Chapter 3 – Materials and Procedures

3.1 Introduction

The overall approach to this research was to test multiple-bolt, single-shear connections under both monotonic and reverse cyclic loading with various spacing between bolts in a single row. Testing methods included the use of five bolts spaced at a variety of distances: 3 times the bolt diameter (3D), 5 times the bolt diameter (5D), 6 times the bolt diameter (6D), 7 times the bolt diameter (7D), and 8 times the bolt diameter (8D). An end distance of 7D was used for all tests. Note that the distance of 4D, which is the current standard presented in the NDS, was not examined as Anderson (2002) has already performed tests with 4D.

Loading of the specimens was parallel to grain and the specimens were tested with both monotonic and reverse cyclic loading. The reverse cyclic loading followed the protocol that was developed by the CUREE (Krawinkler et al., 2000) for wood structures. The experimental design is given in Table 3.1. The table includes material description, the predicted yield mode, the type of loading, the spacing between bolts, and the number of replications.

The testing procedures were chosen based on available materials and because they represent typical connections utilized in industry. Also, the connection configurations were chosen because they were predicted to yield in accordance with Yield Modes II, III, and IV.

Three of the four yield modes were tested. Yield Mode I is nearly impossible to achieve if construction tolerances are included in connection fabrication (Dolan and Loferski, 2002). Yield Mode I would only occur if the dowel is tightly fitted. Because oversized holes are typically used in construction, Yield Mode I would rarely occur. Therefore, only Yield Modes II, III, and IV were examined.

For predicted Yield Mode II specimens, 3/4 in. diameter bolts were used with 2x6 lumber and tested using the five different bolt spacings. Ten replications under cyclic loading were preformed for each bolt spacing pattern. A sample size of ten assures that the estimated mean is within an acceptable range from the true mean. See Section 3.1.1 for sample size determination. Three replications under monotonic loading were performed for each bolt spacing pattern. The primary purpose of the monotonic tests was to establish input data for the cyclic protocol; thus, a sample set of three is sufficient to provide an average data set. For predicted Yield Mode III specimens, 1/2 in. diameter bolts were used with a 0.25 in. steel plate and 4x6 lumber and tested using the five different bolt spacings. Ten replications under cyclic loading were performed for each bolt spacing pattern. Three replications under monotonic loading were performed for each bolt spacing pattern. For predicted Yield Mode IV specimens, 3/8 in. diameter bolts were used with 2x6 lumber and tested using the five different bolt spacings. Ten replications under cyclic loading were preformed for each bolt spacing pattern. Three replications under monotonic loading were performed for each bolt spacing pattern.

Table 3.1: Experimental Design.

Bolt Size	**Materials**	**Expected Yield Mode**	**No. of Rows**	**Type of Loading**	**Replications**	**Spacing**
3/4"	(2) 2x6 lumber	II	1	Monotonic	3	3D
						5D
						6D
						7D
						8D
				Cyclic	10	3D
						5D
						6D
						7D
						8D
1/2"	1/4" Steel plate, (1) 4x6 lumber	III	1	Monotonic	3	3D
						5D
						6D
						7D
						8D
				Cyclic	10	3D
						5D
						6D
						7D
						8D
3/8”	(2) 2x6 lumber	IV	1	Monotonic	3	3D
						5D
						6D
						7D
						8D
				Cyclic	10	3D
						5D
						6D
						7D
						8D

3.1.1 Sample Size Determination

The sample size for the number of replications for the cyclic loading tests was determined from the following equation (Heine, 2001):

$$n = \frac{2 * Z^2_{\alpha/2} * COV^2}{e^2} \quad (3.1)$$

where: $COV = \sigma / mean$ (3.2)

$e = \Delta / mean$ (3.3)

COV = the coefficient of variance, unitless

σ = the standard deviation, same unit as mean

Mean = the population mean, any unit

e = the relative error, %

Δ = the absolute error, same unit as mean

$Z_{\alpha/2}$ = the area under the curve associated with a $100(1-\alpha)\%$ confidence interval

Heine (2001) used an estimated COV value obtained from work performed by Gutshall (1994) in order to determine the sample size, *n*. Gutshall found a maximum COV value of 16.1% for testing of a single bolt in shear under Sequential Phased Displacement loading. Therefore from Equation (3.1), a sample size of ten assures with 90% confidence that the estimated mean is within 12% of the true mean.

A similar type calculation was not performed for the monotonic tests since the primary purpose of the monotonic tests was to establish input data for the cyclic protocol. The CUREE protocol suggests performing one monotonic test; however, to be consist with previous research, three monotonic tests were performed to generate data for the CUREE cyclic protocol.

3.1.2 Specimen Identification

The identification of each specimen will be necessary when evaluating and discussing the results of this research. Thus, the following nomenclature was developed. Naming of each specimen consists of five digits. The first digit refers to the bolt size used in the test and is either a “F”, “H”, or “E”. A “F” refers to three-Fourths inch bolts. A “H” refers to one-Half inch bolts and an

"E" refers to three-Eighths inch bolts. The next digit refers to the spacing between the bolts. Therefore, a 3 would refer to the 3D spacing, a 5 refers to the 5D spacing and so forth. The third digit refers to the type of loading. A "M" is used for monotonic loading tests and a "C" for cyclic loading tests. The fourth digit is the number of the test. Ten cyclic tests were performed so the fourth number ranges from 1 to 10 for cyclic tests. Three monotonic tests were performed so the fourth number ranges from 1 to 3 for monotonic tests. The final digit is either a "T" or a "B" and refers to whether the specimen is the member affixed to the top or bottom fixture respectively. For example, a top member in the fifth cyclic test performed using the 3D spacing between the bolts and 3/4 in. bolts has the designation of "F3C5T". When reporting the results, the last digit is missing since the data is for the combination of the top and bottom members working together.

3.2 Materials

Bolts were SAE J429 Grade 2 hexagonal head bolts and the bolt holes were oversized by 1/16 in. SAE J429 Grade 2 bolts are formed from low or medium carbon steel and have minimum yield strength of 57,000 psi and a minimum tensile strength of 74,000 psi (SAE, 1999). NDS allows bolt holes to be oversized a maximum of 1/16 in. and is typical in practice. Also, the oversize is a worse case scenario as compared to not over sizing the bolt hole. Species of wood was Southern Yellow Pine (*Pinus spp.*) which has an assigned specific gravity of 0.55 by the NDS (AF&PA, 2001). All wood was equilibrated to have an approximate moisture content of 12% prior to testing. To obtain the 12% moisture content, specimens were placed in a conditioning chamber of constant relative humidity of 65% and temperature of 20 degrees Celsius for several months until equilibrium was reached. Twelve percent moisture content is widely used as a standard moisture content. Specimens for the 2x6 lumber were Grade 1 or better. Specimens for the 4x6 material were Grade 2 or better and were graded as Mixed Southern Yellow Pine. NDS (AF&PA, 2001) assigns a specific gravity of 0.51 for Mixed Southern Yellow Pine. The 4x6 material was donated by Morgan Lumber Company, Inc. of Red Oak, VA.

3.3 Connection layout

The member layout is shown in Figures 3.1 through 3.4. The abbreviations used in the figures are described in subsequent paragraphs. NDS (AF&PA, 2001) provides minimum end distances in table 11.5.1B. The distances are based on the direction of loading and design value. Values are given for either a reduced or full design value. A larger end distance is required if the full nominal design value is needed to resist the applied load. A smaller end distance can be used if a reduction factor, C_Δ, is applied to the design value. Calculation of the reduction factor can be found in section 11.5 of the 2001 edition of NDS. Because the full design value was needed to resist the applied load in this research, the end distance for full design values was used. For loading parallel to grain in tension, the minimum end distance is 7D for full design values.

