Advancing Technology to Manufacture Trusses From Hardwood Lumber

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ABSTRACT

Low-grade hardwood lumber is abundant across the Lake States and the Northeast United States. This product has historically been used as pallet lumber, crating material, and firewood with values of $200-$300 per thousand board feet. Further, several low-valued hardwood species have become prevalent in these areas through past forestry practices. In order to actively manage the forests for historical species, new and higher value markets must be established.

The purpose of this project was to evaluate the use of sugar maple *(Acer saccharum)* and red maple *(Acer rubrum)* as structural lumber in metal plate pitched and parallel chord trusses. Groups of trusses were manufactured with both chords and webs from hardwood lumber, from softwood chords and hardwood webs and from chords and webs from softwood lumber. Testing was completed according to ANSI/TPI 2-1995, Standard for Testing Metal Plate Connected Wood Trusses. Results showed that both pitched and parallel chord trusses manufactured from hardwood lumber had strength and stiffness that was equivalent to or better than softwood trusses manufactured from spruce-pine-fir (SPF) and southern yellow pine (SYP) lumber. Trusses manufactured with SPF chords and hardwood webs had properties that were equivalent to or better than complete SPF trusses. The findings indicate that the potential use of low-grade hardwood lumber as truss lumber would result in large volumes of this material being utilized in a higher value application.

INTRODUCTION

The hardwood lumber industry is a key component of the forest products industry in the Lake States and Northeast United States. Two of the primary lumber species include sugar maple *(Acer saccharum)* and red maple *(Acer rubrum)*. High grade lumber from these species has an extremely high value, often exceeding $1,500/thousand board feet (M bdft). Lower grades of maple including pallet lumber usually sell for $200-$250/M bdft. The focus of this project was to develop the technical and economic basis for using these species in structural applications. A regional cooperative research team was developed to focus on a wide range of research topics including:

- Determination of lumber yields and recovery information.
- Evaluation of engineering properties of lumber from hardwood species including sugar and red maple, yellow birch, and aspen.
- Development of appropriate and cost-effective drying schedules.
- Assessment of truss plate fasteners.
- Development of engineering designs for trusses and I-joists.
- Preparation of preliminary financial assessments.

The project work has been completed through a cooperative research team including the USDA Forest Products Laboratory, Michigan Technological University (MTU), Natural Resources Research Institute (NRRI) of the University of Minnesota, Duluth, Northern Initiatives, and Qualtim Technologies. Private company research partners have included Rossi - Northern Hardwoods, Kylmala Truss, and Superior Wood Systems.

Specifically, the objective of this project was to implement the use of low-grade, underutilized red and sugar maple as visual and machine stress rated (MSR) structural lumber in metal plate

trusses. Truss plate testing completed at the Michigan Technological University has shown that hardwood lumber can successfully be utilized as truss components with performance that exceeds traditional softwood species. The focus of this project was to manufacture pitched and parallel chord trusses, identify manufacturing challenges, and complete structural testing.

METHODS AND MATERIALS

Sugar and red maple 2- by 4-in lumber was obtained from Northern Hardwoods in South Range, Michigan. This material had been sawn from hardwood cants. Additional red maple cant material was obtained from the Delaware Department of Natural Resources and was sawn into 2- by 4-in. dimension lumber at Michigan Technological University. The modulus of elasticity (MOE) was determined in the green condition using transverse vibration techniques on a commercial E-computer. The lumber was dried to a target moisture content of 15-19 percent. The lumber had a moisture content of 12-15 percent when the final transverse vibration MOE was conducted. Figure 1 shows a sugar maple sample being E-rated.

Figure 1.--Grading hardwood lumber using a commercial E-computer.

The lumber was sorted by MOE into four separate grade classifications. Grade 1 included lumber with a MOE <1,500,000 pounds per square in (psi). Grade 2 included lumber with a MOE between >1,500,000 and <1,750,000 psi. The lumber from Grade 3 had a MOE between >1,750,000 and <2,000,000 psi, while Grade 4 had a MOE >2,000,000 psi.

A pitched chord and parallel chord truss design was chosen from Kylmala Truss in Duluth, Minnesota. The pitched chord truss was constructed from 2- by 4-in lumber and had a 24 ft span with a 4:12 pitch. The parallel chord truss was constructed from 2- by 4-in lumber. The truss depth was 14 in with a 15 ft span. Figures 2 and 3 show the truss designs selected for

manufacture. The software program used by Kylmala Truss is from KeyMark Engineering in Boulder, Colorado. For the pitched chord trusses, the program specified SPF 2,100f_b - 1.8E MSR lumber grade for the chord material and SPF visual grade #3 for the web stock lumber. The lumber specified for the parallel chord trusses was SPF 1,650f_b - 1.4E for the chords and SPF visual grade #3 for the web stock. Since Kylmala Truss did not stock this MSR grade, visual grade #2 SPF was E-rated to determine MOE for each piece.

