Research Report

Task Order #1
Strength of Timberlinx A475 Connectors

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Introduction

The Timberlinx A475 connector is a proprietary product consisting of a hollow tension tube and a cast-iron expansion anchor used to connect two members in heavy timber construction. When installed, the connection system is entirely concealed within the connection. The University of Wyoming College of Engineering performed a series of tests with the Timberlinx connector for the Timberlinx company. The objective of the tests was to evaluate the strength of the connection system when loaded parallel to grain and perpendicular to grain in three different species of timber. The tests consisted of tension loading of heavy timber specimens containing Timberlinx A475 tube connectors with cast-iron expansion anchors. To the extent possible, test methods followed ASTM D 1761[1]. Determination of moisture content and specific gravity for the timber specimens followed ASTM D2395[2].

Specimen preparation and testing was performed under the supervision of Dr. Richard J. Schmidt, Professor of Civil and Architectural Engineering and Associate Dean of Engineering at the University of Wyoming. Dr. David Carradine, Technical Director of the Wood Materials and Engineering Laboratory (WMEL) at Washington State University in Pullman, WA, observed all specimen preparation and testing in order to assure compliance with ASTM standards and procedures.

Specimens and Apparatus

The Timberlinx connector (part number A475) is a 4.75-inch long hollow tube manufactured from ASTM A 500[3] Grade C structural tubing with specified outside diameter of 1.094 inches and inside diameter of 0.820 inches. The top of the tube contains an elongated slot 0.776 inches wide and 1.5 inches long. The bottom of the tube contains internal 0.875-inch UNC internal threads for a length of 1.5 inches. The expansion pin consists of two approximately semi-cylindrical shells, two wedges and a draw bolt. Clockwise twisting of the bolt draws the wedges together, forcing the shells to separate. The shells are manufactured from Grade 32510 cast iron produced according to ASTM A 47[4]. The wall thickness of the pin shells is 0.225 inches. Photographs of the tension tube and expansion anchor are shown in Figure 1.

1. ASTM D 1761 — Standard Test Methods for Mechanical Fasteners in Wood
2. ASTM D 2395 — Standard Test Methods for Specific Gravity of Wood and Wood-Based Materials
3. ASTM A 500 — Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
4. ASTM A 47 — Standard Specification for Ferritic Malleable Iron Castings

Figure 1 — Timberlinx A475 Tension Tube (left) and Expansion Pin (right)

The Timberlinx company supplied the connection hardware: the A475 tube connectors and cast iron expansion anchors. Each tube connector and expansion anchor contained an adhesive label bearing the U. S. patent number 5,741,083, Canadian patent number 2,119719, and CCMC code report number 13091-R. The tube connectors also contained a part number label.

Specimens consisted of short lengths of timber with nominal 6-in by 6-in cross sections. Species of timber used the test program included eastern white pine, Port Orford cedar, and white oak. For specimens constructed with white pine or Port Orford cedar, ten specimens were tested for each loading configuration. For the specimens constructed with white oak, only five specimens were tested for each loading configuration. Complete load-deflection data were recorded.

Tests were conducted in an Instron Model 1332 servo-hydraulic test frame with a 55-kip capacity ram and were controlled using an MTS Teststar IIs controller and software. Data was recorded from an Interface 1220AF 25-kip load cell and two string potentiometers. All instrumentation utilized for testing was calibrated by MTS, the instrument manufacturer, or according to the WMEL Quality System Manual. Calibrations are traceable to NIST standards.

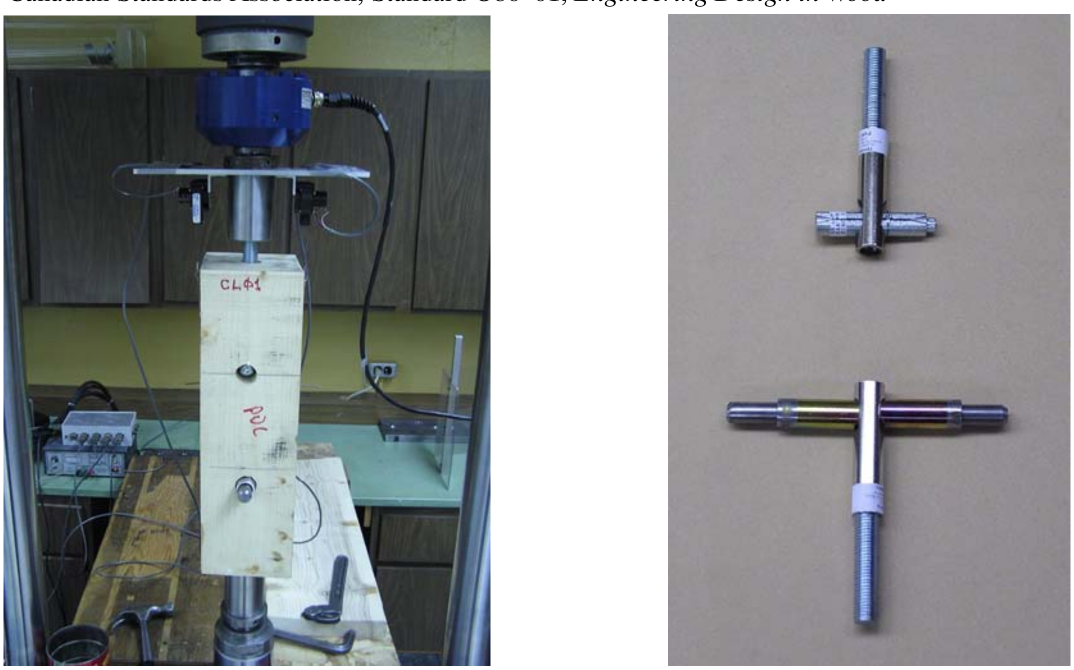
Tension parallel to grain specimens were at least 16 inches long. Tension perpendicular to grain specimens were at least 18 inches long. Holes for tension tubes and expansion anchors were drilled in the specimens according to the manufacturer's recommendations and using a drilling jig supplied by the manufacturer. Tension tube holes were centered on the end or on the face of the specimen. Holes for expansion anchors were placed such that end and edge distance requirements for full-strength connections specified in the AF&PA 2005 NDS©[5] and CSA O86-01[6] standards were satisfied.

For tension parallel to grain (also referred to as longitudinal loading) tests, the specimen was held within the test frame using one Timberlinx tension tube at each end of the specimen. Each tension tube was threaded on to a 7/8-inch diameter threaded rod. Each rod was in turn threaded into a spherical swivel joint mounted in the test frame. Hence, the test fixtures permitted pure uniaxial tension loading of the specimen. A typical specimen is shown in Figure 2a.

The top tension tube was held in the specimen with a Timberlinx expansion pin. For the pine and cedar specimens, a $1\,{}^{1}/_{8}$-inch diameter transverse hole for the expansion pin was centered $5\,{}^{7}/_{16}$-inch below the top surface of the specimen. In the oak specimens, the expansion pin hole was centered $3\,{}^{15}/_{16}$-inch below the top surface of the specimen. These dimension correspond to fastener (expansion pin) end distances of 7*D* and 5*D* for the softwood and hardwood specimens, respectively, where *D* is the effective diameter of the expansion pin (${}^{3}/_{4}$-inch).

The top portion of the specimen was considered as the gage section for the test. That is, displacement of the connection was measured in this region and failure of the joint was expected to occur in this portion of the specimen. Wood or expansion pin failure in the bottom portion of the

5. American Forest and Paper Association, *National Design Specification (NDS©) for Wood Construction*, 2005 Edition.
6. Canadian Standards Association, Standard O86-01, *Engineering Design in Wood*



a. Typical Sepcimen **b. Top and Bottom Pin-Tube Assemblies**

Figure 2 — Tension Parallel to Grain Test

specimen would render the results for a specimen invalid. However, tension failure of the bottom tube would be considered a valid test result, since all tension tubes were nominally identical and their capacity is unaffected by other specimen characteristics (end distance, timber species, or expansion pin strength). To increase the likelihood of failure in the gage section, the bottom expansion pin was replaced with a $^{3}/_{4}$-inch diameter solid steel bar (ASTM A108 Grade 1018, F_y = 70 ksi) and a pair of $1^{1}/_{8}$-inch diameter steel sleeves to increase the width of bearing inside the transverse drill hole. To further strengthen the bottom portion of the specimen, the end distance on the bottom connector was set at 7-inches or the bottom portion of the specimen was reinforced transversely with screws. These techniques were successful in that all wood and pin failures occurred in the top gage section of the specimen. Failures of the tension tube occurred in both the top and bottom locations. Top and bottom pin-tube assemblies are shown in Figure 2b.