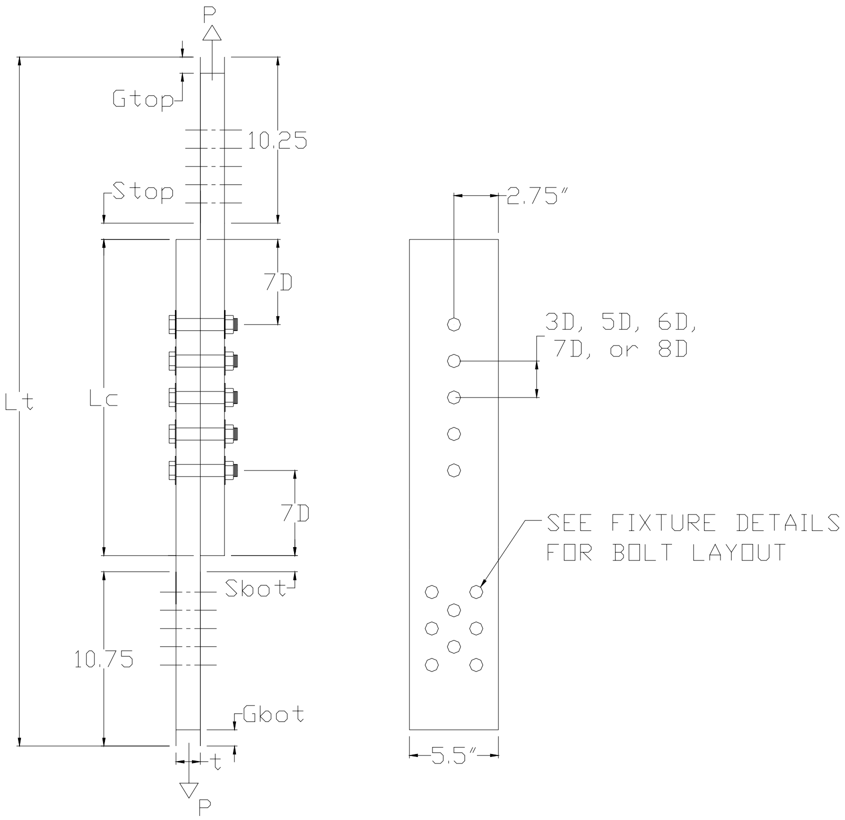


Figure 3.1: Wood-Wood Connection Layout.

Figure 3.2: Wood-Wood Connection.

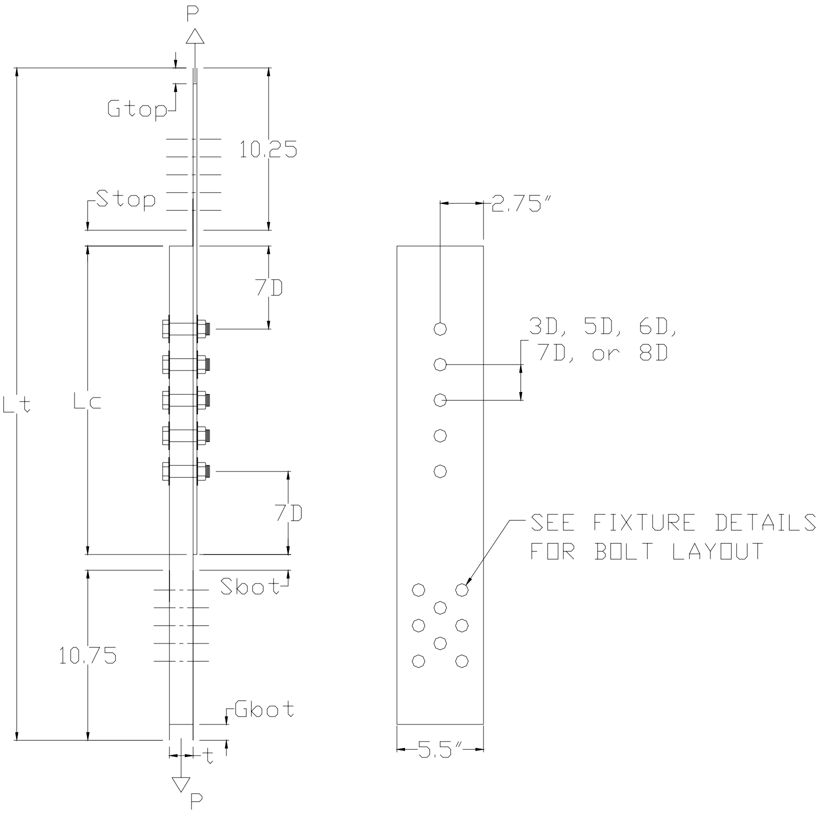


Figure 3.3: Wood-Metal Connection Layout.

Figure 3.4: Wood-Metal Connection.

G_{top} refers to the gap between the end face of the wood member or metal to the top of the top fixture. G_{bot} is the gap between the end face of the wood member to the bottom of the bottom fixture. S_{top} is the space between the bottom of the top fixture to the end face of the bottom wood member. S_{bot} is the space between the top of the bottom fixture to the end face of the either the top wood member or metal. L_t is the total length from the top of the top fixture to the bottom of the bottom fixture. L_c is the length of the connection, the distance from the end faces of the top and bottom wood members or metal. t is the thickness of the bottom wood member. The thickness of the wood top member was 1.5 in. For steel top members, the thickness was 0.25 in. All member dimensions are tabulated in Table 3.2. Some variation of the gap at the top and bottom of the fixture, G_{top} and G_{bot}, occurred because of slight variability of member length. However, the spacing between the end of the member and the fixture, S_{top} and S_{bot}, was always a minimum of 1.5 in. so that there was clearance for the members to deform and displace. Total member length, L_{tot}, was held constant.

Table 3.2: Member Dimensions.

Material	Exp. Yield Mode	Bolt Space	Member Dimensions								
			t (in)	L_c(in)	G_{top} (in)	G_{bot} (in)	S_{top} (in)	S_{bot} (in)	L_{top} (in)	L_{bot} (in)	L_{tot} (in)
2x6 3/4" bolt	II	3D	1.5	19.5	1	2	3	2	31.75	30.25	42.5
		5D	1.5	25.5	0.25	2	2.25	2	37.75	36.25	48.5
		6D	1.5	28.5	0	2	2	2	40.75	39.25	51.5
		7D	1.5	31.5	0	2	2	2	43.75	42.25	54.5
		8D	1.5	34.5	0.25	0	2	2	46.5	44.5	56.5
4x6, 1/4" steel plate 1/2" bolt	III	3D	3.5	13	0	2	2	1.5	25.25	23.25	35.5
		5D	3.5	17	0	2	2	1.5	29.25	27.25	39.5
		6D	3.5	19	0	2	2	1.5	31.25	29.25	41.5
		7D	3.5	21	0	2	2	1.5	33.25	31.25	43.5
		8D	3.5	23	0	2	2	1.5	35.25	33.25	45.5
2x6 3/8" bolt	IV	3D	1.5	9.75	0	2	2	1.5	22	20	32.25
		5D	1.5	12.75	0	2	2	1.5	25	23	35.25
		6D	1.5	14.25	0	2	2	1.5	26.5	24.5	36.75
		7D	1.5	15.75	0	2	2	1.5	28	26	38.25
		8D	1.5	17.25	0	2	2	1.5	29.5	27.5	39.75

3.3.1 Test Fixture Details

To hold the lumber and metal members, fixture connections were designed and fabricated. The fixtures needed to have a minimum of eight SAE J429 Grade 8 bolts in double shear so that the forces in the members could be transferred to the testing machine thus causing failure to occur in the connection that was being tested rather than the fixture connection. SAE J429 Grade 8 bolts are made from medium carbon alloy steel which is quenched and tempered. A Grade 8 bolt has a minimum yield strength of 130,000 psi and a minimum tensile strength of 150,000 psi (SAE, 1999). A grade 8 bolt can be identified by the mark on the head of the bolt. Grade 8 bolts have six radial ridges spaced equally on the head. The testing machine is limited by the vertical clearance that the ram can travel. Therefore, the fixture connections needed to be as short as possible while still maintaining edge, end, and spacing requirements. The vertical clearance in the testing machine is 70 in. The load cell is 8.5 in. and a minimum of 3 in. clearance between the end faces of the members and the fixtures was required so there was sufficient distance for the wood members to deform and displace. The maximum connection length was 34.5 in. Therefore, 24 in. remain for both fixtures. Thus, the following design was utilized.

