Bridge Joist Tests

Prepared for:
Timothy Andrews

Barns and Bridges of New England

US Dept. of the Interior, National Park Service, Cooperative Agreement # P14AC01002, Task Agreement # P14AC01504

University of Maine's Advanced Structures and Composites Center
Report Number: 17-23-1481

April 26, 2017

Prepared by:

Thomas Snape

Research Engineer

Reviewed by:

Shawn Eary, PE

Research Engineer

The University of Maine Advanced Structures and Composites Center is an ISO 17025 accredited testing laboratory, accredited by the International Accreditation Service.

Advanced Structures and Composites Center
35 Flagstaff Rd
University of Maine
Orono, ME 04469

Telephone: 207-581-2123
FAX: 207-581-2074
composites@maine.edu
www.composites.umaine.edu

Table of Contents

Summary

The Advanced Structures and Composites Center (ASCC) was contracted to perform tests on wooden bridge joists by Barns and Bridges of New England (BBNE).

The following tests were performed:

1. Four-point bend tests to failure of three Douglas fir bridge joists
2. Compression tests on samples prepared from the failed bridge joists.

Specimen Description

The three bridge joists were received at ASCC on December 14, 2016. One of the joists had a section of deck boards attached. Each joist was marked with identification (#1, #2, or #3). One end of each joist was marked "west". Nominal dimensions of all joists were 12" deep by 4" wide. Bearing points 180" apart were marked on each joist.

Joist #1 included a section of deck attached. The width of the deck was 44". The deck planks were of nominal size 10.5" by 2.75" and were spiked to the joist. Figure 1 shows joist #1 mounted in the test frame before being loaded. Figure 2 shows sketches of the locations of large knots on each side of the joist.

Figure 1: Joist #1 with deck attached, set up in test frame, before test.

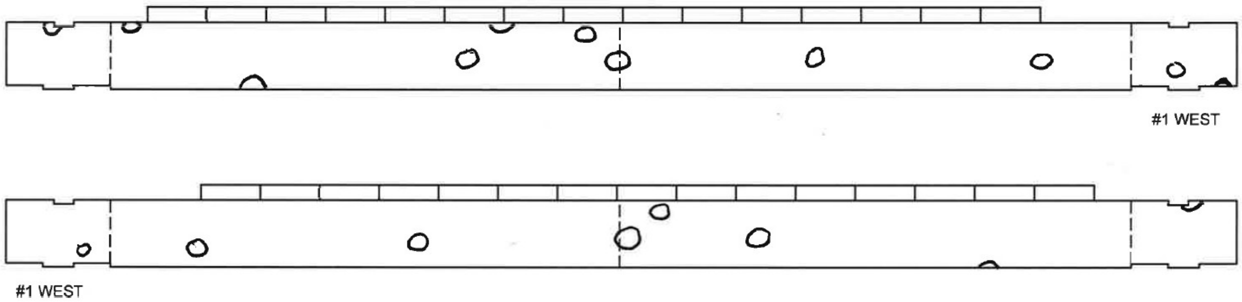

Figure 2: Joist #1; sketch showing locations of large knots. Dashed lines represent the bearing and mid-span locations.

Figure 3 shows sketches of the locations of large knots on each side of joist #2. A large knot is also pointed out on the bottom surface of the joist.

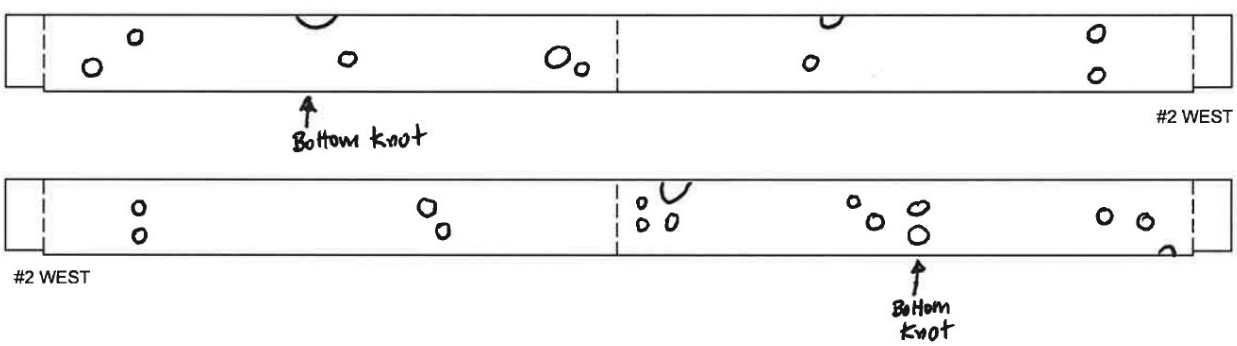

Figure 3: Joist #2; sketch showing locations of large knots. Dashed lines represent the bearing and mid-span locations.

Figure 4 shows sketches of the locations of large knots on each side of joist #3. Two large bottom knots are also pointed out on the bottom surface of the joist.