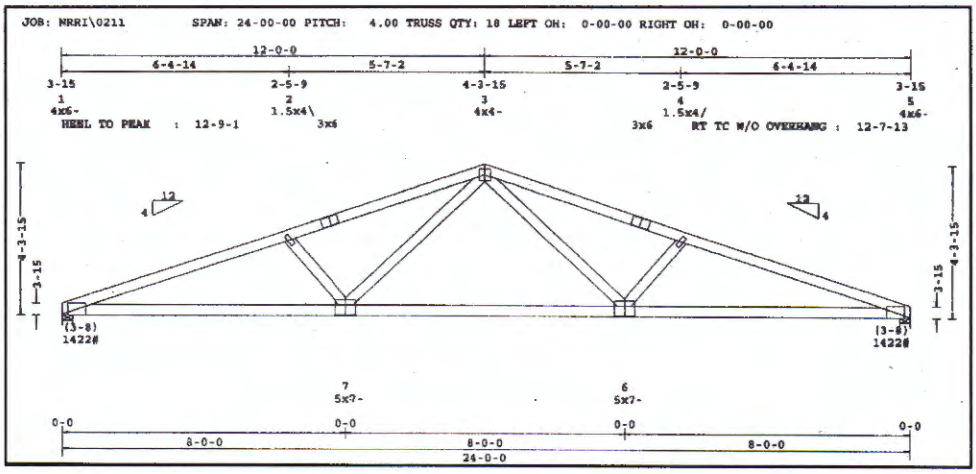

Figure 2.--Pitched chord truss design.

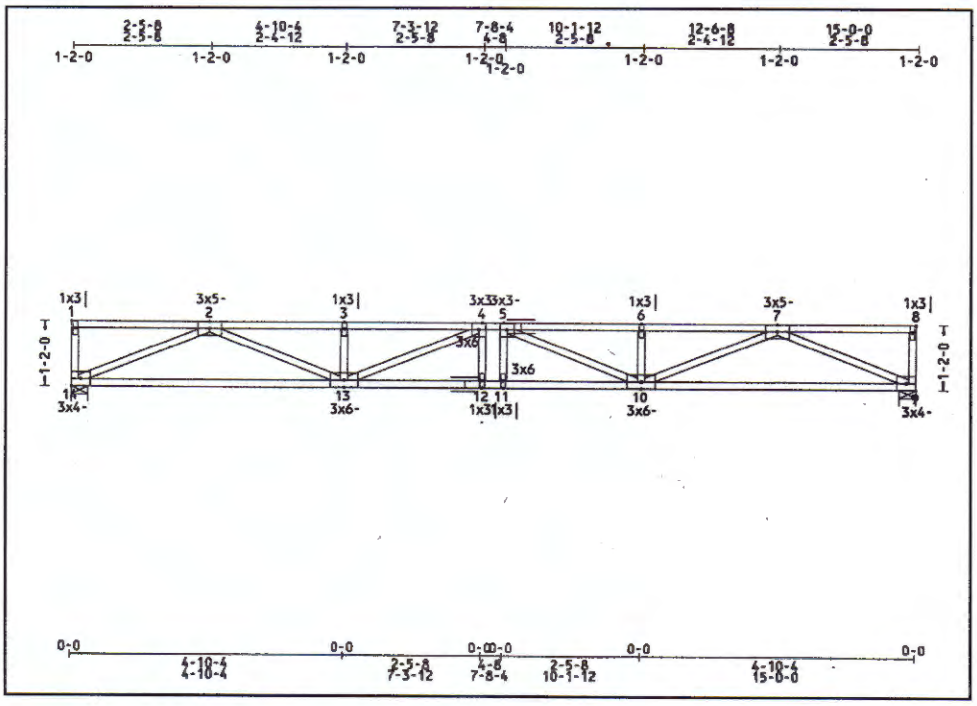

Figure 3.--Parallel chord truss design.

Table 1 lists each group of pitched chord trusses that were manufactured and the grade of lumber used. The lumber was sorted by MOE and used to create groups of trusses that had MOE matched chord lumber. The pitched chord trusses were manufactured at Kylmala's Duluth plant. Eagle Metal Products 20 gauge truss plates were pressed into the lumber using portable hydraulic presses. Six trusses were manufactured for each group. From each group, five trusses were randomly selected for testing. Figure 4 shows pitched chord trusses being manufactured at Kylmala Truss.

SPF chord MSR lumber was obtained from Kylmala Truss. Southern yellow pine (SYP) MSR chord lumber was purchased from Weekes NorthStar, a lumber wholesaler in St. Paul, Minnesota. This lumber was also E-rated using a commercial E-computer.

Figure 4.--Hardwood truss manufactured using hydraulic presses.

Table 2 lists each group of parallel chord trusses that were manufactured and the grade of lumber used. The parallel chord trusses were manufactured at Kylmala's Embarrass, Minnesota plant. Eagle Metal Products 20 gauge truss plates were pressed into the lumber using portable hydraulic presses and a roller press. Six trusses were manufactured for each group. From each group, five trusses were randomly selected for testing.

Table 1.--Description of pitched chord truss groups that were manufactured for testing.

