOR91... by year91
W = 3121, p-value = 0.01277
alternative hypothesis: true location shift is not equal to 0
> wilcox.test(MOE2x6 ~ year2x6, data=ES2x6.2x8)

Wilcoxon rank sum test with continuity correction

data:  MOE2x6 by year2x6
W = 3098, p-value = 0.01928
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x6.. ~ year2x6, data=ES2x6.2x8)

Wilcoxon rank sum test with continuity correction

data:  MOR2x6.. by year2x6
W = 3351, p-value = 0.0007645
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x6... ~ year2x6, data=ES2x6.2x8)

Wilcoxon rank sum test with continuity correction

data:  MOR2x6... by year2x6
W = 3339, p-value = 0.0009108
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOE2x8 ~ year2x8, data=ES2x6.2x8)

Wilcoxon rank sum test with continuity correction

data:  MOE2x8 by year2x8
W = 3707, p-value = 1.321e-08
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x8.. ~ year2x8, data=ES2x6.2x8)

Wilcoxon rank sum test with continuity correction

data:  MOR2x8.. by year2x8
W = 3688, p-value = 2.112e-08
alternative hypothesis: true location shift is not equal to 0

> wilcox.test(MOR2x8... ~ year2x8, data=ES2x6.2x8)

Wilcoxon rank sum test with continuity correction

data:  MOR2x8... by year2x8
W = 3685, p-value = 2.273e-08
alternative hypothesis: true location shift is not equal to 0
Figure B.1. Survey received from mill A.
Urgent Response Requested

October 27, 2016

Below is the industry information needed from each NELMA Dimension mill to develop an accurate sampling plan to submit to ALSC for approval. The data required is annual production of SPF(s) lumber, approximate percent by species and the state(s) where SPF's logs were procured. The calendar year of 2015 will be used as basis for the data.

Thank you for your participation in this important monitoring program.

<table>
<thead>
<tr>
<th>For the period of January 1st, 2015 to December 31st, 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Production of SPF(s)</td>
</tr>
<tr>
<td>% of Eastern Spruce</td>
</tr>
<tr>
<td>% of Balsam Fir</td>
</tr>
<tr>
<td>% of Jack Pine</td>
</tr>
<tr>
<td>% of Red Pine</td>
</tr>
<tr>
<td>% of Other</td>
</tr>
</tbody>
</table>

Procurement of Log Supplies in the Following States:

1. Maine
2. 
3. 

I hereby certify the above to be a true account and representation of the production of SPF(s) lumber for this twelve month period.

*All information will be kept confidential throughout this testing process*

Scan and Email Directly to Ben Farber: Bfarber91@gmail.com

Please Submit Data by Friday, NOVEMBER 4, 2016

Figure B.2. Survey received from mill B.
Figure B.3. Survey received from mill C.
Below is the industry information needed from each NELMA Dimension mill to develop an accurate sampling plan to submit to ALSC for approval. The data required is annual production of SPF(s) lumber, approximate percent by species and the state(s) where SPF(s) logs were procured. The calendar year of 2015 will be used as basis for the data.

Thank you for your participation in this important monitoring program.

For the period of January 1st, 2015 to December 31st, 2015

<table>
<thead>
<tr>
<th>Annual Production of SPF(s)</th>
<th>83,517,000 BF</th>
</tr>
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<tbody>
<tr>
<td>% of Eastern Spruce</td>
<td>62 %</td>
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<td>% of Balsam Fir</td>
<td>38 %</td>
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<td>% of Jack Pine</td>
<td>%</td>
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<tr>
<td>% of Red Pine</td>
<td>%</td>
</tr>
<tr>
<td>% of-</td>
<td>%</td>
</tr>
</tbody>
</table>

Procurement of Log Supplies in the Following States:
1. Maine
2. 
3. 

I hereby certify the above to be a true account and representation of the production of SPF(s) lumber for this twelve month period.