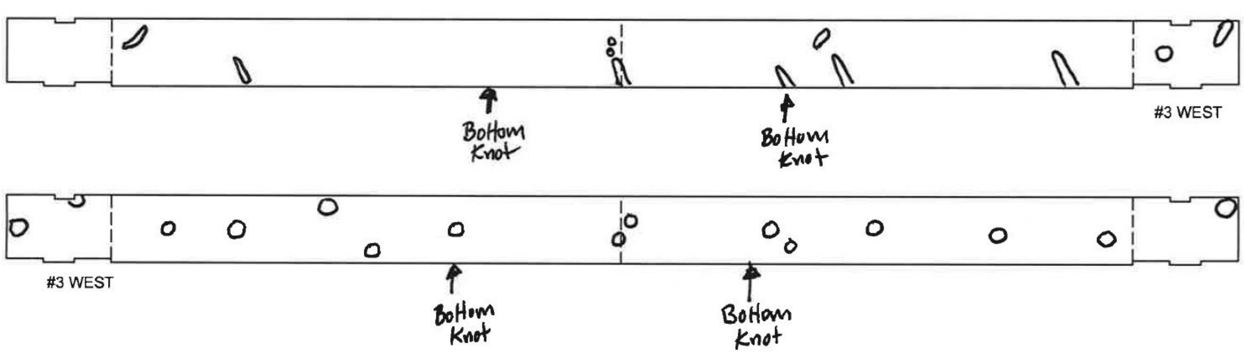

Figure 4: Joist #3; sketch showing locations of large knots. Dashed lines represent the bearing and mid-span locations.

Bending Test Description

Figure 1 shows the dimensions that were specified by BBNE for setting up the four-point bending tests on the joists.

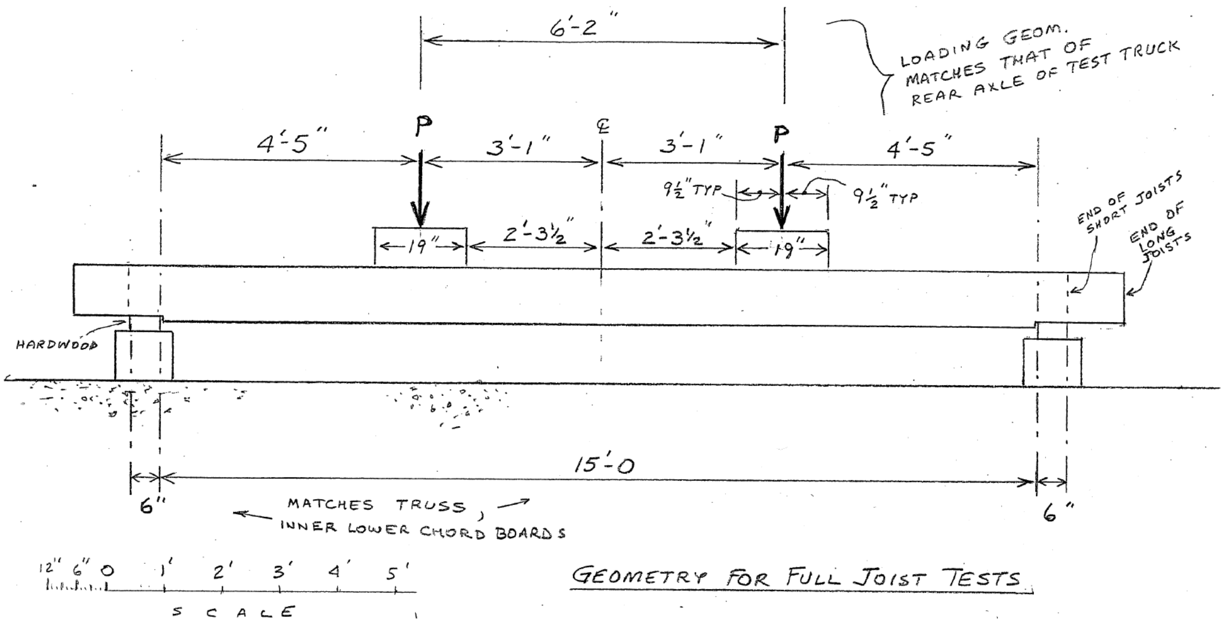

Figure 5: Dimensions for bending tests as specified by BBNE (BBNE drawing).

BBNE supplied the wooden blocks that served as supports and load heads. Lateral supports were used near the load points to prevent any transverse bending that might occur. Load was applied through a servo-hydraulic controlled actuator using a constant speed of 1 inch per second. The actuator load was distributed to the two load points through a steel beam. The beam was mounted to the actuator on a swivel joint to allow the two loads to equalize if the joist displacement was different at each load point. A pre-load of 150-200 lbs was applied before the start of each test to remove free-play from the loading system.

The test setup for joist #1 including the lateral supports is shown in Figure 1. Figure 6 shows the overall setups for joists #2 and #3. Figure 7 shows one end support arrangement for joist #1, which was typical of all joist tests. Figure 8 shows the load head arrangement used for all tests, and the lateral support type used for joists #2 and #3.

