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Metal-Plate-Connected Wood Joints: A Literature Review

by

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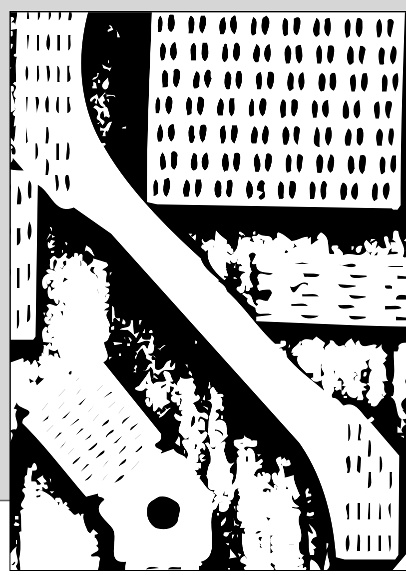

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Note

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Introduction

The history of mechanical fasteners used in connecting wooden members dates back to ancient Egypt and Rome (Patton-Mallory 1986). In modern times, with the development of the wood truss industry, problems encountered in connecting truss members have resulted in the production of numerous hardware items designed to improve performance at the joints.

Among all of the connectors developed (e.g., bolts, split rings, nailed-on plywood, and metal gusset plates), none is more economical and less labor intensive than punched metal connector plates. These plates are the most widely used connector for the fabrication of light-frame roof and floor trusses because of their low cost and ease of installation, as well as their higher efficiency and effectiveness compared with other connectors. Several other advantages of using metal connector plates in the fabrication of light trusses are outlined in the recently published Metal Plate Connected Wood Truss Handbook (Callahan 1993).

Metal connector plates were originally introduced in the U.S. after World War II; their use subsequently spread worldwide (Stern 1992). The first metal connector plate was invented in Florida in 1952, and it revolutionized the wood truss industry. Ever since, hundreds of millions of wooden trusses with metal connector plates have been successfully manufactured and used in construction. In 1978, total metal connector plate sales were well over $100 million (Meeks 1979a).

Metal-plate-connected (MPC) wood trusses for roofs and floors have been used in light-frame residential, industrial, and commercial construction for the last three to four decades. Today, more than 90 percent of all homes and apartments in the U.S. are built with engineered MPC wood trusses (Carlson 1991). There are about 2000 MPC truss manufacturers with total annual gross sales of about $2 billion. At the present time, the size of the metal connector plate industry is around $250 million (gross annual sales), with no more than a dozen manufacturers in the U.S. (D.O. Carlson, Automated Builder, personal communication, 1992).

The vast majority of metal connector plates are sheet metal plates that are die-punched from 14 to 20 gage (0.9 to 2.0 mm) galvanized sheet steel (Stern 1992) to form teeth perpendicular to the plate. Several different types of metal connector plates are currently used in assembling trusses (Figure 1). Metal connector plates are pressed into the lumber with one plate on each side of the jointed members with (usually) 2-in. nominal thickness, although heavier members are also used (McLain 1983). Moreover, there are numerous different configurations of joints, as shown in Figure 2.

Since the invention of the metal connector plates for timber trusses about 40 years ago, there has been much improvement in their design. However, the available literature on joint stiffness and strength is scarce because of the proprietary nature of metal connector plates. The current design methodology for MPC trusses does not take advantage of joint behavior to produce material savings. Yet, it has been estimated that we could reduce the amount of wood in all structures by 20 to 30 percent by applying current technology, such as including connection and system