Group	Number of Trusses	Chord Lumber			Web Lumber		
		Species	Grade	Moisture Content (%)	Species	Grade	Moisture Content (%)
1	6	Sugar Maple	2,100f_b 1.8E	12-15	Sugar Maple	#3 or better	12-15
2	6	Red Maple	2,100f_b 1.8E	12-15	Red Maple	#3 or better	12-15
3	6	Delaware Red Maple	2,100f_b 1.8E	12-15	Delaware Red Maple	#3 or better	12-15
4	6	SYP	2,100f_b 1.8E	12-15	SYP	#3 or better	12-15
5	6	SPF	2,100f_b 1.8E	12-15	SPF	#3 or better	12-15
6	6	SPF	2,100f_b 1.8E	12-15	Red Maple	#3 or better	12-15
7	3	SPF	2,100f_b 1.8E	12-15	Red Maple	#3 or better	50-60

Note: SYP - Southern yellow pine species classification
SPF - Spruce-pine-fir species classification

Table 2.--Description of parallel chord truss groups that were manufactured for testing.

Group	Number of Trusses	Chord Lumber			Web Lumber		
		Species	Grade	Moisture Content (%)	Species	Grade	Moisture Content (%)
8	6	Sugar Maple	1,650f_b 1.4E	12-15	Sugar Maple	#3 or better	12-15
9	6	Delaware Red Maple	1,650f_b 1.4E	12-15	Delaware Red Maple	#3 or better	12-15
10	6	SPF	1,650f_b 1.4E	12-15	SPF	#3 or better	12-15
11	6	SPF	1,650f_b 1.4E	12-15	Red Maple	#3 or better	12-15
12	3	SPF	1,650f_b 1.4E	12-15	Red Maple	#3 or better	50-60

Note: SPF - Spruce-pine-fir species classification

PITCHED CHORD TESTING

Testing was completed at NRRI on a full scale truss test machine. Figure 5 shows a pitched chord truss during testing. ANSI/TPI 2-1995, Standard for Testing Metal Plate Connected Wood Trusses was used as a guideline. Generally, the trusses were loaded on the top chords through hydraulic cylinders placed approximately 1 ft on center. The trusses were loaded to dead load design and held for five minutes. This load was then removed. Dial gauge indicators were placed on the test frame at each reaction and at the center span. Loading commenced after the five minute rest period. Deflection was recorded at the following end reaction loads; 100 lbs, 600 lbs, 800 lbs, 1,100 lbs, 1,422 lbs, 1,700 lbs, 2,000 lbs, 2,300 lbs, and 2,600 lbs. The midspan deflection was corrected for reaction settlement. The dial gauges were then removed and the truss was loaded until failure.

PARALLEL CHORD TRUSS TESTING

Testing was completed at NRRI on a full scale truss test machine. Figure 6 shows a parallel chord truss during testing. ANSI/TPI 2-1995, Standard for Testing Metal Plate Connected Wood Trusses was used as a guideline. Generally, the trusses were loaded on the top chords through hydraulic cylinders placed approximately 1 ft on center. The trusses were loaded to dead load design and held for five minutes. This load was then removed. Dial gauge indicators were placed on the test frame at each reaction and at the center span. Loading commenced after the five minute rest period. Deflection was recorded at the following end reaction loads; 100 lbs, 300 lbs, 450 lbs, 600 lbs, 750 lbs, 865 lbs, 1,000 lbs, and 1,300 lbs. The midspan deflection was corrected for reaction settlement. The dial gauges were then removed and the truss was loaded until failure.

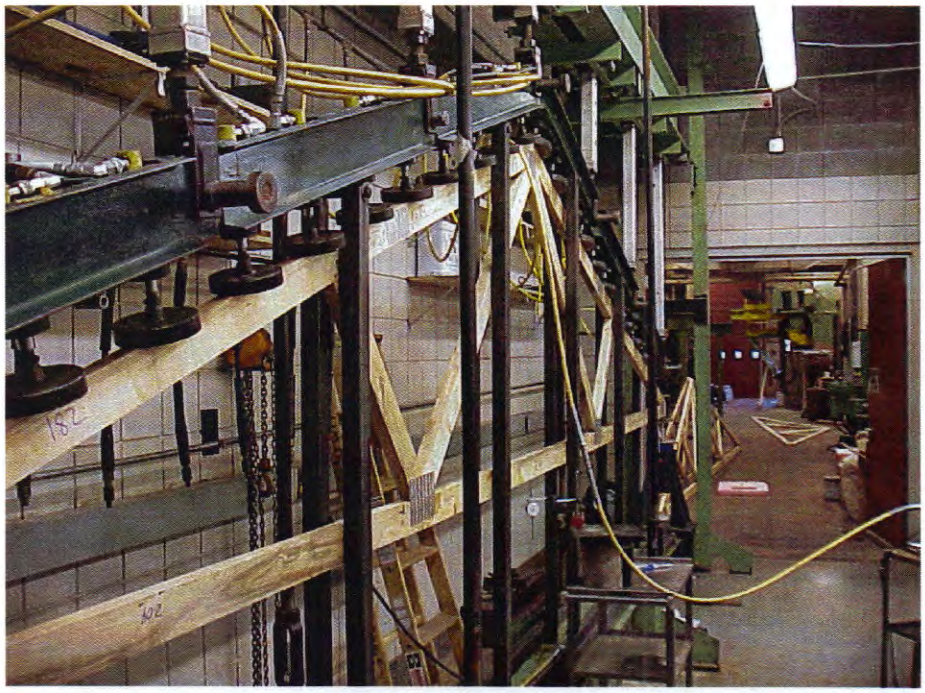

Figure 5.--Hardwood pitched chord truss during full scale testing.