Figure 6: Bending test setup for joists #2 and #3 (Joist #3 shown)

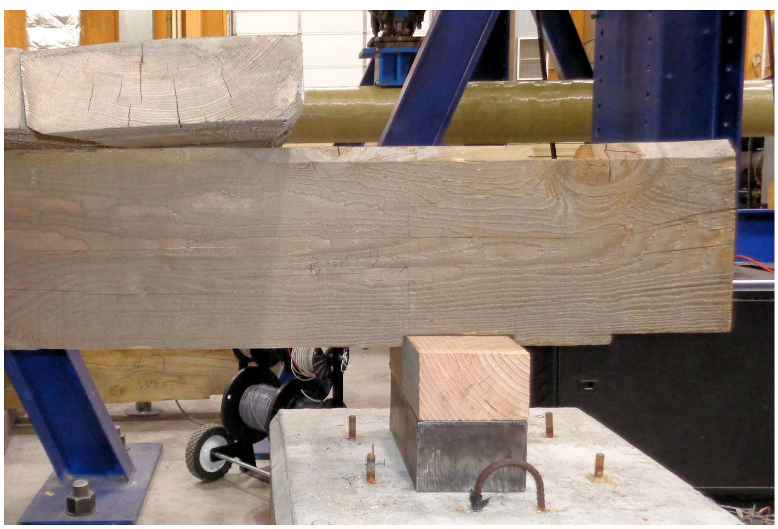

Figure 7: End support for joist tests (Joist #1 shown)

Figure 8: Load head and lateral support (Joist #2 shown)

Mid-span deflection of the test joist was measured using a string-potentiometer. The string-potentiometer was attached to a wire yoke, which in turn was suspended from small nails placed at mid-height on each vertical side of the joist.

Test load was measured by a 55 kip capacity load attached to the rod end of the 55 kip capacity actuator.

Five moisture readings per joist were taken using a pin-type moisture meter.

Bending Test Results

Table 1 contains a summary of the data recorded for the three joist tests. Figure 9 contains plots of the load vs. the mid-span deflections. In all three tests, failure of the joist was initiated around clusters of knots. Bearing areas at the supports were inspected after each test, and in no case was there evidence of crushing traverse to the grain.

Table 1: Summary of test data from joist bending tests

Joist	Ult. Load (lb)	Mid-span deflection at Ult. Load (in)	Moisture (%) Avg. 5 readings	Date tested
1 with deck	20,378	3.79	8.3	12/28/2016
2	13,581	2.58	8.0	12/21/2016
3	19,839	2.82	8.9	12/22/2016