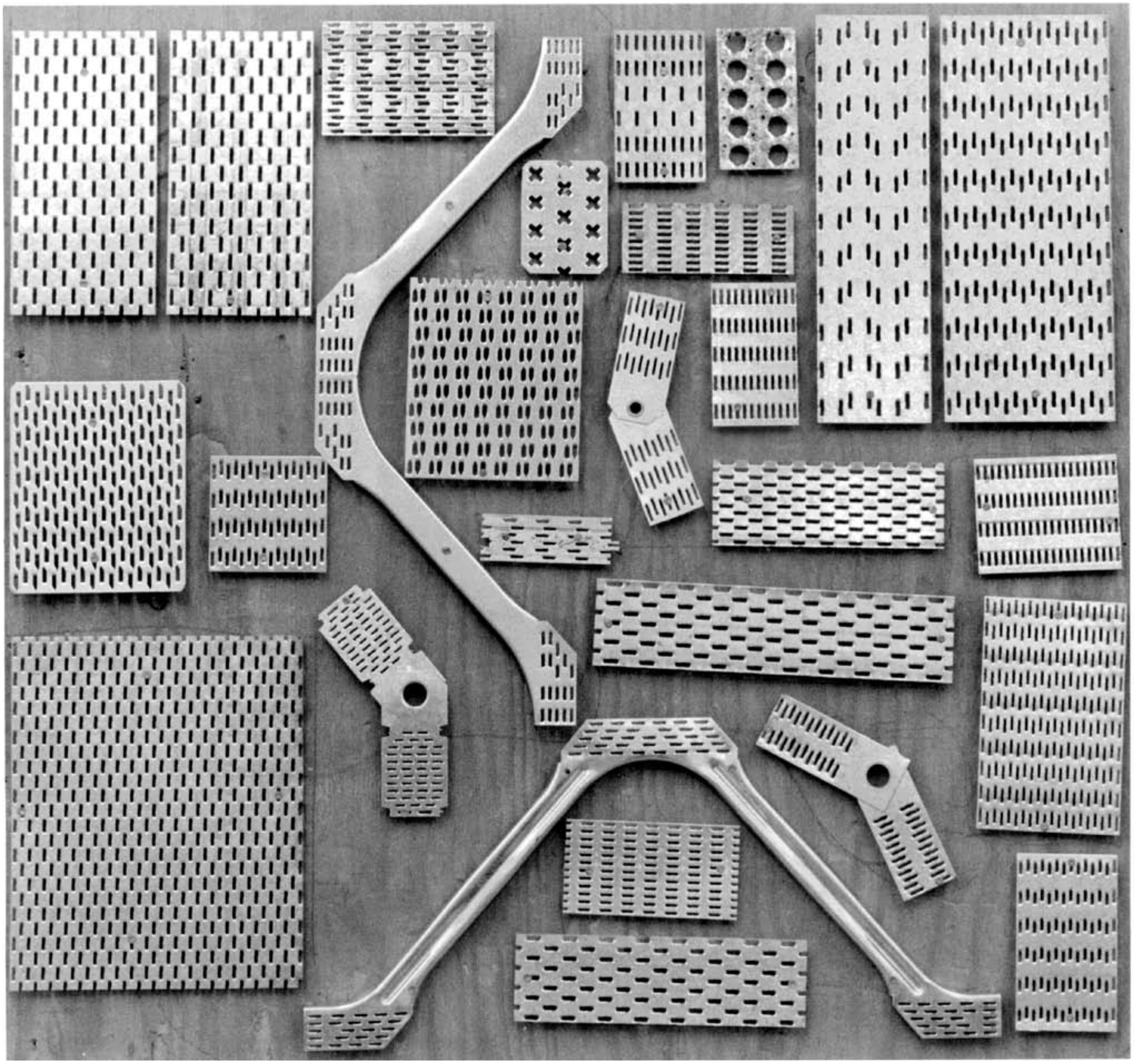

Figure 1. Common metal connector plates currently used in wood trusses.

behavior in analysis and design of trusses (Hoyle and Woeste 1989).

Thus far, there are very few papers summarizing the past literature and research needs in this area. In 1963, Suddarth summarized the results of several analyses of metal gusseted trussed rafters. The paper was intended to record the progress up to 1963. Three papers were presented on joints at the Metal Plate Wood Truss Conference in 1979 (FPS 1979). Stern (1992) described some of his personal experiences with the metal