The bottom fixture was two “L” or angled shaped pieces with two stiffening elements between the legs. Each bottom leg of the angle had dimensions of 10 in. long, 12 in. wide, and 1 in. thick. The vertical legs were 10.75 in. high, 12 in. wide, and 1/2 in. thick. The bottom legs had slotted holes at 10 in. o.c. for connection to the testing machine. The two angle pieces could be bolted at any spacing thus accommodating both the 4x6 material and the 2x6 material. Eight staggered 0.75 in. Grade 8 bolts were used to tighten the two vertical legs together and hold the testing material. The bolts underwent double shear because there are two shear planes. Double shear gave the connection greater strength in resisting applied loads. See Figures 3.5 and Figure 3.6 for bottom fixture connection details.

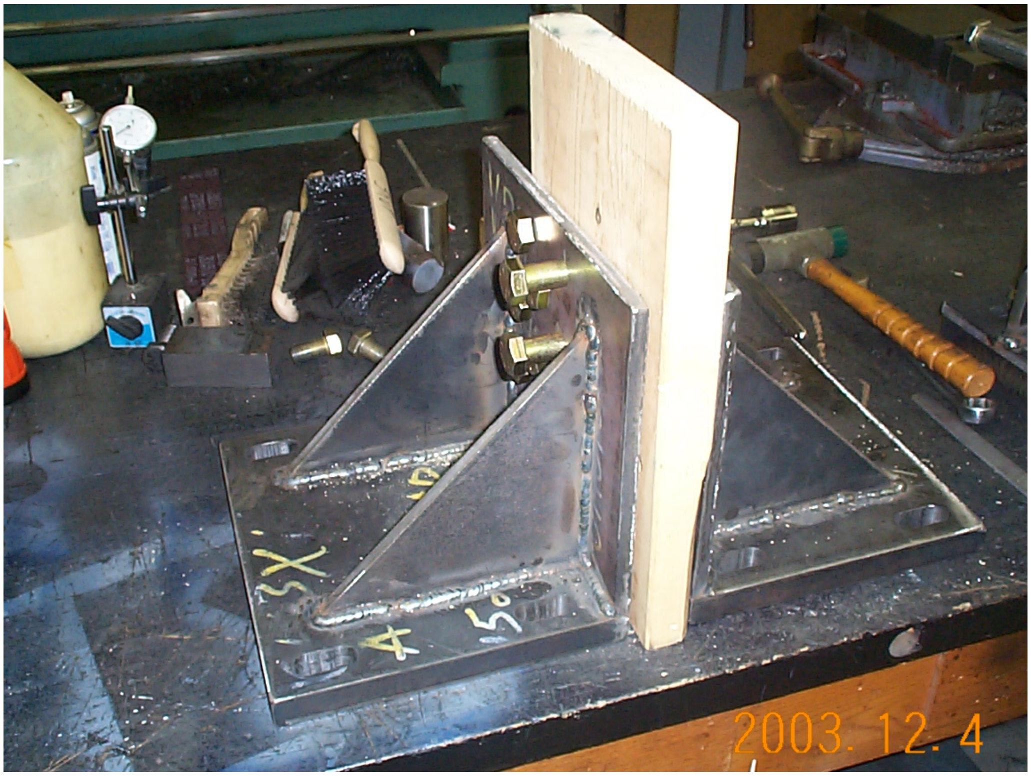
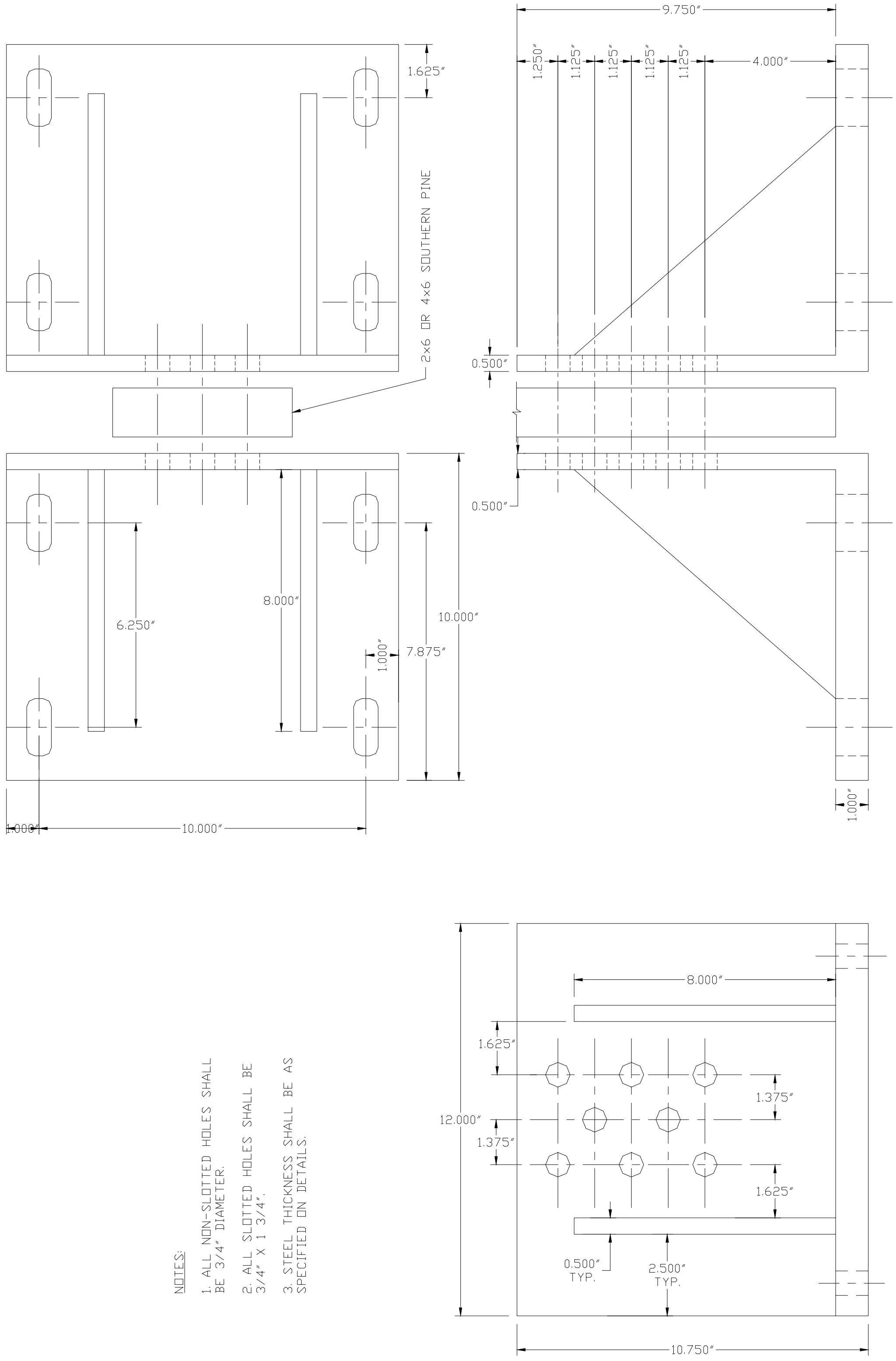


Figure 3.5: Bottom Fixture.



NOTES:

1. ALL NON-SLOTTED HOLES SHALL BE 3/4" DIAMETER.
2. ALL SLOTTED HOLES SHALL BE 3/4" X 1 3/4".
3. STEEL THICKNESS SHALL BE AS SPECIFIED ON DETAILS.

Figure 3.6: Bottom Fixture Connection Details.

The top fixture was a “T” shape with two angled pieces connected to a top plate. The angled pieces had the long legs back to back with two stiffening elements between the legs. The vertical legs were 10.25 in. high, 12 in. wide, and 1.25 in. thick. One of the vertical legs had three 0.75 in. threaded holes on both sides to accommodate 0.75 in. bolts which were used as part of the side bracing system. The horizontal or top legs were 4.75 in. long, 12 in. wide, and 0.5 in. thick. The top legs had slotted holes for 3/4 in. bolts so the two angled pieces could be adjustable to accommodate either 2x6 material or a 0.25 in. plate. The angled pieces were located such that the load cell applied load along the shear plane which was along the face of either the 2x6 material or 0.25 in. plate.