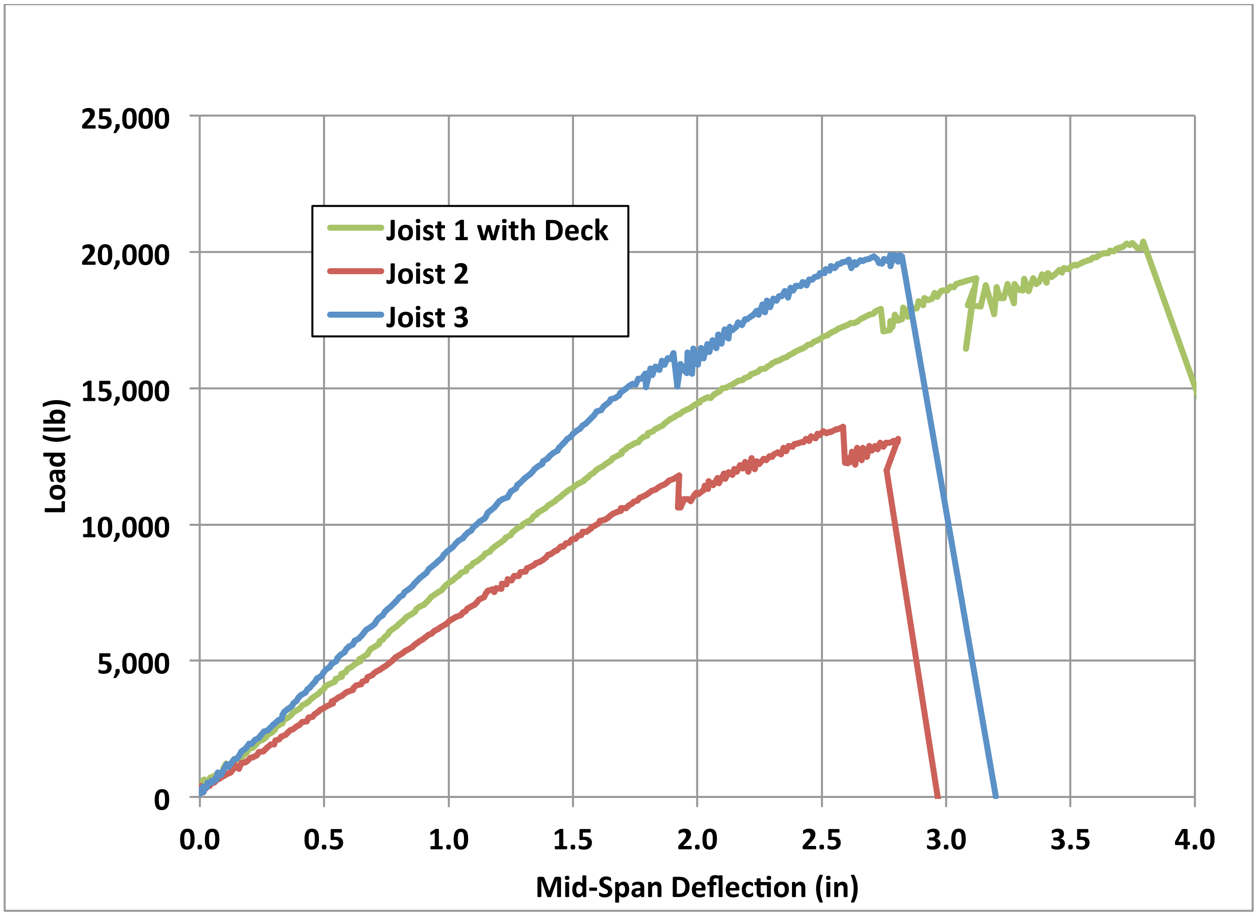

Figure 9: Load vs. mid-span deflection plots for bending tests

Figure 10 shows a sketch of the main paths along which joist #1 failed during the test. Figure 11 and Figure 12 show the main failure zone before and after the test.

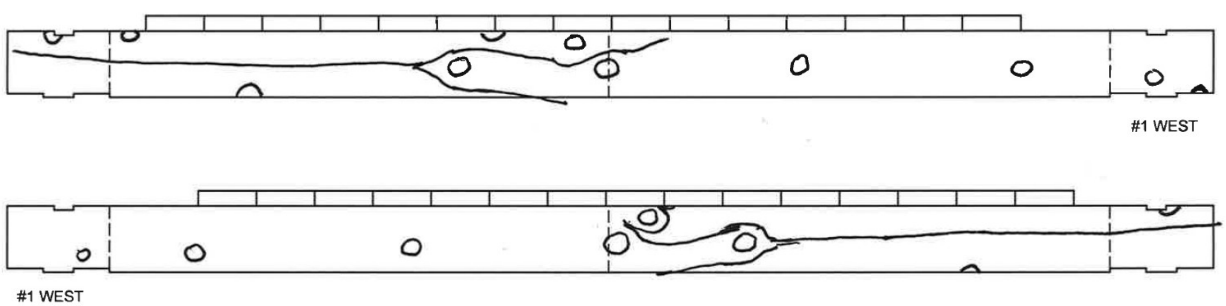

Figure 10: Joist #1 bending test failure mode

Figure 11: Joist #1 failure zone shown prior to test

Figure 12: Joist #1 bending test failure

Figure 13 shows a sketch of the main paths along which joist #2 failed during the test. Figure 14 and Figure 15 show the failure zone before and after the test.

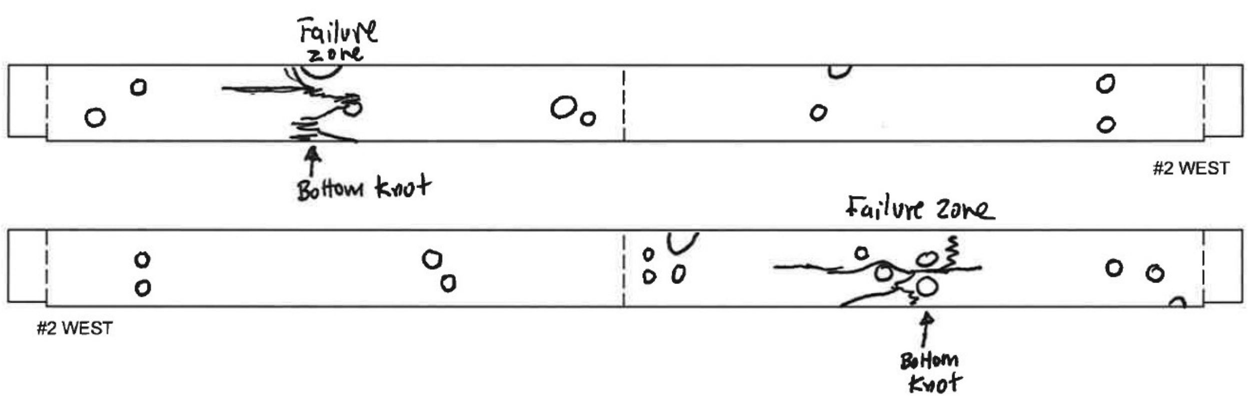

Figure 13: Joist #2 bending test failure mode

Figure 14: Joist #2 failure zone shown prior to test

Figure 15: Joist #2 bending test failure

Figure 16 shows a sketch of the main paths along which joist #3 failed during the test. Figure 17 and Figure 18 show the failure zone before and after the test.