*All information will be kept confidential throughout this testing process*

Scan and Email Directly to Ben Farber: Bfarber91@gmail.com

Please Submit Data by Friday, NOVEMBER 4, 2016

Figure B.4. Survey received from mill D.
October 27, 2016

Below is the industry information needed from each NELMA Dimension mill to develop an accurate sampling plan to submit to ALSC for approval. The data required is annual production of SPF(s) lumber, approximate percent by species and the state(s) where SPF’s logs were procured. The calendar year of 2015 will be used as basis for the data.

Thank you for your participation in this important monitoring program.

<table>
<thead>
<tr>
<th>Annual Production of SPF(s)</th>
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<tbody>
<tr>
<td>% of Eastern Spruce</td>
<td>55 %</td>
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<tr>
<td>% of Balsam Fir</td>
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<td>0 %</td>
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<tr>
<td>% of-</td>
<td></td>
</tr>
</tbody>
</table>

Procurement of Log Supplies in the Following States:
1. NH
2. ME
3. VT

I hereby certify the above to be a true account and representation of the production of SPF(s) lumber for this twelve month period.

*All information will be kept confidential throughout this testing process*

Scan and Email Directly to Ben Farber: Bfarber91@gmail.com

Please Submit Data by Friday, NOVEMBER 4, 2016

Figure B.5. Survey received from mill E.
Below is the industry information needed from each NELMA Dimension mill to develop an accurate sampling plan to submit to ALSC for approval. The data required is annual production of SPF(s) lumber, approximate percent by species and the state(s) where SPF(s) logs were procured. The calendar year of 2015 will be used as basis for the data.

Thank you for your participation in this important monitoring program.

<table>
<thead>
<tr>
<th>Annual Production of SPF(s)</th>
<th>63500000 BF</th>
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<tbody>
<tr>
<td>% of Eastern Spruce</td>
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<tr>
<td>% of Balsam Fir</td>
<td>20%</td>
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<td>% of Jack Pine</td>
<td>%</td>
</tr>
<tr>
<td>% of Red Pine</td>
<td>%</td>
</tr>
<tr>
<td>% of-</td>
<td>%</td>
</tr>
</tbody>
</table>

**Procurement of Log Supplies in the Following States:**

1. Maine  
2. New Hampshire  
3. Vermont

I hereby certify the above to be a true account and representation of the production of SPF(s) lumber for this twelve month period.

*All information will be kept confidential throughout this testing process*

Scan and Email Directly to Ben Farber: Bfarber91@gmail.com

**Please Submit Data by Friday, NOVEMBER 4, 2016**

Figure B.6. Survey received from mill F.
APPENDIX C - E-MAILS

Hi Jeff,

As per our conversation yesterday, I verified our member facilities which have SPFAs stamps in their possession.

There are currently eight (8) facilities which have SPFAs stamps. Of these 6 facilities, seven (7) of them are located in New Brunswick and one (1) in Nova Scotia.

The only facility which has the potential to run U.S. logs and stamp SPFAs at this time is JDI St. Leonard. All other facilities are not stamping SPFAs and if they do, it is very sporadic.

In saying this about JDI St. Leonard, they are typically mixing U.S. and Canadian logs and stamping their production as S-P-F/SPFAs at this time.

Let me know how you would like to proceed and I will do my best to help you out. Thanks Jeff.

Kindest regards,

Kevin Merriam
Executive Director
Maritime Lumber Bureau
Cell: (902)664-1432
Office: (902)667-3889
kmerriam@mlb.ca

Figure C.1. Email 1 of 2 concerning the exclusion of Canadian border mills.

From: jeff@neima.org
Sent: October 25, 2016 6:13 PM
To: kmerriam@mlb.ca
Subject: Re: SPFAs facilities in the Maritimes

Thanks Kevin for the info. Based on your information and our phone discussion, I do not believe we could reliably get SPFAs lumber samples from NB. This should not affect the purpose of monitoring I don't believe as the research is all about checking current production from Maine logs. We may not need QB border mill samples either since they take logs from the exact same timber basket as all the New England mills! We will see if ALSC will sign off on that argument. Can you provide me with actual mill locations of SPFAs stamp holders just for the record?