The top plate was 10 in. long, 12 in. wide, and 2 in. thick. The plate had non-slotted holes for the connection to the two angled pieces and had a threaded 1.5 in. diameter hole for connection to the load cell in the center of the plate.

Eight staggered 3/4 in. Grade 8 bolts were used to tighten the two vertical legs together and hold the testing material. The bolts underwent double shear because there are two shear planes. Double shear gave the connection greater strength in resisting the applied loads. See Figures 3.7 and 3.8 for top fixture connection details.

Figure 3.7: Top Fixture (upside down).

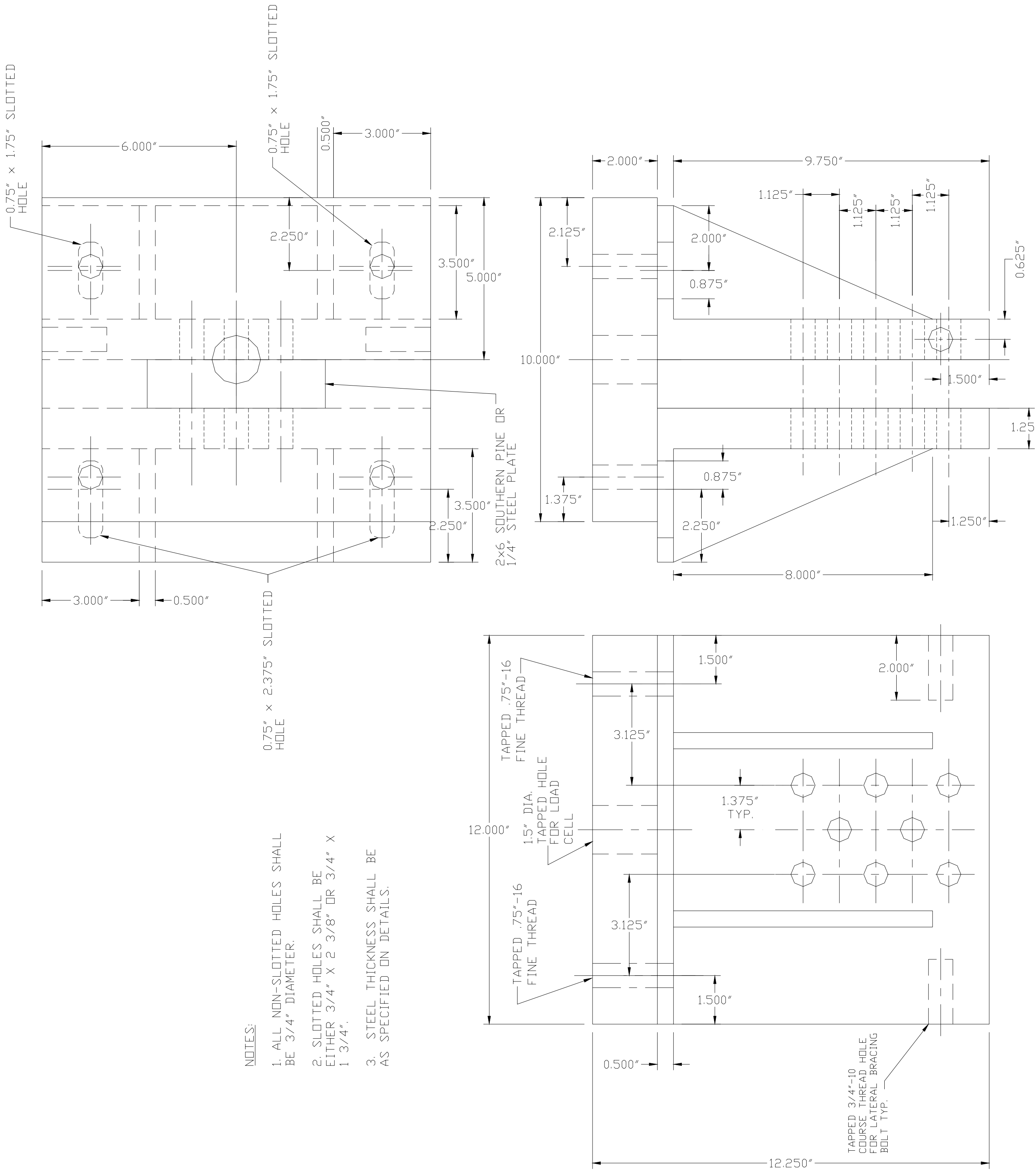


Figure 3.8: Top Fixture Connection Details.

A side bracing system was used to reduce the thrust on the load cell due to joint eccentricity. Bracing could not be incorporated on the faces of the connection due to possible interference with bolts. Therefore, a one inch thick steel plate and L4x4x3/4 angles with slotted holes in the extended leg was used as the bracing system as pictured in Figure 3.9. Alignment studs which were attached to the top fixture moved vertically in the slotted holes. The slotted holes were greased so as to reduce the effects of friction.

Figure 3.9: Side Bracing System.

3.4 Testing Equipment

All testing was performed at the Wood Engineering Laboratory located at the Brooks Forest Products Center. The Brooks Center is operated by the Department of Wood Science and Forest Products at Virginia Polytechnic Institute and State University located in Blacksburg, VA. The test machine is servo-hydraulic and is made by Material Testing System (MTS). It has a 55,000 pound capacity with a ± 6 in. displacement range. A ± 50,000 pound load cell and a ± 2.5 in. displacement range card was used during the testing procedure. Two potentiometers were utilized in addition to the machine’s linear variable differential transformer (LVDT) to measure displacement. Two potentiometers were used in order to neglect any effects due to slippage of the grips or elongation of the lumber. One potentiometer was attached to the main member while the second was attached to the secondary or side member. The potentiometer bases sat on the bottom fixture and attached through the use of a magnet. For wood members, a hole was predrilled approximately one inch away from the right front face of the member at a location half way between the second and third holes from the bottom. A 1/4 in. screw 5 in. long was then driven into the predrilled hole and the wire from the potentiometer was attached. For steel members, a magnet with a steel rod extended horizontally was attached approximately one inch away from the face of the member at a location half way between the second and third holes from the bottom. The wire from the potentiometer was then attached to the horizontal steel rod.

The two potentiometers were added to the assembly in addition to the MTS LVDT for several reasons. First, the readings from the potentiometers were taken near the center of the connection so that the displacement values were at the actual location of the connection as opposed to the MTS LVDT which takes readings at the top of the setup where the load cell was located. Thus, inaccuracies from slippage in the top fixture connection did not enter into the results. Second, the potentiometers were placed on both members so that the relative movement between the members could be recorded. Thus, inaccuracies from any slippage in the bottom fixture did not enter into the results. It would have be ideal to place the potentiometers so that the readings were taken at the centerline of the connection, however, splitting typically occurred in that area so the screw drilled into the wood member would have loosened and caused inaccuracies. Therefore, the screws were placed at the same height and on apposing sides so that any twisting action in the connection was canceled. Finally, by having two potentiometers, the effect of the lumber stretching or elongating was neglected. Thus, the displacements that are reported in this research are the difference between the two potentiometer readings. The test configuration can be seen in Figure 3.10 and 3.11.

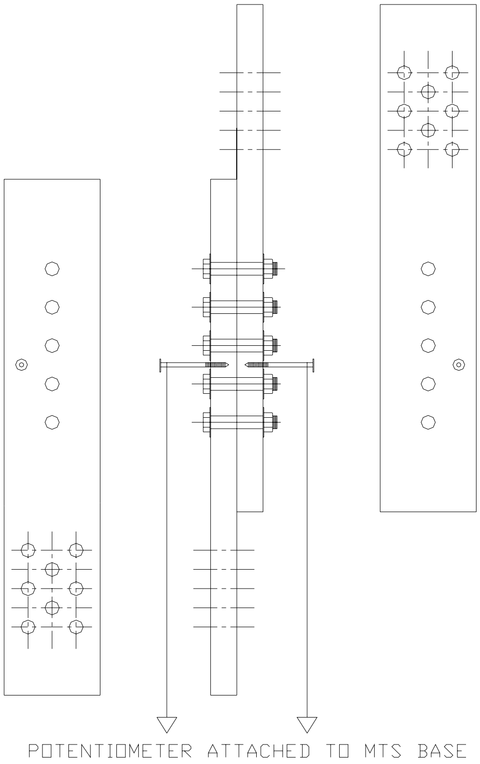


Figure 3.10: Potentiometer Configuration.