Figure 6.--Parallel chord truss testing setup.

RESULTS AND DISCUSSION

PITCHED CHORD TRUSSES

The use of hardwood lumber during manufacturing was evaluated through witness of manufacturing and general discussions with Kylmala Truss employees. Two challenges were noted during manufacturing. The first was that some of the hardwood lumber had more dimensional stability issues than SPF lumber. Warp and twist were the two primary issues that were noted. This caused challenges when the lumber was placed into the jigs for pressing metal plates into the lumber. The primary result was some gaps at joints. The other issue was the additional truss splice joints that were required because only 8 ft long hardwood lumber was available. Gaps were noted between the lumber at the splice and this caused off-center loading for several specimens during testing. This extra joint caused additional set up time, pressing time, and four extra metal plates for each truss. The density of the hardwood did not cause substantial problems during pressing of the truss plates.

The data was analyzed to determine the descriptive statistics of the deflection at dead load and design load. The dead load on the truss was approximately 600 lbs at each reaction (1,200 lbs total load) and the design load was at 1,422 lbs at each reaction (2,844 lbs total load). Further analysis was completed on the ultimate failure load of each truss. Each truss was loaded until some sort of failure occurred. Failure mechanisms included peak plate withdrawal from the lumber, metal plate failures, and out-of-plane conditions due to truss plate buckling, lumber rotation at the reaction or twist in the truss caused by the lumber. Table 3 shows the results of the testing for each truss tested. The trusses containing hardwood lumber chords and webs failed 90 percent of the time due to plate failures. The metal plates tore at the bottom splice joints where the webs joined with the chords. Many of the SPF chords with maple webs failed due to

out-of-plane deflection. This was caused by the chord to chord splice on the top left of the truss. There was a ¼-in. gap between the two chords. The metal plate dimpled at this joint, causing lateral loading. This required the test be stopped prior to failure. This splice joint was required because of the use of 8 ft long lumber.

Table 3.--Testing results for each pitched chord metal plate truss.

Group	Species		Truss Number	Deflection at Dead Load (in)	Deflection at Design Load (in)	Total Ultimate Load (lbs)	Failure Type
	Chord	Web					
1	Sugar Maple	Sugar Maple	2	0.104	0.310	6,580	Plate failure
			3	0.112	0.324	6,929	Plate failure
			4	0.124	0.309	6,914	Plate failure
			5	0.127	0.343	6,476	Plate failure
			6	0.116	0.307	6,798	Plate failure
2	Red Maple	Red Maple	1	0.095	0.312	8,047	Plate failure
			2	0.111	0.334	7,815	Plate failure
			3	0.135	0.355	5,744	Peak plate w/d
			5	0.126	0.347	7,832	Plate failure
			6	0.130	0.399	5,877	Out-of-plane
3	Delaware Red Maple	Delaware Red Maple	1	0.127	0.375	5,171	Plate failure
			2	0.111	0.322	7,417	Plate failure
			3	0.137	0.468	7,567	Plate failure
			5	0.136	0.352	6,419	Out-of-plane
			6	0.103	0.300	7,450	Plate failure
4	SYP	SYP	1	0.098	0.318	5,116	Peak plate w/d
			2	0.111	0.356	6,132	Peak plate w/d
			3	0.121	0.323	5,315	Peak plate w/d
			5	0.135	0.377	5,352	Peak plate w/d
			6	0.126	0.352	4,884	Peak plate w/d
5	SPF	SPF	2	0.112	0.328	6,112	Peak plate w/d
			3	0.129	0.340	5,973	Peak plate w/d
			4	0.138	0.366	4,368	Out-of-plane
			5	0.131	0.366	5,047	Out-of-plane
			6	0.135	0.350	6,225	Peak plate w/d
6	SPF	Red Maple	1	0.104	0.324	6,022	Out-of-plane
			2	0.116	0.344	6,037	Out-of-plane
			3	0.115	0.321	6,384	Rotation
			5	0.140	0.378	5,390	Out-of-plane
			6	0.102	0.341	6,417	Out-of-plane
7	SPF	Green Red Maple	1	0.130	0.380	5,279	Peak plate w/d
			2	-	-	-	Load cell
			3	0.148	0.379	5,100	Out-of-plane

Note: SYP = southern yellow pine species classification
SPF = spruce-pine-fir species classification

Table 4 and Figures 7 and 8 summarize the testing results for each group of pitched chord trusses. The truss groups manufactured from hardwood chords and webs were the strongest. The softwood trusses had lower strength values, with the primary failure mode being plate withdrawal from the peak. This was partially caused by offset placement of the peak plate, but even those members where the proper number of plate teeth were in the lumber, the failure load was lower than the hardwood lumber trusses. The use of red maple web stock also proved to be stronger than softwood web members. The deflection at design load was similar for all groups of trusses, with the sugar maple trusses having the lowest deflection at design load.