For tension perpendicular to grain (also referred to as transverse loading) tests, the specimen was clamped to a stiff steel reaction frame mounted to the head of the loading ram. Load was applied to the Timberlinx tension tube mounted transversely at midlength of the specimen. The tension tube was threaded on to a 7/8-inch diameter threaded rod. The rod was in turn threaded into a spherical swivel joint mounted in the test frame to permit pure uniaxial tension loading of the connector. A typical test specimen is shown in Figure 3. For all specimens, a $1^{1}/_{8}$-inch diameter transverse hole for the expansion pin was centered $3^{3}/_{16}$-inch below the top face of the specimen. This dimension corresponds to fastener edge distance of 4D for all specimens.

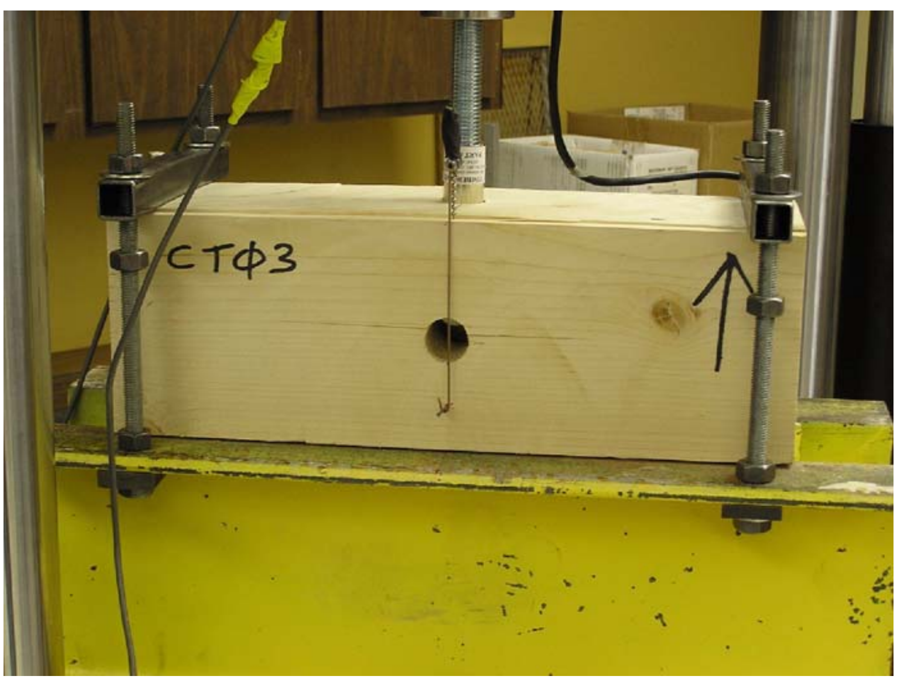


Figure 3 — Tension Perpendicular to Grain Specimen

The specimens were secured in the reaction frame with 1-inch square steel tubes and steel rods spaced 16-inches center to center. All specimens failed within the vicinity of the expansion pin.

Sampling

Results from the test program are analyzed to determine design values for the Timberlinx connectors for the three species of timber used in the tests. All timber was air-dried to equilibrium conditions. Specimens were cut down to the target cross section dimensions and stored in the test lab in order to reach local environmental conditions. Local equilibrium moisture content is normally in the range of 6%.

Samples of Timberlinx product (tension tubes and expansion anchors) were selected randomly from stock provided by the Timberlinx company in Canada. To confirm that the product supplied by the Timberlinx company was representative of the commercially available stock, additional product was ordered from a supplier in Idaho. Subsequent comparative testing of the company-provided product against that provided by the supplier confirmed that the company-supplied product was indeed representative of commercially available product. See Appendix A for detailed test results.

Specimen Preparation and Test Procedure

Holes for tension tubes and expansion anchors were drilled in advance of joint assembly. Specimens were fully seasoned (air dried), so drilling prior to joint assembly did not cause any localized effects due to subsequent drying around the holes.

During assembly of the joint, the wedges in the expansion anchors were drawn in to approximately the position that they normally hold when installed in an actual structure. As a standard wedge position, the wedges in each expansion anchor were drawn in by the center bolt until the back face of the wedge was flush with the ends of the anchor shells. The position of the bolt was adjusted to assure that the shells were parallel, with a uniform gap between the two shells of approximately 1/16-inch (see Figure 4).

Tests were conducted at a uniform machine stroke rate appropriate to produce ultimate load or total deformation of 0.6 inches in not less than 5 minutes or more than 20 minutes. Based on prior work, the initial machine stroke rate was set at 0.05 inches/minute. Load and stroke data was recorded continuously during the test at one-second intervals.

Figure 4 — Expansion Pin, Wedges Drawn In Flush With Ends

Joint displacement was measured by a pair of string potentiometers mounted above the spherical swivel in the load frame with their strings attached to the sides of the timber specimen below the hole for the expansion anchor. The potentiometers thus recorded localized deformation of the wood, bending of the expansion pin, and withdrawal of the tension tube from the timber specimen.

Upon completion of the load test, the failure mode was noted and the specimen was photographed. Following termination of the load test, coupon samples were cut from each specimen for moisture content and specific gravity testing according to ASTM D 2395. Coupon samples were cut from undamaged regions of the timber specimen.

Test Results and Analysis

For tests using pine and cedar timber, ten specimens were tested for each group. All pine specimens, all transversely loaded cedar specimens, and five of the longitudinally loaded cedar specimens experienced timber and/or expansion pin failure. Five of the longitudinally loaded cedar specimens experienced fracture of the tension tube. For tests using oak timber, only five specimens were tested for each group. All oak specimens failed by tension tube fracture, hence these specimens experienced more consistent strength, warranting a smaller number of specimens.

Results of the load tests are presented in the following tables and figures. Table 1 contains general specimen characteristics, test parameters, and test duration. The specimen identifier is a four-character code in which the first character identifies the timber species (p = pine, c = cedar, o = oak), the second character identifies the loading direction (l = longitudinal, t = transverse), and the last two characters identify the sequence number for the specimen. Table 2 contains moisture content and specific gravity results for the test specimens. Table 3 contains the summary results for each specimen. Tests pl07 and pl09 are disregarded because they inadvertently included older style tension tubes with thinner walls and thus lower tension strength. Test cl04 is also disregarded since