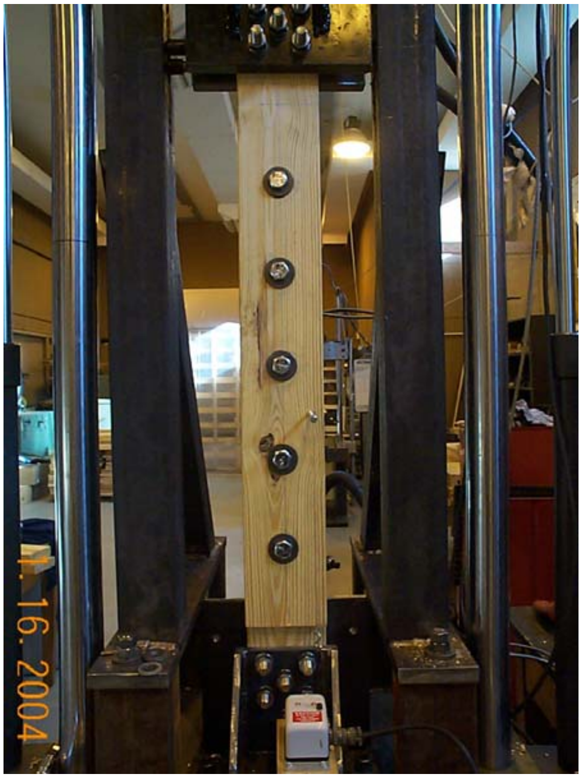


Figure 3.11: Connection Test Configuration.

3.5 Test Procedures

3.5.1 Monotonic Test Procedure

Three monotonic tests were performed for each connection layout. Each wood member was placed in the test fixture where a maximum of eight holes were drilled through the test fixture and the wood members. A maximum of eight and a minimum of five Grade 8 bolts were then placed through the member and fixture depending on the test connection layout. A pneumatic air wrench was used to tighten the bolts between the fixture and the specimen. For steel members, the holes were predrilled so the Grade 8 bolts were placed through the plate and fixture and tightened using the pneumatic air wrench. Finally, the five connection bolts, which are described in the materials section of this document, were placed through the predrilled holes in the wood members and hand tightened. The connection bolts were hand tightened because relaxation could occur in construction.

The monotonic tests were performed in accordance with ASTM D 1761-88(2000)e1, *Standard Test Methods for Mechanical Fasteners in Wood* (ASTM, 2003a). The rate of the test was 0.0714 in/min (1.81 mm/min) so that a 0.5 in. displacement was reached in 7 minutes. ASTM D 1761-88(2000)e1 requires that the maximum load be attained in no less than 5 minutes and no more than 20 minutes. To match the procedure performed by Anderson (2001), the same rate of testing was used. Data was recorded every 0.08 seconds by a computer data acquisition system.

The connection was tested in compression until the applied load dropped below 80% of the maximum load that was applied. Compression testing was used rather than tension because of the vertical clearance limitations. Tension testing would require more clearance. For tests using steel plates, the plate was examined between tests for any warping or damage. If any damage due to loading was observed, the plate was replaced.

3.5.2 Cyclic Test Procedure

Ten cyclic tests were performed for each connection layout. Each wood member was placed in the fixtures where a maximum of eight holes were drilled through the fixture and the wood members. A maximum of eight and a minimum of five Grade 8 bolts were then placed through the member and fixture depending on the test connection layout. A pneumatic air wrench was used to tighten the bolts. For steel members, the holes were predrilled so the Grade 8 bolts were simply placed through the plate and fixture and tightened using the pneumatic air wrench. Finally, the five connection bolts, which are described in the materials section of this document, were placed through the predrilled holes in the members and hand tightened. The connection bolts were hand tightened because this could occur in construction.

The CUREE testing protocol for deformation controlled quasi-static cyclic testing with the loading history for ordinary ground motions was used for all cyclic tests (Krawinkler, et. al., 2000). The displacement rate was 4.724 in/min. To match the procedure performed by Anderson (2001), the same rate of testing was used. Data was recorded every 0.08 seconds. For tests using steel plates, the plate was examined between tests for any warping or damage. If any damage due to loading was observed, the plate was replaced.

To determine the cyclic loading protocol, results from the monotonic tests were examined. The deformation recorded when the load dropped below 80% of the maximum load applied was determined and averaged for the three monotonic tests. According to the CUREE protocol (Krawinkler, et. al., 2000), the cyclic loading pattern was based on the averaged deformation from the monotonic tests, which is called the monotonic deformation capacity, Δ_m. A fraction of Δ_m was used to set the reference deformation, Δ, in the protocol. The authors of the CUREE protocol suggest 60% (Krawinkler, et. al., 2000). Therefore, Δ was equal to $0.6*\Delta_m$.

The reference deformation, Δ, was used to determine the loading cycles that are experienced by the connections. The loading cycle consisted of initiation cycles, primary cycles, and trailing cycles of symmetrical amplitude. Initiation cycles were performed at the beginning of the test to serve as a check of equipment and data recording measurements. A primary cycle was a larger cycle that proceeded the subsequent trailing cycles which were of smaller magnitude. A trailing cycle had a magnitude equal to 75% of the preceding primary cycle. The loading cycle was as follows:

- Six initiation cycles with amplitude equal to $0.05*\Delta$
- One primary cycle with amplitude equal to $0.075*\Delta$
- Six trailing cycles

- One primary cycle with amplitude equal to 0.1*Δ
- Six trailing cycles
- One primary cycle with amplitude equal to 0.2*Δ
- Three trailing cycles
- One primary cycle with amplitude equal to 0.3*Δ
- Three trailing cycles
- One primary cycle with amplitude equal to 0.4*Δ
- Two trailing cycles
- One primary cycle with amplitude equal to 0.7*Δ
- Two trailing cycles
- One primary cycle with amplitude equal to 1.0*Δ
- Two trailing cycles

The CUREE protocol states that subsequent primary cycles step at an increase of 0.5*Δ followed by two trailing cycles. For example the next primary cycle after 1.0*Δ would be equal to 1.5*Δ. The cycle should be continued until the maximum load resisted by the specimen in a cycle decreases to a small fraction of the maximum load. Therefore, based on previous testing performed by Anderson (2001), the cyclic tests were stopped when the trailing cycles after the primary cycle equal to 2.5*Δ was completed. The CUREE protocol is illustrated in Figure 3.12.

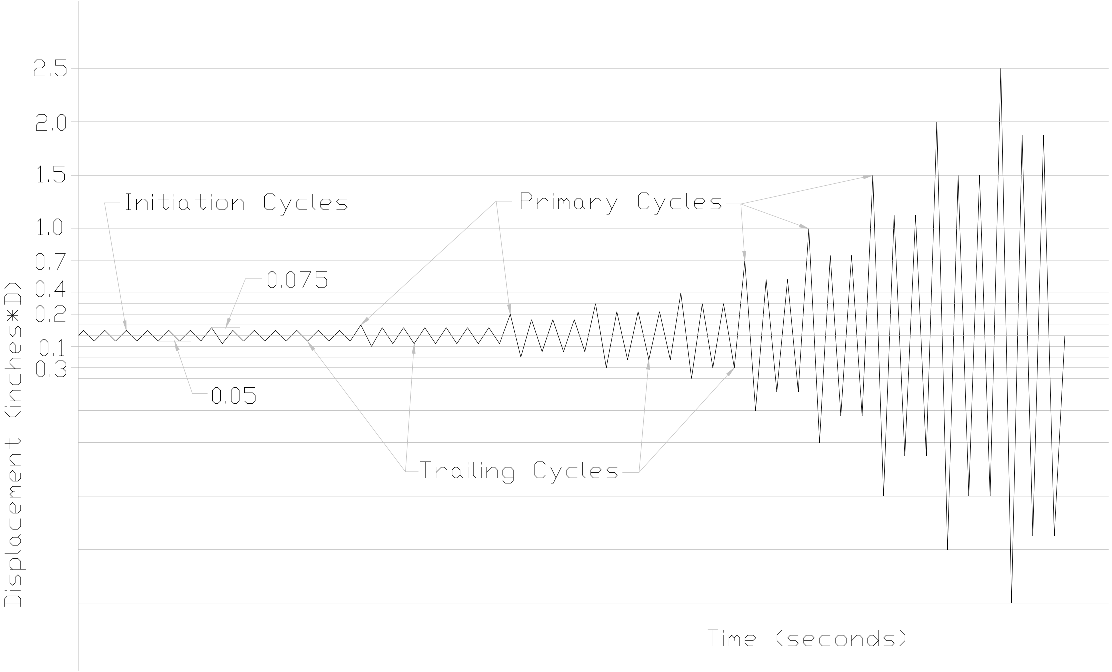


Figure 3.12: Cyclic Loading History for Ordinary Ground Motion (Krawinkler, et. al., 2000).