I am in transit to the NAVILA Traders Market now but will get you our Grading Policy document by tomorrow!

Thank you

Jeff

Figure C.2. Email 2 of 2 concerning the exclusion of Canadian border mills.
Figure D.1. Instron calibration certificate
### Certificate of Calibration

**Issued by:** INSTRON CALIBRATION LABORATORY  
**Type of Calibration:** Speed  
**Relevant Standard:** ASTM E2658-15  
**Date of Calibration:** 12-Jun-2017

<table>
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<th>Machine</th>
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<tbody>
<tr>
<td>Name: University of Maine</td>
<td>Serial Number: 99657_AS#263</td>
</tr>
<tr>
<td>Address: Advanced Structures &amp; Composites Ctr</td>
<td>Make: Instron/Parker</td>
</tr>
<tr>
<td>Orono, ME 04469</td>
<td>Model: 80091202_AS#566</td>
</tr>
<tr>
<td>P.O. Number: BA07463_7</td>
<td>Ambient Temperature: 85.8°F</td>
</tr>
<tr>
<td>Contact: Curtis Libby</td>
<td></td>
</tr>
</tbody>
</table>

#### Readout Verified

1. Digital Readout (in/min)

#### Resolution of Indicator: .001 in/min

#### Certification Statement

This certificate that each speed verified with machine indicator 1 (listed above) was verified by Instron in accordance with ASTM E2658 (Start and Stop Method) and Instron work instruction ICA-847, and that the ASTM E2658 classification for each speed was:

- PASSED Class B - for .5 in/min speed
- PASSED Class A - for 1.0 in/min speed
- PASSED Class B - for 2.0 in/min speed

#### Method of Verification

The verification and equipment used conform to a controlled Quality Assurance program which meets the specifications outlined in ANSI/NCSLZ540.1-1994, ISO 10012-2003, ISO 9001:2008, and ISO/IEC 17025:2005. The Instron measurement equipment used for verification is traceable to NIST.

The testing machine was verified on-site at customer location. The testing machine was verified in the 'As Found' condition with no adjustments or repairs carried out. This is also the 'As Left' condition.

---

CalproSDS version 3.13

The results indicated on this certificate and report relate only to the items verified. If there are methods or data included that are not covered by the NVLAP accreditation it will be identified in the comments. Any limitation of use as a result of this verification will be indicated in the comments. This report must not be used to claim product endorsement by NVLAP or the United States government. This report shall not be reproduced, except in full, without the approval of Instron.

---

Figure D.2. Speed calibration certificate.
**Figure D.3. AS104 calibration certificate.**
Figure D.4. Electronic scale calibration certificate page 1 of 2.
Certificate Of Calibration

Electronic Scale
Report No 020717-4-09A
Limited Calibration ≤ 10000 g *See Notes

As Found / As Left 0 to 32000 g range

<table>
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<tr>
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<th>Standard/Actual Measured (UUT)</th>
<th>Correction (UUT)</th>
<th>Units</th>
<th>Tolerance</th>
<th>Uncertainty</th>
<th>Pass/Fail</th>
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</thead>
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<td>0</td>
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<td>0.6</td>
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<tr>
<td>Span</td>
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<td>0.6</td>
<td>P</td>
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<td>Span</td>
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<td>g</td>
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<td>g</td>
<td>&lt; 0.5</td>
<td></td>
<td>P</td>
</tr>
</tbody>
</table>