Table 1 -- Timberlinx A475 Strength Testing Summary Data General Specimen Characteristics									
Specimen	test date	start time	stroke rate (in/min)	test duration (sec)	b_1 (inches)	b_2 (inches)	d_1 (inches)	d_2 (inches)	length (inches)
pl01	3-Oct-06	7:10	0.05	1330	6.09	6.03	5.92	5.98	17.69
pl02	3-Oct-06	7:40	0.05	961	5.90	5.97	5.67	5.54	18.13
pl03	3-Oct-06	8:07	0.05	1073	5.68	5.58	5.96	5.94	17.81
pl04	3-Oct-06	8:30	0.05	1086	5.96	6.01	5.96	5.87	20.00
pl05	3-Oct-06	8:56	0.05	696	5.99	5.99	6.04	6.04	19.94
pl06	3-Oct-06	9:13	0.05	1322	6.08	6.09	5.98	6.07	20.00
pl07	3-Oct-06	9:35	0.05	556	6.04	6.00	5.93	5.89	17.56
pl08	3-Oct-06	9:58	0.05	954	5.96	5.94	6.02	5.92	19.94
pl09	3-Oct-06	10:20	0.05	852	5.99	5.97	5.64	5.51	17.94
pl10	3-Oct-06	10:42	0.05	1073	6.13	6.00	5.66	5.57	17.94
pl11	3-Oct-06	12:03	0.05	1280	5.59	5.58	5.98	6.22	17.81
pl12	3-Oct-06	12:32	0.05	541	5.56	5.68	5.95	5.94	17.81
cl01	2-Oct-06	11:28	0.05	888	5.29	5.21	5.83	5.77	17.94
cl02	2-Oct-06	12:11	0.05	773	5.85	5.87	5.25	5.32	17.38
cl03	2-Oct-06	12:37	0.05	676	5.91	5.90	5.24	5.32	17.75
cl04	2-Oct-06	14:58	0.05	554	5.99	5.86	5.27	5.36	18.06
cl04a	2-Oct-06	15:13	0.05	1062	5.99	5.86	5.27	5.36	18.06
cl05	2-Oct-06	15:44	0.05	587	6.18	6.11	6.09	6.02	18.00
cl06	2-Oct-06	16:05	0.05	670	6.10	6.16	5.40	5.28	18.00
cl07	2-Oct-06	16:40	0.05	1083	6.09	6.21	6.15	6.06	18.00
cl08	2-Oct-06	17:09	0.05	922	5.89	5.90	5.32	5.22	18.00
cl09	2-Oct-06	17:44	0.05	1464	5.32	5.25	6.02	6.17	17.50
cl10	2-Oct-06	18:20	0.05	661	5.95	6.01	5.97	5.91	15.88
ol01	4-Oct-06	10:15	0.05	632	6.66	6.69	6.05	6.22	18.25
ol02	4-Oct-06	10:34	0.05	582	5.92	6.04	6.69	6.57	18.00
ol03	4-Oct-06	10:52	0.05	562	6.67	6.71	5.92	5.86	18.00
ol04	4-Oct-06	11:07	0.05	609	6.64	6.59	5.98	5.97	18.06
ol05	4-Oct-06	11:22	0.05	638	6.63	6.58	5.94	5.95	18.19
pt01	3-Oct-06	14:08	0.06	922	5.981	5.956	5.953	6.007	18.06
pt02	3-Oct-06	14:31	0.075	775	5.997	6.154	5.977	6.044	18.00
pt03	3-Oct-06	14:50	0.075	643	6.129	6.159	6.314	6.206	18.00
pt04	3-Oct-06	15:08	0.075	761	5.982	6.019	5.967	5.999	18.00
pt05	3-Oct-06	15:28	0.075	782	5.985	6.107	5.979	6.062	18.06
pt06	3-Oct-06	15:50	0.075	526	5.569	5.703	5.968	6.009	18.13
pt07	3-Oct-06	16:04	0.075	611	5.957	5.969	5.647	5.629	17.94
pt08	3-Oct-06	16:21	0.075	743	5.997	6.063	6.136	6.134	17.75
pt09	3-Oct-06	16:39	0.075	983	6.047	6.064	6.053	6.008	18.06
pt10	3-Oct-06	17:02	0.075	788	5.549	5.682	5.951	5.815	17.94
ct01	3-Oct-06	17:22	0.075	699	5.387	5.314	6.025	6.005	18.06
ct02	3-Oct-06	17:43	0.075	763	5.864	5.779	6.109	6.446	18.19
ct03	3-Oct-06	18:02	0.075	814	6.195	6.074	6.049	6.121	17.94
ct04	3-Oct-06	18:36	0.075	623	6.129	6.071	5.97	6.04	18.00
ct05	3-Oct-06	18:43	0.075	956	6.135	6.061	6.067	6.01	18.00
ct06	3-Oct-06	19:04	0.075	798	6.406	6.323	6.058	6.024	18.00
ct07	3-Oct-06	19:23	0.075	876	6.205	6.131	5.932	6.039	18.06
ct08	3-Oct-06	19:44	0.075	915	5.297	5.392	6.035	6.036	18.06
ct09	3-Oct-06	20:05	0.075	752	6.114	6.056	6.059	5.995	18.00
ct10	3-Oct-06	20:24	0.075	850	5.387	5.308	5.946	5.962	18.06
ot01	3-Oct-06	20:45	0.035	1146	5.744	5.932	6.527	6.601	18.00
ot02	3-Oct-06	21:10	0.05	742	6.569	6.674	5.967	5.921	18.25
ot03	3-Oct-06	21:30	0.05	724	6.169	6.402	6.554	6.516	18.44
ot04	3-Oct-06	21:52	0.05	716	5.768	6.009	6.593	6.491	18.00
ot05	3-Oct-06	22:09	0.05	794	5.997	5.877	6.541	6.527	19.81

Table 2 -- Timberlinx A475 Testing
Specimen Moisture Content and Specific Gravity

Specimen	MC	Oven Dry SG		Specimen	MC	Oven Dry SG
pl01	6.8%	0.354		pt01	5.6%	0.339
pl02	5.7%	0.377		pt02 *	7.0%	
pl03	5.7%	0.369		pt02 **		0.320
pl04	5.2%	0.398		pt03	5.9%	0.359
pl05	5.3%	0.401		pt04	7.5%	0.417
pl06	5.9%	0.415		pt05	6.4%	0.372
pl08	5.3%	0.393		pt06	5.8%	0.312
pl10	5.7%	0.373		pt07	5.6%	0.351
pl11	5.6%	0.350		pt08 *	7.3%	
pl12	5.9%	0.346		pt08 **		0.467
mean	5.7%	0.378		pt09	6.9%	0.408
std dev	0.5%	0.024		pt10	5.9%	0.324
				mean	6.4%	0.367
				std dev	0.7%	0.050
cl01	6.8%	0.386		ct01	10.0%	0.361
cl02	7.3%	0.406		ct02	6.6%	0.407
cl03	6.9%	0.421		ct03	9.4%	0.385
cl04A	9.9%	0.385		ct04	10.4%	0.422
cl05 *	10.9%			ct05	9.4%	0.388
cl05 **		0.402		ct06	9.1%	0.366
cl06	10.1%	0.372		ct07	9.7%	0.370
cl07	7.0%	0.376		ct08 *	9.6%	
cl08 *	7.0%			ct08 **		0.388
cl08 **		0.378		ct09 *	11.2%	
cl09	6.6%	0.494		ct09 **		0.396
cl10	7.0%	0.449		ct10 *	12.1%	
mean	8.0%	0.407		ct10 **		0.407
std dev	1.6%	0.039		mean	9.7%	0.389
				std dev	1.4%	0.020
ol01	6.6%	0.828		ot01	7.3%	0.811
ol02	9.0%	0.844		ot02	7.5%	0.840
ol03	8.8%	0.832		ot03	7.4%	0.830
ol04	7.8%	0.786		ot04	7.0%	0.857
ol05	8.7%	0.816		ot05	7.7%	0.759
mean	8.2%	0.821		mean	7.4%	0.819
std dev	1.0%	0.022		std dev	0.3%	0.038

Notes: * indicates that the specimen contained a knot.
** indicates that the SG is measured after the knot

Table 3 -- Timberlinx A475 Strength Testing Summary Data				
Specimen Test Results				
Specimen	max load (pounds)	displ at max load (inches)	Stiffness (kips/in)	failure mode
pl01	10,293	0.60629	48.235	modes Is & III; specimen split at top anchor
pl02	10,976	0.64619	61.547	modes Is & III; specimen split at top anchor
pl03	10,639	0.40124	56.870	modes Is & III; no other visible failure
pl04	10,445	0.78841	43.331	modes Is & III; splitting, brash shear plut at top anchor
pl05	10,069	0.28002	52.964	modes Is & III; shear plug at top anchor
pl06	11,693	0.46021	60.670	modes Is & III; no other visible failure
pl07	8,537	0.23435		tube failure -- old style tube was used -- invalid test
pl08	11,482	0.41916	61.589	modes Is & III; no other visible failure
pl09	9,002	0.21276		tube failure -- old style tube was used -- invalid test
pl10	11,261	0.65466	58.824	modes Is & III; no other visible failure
pl11	10,925	0.72693	49.562	modes Is & III; no other visible failure
pl12	8,995	0.28156	48.762	modes Is & III; lengthwise split of specimen
cl01	11,641	0.55908	48.675	modes Is & III; lengthwise split of specimen
cl02	12,320	0.43959	64.583	tube fracture, top end
cl03	12,329	0.31933	68.858	tube fracture, bottom end
cl04		0.31799		stroke limit reached, no failure
cl04a	10,841	0.64349	71.886	modes Is & III; shear plug at top anchor
cl05	11,499	0.36115	56.640	modes Is & III; specimen split at top anchor
cl06	9,868	0.38158	45.536	modes Is & III; split above and below top pin
cl07	11,467	0.66950	47.728	modes Is & III; top and bottom splitting and shear plug
cl08	12,286	0.38043	74.251	tube fracture, bottom end
cl09	12,965	0.33706	69.063	tube fracture, top end
cl10	12,878	0.35248	72.807	tube fracture, bottom end
ol01	12,500	0.22436	87.752	tube fracture, top end
ol02	12,534	0.26580	96.675	tube fracture, top end
ol03	12,363	0.23776	91.218	tube fracture, bottom end
ol04	12,352	0.22485	99.387	tube fracture, top end
ol05	12,063	0.27366	86.868	tube fracture, top end
pt01	8,146	0.79296	18.545	modes Is & III; tension perp splitting
pt02	7,096	0.86184	9.0622	modes Is & III; tension perp splitting
pt03	8,565	0.63892	26.644	modes Is & III; tension perp splitting, irregular grain above pin hole
pt04	6,888	0.83878	15.701	modes Is & III; tension perp splitting, flexural failure on top
pt05	9,023	0.87835	17.991	modes Is & III; tension perp splitting
pt06	7,768	0.44566	34.015	modes Is & III; tension perp splitting, flexural failure on top
pt07	9,487	0.55940	31.4	modes Is & III; tension perp splitting, flexural failure on top
pt08	7,575	0.78059	12.556	modes Is & III; tension perp splitting
pt09	6,748	1.11430	10.628	modes Is & III; tension perp splitting
pt10	6,068	0.70134	10.604	modes Is & III; tension perp splitting
ct01	7,852	0.69425	12.959	modes Is & III; tension perp splitting
ct02	9,313	0.78459	26.655	modes Is & III; tension perp splitting
ct03	8,940	0.89063	10.641	modes Is & III; tension perp splitting
ct04	7,122	0.63885	10.087	modes Is & III; tension perp splitting, flexural failure on top
ct05	9,605	1.00892	14.022	modes Is & III; tension perp splitting
ct06	7,636	0.78966	13.179	modes Is & III; tension perp splitting
ct07	8,440	0.95274	10.201	modes Is & III; tension perp splitting near a knot
ct08	8,506	0.86333	15.903	modes Is & III; tension perp splitting
ct09	8,636	0.67948	14.034	modes Is & III; tension perp splitting
ct10	9,451	0.83582	15.237	modes Is & III; tension perp splitting, flexural failure on top
ot01	13,121	0.37852	51.964	tube fracture
ot02	12,817	0.39577	49.687	tube fracture
ot03	12,302	0.35500	59.194	tube fracture
ot04	12,481	0.34167	47.242	tube fracture
ot05	12,597	0.37284	50.889	tube fracture