A small subset of trusses (group 7) was manufactured using SPF chords and green red maple webs. The moisture content of the web stock at the time of testing was 50-60 percent. The strength and deflection performance of these trusses was slightly lower than the other groups, suggesting that it may be possible to use green hardwood lumber as web stock. Further testing of this concept is warranted.

Table 4.--Summary of pitched chord truss testing results.

Group	Species		Number of Trusses Tested	Mean Deflection and Strength Results			
	Chord	Web		Deflection at Dead Load (in)	Deflection at Design Load (in)	Total Ultimate Load (lbs)	Failure Load/Design Load
1	Sugar Maple	Sugar Maple	5	0.117 (0.009)	0.319 (0.015)	6,739 (202)	2.37 (0.07)
2	Red Maple	Red Maple	5	0.119 (0.016)	0.349 (0.032)	7,063 (1,148)	2.48 (0.40)
3	Delaware Red Maple	Delaware Red Maple	5	0.123 (0.015)	0.363 (0.065)	6,805 (1,023)	2.39 (0.36)
4	SYP	SYP	5	0.118 (0.014)	0.345 (0.025)	5,360 (470)	1.88 (0.17)
5	SPF	SPF	5	0.129 (0.010)	0.350 (0.017)	5,545 (806)	1.95 (0.28)
6	SPF	Red Maple	5	0.115 (0.015)	0.342 (0.023)	6,050 (413)	2.13 (0.15)
7	SPF	Green Red Maple	2	0.139 (0.013)	0.380 (0.001)	5,190 (127)	1.82 (0.04)

Note: Standard deviation for each value is shown in parentheses.
SYP = southern yellow pine species classification
SPF = spruce-pine-fir species classification

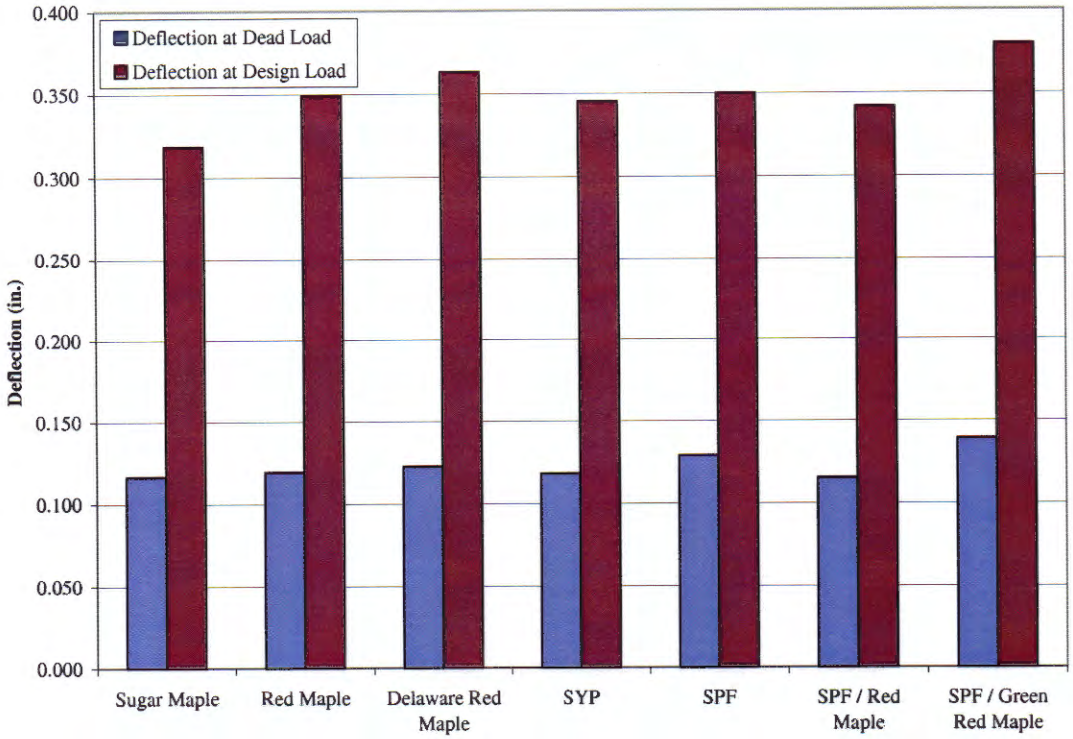

Figure 7.--Summary of deflection results for pitched chord truss groups.