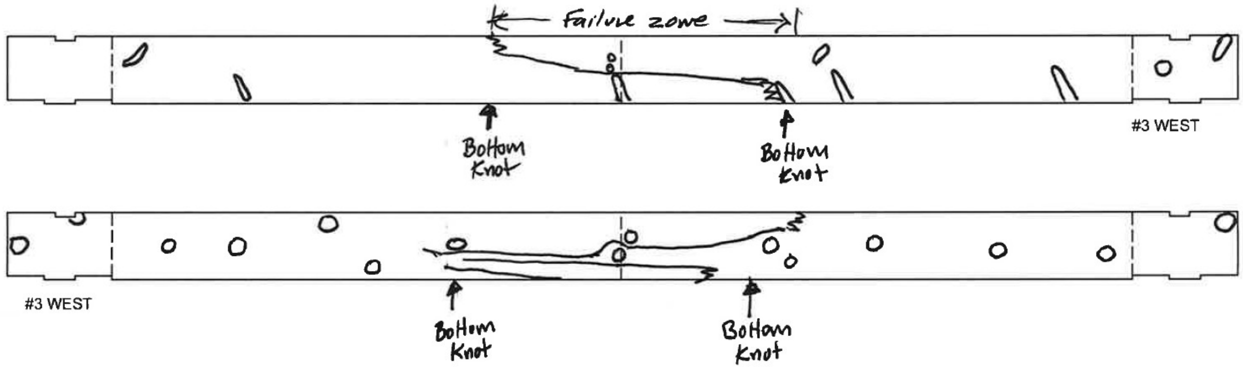

Figure 16: Joist #3 bending test failure mode

Figure 17: Joist #3 failure zone before test (montage of three photographs)

Figure 18: Joist #3 bending test failure

Bending Test Calculated Properties

Data from the bending tests was used to calculate flexural properties of the joists.

ASTM D198-14 is referenced here as a source for the equations used in the following calculations. Figure 19 shows some of the test parameters used to calculate flexural properties for a four-point bending test.

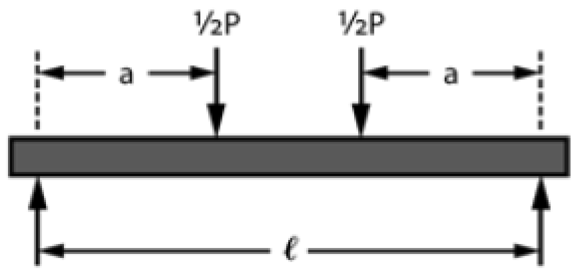

Figure 19: Four-point bend test parameters (Image from ASTM D198-14)

The apparent stiffness of each joist, often denoted "EI", was calculated using the following equation:

$$EI = \frac{P}{y_{MS}} \frac{a(3l^2 - 4a^2)}{48}$$

Where:

$\frac{P}{y_{MS}}$ = the slope of the load over the mid-span deflection, for a linear range, usually taken near the start of the test. In this case, the deflection range of 0.25" to 0.75" was used for each joist.

a = the distance from an end support (bearing) to the adjacent load point.

l = the distance between supports

The apparent modulus of elasticity "E" was calculated by dividing EI by the area moment of inertia, "I" for each joist. Note that the deck was ignored for the calculation of I for joist #1, as the deck boards generally had small gaps between them, and it was felt that they would not significantly contribute to the stiffness of the assembly for small deflections.

The modulus of rupture, "S_R", is a measure of maximum load carrying capacity, and was calculated for each joist using the following equation:

$$S_R = \frac{P_{max} l}{bd^2}$$

Where:

P_{max}= the maximum load carried by the joist before failure

l = the distance between supports

b = the width of beam

d = the depth of beam

Table 2: Calculation of flexural properties from test results

Parameter	Variable	Units	Joist 1	Joist 2	Joist 3
Maximum load	P_{max}	lbf	20,378	13,581	19,839
Slope of load over mid-span deflection in elastic range	P/Y_{MS}	lbf/in	7506	6267	9158
Distance from bearing to nearest load point	a	in	53.0	53.0	53.0
Support span (distance between bearings)	l	in	180.0	180.0	180.0
Beam width (average of 5 measurements)	b	in	3.770	4.058	3.907
Beam depth (average of 5 measurements)	d	in	11.923	11.911	11.901
Calculations:					
Apparent bending stiffness	EI	$lbf\text{-}in^2$	712,500,000	594,800,000	869,300,000
Apparent modulus of Elasticity	E_{app}	psi	1,338,000	1,041,000	1,584,000
Modulus of Rupture	S_R	psi	6,844	4,246	6,454

Compression Test Description

Fifteen specimens for axial compression (parallel to grain) tests were prepared from the failed joists. The specimens were obtained as close as possible from the locations shown in Figure 20. In addition, four compression test specimens were cut from two of the deck planks from joist #1. Eight of the joist compression specimens and two of the deck compression specimens were tested in axial compression, using ASTM D143 as a guide. The other two deck specimens were tested for compression perpendicular to grain, using ASTM D143 as a guide. Untested specimens were returned to BBNE.