the test terminated due to a stroke limit on the test machine, rather than failure of the specimen. The test was restarted as cl04a with new connection hardware and the specimen was successfully loaded to failure.

Load-displacement plots for the six groups of tests are shown in Figures 3, 4, 5, 6, 7, and 8. Each group of curves exhibits a relatively low initial stiffness, a small amount of yield behavior in the vicinity of 1.5 kips, and then a stiffer response. This "start-up" behavior is associated with initial bending deformation of the expansion pin shells. After the shells have bent to the configuration that they are both in contact with the draw bolt, then the stiffening behavior commences.

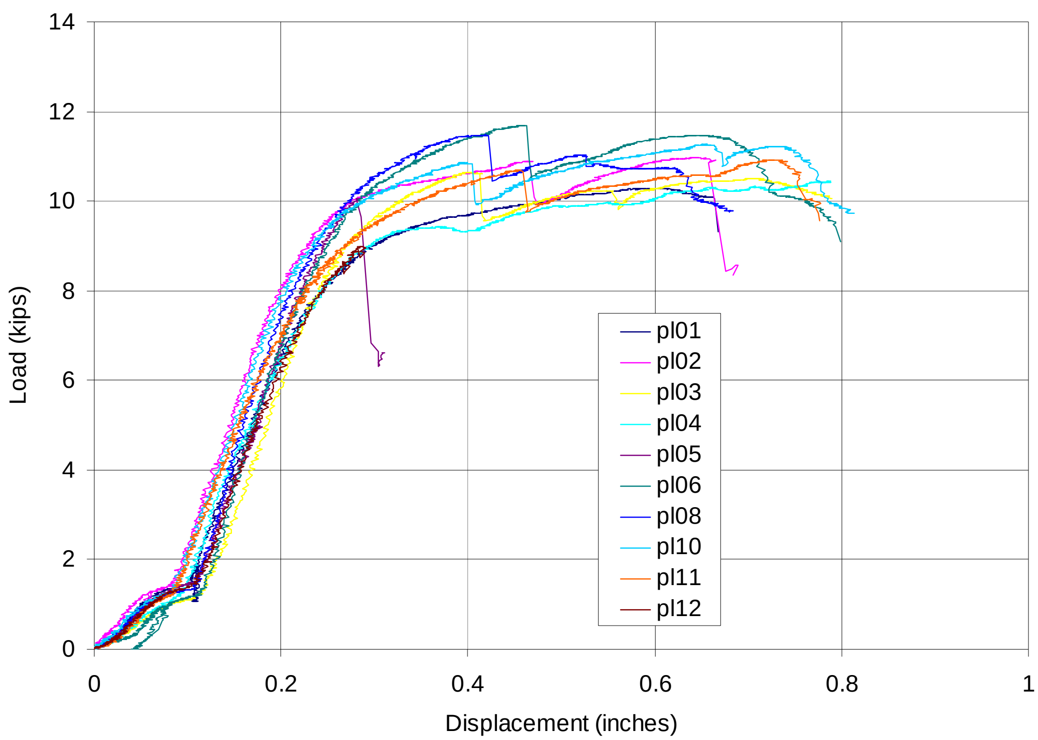


Figure 3 — Load-Displacement Curves, Pine Specimens, Longitudinal Loading

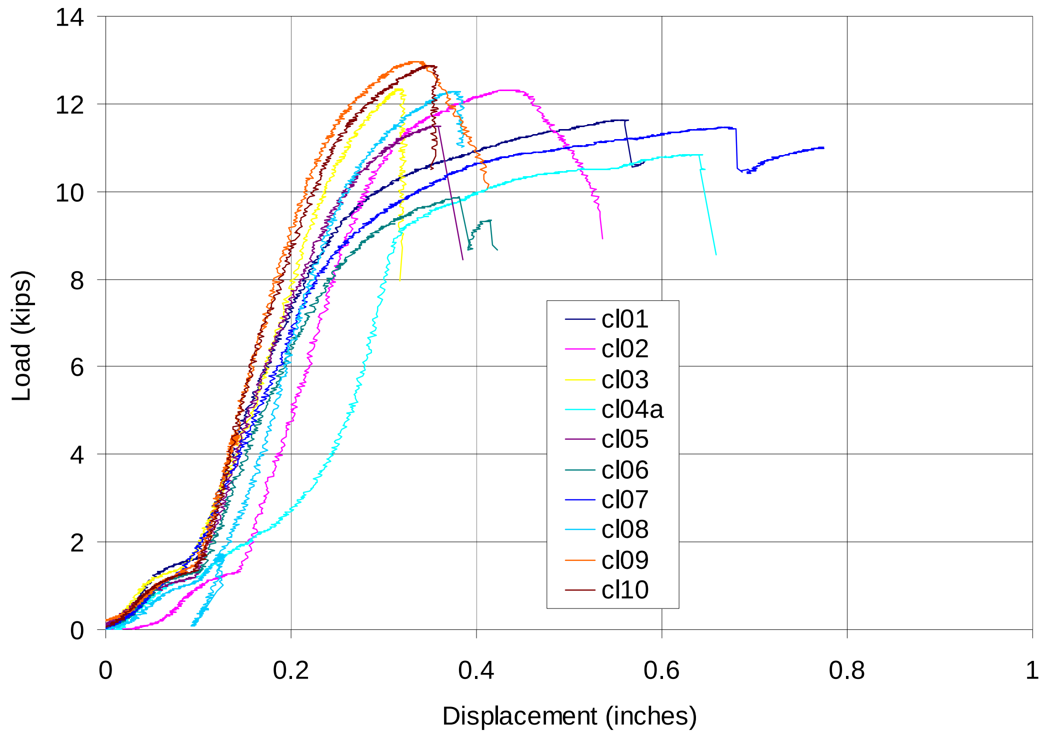


Figure 4 — Load-Displacement Curves, Cedar Specimens, Longitudinal Loading

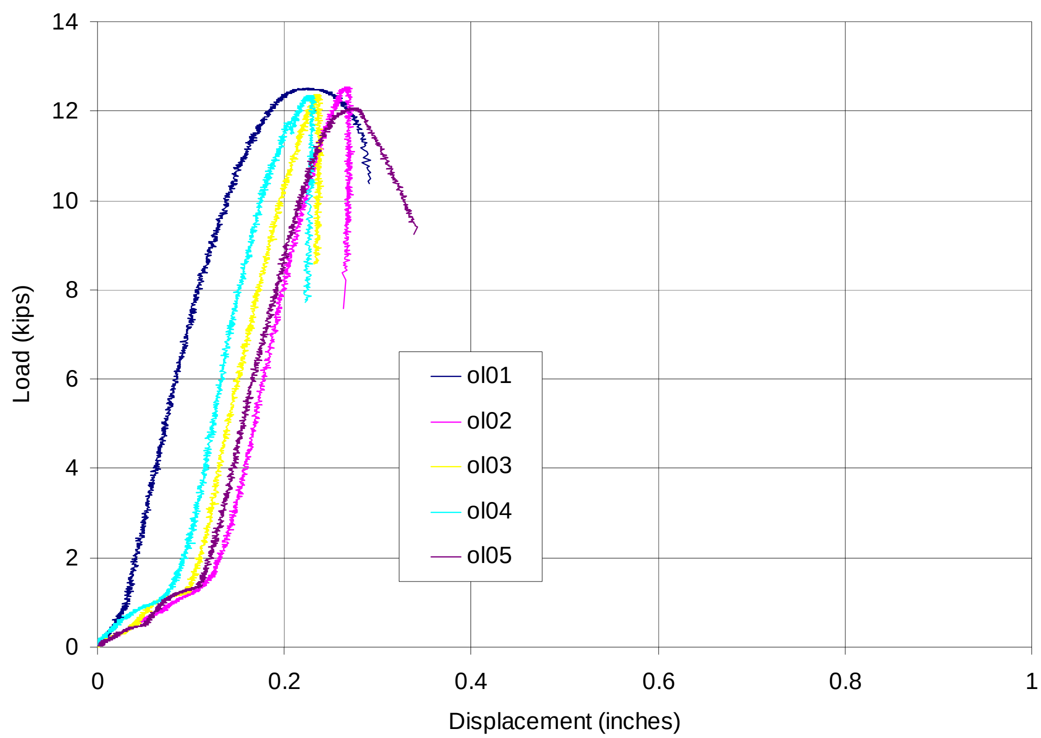


Figure 5 — Load-Displacement Curves, Oak Specimens, Longitudinal Loading

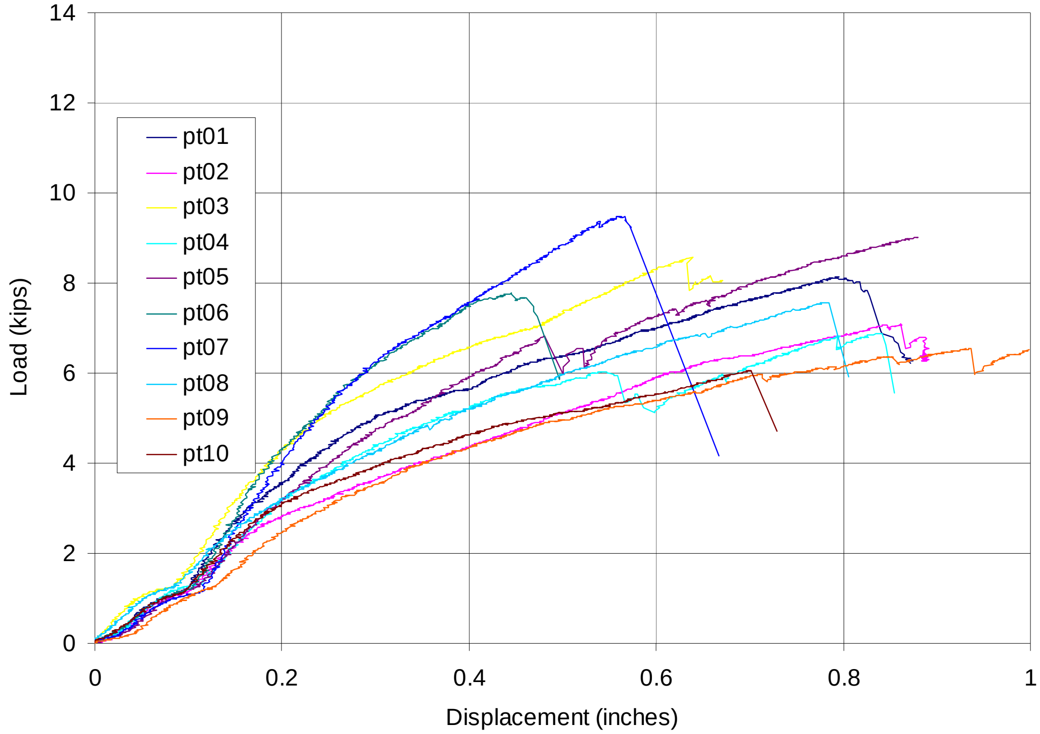


Figure 6 — Load-Displacement Curves, Pine Specimens, Transverse Loading

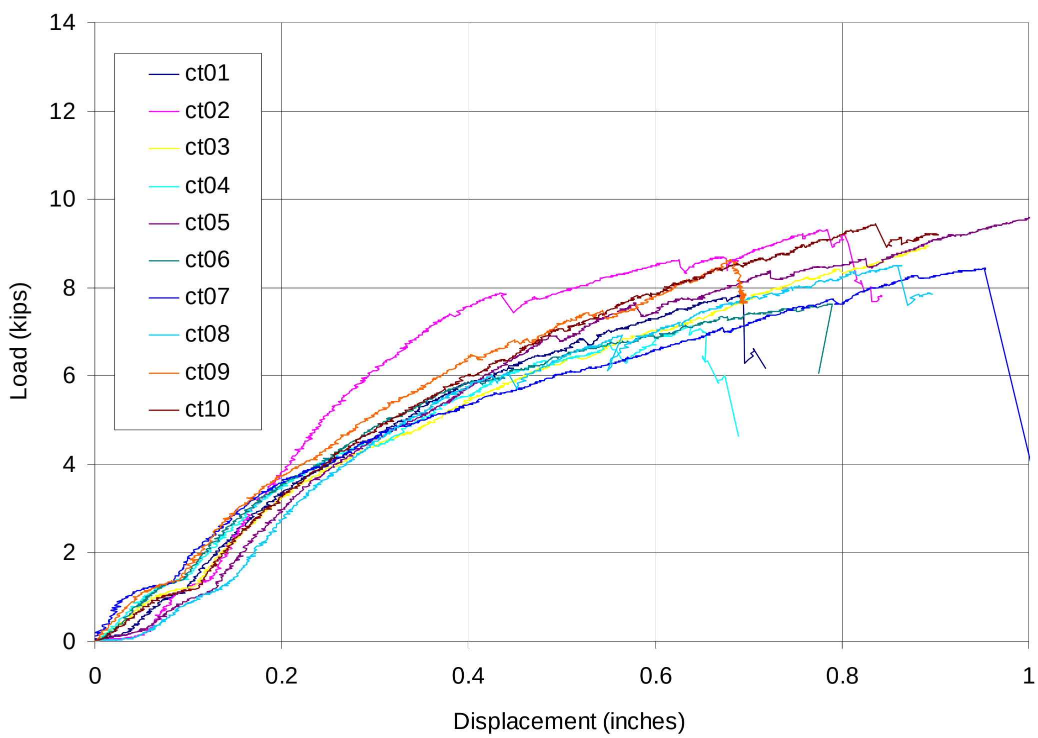


Figure 7 — Load-Displacement Curves, Cedar Specimens, Transverse Loading

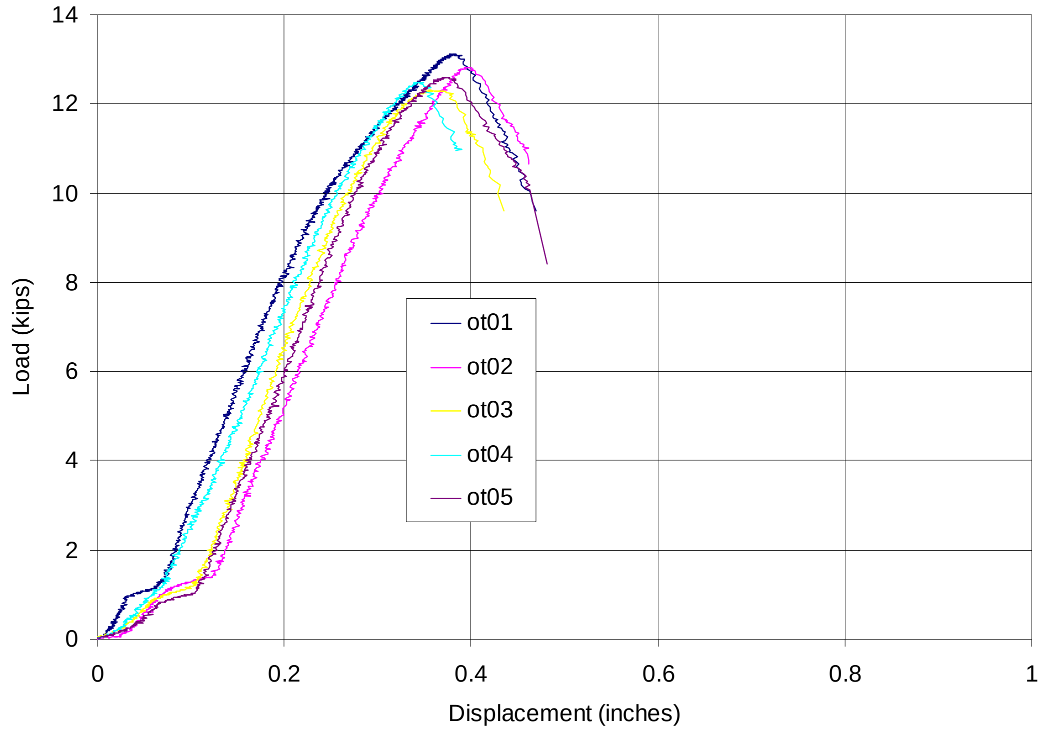


Figure 8 — Load-Displacement Curves, Oak Specimens, Transverse Loading

Table 4 contains the results of the statistical analysis of the strength results. The fifth percentile reference resistance is estimated from a two-parameter Weibull analysis following ASTM D 5457[7]. The reference resistance R_n identifies the nominal design capacity for each group of tests.

All oak specimens failed by tension fracture within the next cross sectional area, adjacent to the slot. Block shear rupture of the end of the tube was not observed. Since steel properties alone controlled the strength of these specimens, the reference resistance R_n in Table 4 for these specimens is not used. Rather, design capacity of the tension tube is based on the rated strength of the steel using standards steel design procedures, outlined in Figure 9.