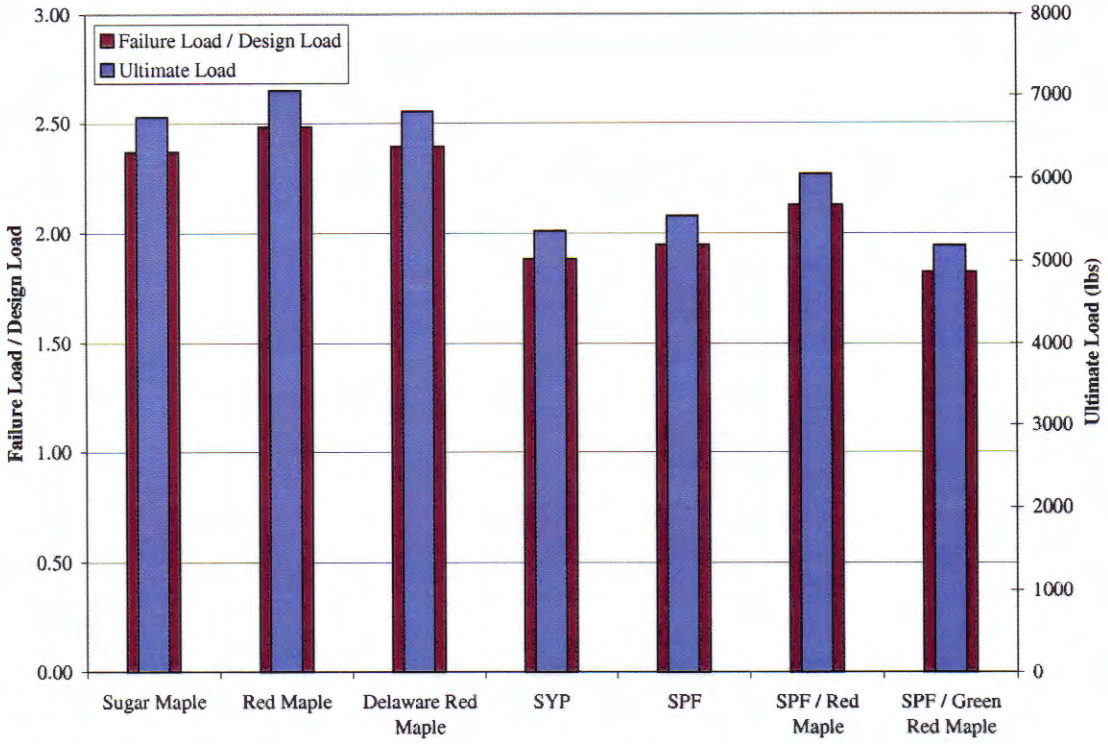

Figure 8.--Failure load performance of truss groups.

PARALLEL CHORD TRUSSES

The data was analyzed to determine the descriptive statistics of the deflection at dead load and design load. The dead load on the truss was approximately 300 lbs at each reaction (600 lbs total load) and the design load was at 865 lbs at each reaction (1,730 lbs total load). Further analysis was completed on the ultimate failure load of each truss. Each truss was loaded until some sort of failure occurred. The primary failure condition noted was that the metal truss plate pulled out from either the chord or web member. There were not any plate failures as noted during the pitched chord testing. Table 5 shows the results of the testing for each truss tested. Figure 9 shows a typical parallel chord truss failure.

Table 6 and Figures 10 and 11 summarize the testing results for each group of trusses. The mean failure load of the sugar maple trusses was almost 800 pounds greater than the other groups evaluated. The deflection for the sugar maple trusses was also the lowest. The other groups of hardwood and softwood trusses performed very similarly to each other. It appears that the use of hardwood web lumber performed better than those with SPF lumber webs. This was due to the greater holding strength of truss plates in the hardwood lumber. As with the pitched chord trusses, the use of green red maple as web lumber appears to be possible without affecting the structural performance. Further testing to verify this effect and to evaluate the dimensional stability is warranted.

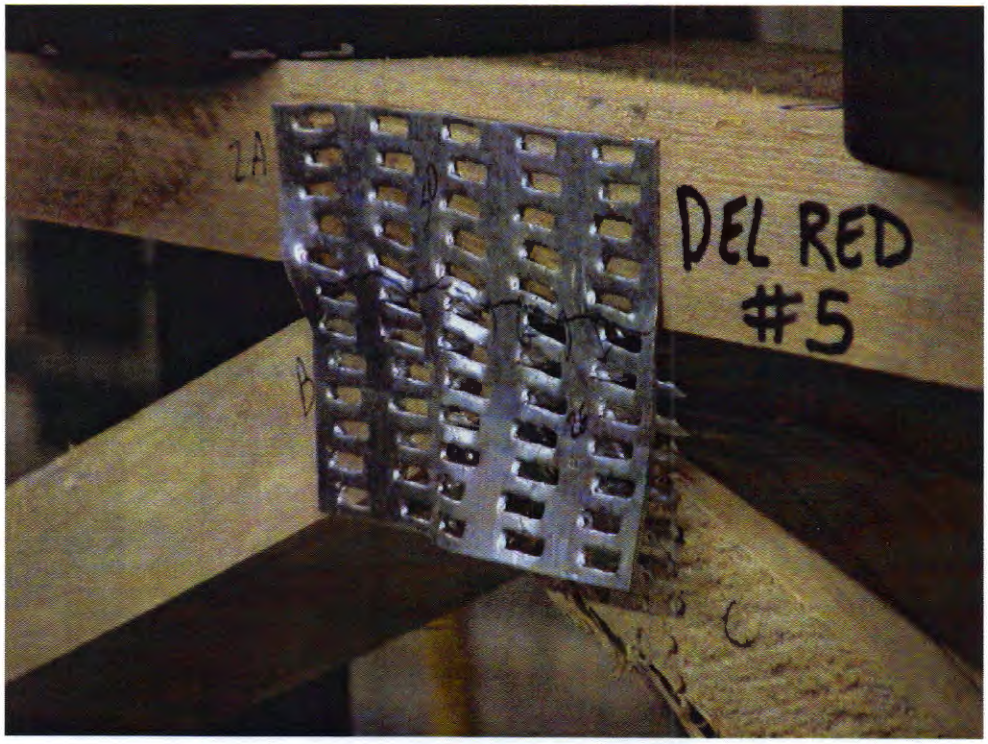

Figure 9.--Typical failure mode for parallel chord trusses tested during this project.