A rounded to the UUT’s readability

The measurement traceability and calibration process used for conformance verification of the above instrument meets or exceeds the requirements of 17025-2005. The reported uncertainties reflect those of type B (Systematic errors associated with the standards and the procedure used), and type A (Random errors of the process). The type A and type B uncertainties where calculated in accordance with NIST Technical Note 1297 using the RSS method and are reported at the coverage factor k=2 to approximate a confidence level of 95%. The due date as it appears on this report does not imply that the instrument will maintain its accuracy for any given length of time unless supported with further documentation (E.g. statistical etc.) which affirms such stability and is the responsibility of the end user. Many factors may contribute to instrument in-accuracy over time such as drift, environment, transportation, frequency of use etc. The reported results reflect readings obtained at the time of test only. The reported uncertainties reflect those associated with the calibration process itself and the display resolution of the unit under test (UUT) 0.5 g x 0.6. The instrument is considered to be in-tolerance based on the observed results (Deviation or departure from nominal value) falling anywhere within its specified tolerance limits with consideration of applied uncertainty. This document shall not be reproduced except in full without the written approval of Q.C. Services, Inc.

Calibration Procedure: QCS 3000 Rev E, QCSTD 022409-7
Notes: Unit was validated to 10000 g OK per Kenneth Williams.

TRACEABLE STANDARD USED:

Weight Set  S/N: 120407  Cal Due: 4/2017
Weight Set  S/N: 080698P  Cal Due: 9/2017

Certified by: Jerry Adams  Date: 2/7/2017
Approved By: Howard W. Maxum  Title: Metrologist  Date: 2/7/2017

Page 2 of 2  QCSF2019 Rev. B 10/1/10

Figure D.5. Electronic scale calibration certificate page 2 of 2.
APPENDIX E- GQI IMAGES

Figures E.1-E.19. Possible incorrect calculations for hand drawn diagrams as per ASTM D4761-13, Appendix X1

**Figure E.1. Sample F-4-2-12-BF**

**Figure E.2. Sample 2 B-4-2-13-BF**

**Figure E.3. Sample E-4-2-13-BF**

**Figure E.4. Sample F-4-2-5-BF**
Figure E.5. Sample C-4-2-6-BF

Figure E.6. Sample C-4-2-2-BF

Figure E.7. Sample D-4-2-6-BF

Figure E.8. Sample F-4-2-7-BF

Figure E.9. Sample B-4-2-15-ES.
Figure E.10. Sample F-4-2-9-ES.

Figure E.11. Sample B-4-2-4-ES

Figure E.12. Sample D-8-2-3-BF.

Figure E.13. Sample F-8-2-2-BF.

Figure E.14. Sample B-8-2-8-ES.

Figure E.15. Sample A-6-2-7-ES.
Figures E.20-E.36 questions on how was it calculated and other inconsistencies
Figure E.22. Sample C-6-2-6-ES

Figure E.23. Sample D-6-2-11-ES.

Figure E.24. Sample F-6-2-6-ES.

Figure E.25. Sample E-8-2-12-ES.

Figure E.26. Sample A-8-2-11-ES.

Figure E.27. Sample B-8-2-15-ES.
Figure E.28. Sample F-8-2-1-ES.

Figure E.29. Sample E-8-2-3-ES.

Figure E.30. Sample A-8-2-8-ES

Figure E.31. Sample E-4-2-14-BF.

Figure E.32. Sample C-6-2-2-BF.

Figure E.33. Sample A-6-2-8-BF
Figure E.34. Sample D-6-2-10-BF.

Figure E.35. Sample B-6-2-9-BF.

Figure E.36. Sample A-6-2-13-BF.
BIOGRAPHY OF THE AUTHOR

Benjamin Farber was born in San Ramon, California in 1991 and was raised there for eleven years until moving to Connecticut. After Graduating from Danbury high school in Danbury, CT, he attended two schools in three years until transferring to the University of Maine where he worked at the Advanced Structures and Composite Center and received a degree in Forest Operations, Bioproducts and Bioenergy in 2016. He continued his education at the University of Maine and joined the multicultural fraternity Iota Nu Kappa. Following graduation, he was hired by Mississippi State University to work in conjunction with the USDA Forest Products Lab in Madison, WI. Benjamin Farber is a candidate for the Masters of Science degree in Forest Resources from the University of Maine in August, 2018.