For the cedar specimens loaded parallel to grain, five specimens failed by tension tube fracture. Hence, capacity of the steel rather than the timber limited the connection strength. It is conservative to include the results of the steel-limited specimens in the statistics for that group of specimens. The limit states design capacities of the Timberlinx A475 connector in eastern white pine, Port Orford cedar, and white oak timbers are presented in Table 5. The design values in Table

7. ASTM D 5457 — Standard Specification for Computing the Reference Resistance of Wood-Based Materials and Structural Connections for Load and Resistance Factor Design

Table 4 -- Timberlinx Test Results -- Weibull Analysis of Design Values (re: ASTM D 5457)

Pine Specimens -- Parallel to grain loading

Rank	Specimen	max load (pounds)	x_i	y_i	$x_i * y_i$	$x_i * x_i$
1	pl12	8,995	-2.664	9.104	-24.253	7.096
2	pl05	10,069	-1.723	9.217	-15.884	2.970
3	pl01	10,293	-1.202	9.239	-11.106	1.445
4	pl04	10,445	-0.822	9.254	-7.604	0.675
5	pl03	10,639	-0.509	9.272	-4.716	0.259
6	pl11	10,925	-0.230	9.299	-2.142	0.053
7	pl02	10,976	0.033	9.303	0.306	0.001
8	pl10	11,261	0.299	9.329	2.790	0.089
9	pl08	11,482	0.594	9.349	5.553	0.353
10	pl06	11,693	0.993	9.367	9.298	0.985
		SUM	-5.231	92.734	-47.757	13.926

n =	10	number of samples
1/alpha =	0.0673	
alpha =	14.849	shape parameter
eta =	11,032	scale parameter
R_{05} =	9,032	5th percentile value
CV_W =	0.0836	Weibull coefficient of variation
omega =	0.9286	data confidence factor
R_n =	8,388	reference resistance

Pine Specimens -- Perpendicular to grain loading

Rank	Specimen	max load (pounds)	x_i	y_i	$x_i * y_i$	$x_i * x_i$
1	pt10	6,068	-2.664	8.711	-23.204	7.096
2	pt09	6,748	-1.723	8.817	-15.194	2.970
3	pt04	6,888	-1.202	8.838	-10.623	1.445
4	pt02	7,096	-0.822	8.867	-7.286	0.675
5	pt08	7,575	-0.509	8.933	-4.543	0.259
6	pt06	7,768	-0.230	8.958	-2.064	0.053
7	pt01	8,146	0.033	9.005	0.296	0.001
8	pt03	8,565	0.299	9.055	2.708	0.089
9	pt05	9,023	0.594	9.108	5.410	0.353
10	pt07	9,487	0.993	9.158	9.091	0.985
		SUM	-5.231	89.449	-45.409	13.926

n =	10	number of samples
1/alpha =	0.1236	
alpha =	8.091	shape parameter
eta =	8,181	scale parameter
R_{05} =	5,667	5th percentile value
CV_W =	0.1461	Weibull coefficient of variation
omega =	0.8753	data confidence factor