Compression Test Results Parallel to Grain

Compression parallel to grain tests were performed on an Instron servo-hydraulic test machine with a capacity of 55 kips. Load was measured using the Instron's 55 kip load cell. Specimen deformation was recorded using the Instron's actuator position. The load was applied to the specimen through a self-aligning (spherical seat) platen, at a constant rate of 0.024 inches per minute. Table 3 contains the data generated from the compression tests. The locations listed in Table 3 reference the numbered positions shown in Figure 20. Figure 21shows plots of the stress vs. strain results for the specimens from the joists.

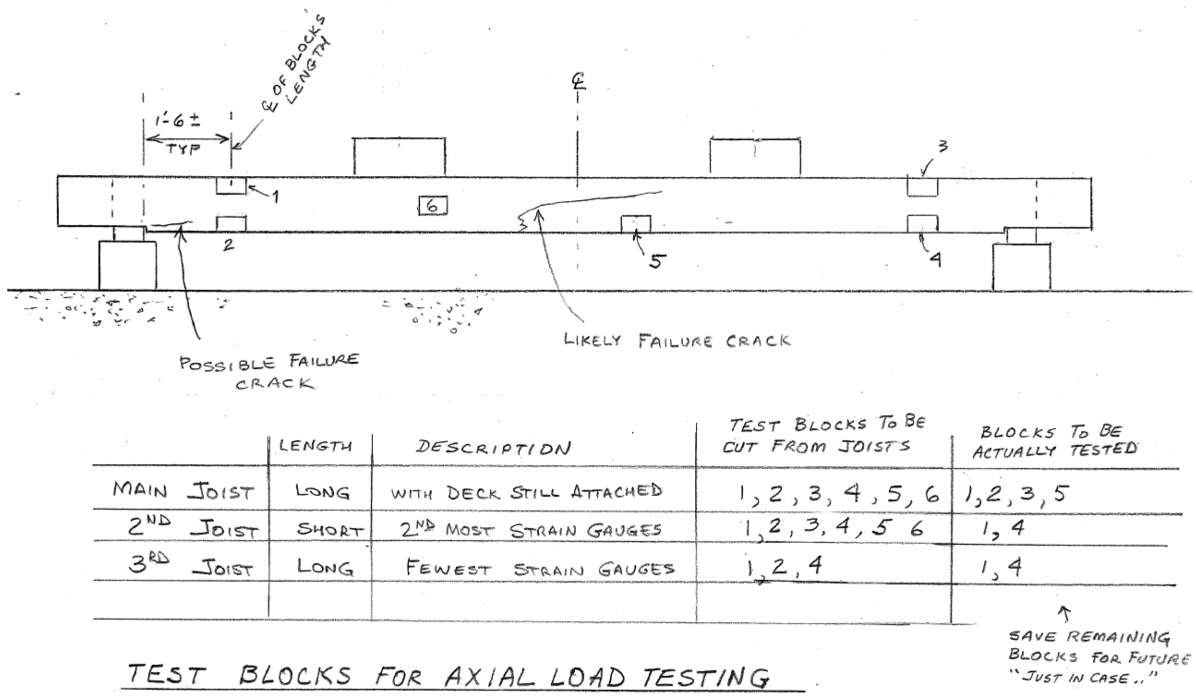

Figure 20: Locations to obtain compression test specimens, as specified by BBNE (BBNE drawing)

Table 3: Compression test data; parallel to grain

Specimen					Ult.	
Joist	Location	Width 1 (in)	Width 2 (in)	Length (in)	Load (lb)	Failure mode
1	1	1.991	1.995	7.952	23,376	Crushing at top
1	2	1.998	1.993	7.953	27,078	Wedge split
1	3	1.999	1.984	7.952	26,729	Wedge split at top
1	5	2.002	2.008	7.953	22,597	Crushing
2	1	1.999	1.986	7.965	21,802	Crushing (away from small knot in specimen)
2	4	2.012	1.997	7.966	21,464	Crushing
3	1	1.985	1.978	7.958	24,229	Crushing near cluster of small knots
3	4	1.990	1.989	7.965	34,964	Crushing
Deck 1	n/a	1.941	1.990	7.975	23,217	Crushing
Deck 2	n/a	1.971	1.986	7.991	25,507	Crushing on end