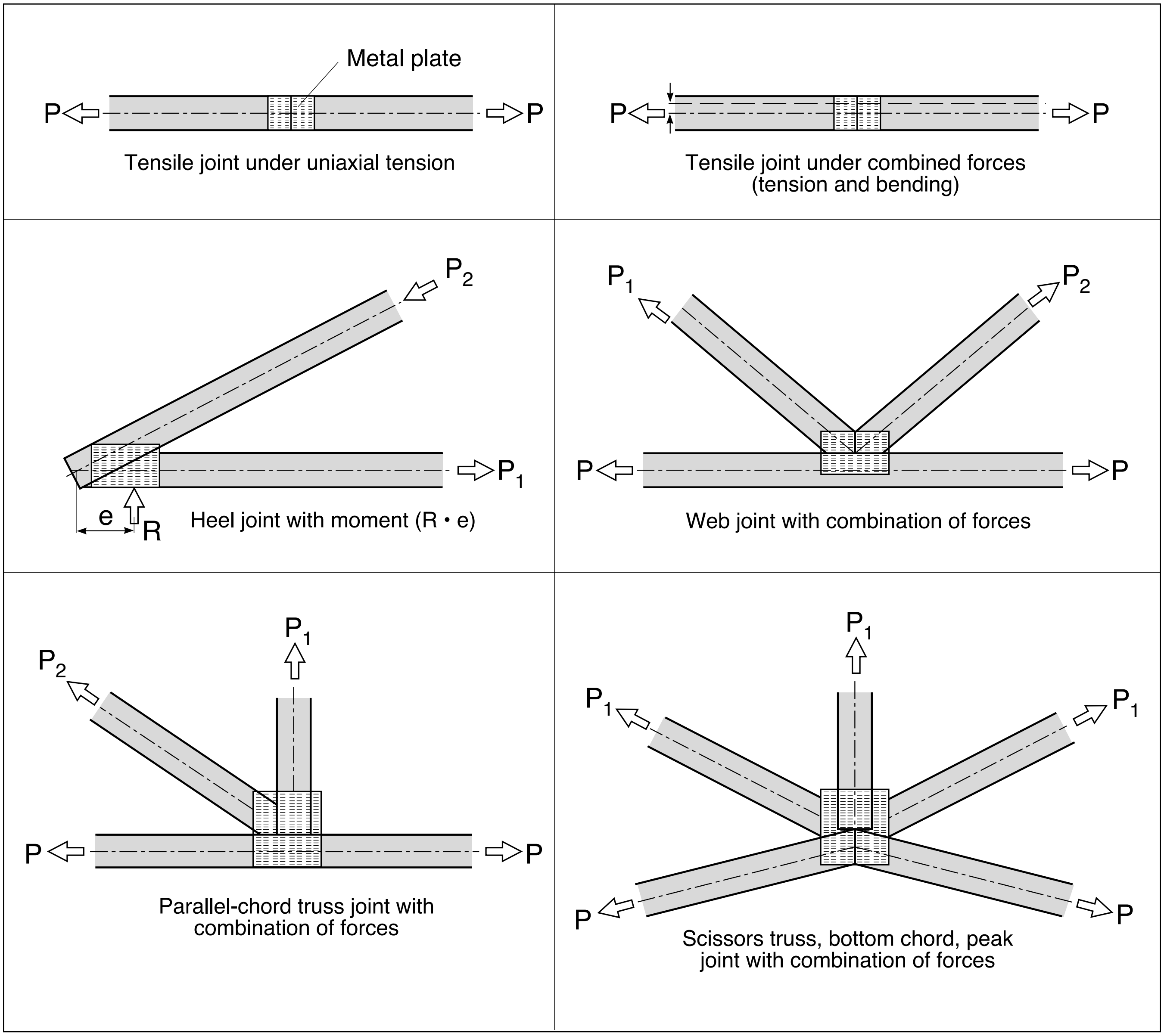

Figure 2. Different MPC joint configurations and loadings. P = force, R = reaction, e = eccentricity.

connector plates used for the assembly of wood structures. Most recently, the Wood Truss Council of America published a comprehensive Metal Plate Connected Wood Truss Handbook (Callahan 1993), which provided information on MPC wood trusses manufactured throughout the U.S., Canada, and other parts of the world from lumber and galvanized, light-gauge, cold-formed, structural-grade steel. The objective of this paper is to review the literature on MPC joints and to draw attention to possible future research directions that could help improve the understanding of MPC joints.

Standards

There are several standards that provide testing procedures to determine the structural characteristics of metal connector plates and MPC joints (Table 1). American Society for Testing and Materials (ASTM) standard E8 (ASTM 1991a) covers the tensile testing of metallic materials to determine yield strength, yield point, tensile strength, elongation, and reduction of area. ASTM E489 (ASTM 1991b) describes the test method for determining tensile strength properties of metal connector plates. A standard test method that provides a basic procedure for evaluating the effective shear resistance of the net section of steel truss plates is given in ASTM E767 (ASTM 1991c).

ASTM D1761 (ASTM 1991d) describes a tension test to determine tensile strength and stiffness of MPC joints, which will provide information on tooth-holding characteristics. This method has been designed especially for determining the tensile properties of connections.