R_n =	4,960	reference resistance

Cedar Specimens -- Parallel to grain loading

Rank	Specimen	max load (pounds)	x_i	y_i	$x_i * y_i$	$x_i * x_i$
1	cl06	9,868	-2.664	9.197	-24.500	7.096
2	cl04a	10,841	-1.723	9.291	-16.011	2.970
3	cl07	11,467	-1.202	9.347	-11.236	1.445
4	cl05	11,499	-0.822	9.350	-7.683	0.675
5	cl01	11,641	-0.509	9.362	-4.762	0.259
6	cl08	12,286	-0.230	9.416	-2.169	0.053
7	cl02	12,320	0.033	9.419	0.310	0.001
8	cl03	12,329	0.299	9.420	2.817	0.089
9	cl10	12,878	0.594	9.463	5.621	0.353
10	cl09	12,965	0.993	9.470	9.401	0.985
		SUM	-5.231	93.736	-48.211	13.926

n =	10	number of samples
1/alpha =	0.0736	
alpha =	13.585	shape parameter
eta =	12,235	scale parameter
R_{05} =	9,833	5th percentile value
CV_W =	0.0907	Weibull coefficient of variation
omega =	0.9226	data confidence factor
R_n =	9,071	reference resistance

Cedar Specimens -- Perpendicular to grain loading

Rank	Specimen	max load (pounds)	x_i	y_i	$x_i * y_i$	$x_i * x_i$
1	ct04	7,122	-2.664	8.871	-23.631	7.096
2	ct06	7,636	-1.723	8.941	-15.407	2.970
3	ct01	7,852	-1.202	8.969	-10.780	1.445
4	ct07	8,440	-0.822	9.041	-7.428	0.675
5	ct08	8,506	-0.509	9.049	-4.602	0.259
6	ct09	8,636	-0.230	9.064	-2.088	0.053
7	ct03	8,940	0.033	9.098	0.300	0.001
8	ct02	9,313	0.299	9.139	2.733	0.089
9	ct10	9,451	0.594	9.154	5.437	0.353
10	ct05	9,605	0.993	9.170	9.103	0.985
		SUM	-5.231	90.494	-46.364	13.926

n =	10	number of samples
1/alpha =	0.0871	
alpha =	11.479	shape parameter
eta =	8,911	scale parameter
R_{05} =	6,879	5th percentile value
CV_W =	0.1059	Weibull coefficient of variation
omega =	0.9096	data confidence factor
R_n =	6,257	reference resistance

Oak Specimens -- Parallel to grain loading

Rank	Specimen	max load (pounds)	x_i	y_i	$x_i * y_i$	$x_i * x_i$
1	ol05	12,063	-1.974	9.398	-18.556	3.898
2	ol04	12,352	-0.973	9.422	-9.164	0.946
3	ol03	12,363	-0.367	9.422	-3.453	0.134
4	ol01	12,500	0.145	9.433	1.366	0.021
5	ol02	12,534	0.714	9.436	6.742	0.510
		SUM	-2.454	47.112	-23.066	5.510

n =	5	number of samples
1/alpha =	0.0140	
alpha =	71.241	shape parameter
eta =	12,447	scale parameter
R_{05} =	11,938	5th percentile value
CV_W =	0.0197	Weibull coefficient of variation
omega =	0.9762	data confidence factor
R_n =	11,654	reference resistance