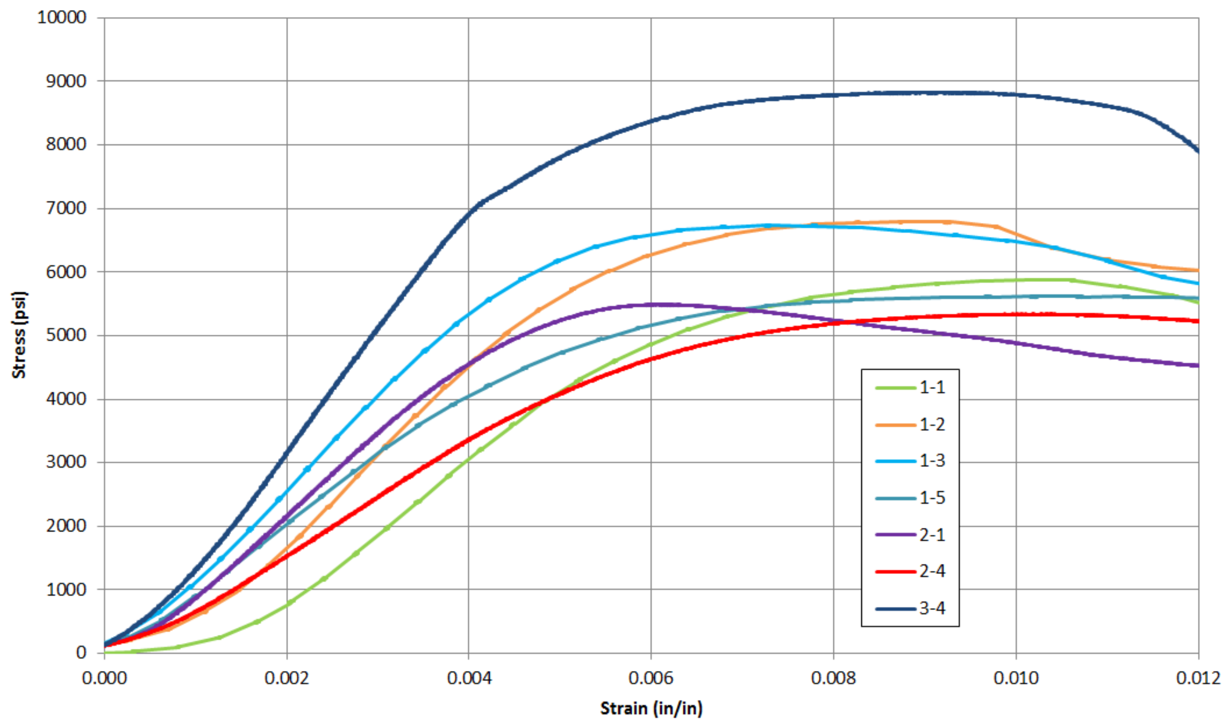

Figure 21: Stress vs. strain results for compression tests of joist specimens

The ultimate compressive strength for each specimen was calculated by dividing the maximum compression load borne by the specimen by the cross-section area. The modulus of elasticity in compression was determined by taking the slope of the initial straight line portion of the stress vs. strain plot for each specimen. The strain range over which the slope was determined varied from about 0.001-0.002 to 0.002-0.003 strain, depending upon the shape of the plot for each specimen. Table 4 contains the calculated results. The strain data for specimen 2-4 was corrupted and therefore the MOE could not be computed.

Table 4: Calculated compression properties: parallel to grain

Specimen		Ult. Comp Str.	MOE in Comp.
Joist	Location	(psi)	(psi)
1	1	5885	1,171,504
1	2	6800	1,408,162
1	3	6740	1,422,789
1	5	5621	1,128,050
2	1	5492	1,294,637
2	4	5342	913,125
3	1	6171	no data
3	4	8834	1,800,779
Deck 1	n/a	6011	939,929
Deck 2	n/a	6516	936,302

Compression Test Results Perpendicular to Grain

Compression perpendicular to grain tests were performed on an Instron servo-hydraulic test machine with a capacity of 22 kips. Load was measured using the Instron's 10 kip load cell. Specimen deformation was recorded using the Instron's actuator position. The load was applied to the specimen through a self-aligning 2" wide bearing plate, at a constant rate of 0.012 inches per minute. The specimens were oriented so that the load was applied to a radial surface.