Table 5.--Testing results for each parallel chord metal plate truss.

Group	Species		Truss Number	Deflection at Dead Load (in)	Deflection at Design Load (in)	Total Ultimate Load (lbs)	Failure Type
	Chord	Web					
8	Sugar Maple	Sugar Maple	2	0.083	0.303	3,791	Wood failure at bottom plate
			3	0.093	0.313	2,710	Plate w/d from bottom chord
			4	0.104	0.321	4,375	Plate failure
			5	0.085	0.284	4,222	Plate failure
9	Delaware Red Maple	Delaware Red Maple	1	0.103	0.378	3,513	Plate w/d from top chord
			2	0.107	0.377	2,981	Plate w/d from web
			3	0.100	0.376	2,940	Plate w/d from web
			4	0.112	0.396	2,753	Plate w/d from top chord
			5	0.113	0.395	2,752	Plate w/d from web
10	SPF	SPF	1	0.120	0.456	2,767	Plate w/d from top chord
			2	0.109	0.404	2,493	Plate w/d from web
			3	0.112	0.399	2,969	Plate w/d from web
			4	0.124	0.454	2,606	Plate w/d from web
			5	0.126	0.424	2,636	Plate w/d from top chord
11	SPF	Red Maple	1	0.106	0.373	2,707	Plate w/d from SPF top chord
			2	0.097	0.360	2,962	Plate w/d from maple web
			3	0.108	0.408	2,576	Plate w/d from SPF top chord
			4	0.110	0.385	2,830	Plate w/d from maple web
			5	0.110	0.416	2,700	Plate w/d from SPF top chord
12	SPF	Green Red Maple	3	0.105	0.369	2,921	Plate w/d from SPF top chord
			4	0.104	0.429	2,473	Plate w/d from SPF top chord
			5	0.092	0.372	3,108	Plate w/d from SPF top chord

Note: SPF = spruce-pine-fir species classification

Table 6.--Summary of pitched chord truss testing results.

Group	Species		Number of Trusses Tested	Mean Deflection and Strength Results			
	Chord	Web		Deflection at Dead Load (in)	Deflection at Design Load (in)	Total Ultimate Load (lbs)	Failure Load/Design Load
8	Sugar Maple	Sugar Maple	4	0.091 (0.010)	0.305 (0.016)	3,775 (752)	2.2 (0.4)
9	Delaware Red Maple	Delaware Red Maple	5	0.107 (0.006)	0.384 (0.010)	2,988 (312)	1.7 (0.2)
10	SPF	SPF	5	0.118 (0.007)	0.427 (0.027)	2,694 (182)	1.6 (0.1)
11	SPF	Red Maple	5	0.106 (0.005)	0.388 (0.023)	2,755 (146)	1.6 (0.1)
12	SPF	Green Red Maple	3	0.100 (0.007)	0.390 (0.034)	2,834 (326)	1.6 (0.2)

Note: Standard deviation for each value is shown in parentheses.
SPF = spruce-pine-fir species classification