Oak Specimens -- Perpendicular to grain loading

Rank	Specimen	max load (pounds)	x_i	y_i	$x_i * y_i$	$x_i * x_i$
1	ot03	12,302	-1.974	9.418	-18.594	3.898
2	ot04	12,481	-0.973	9.432	-9.174	0.946
3	ot05	12,597	-0.367	9.441	-3.460	0.134
4	ot02	12,817	0.145	9.459	1.369	0.021
5	ot01	13,121	0.714	9.482	6.774	0.510
		SUM				

n =	5	number of samples
1/alpha =	0.0232	
alpha =	43.166	shape parameter
eta =	12,805	scale parameter
R_{05} =	11,954	5th percentile value
CV_W =	0.0313	Weibull coefficient of variation
omega =	0.9622	data confidence factor
R_n =	11,502	reference resistance

Steel properties per ASTM A 500

$$F_y = 46,000 \text{ psi}, \ F_u = 62,000 \text{ psi}$$

Outside diameter, inside diameter, and slot width per Timberlinx part details

$$OD = 1.094 \text{ in}^2, \ ID = 0.820 \text{ in}^2, \ w_{\text{slot}} = 0.776 \text{ in}$$

Gross area, net tension area, net block shear area per Timberlinx part details

$$A_g = 0.4119 \text{ in}^2, \ A_{nt} = 0.1611 \text{ in}^2, \ A_{nv} = 0.1644 \text{ in}^2$$

Gross section yield design capacity

$$\phi T_g = \phi A_g F_y = 0.9(0.4119)46,000 = 17,0523 \text{ lb}$$

Net section fracture design capacity

$$\phi T_n = 0.85\phi A_n F_u = 0.85(0.9)(0.1611)62,000 = 7,640 \text{ lb}$$

Block shear rupture design capacity

$$\phi V = 0.85\phi A_{nv} F_u = 0.85(0.9)(0.1644)62,000 = 7,797 \text{ lb}$$

Expansion pin bearing design capacity

$$\phi B = 3\phi_b t d n_s F_u = 3(0.67)0.137(2)62,000 = 34,146 \text{ lb}$$

Conclusion: Design capacity is limited by net section fracture

$$\phi T_n = 7,640 \text{ lb}$$

Figure 9 — Reference Resistance Calculations for Steel Tension Tube (per CSA S16.1)

5 for eastern white pine and Port Orford cedar are the reference resistances in Table 4 modified by a resistance factor of $\phi = 0.7$ and a factor for standard term loading $A = 0.8$ according to CSA O86-01[8].

8. From CSA o86-01: “Standard term means that condition of loading in which the duration of specified loads exceeds that of short-term loading but is less than permanent loading. Examples include snow loads, live loads due to occupancy ... ”

Table 5 — Limit States Design Capacities of Timberlinx A475 Connectors (per CSA O86-01)			
Loading	**Species**	**Capacity (lb)**	***G***
Parallel to Grain	Eastern White pine	4,700	0.378
	Port Orford cedar	5,080	0.407
	White oak	7,640	0.821
	Regression: $P_r = 13{,}100G - 253 \leq 7{,}640$ (lb)		
Perpendicular to Grain	Eastern White pine	2,780	0.367
	Port Orford cedar	3,500	0.389
	White oak	7,640	0.819

The working stress design capacities of the Timberlinx A475 connector in eastern white pine, Port Orford cedar, and white oak timbers are presented in Table 6. The values are derived from the limit states capacities in Table 5 by a soft conversion using a live load to dead load ratio of $L/D = 3.0$. Capacities in Table 6 are obtained by dividing those in Table 5 by the format conversion factor K_F derived using a controling load combinatin of $1.25D + 1.5L$ as follows.

$$K_F = \frac{1.25(1) + 1.5(3)}{1 + 3} = 1.438$$

Table 6 — Working Stress Design Capacities of Timberlinx A475 Connectors (per CSA O86-01)			
Loading	**Species**	**Capacity (lb)**	***G***
Parallel to Grain	Eastern White pine	3,270	0.378
	Port Orford cedar	3,530	0.407
	White oak	5,320	0.821
	Regression: $P_r = 8970G - 120 \leq 5{,}320$ (lb)		
Perpendicular to Grain	Eastern White pine	1,930	0.367
	Port Orford cedar	2,440	0.389
	White oak	5,320	0.819

Appendix A

Sampling

Comparative testing was performed to verify that the samples of Timberlinx product (tension tubes and expansion anchors) supplied by the Timberlinx company (the owner) were substantially the same as that stocked by a local distributor. Three-point bending tests were performed on the shells of the expansion pins supplied by both sources. Ten bending specimens, consisting of both shells from each of five expansion pins, were tested from each source. In addition, tension tests of the A475 tubes were performed on five specimens from each source. Bending tests were performed at a displacement rate of 0.125 in/min and tension tests were conducted at a rate of 0.01 in/min.

The specimen identifier is a four-character code in which the first character identifies the type of specimen (s = expansion pin shell, t = tube) the second character identifies the source (o = owner, d = distributor), and the last two characters identify the sequence number for the specimen. Table A1 contains the results of the comparative tests. The capacity values listed in the table are the ultimate loads required to fail each specimen. These values can be compared directly, so no additional data analysis is required. Load-displacement plots are shown in Figures A1, A2, A3 and A4.

The load-displacement curves for shell bending illustrate that the two sets of shells exhibited fundamentally the same behavior. Mean maximum loads for the two sets of specimens are within one standard deviation of each other. Tube tension tests for the two sets of specimens also exhibited the same load-displacement behavior. Failure capacities for both sets of specimens are also within one standard deviation of each other. In addition, all failure capacities exceed the nominal strength of the tube for net section fracture (A_nF_u = 9988 lb; see Figure 9). Hence, the results indicate that the company-supplied product was indeed representative of commercially available product.

Table A1 -- Comparison Test Results

Shell Bending Tests				Tube Tension Tests			
Owner Supplied		Distributor Supplied		Owner Supplied		Distributor Supplied	
Specimen	Capacity (lb)	Specimen	Capacity (lb)	Specimen	Capacity (lb)	Specimen	Capacity (lb)
so01	1,507	sd01	1,285	to01	12,637	td01	12,942
so02	2,083	sd02	1,433	to02	12,424	td02	13,458
so03	1,891	sd03	1,673	to03	13,024	td03	13,024
so04	1,693	sd04	1,443	to04	12,964	td04	13,545
so05	1,636	sd05	1,663	to05	13,448	td05	13,207
so06	1,761	sd06	1,650	mean	12,899	mean	13,235
so07	1,472	sd07	1,381	std dev	393	std dev	263
so08	1,562	sd08	1,642				
so09	1,899	sd09	1,813				
so10	1,740	sd10	1,740				
mean	1,724	mean	1,572				
std dev	193	std dev	173				