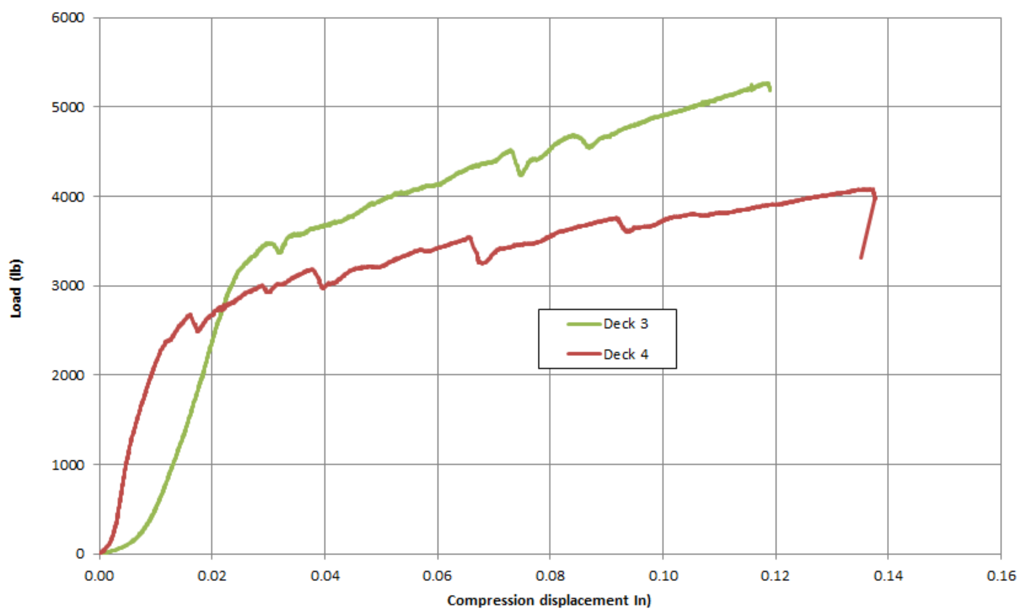

Figure 22: Load vs displacement plots for compression perpendicular to grain tests on specimens cut from deck planks.

Due to the manner in which wood compresses from a perpendicular load, an ultimate strength is not reported. As per ASTM D143, the test is stopped after 0.10" compression is seen in the specimen. ASTM D143 also does not describe a calculation of the modulus of elasticity for this test. However, using the specimen initial dimensions and the test data, the stress and strain can be calculated. Figure 23 contains plots of the stress vs. strain plots for the compression perpendicular to grain, and compression parallel to grain tests for the specimens cut from deck planks. Table 5 contains a summary of the results from the compression perpendicular to grain tests on the specimens cut from the deck planks.

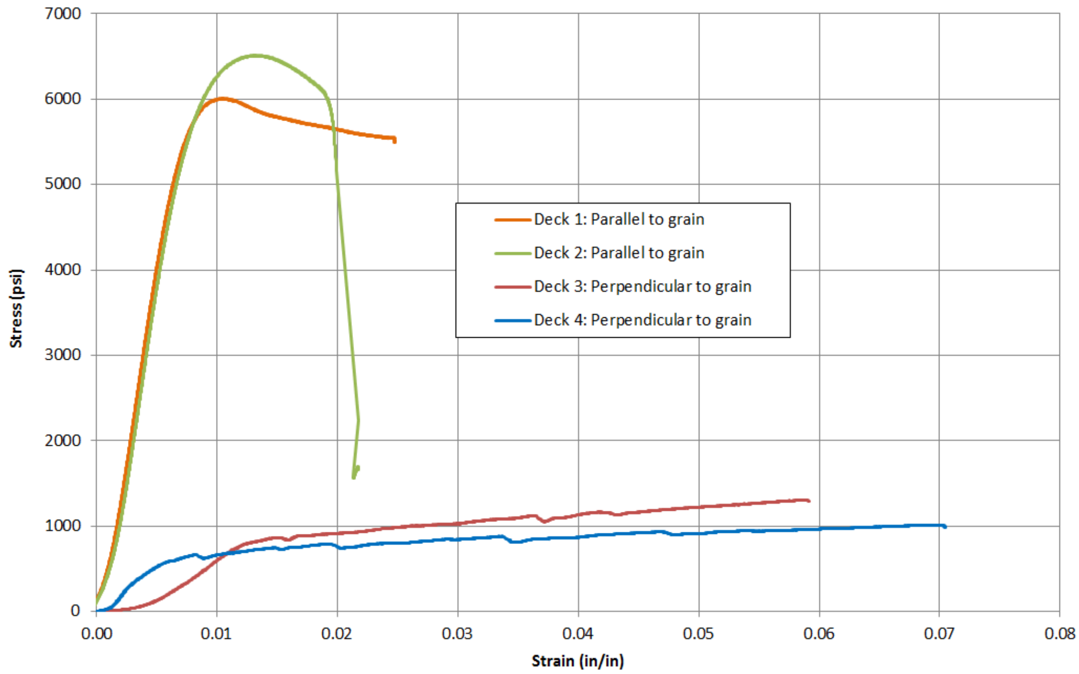

Figure 23: Compression test results for deck planks; stress vs. strain.

Table 5: Test result summary for compression perpendicular to grain

Specimen	Height (in)	Width (in)	Length (in)	Compressed area (in^2)	Load at 0.1" compression	
					(lb)	(psi)
Deck 3	2.011	2.007	6.008	4.027	4901	1217
Deck 4	1.953	1.981	5.897	3.975	3720	935.8

Equipment list

Table 6 contains a list of the equipment used to perform the tests for this project.

Table 6: Equipment list

Equipment used in joist bending tests:	ASCC Number
55 kip capacity actuator	AS264
55 kip capacity load cell	AS650
String pot - 25"	AS1474
Moisture meter, Delmhorst J-2000	AS1741
Equipment used in compression tests:	ASCC Number
55 kip capacity Instron test frame	AS2199
55 kip capacity load cell	AS2200
22 kip capacity Instron test frame	AS108
10 kip capacity load cell	AS610
Digital caliper - 8"	AS435