The Truss Plate Institute (TPI) provides standard test methods for determining tensile strength properties and effective shear resistance of metal connector plates in the U.S. (TPI 1995). The standard method for determining lateral resistance strength of metal connector plates is also described in the TPI Standard (TPI 1995).

There are also other standards throughout the world. The Canadian Standards Association (CSA) gives basic procedures for determination of the lateral resistance and stiffness of truss plate teeth embedded in lumber members and for determining the tensile and shear strengths of the net sections of the plates (CSA 1980). The CSA standard includes four configurations of joints with various orientations of plate and wood grain to loading direction.

The International Standard Organization (ISO) specifies test methods for determining the tensile, compression, and shear strength of the plate at various angles (ISO 1990). Although the ISO standard (ISO 1990) does not provide a method for testing different joint configurations under combined loadings (the realistic situation), it does account for different plate angles and recommends shear tests, whereas ASTM D1761 (ASTM 1991d) prescribes tensile tests of axial joints only.

The European Union of Agreement published a report that specifies a rule for the assessment of MPC joints (UEAtc 1994). This document specifies preferred test methods for determining lateral resistance of the embedded teeth, bending strength of a single tooth, and the tensile and shear strength of the complete fasteners.

Most of the current standards oversimplify actual conditions at the joints. MPC joints in real trusses are generally subjected to some type of combined or eccentric loading. ASTM D1761 (ASTM 1991d) only accounts for axial loading of one type of joint. In all of these standards, not only are the loads unrepresentative of the in-service loading conditions, but also the joints used in the tests are not the actual connections used in structural assemblies. No standard exists for testing actual configurations of MPC joints from a wood truss under simulated, in-service loading conditions (e.g., combined bending and tension). A standard is required to determine structural characteristics (e.g., strength, stiffness, failure modes)

Table 1. Standards used in testing metal plates and MPC joints._

Standard	Loading condition	Joint type	Purpose
CSA S347-M1980 (CSA 1980)	Tension	Tensile—four load-to-grain orientations	To determine lateral resistance and stiffness of truss plate teeth and tensile strength of net section of the plates
	Tension/compression to produce shear in plate	Two configurations of special test specimen	To determine shear strength of the net section across the plate
	Tension	Solid-plate specimen	To determine ultimate tensile strength of plate (same as ASTM E8)
ASTM E8 (ASTM 1991a)	Tension	Solid-plate specimen	To determine yield and ultimate tensile strength of solid steel used in fabrication of plates
ASTM E489 (ASTM 1991b)	Tension	Tensile—two plate-to-grain orientations	To evaluate the tensile strength properties of the net section of steel truss plates
ASTM E767 (ASTM 1991c)	Compression to produce shear in plates	One special test specimen with various plate-to-grain orientations	To evaluate effective shear resistance of the net section of steel truss plates
ANSI/TPI 1-1995 (TPI 1995)	Tension	Tensile—four load-to-grain orientations	To determine lateral resistance strength of metal connector plate teeth
	Compression to produce shear at plate	One special test specimen with various plate-to-grain orientations	To evaluate the effective shear resistance of the net section of metal connector plates
	Tension	Tensile—two plate-to-grain orientations	To evaluate the tensile strength properties of the net section of metal connector plates
ASTM D1761 (ASTM 1991d)	Tension	Tensile—only one configuration	To determine the tensile strength and stiffness characteristics of plate connectors
ISO 8969 (ISO 1990)	Tension	Tensile—six plate-to-grain orientations	To determine load-slip characteristics of contact surface of plate and timber
	Tension	Tensile—three plate-to-grain orientations	To determine plate's tensile strength
	Compression	Tensile—two plate-to-grain orientations	To determine plate's compressive strength
	Compression to produce shear at plate	Special test specimen— four plate-to-grain orientations	To determine plate's shear strength
UEAtc M.O.A.T. No. 16 (UEAtc 1994)			Similar to ISO 8969
RILEM/CIB-3TT (1982)			Similar to ISO 8969

of actual MPC joints that are directly relevant to truss design. Specimens that are currently used in existing standards are not the most efficient for this purpose, and testing of actual truss joints should be performed (Quaile and Keenan 1979; Lau 1987).

There is no standard to evaluate dynamic properties and behavior of MPC joints. Dolan (1993) recently proposed a standard test method for evaluating the dynamic behavior of all types of wood connections. It uses a sequential phase displacement method that incorporates full reversal cyclic loading. The cyclic frequency of 1.0 Hz approximates the frequency range expected during an earthquake or high-wind event.