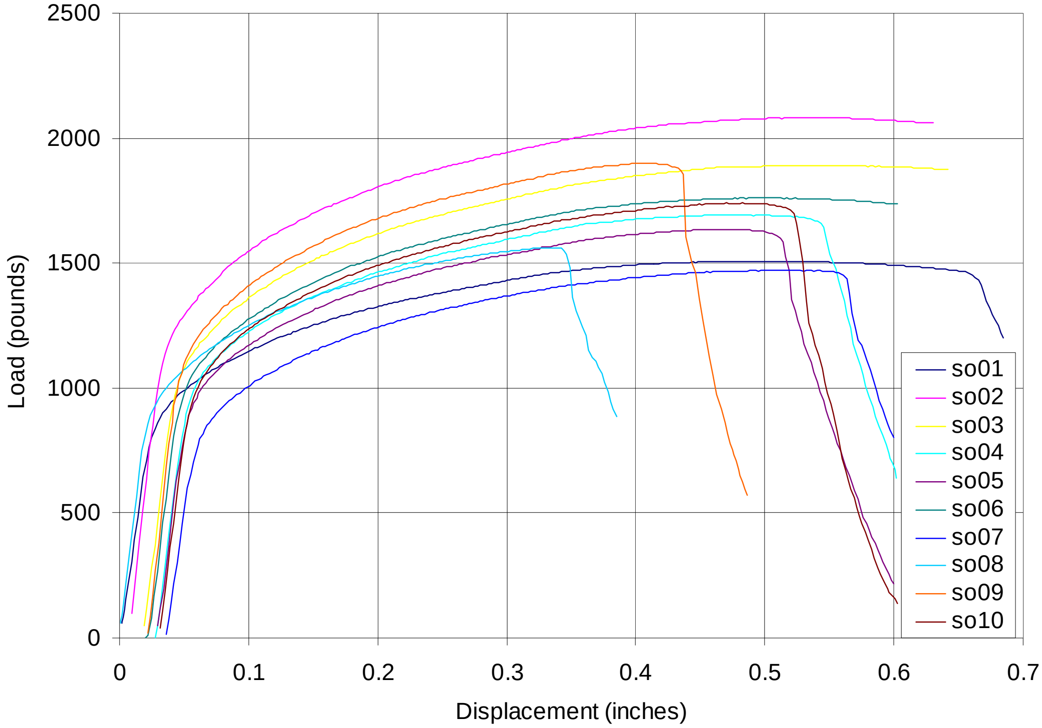


Figure A1 — Owner-Supplied Shell Bending Load-Displacement Curves

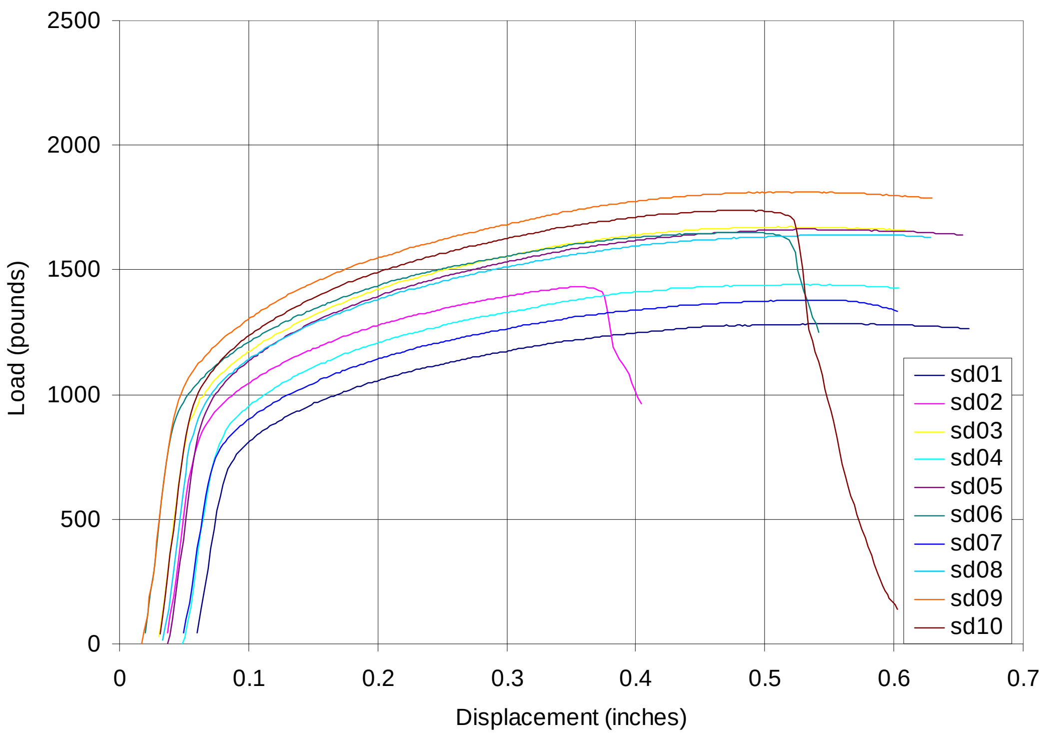


Figure A2 — Distributor-Supplied Shell Bending Load-Displacement Curves

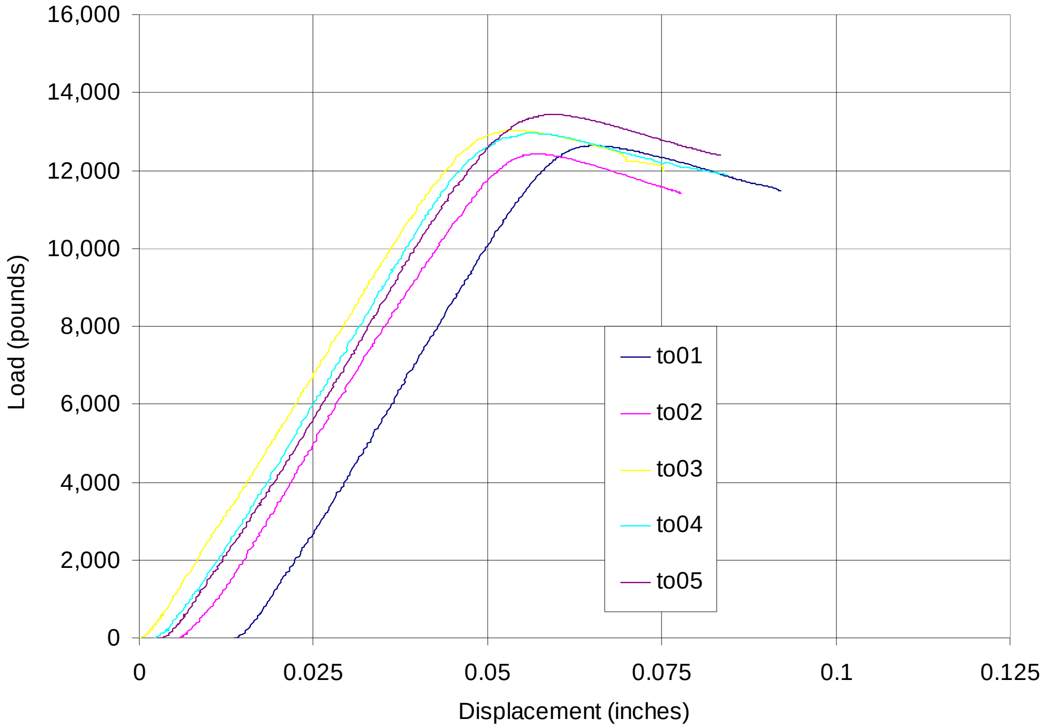


Figure A3 — Owner-Supplied Tube Tension Load-Displacement Curves

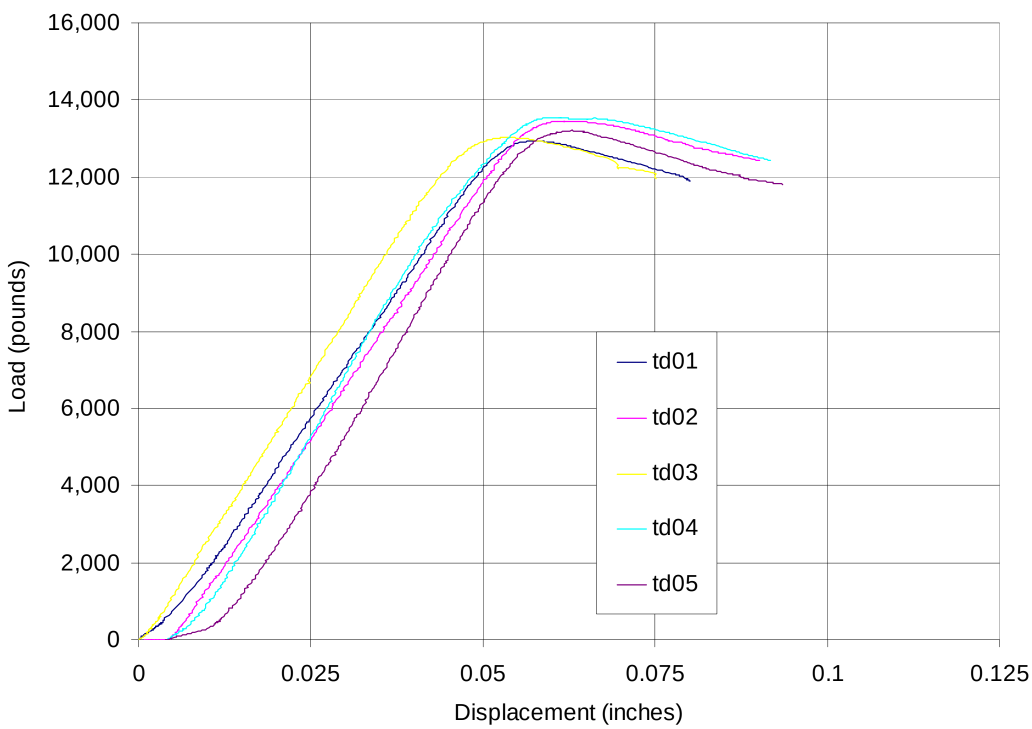


Figure A1 — Distributor-Supplied Tube Tension Load-Displacement Curves