3.6 Bearing Test Methods and Procedures

Tests to measure the property for both the wood and the bolts were performed. To determine the wood member dowel bearing strength, load was applied to a steel dowel that was bearing on the end grain of the wood specimens. The wood specimens were taken from undamaged areas in the connection members after connection tests were finished. To determine the bolt bending yield strength, load was applied to a cantilevered bolt. The results from these tests were used in the yield model to calculate the probable yield modes, 5% offset yield strength, and the yield capacity of the connection. The machine used to perform the tests is a 20,000 pound capacity servo-hydraulic Material Testing System (MTS) and has a ± 5.0 inch displacement range. A 20,000 pound load cell was used.

3.6.1 Dowel Bearing Strength Test

Dowel bearing strength is a property that which measures a wood member's resistance to embedment by a dowel. Tests for the dowel bearing strength conformed to ASTM D 5764-97a(2002), *Standard Test Method for Evaluating Dowel Bearing Strength of Wood and Wood-Based Products* (ASTM, 2003d). Specimens were taken from each member for all of the connection tests performed as near to the bolt locations as feasible.

Target specimen dimensions were 3 in. wide by 1.5 in. thick by 4.5 in. long. Some were smaller because not enough solid wood remained intact after connection testing to allow for a specimen of this size. The full hole testing setup was used because splitting of the wood before the completion of the test was a concern. Half hole testing may cause premature splitting in the specimen. The loaded length for the specimens from the tests which used 3/4 in. and 1/2 in. bolts was 3 in. It was not feasible to cut a specimen of that dimension for some of the tests that used 3/8 in. bolts because the member was significantly broken so the loaded length was reduced to 2 in. This reduction in size still conforms to the minimum dimensions specified in ASTM D 5764-97a(2002) section 8.2.2.1. The holes in the specimens were predrilled on a drill press and were 1/16 in. oversized to match the conditions of the connection tests.

The rate of testing was chosen such that the test duration falls between the 1 to 10 minute range as specified in the ASTM standard in section 10.4. The rate was 0.08 in/min.

The test arrangement that was used in the dowel bearing strength tests is shown in Figures 3.13 and 3.14. A steel attachment assembly held the bolt in place while the specimen was loaded. The specimens were loaded until splitting occurred or until the displacement was greater than one half the bolt diameter. The loaded length was above the bolt which was a slight modification to the layout as described in ASTM D 5764-97a(2002). The modification did not change the results of the test, but did allow for an easier test arrangement. Because the testing machine ram applied the load directly to the specimen rather than the dowel, specimens were placed and removed into the fixture more easily. If the ram applied load to the dowel, than a loading apparatus that attached to the ram would have needed to be formed with the dowel permanently connected. Since the load was applied to the specimen, the dowel rested in holes drilled in the fixture, which sat on the testing machine base. Thus, the dowel was removed easily and replaced as needed. The ability of removing the dowel allowed the specimens to be removed easily.

Figure 3.13: Dowel Bearing Strength Test Arrangement.

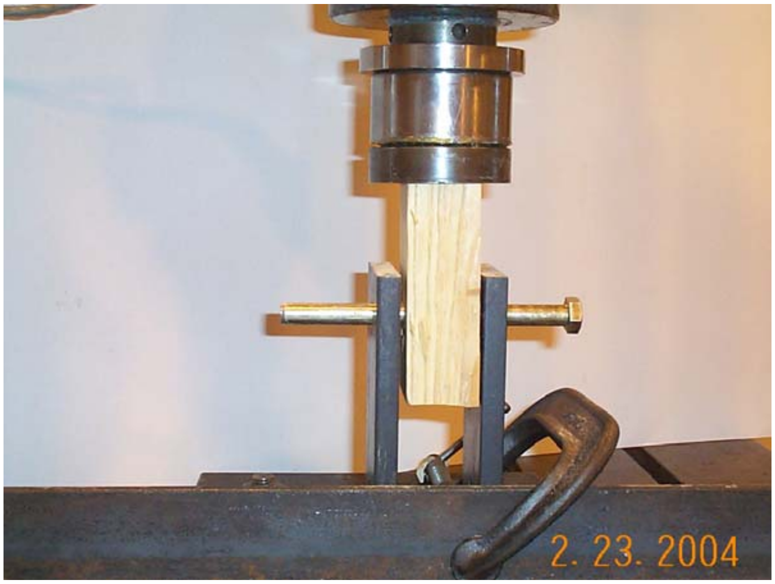


Figure 3.14: Dowel Bearing Strength Test Arrangement.

The interpretation of the results was in accordance to Section 11 of ASTM D 5764-97a(2002). A straight line was fit to the initial linear portion of the load-deformation curve. The proportional limit load was taken as the load at which the load-deformation curve deviated from the straight line. The straight line was then offset by a deformation equal to 5% of the bolt diameter.

Finally, the load at which the offset straight line intersected the load-deformation curve was taken as the dowel bearing strength of the member as illustrated in Figure 3.15.

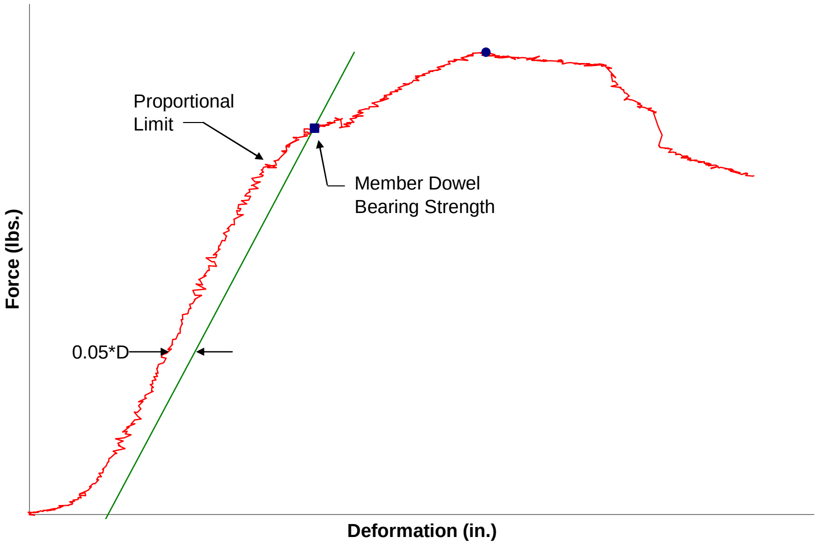


Figure 3.15: Determination of Member Dowel Bearing Strength. (ASTM, 2003d)

To determine the dowel bearing stress, F_e, the dowel bearing strength, F, was divided by the loading area. The dowel bearing strength was calculated from the force-deformation curve as described above. For all tests, the loading area equaled the thickness of the specimen, 1.5 in., multiplied by the diameter of the bolt.