Design

Table 2 summarizes some of the design procedures used for MPC joints around the world. Metal connector plates are proprietary fastening devices, and manufacturers are responsible for establishing basic values for their plates. Allowable loads for joints are determined directly from the basic plate values by a straightforward conversion and generally are not specified by a design manual, such as the National Design Specification for Wood Construction (AFPA 1991) (hereafter, NDS) or the Timber Construction Manual (AITC 1985). Standard procedures for testing MPC joints to determine design loads have been developed by TPI in the U.S. (TPI 1995) and by the Truss Plate Institute of Canada (TPIC) in Canada (TPIC 1988). Also, building code agencies such as the International Council

Table 2. Design procedures for MPC joints.

	Design procedures	Remarks
USA	ANSI/TPI 1-1995 (TPI 1995)	Industry standard in U.S.
	NDS (AFPA 1991)	Refers to ASTM D1761
	AITC (1985)	No mention of MPC joints
	Hoyle and Woeste (1989)	PPSA II
	UBC (1994)	Refers to TPI standard
Canada	Wood Design Manual (CWC 1990)	Gives equations and examples; refers to CSA S347 and CAN/CSA-086.1-M89
	Engineering design in wood	Limit states design procedures (CAN/CSA-086.1-M89) and commentary (CSA 1989)
	Introduction to Design in Wood (CWC 1991)	General description only
	TPIC (1988)	Industry standard in Canada
Others	Eurocode 5	Provides general rules for joints
	Australian Standard	Proprietary
	New Zealand Timber Design Manual	Unknown

of Buildings Officials (ICBO 1988) may require additional testing (McLain 1983).

General guidelines for designing MPC joints in the U.S. are given in the national design standard for metal-plate-connected wood truss construction (TPI 1995). The TPI method accounts for axial and moment effects at the heel joints and for the lateral resistance at butt joints. The design procedure is based on the results of standard test methods for tensile and shear properties of steel truss plates, as well as tensile strength and stiffness properties of joints. The standard includes numerous advances for designing MPC joints and testing requirements. However, it does not provide any guidelines for handling eccentricities (Triche 1991) and combined loadings in connections. The design of other kinds of joints (e.g., crown, web at the bottom, or upper chord joints) is not fully described in TPI's national design standard (TPI 1995).

NDS (AFPA 1991) includes general provisions that apply to metal connector plates, but it does not provide design procedures for connections. The *Timber Construction Manual* (AITC 1985) does not mention MPC joints in the section on fasteners and connections, and all the connections on trusses are assumed to be either pinned or fixed. Hoyle and Woeste (1989) offer different design methods for truss connections, each with a different level of accuracy: the pin-joint method; the modified-pin-joint method; and the computer method [using Purdue Plane Structures Analyzer (PPSA) (Suddarth 1972)], which uses matrix structural analysis to calculate moments, forces, and deflections. Design of MPC joints is not elaborated. McLain (1992) summarized some of the design criteria and analysis methods used for the engineering design of wood trusses assembled with metal connector plates. The recently published *Metal Plate Connected Wood Truss Handbook* (Callahan 1993) has provided several detailed examples for designing MPC joints.

Meeks (1979b) compared U.S. and Canadian joint design techniques. The basic difference in the design of plating for joints was in the lateral resistance value used in the design, but this difference was removed in TPI's national design standard (TPI 1995). Both TPI and TPIC used the same reduction in allowable plate resistance value for heel plates to offset anticipated stresses in the plate caused by rotation or moment, and neither TPI nor TPIC actually specified test procedures or analyses to account for these factors (TPIC 1988; TPI 1995). More recently, Canada has started using a limit states design (LSD) approach for designing MPC joints (CSA 1989). The LSD approach provides design procedures and formulae for MPC joints and refers to TPIC (1988) for additional guidelines. Aasheim (1991) describes the latest truss design methods employed by Eurocode 5. General rules for joints and detailed design rules for dowel-type fasteners are included in the "joint" section of the code.

A recently published handbook (Callahan 1993) describes general truss design principles, as well as research progress in the design of MPC wood trusses. It seems that there is no formal, published design procedure that accounts for different types of MPC joints under different loading conditions. An objective, universal, reliability-based design procedure for MPC joints is needed. Present standards and design procedures result in connections that have been used in many structures and have been proven reliable, but may be overdesigned. Design for handling and erecting trusses is necessary, but is currently experience-based, rather than analytic.