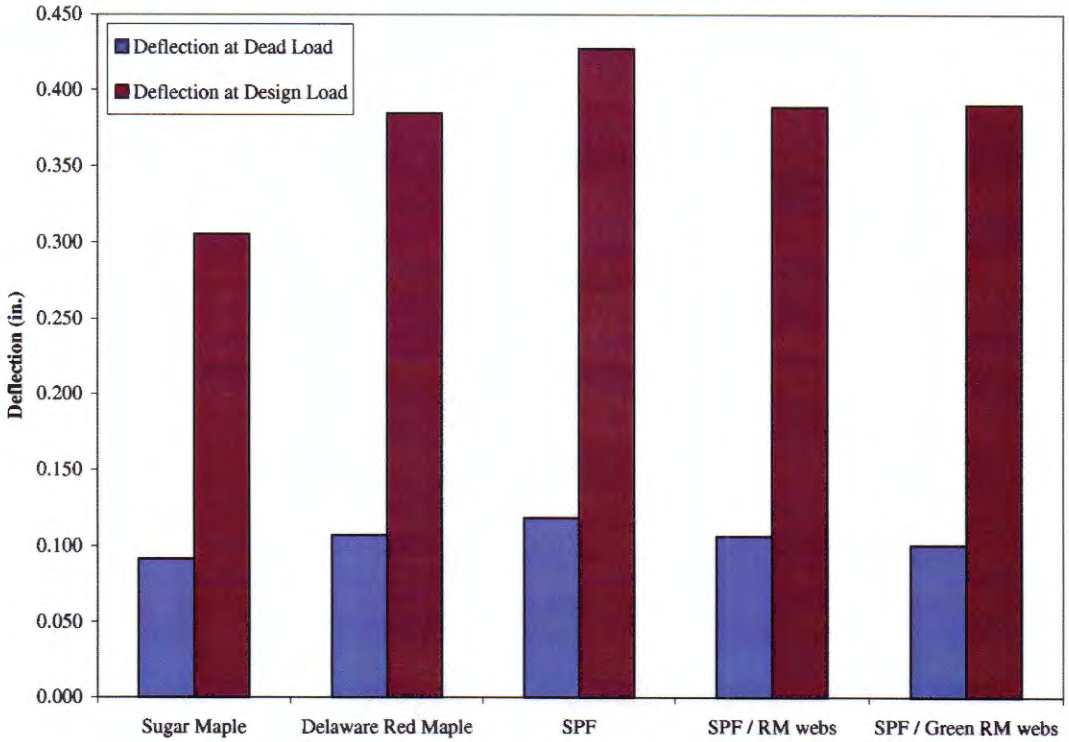

Figure 10. -- Summary of deflection results for pitched chord truss groups.

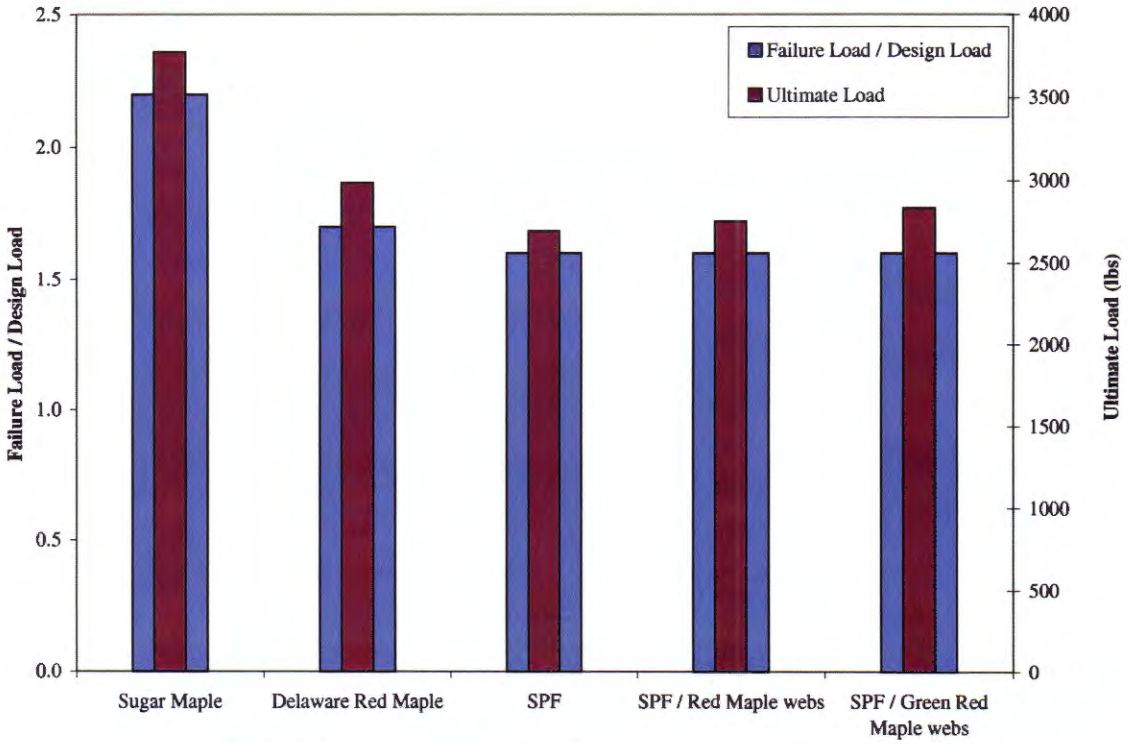

Figure 11.--Failure load performance of truss groups.

CONCLUSIONS

Based on the results of the pitched and parallel chord truss manufacturing and testing that was completed during this project, the following conclusions can be made:

- The use of hardwood lumber in pitched chord trusses resulted in trusses that were equivalent to higher in strength and deflection performance than traditional softwood lumber.

- The typical failure mode for hardwood chord and web pitched trusses was a complete failure or tearing of the truss plate on the bottom chord. Typical failure mode for softwood chord and web trusses was a metal plate withdrawal from the lumber at the truss peak.

- The use of hardwood lumber in parallel chord trusses resulted in trusses that were equivalent to higher in strength and deflection performance than traditional lumber.

- One significant limitation to the use of hardwood lumber as chord material was the length. Most softwood MSR lumber is available in 10-20 ft lengths. The 8 ft length of the hardwood chord lumber required additional splices.

REFERENCES

Truss Plate Institute, 1996. ANSI/TPI 2-1995, Standard for Testing Metal Plate Connected Wood Trusses. Truss Plate Institute, 583 D'Onofrio Dr., Suite 200, Madison, WI 53719