3.6.2 Bolt Bending Strength Tests

Bolt bending tests were used to determine the yield strength of a bolt. Fifteen replications for each type of bolt used in the connection tests were performed. Currently NDS recommends the use of procedures found in ASTM F 1575, *Standard Test Method for Determining Bending Yield Moment of Nails* (AF&PA, 2001) for the testing of bolts. Procedures in the ASTM standard recommend a three point loading configuration as shown in Figure 3.16 (ASTM, 2004). The standard is written for nails and in the past has been used for bolts as well. However, in 2003 changes were made to the standard such that the span length is a function of the diameter of the dowel being tested. Thus, for large diameter bolts the span lengths becomes larger than the tested bolts. Therefore, to test the actual bolts that were used in the connection testing of this research, an alternate testing procedure was utilized.

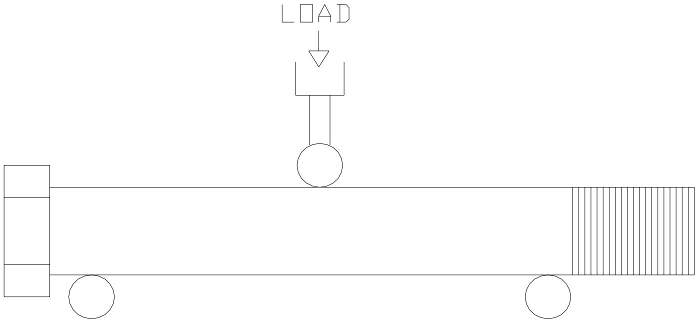


Figure 3.16: Bolt Bending Schematic according to ASTM F 1575.

The alternative method involved cantilevering the bolt as illustrated in Figure 3.17. The bolts were inserted into a hole such that the threads were covered and a load was then applied at the end of the bolt near the head. Three diameters of bolts were used in the connection tests, 3/4 in., 1/2 in., and 3/8 in. The distance from the face of the support to where the load was applied for the 3/4 in. and 3/8 in. bolts was 2 in. The distance for the 1/2 in. bolts was 3 in. The rate of testing was 0.25 in/min. The load was applied with a semicircular dowel which had a diameter of 3/8 in. and was 1/2 in. long.

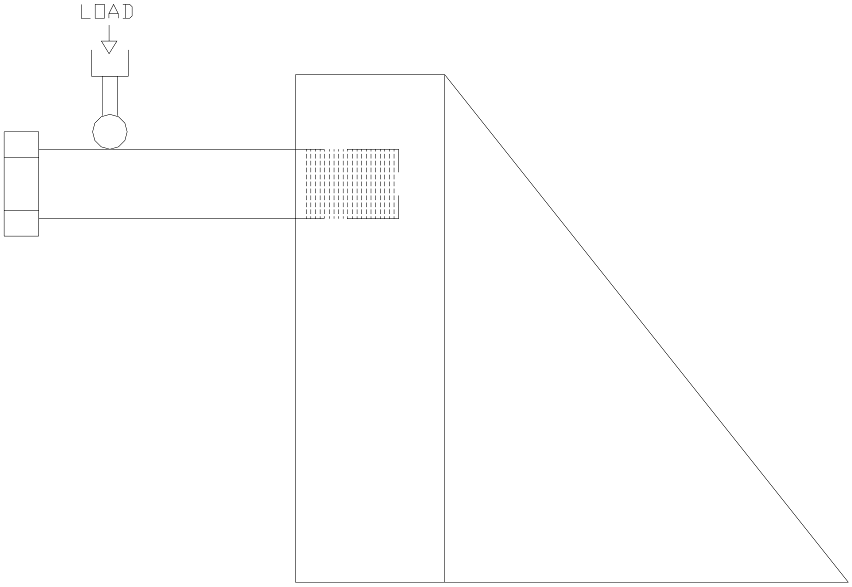


Figure 3.17: Bolt Bending Schematic for Cantilever Method.

The interpretation of the results was partially in accordance to Section 10 of ASTM F 1575-03. A straight line was fit to the initial linear portion of the force-deformation curve. The proportional limit load was taken as the load at which the force-deformation curve deviated from the straight line. The straight line was then offset by a deformation equal to 5% of the bolt diameter. Finally, the load at which the offset straight line intersected the load-deformation curve was taken as the dowel bending yield strength, P, as illustrated in Figure 3.18. If the offset straight line did not intersect the load-deformation curve, than the maximum load was used as the dowel bending yield strength.

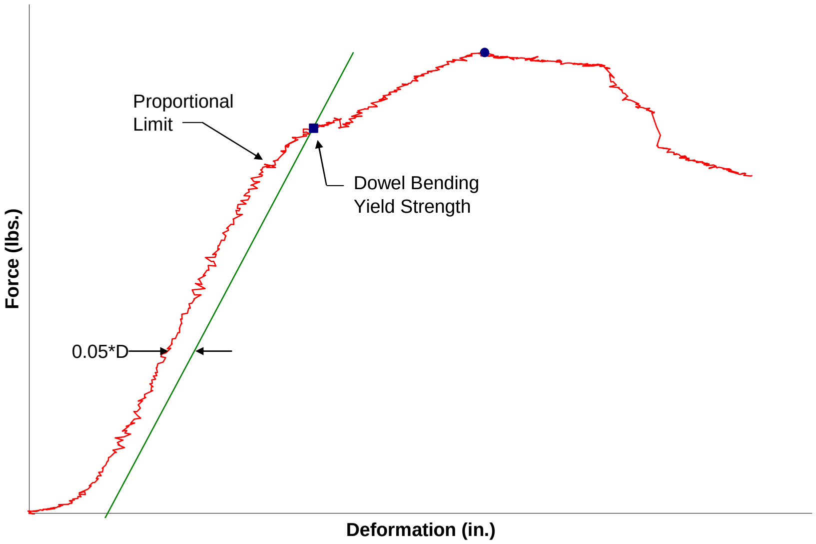


Figure 3.18: Determination of Dowel Bending Yield Strength. (ASTM, 2004)

To determine the calculated bending yield stress, F_{yb}, several calculations were performed. First, the calculated moment, M_y, needed to be determined. The moment was obtained by taking the dowel bending yield strength, P, and multiplying it by the distance from the support to where the load was applied (3 in. for the 1/2 in. bolts and 2 in. for the 3/8 in. and 3/4 in. bolts). The dowel bending yield strength, P, was determined from the force-deformation curve as described above.

$$M_y = P*(3\text{ in. or }2\text{ in.}) \qquad (3.4)$$

Next, the section modulus, S, needed to be determined. For prismatic fasteners, the section modulus is the diameter of the fastener, D, raised to the third power all divided by six.

$$S = D^3/6 \qquad (3.5)$$

The calculated bending yield strength, F_{yb}, was then calculated as the calculated moment, M_y, divided by the section modulus, S.

$$F_{yb} = M_y/S \qquad (3.6)$$

3.6.3 Moisture Content Test

All wood main and side members were tested for moisture content conforming to the testing method given in ASTM D4442-92(2003), *Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials* (ASTM, 2003c). For the 2x6 lumber, an approximate one inch cube was cut from the member in the area near the connection. For the 4x6 material, a rectangle of approximate dimensions 1 in. x 1 in. x 3.5 in. was cut from the members in the area near the connection. After cutting the specimens, an initial weight was determined. Then the specimens were placed in an oven having a constant temperature of 220 ºF for approximately 24 hours thus allowing for the specimens to completely dry. The specimens were then reweighed. The moisture content is the ratio of the difference between the initial and dry weight to the dry weight multiplied by 100 to obtain a percent value.

$$MC = \frac{Wo - Wd}{Wd} * 100\% \qquad (3.7)$$

3.6.4 Specific Gravity Test

All wood main and side members were tested for specific gravity according to ASTM D2395-02, *Standard Test Methods for Specific Gravity of Wood and Wood-Base Materials*, Method "B" Mode II (ASTM, 2003b). The same specimens that were used to measure moisture content were used to measure the specific gravity. After the oven dry weight of the specimen was measured, the specimen was dipped in paraffin wax to seal the surface so no water could be absorbed. A tank of water was placed on an automatic balance and the balance zeroed. Next the specimen was immersed in the tank of water so that the specimen was fully submerged and not touching the sides of the tank. The weight that was measured by the balance was the weight of the water displaced by the specimen. The units of the balance was grams. The specific gravity of water is 1.0 when the weight is in units of grams and the volume in units of cubic centimeter. The weight obtained from the balance was then divided by the specific gravity of 1.0 to obtain the volume of the specimen. The specific gravity of the specimen was found by dividing the ratio of the difference between the initial and dry weight to the dry weight multiplied by 100 to obtain a percent value (moisture content) by the volume.

$$SG = \frac{MC}{Vol} \tag{3.8}$$

3.7 Data Analysis

The data evaluation conformed to methods presented in a previous ASTM draft standard, “Standard Test Method for Cyclic Properties of Connections Assembled with Mechanical Fasteners” (ASTM, 1999). This draft standard was used in the evaluation of research performed by Anderson (2002) and has since been withdrawn from consideration by ASTM subcommittee E0.6. These methods were used for two reasons; first, so that the results obtained by Anderson (2001) can be compared, and second, because no methods are standardized by ASTM at this time.

Several terms and methods are presented in the ASTM draft. Data evaluation begins by generating a load-deflection curve for each of the monotonic and cyclic tests. For cyclic tests, a piecewise load-deflection envelope curve was generated by joining the peaks of each of the primary cycles with linear lines. F_{peak} is defined as the maximum load applied while Δ_{peak} is the corresponding displacement. $\Delta_{failure}$ is the displacement corresponding to $0.8*F_{peak}$. An equivalent energy elastic-plastic (E.E.P.) curve, which is comprised of two line segments, was drawn such that the area under the line segments is equal to the area under the load-deflection curve up to $\Delta_{failure}$. The area under the curves is called the E.E.P. energy. The E.E.P. curve crosses the load-deflection curve at $0.4* F_{peak}$. The load at which the inclined line segment of the E.E.P. curve intersects the horizontal line segment is considered the yield load, F_{yield}, and is called the E.E.P. yield. The corresponding deflection is Δ_{yield}. Note that F_{peak} is greater than F_{yield} which is greater than $0.8*F_{peak}$. The ductility ratio is defined as the ratio of $\Delta_{failure}$ to Δ_{yield}. Elastic stiffness is the slope of the inclined line segment of the E.E.P. curve. A line that is parallel to the inclined line segment of the E.E.P. curve is generated at a distance equal to 5% times the bolt diameter. The load and deflection where the 5% offset line crosses the load-deflection curve are presented in the results. Slack is also reported which is the distance from the origin to the displacement value where the load-deflection curve begins to increase in load. Figures 3.19 and 3.20 are sample charts showing some of the parameters that are reported. For cyclic data, the reported values for the parameters are the average of the positive and negative results.

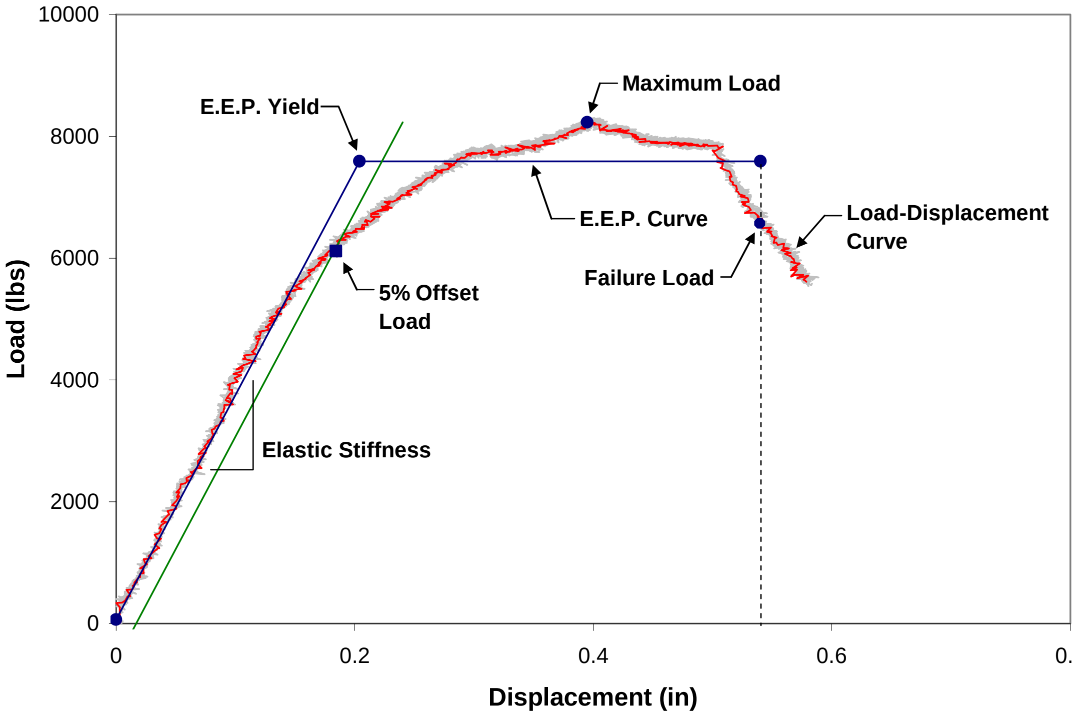


Figure 3.19: Equivalent Energy Elastic-Plastic System for Monotonic Tests.

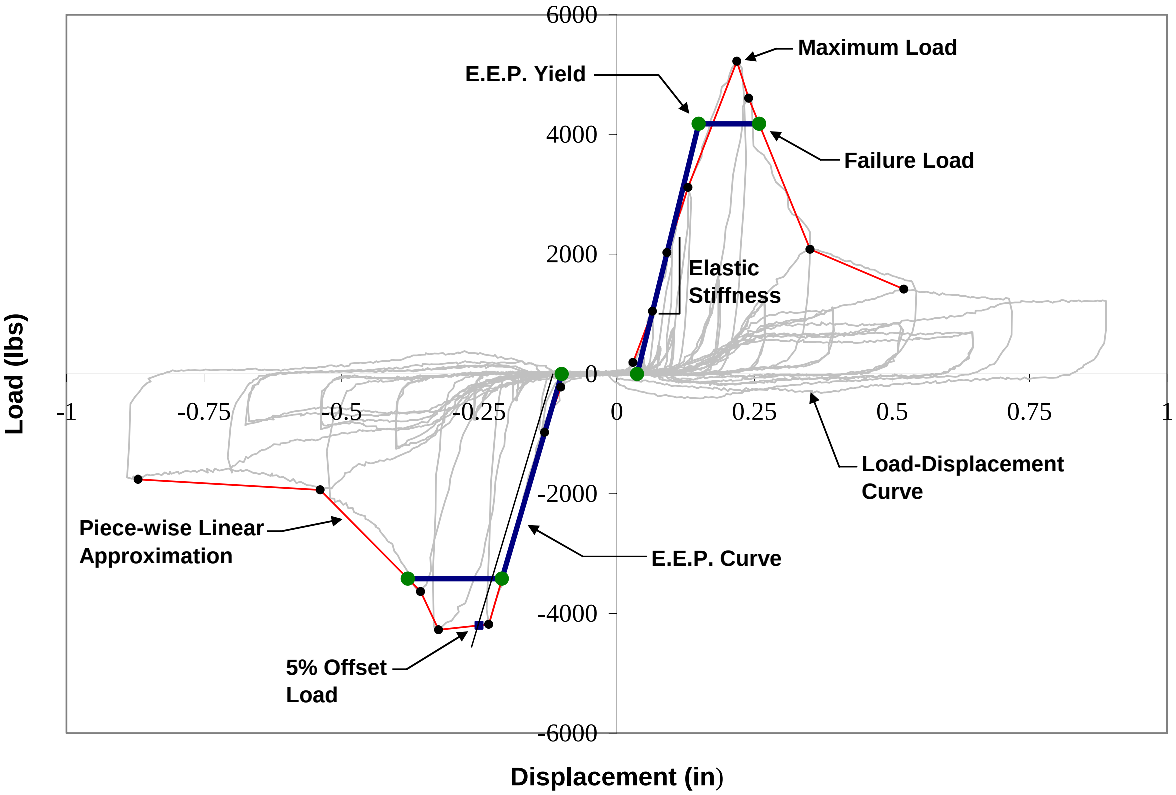


Figure 3.20: Equivalent Energy Elastic-Plastic System for Cyclic Tests