Behavior of MPC Trusses

The simplest and most common assumption in the analysis of wood trusses is that the joints are either totally rigid or totally pinned. However, it is very important to understand that MPC joints in real structures behave as semirigid joints. The semirigid connection has a stiffness between that of the pinned and the rigid connection (Suddarth 1963). The relationship between the load and the corresponding displacement defines the connection response.

Suddarth and Percival (1972) were the first to provide an advanced analytical procedure along with performance tests of actual connections from a king post truss. Brynildsen (1979) developed structural models for trussed rafters and showed connection flexibility, using strain gages. Maraghechi and Itani (1984) showed that moment and axial stiffnesses have appreciable influence on member forces, whereas shear stiffness has little effect. In a similar approach, Masse and Salinas (1988) showed that an improved analysis method that considers connection stiffness would make it possible to predict the truss behavior more accurately and to optimize the designs.

Work on the semirigidity of trusses, using the matrix approach, was done by Sasaki *et al*. (1988) and by Sasaki and Takemura (1990). A method for predicting nodal displacements, member forces, and the failure load of an MPC wood truss was presented. It was based on an approximation of the nonlinear load-displacement relationship and the introduction of this relationship to the stiffness matrix for each member of the truss. Good agreement between analytical and full-scale test results was obtained. Hata *et al*. (1977) and Gupta (1990) have independently developed an element stiffness matrix that includes the effects of axial and rotational stiffness of a connection. Triche and Suddarth (1988) used a nonlinear finite element program to analyze MPC trusses and showed close agreement between theoretical and experimental deformations in four independent truss cases. However, their analytical method is too complex for design practice. Vatovec *et al*. (1995) are currently using a commercially available software package (ANSYS® 1992) to model MPC joints in wood trusses; it is a relatively simple, yet accurate, method that has the potential to be used by practicing engineers.

Testing and Modeling

The behavior of simple MPC joints is very complex, and it is difficult to analyze them without testing to verify their behavior. Almost all researchers who have studied MPC joints have relied on testing to broaden their understanding of the indeterminate behavior of the connections. Published literature on MPC joints is limited because fasteners are proprietary and because the plate geometries are diverse. Table 3 summarizes most of the published literature on testing of MPC joints. Table 4 summarizes the literature on modeling the behavior of MPC joints.

Table 3. Summary of selected literature on the testing of metal-plate-connected (MPC) joints.

Reference	Subject of testing	Type of test (loading)	Failure	Joint description	Remarks
Gupta (1994)	Tensile	Tensile, bending, four levels of tension and bending	Tooth withdrawal	2 x 4[1] SP[2] 3 x 4 in. plate	Axial capacity of MPC joints decreases with an increase in applied moment
Nielsen and Rathkjen (1994)	Splice joint	Tensile	Several different types of failures	45 x 94 mm lumber 76 x 159 mm plates	Tested 200 joints to study influence of the number of teeth rows, edge distance, fixed nail-plate, bending direction, unloading, grain direction, and plate and load direction on the load-displacement curves
Stahl et al. (1994)	Ten special test configurations	Compression	Plate buckling	2 x 4 SP 2 plate types	Determined load capacity of MPC joints using square-cut webs
Gebremedhin et al. (1992)	12 different orientations at 0°, 30°, 45°, 60°, 90°	Tension, shear	Tooth withdrawal with wood failure or plate shear failure	2 x 4 SP lumber 3 x 5 in. plates 36 joints	Determined strength, stiffness, and failure modes
McAlister and Faust (1992)	Four CSA[3] configurations	Tensile	-	2 x 4 yellow poplar and sweetgum	The MPC joints in sweetgum and yellow poplar are equivalent to those in southern pine
Benjamin and Bohnhoff (1990)	Splice joints	Tensile	Tooth withdrawal, yielding in tension	48 joints 3 x 5 in. plate	Per-tooth load slip predicted stresses in plates subjected to bending
Gupta and Gebremedhin (1990)	Tensile, heel, web joint	Simulated actual loading	Wood tearing and tooth failure, tooth failure	2 x 4 SP 3 x 4 in. and 3 x 5 in. plates	Determined strength, stiffness, and failure modes
Wolfe (1990)	Splice joint	Tensile, pure bending, tension and bending	Yielding of steel, tooth pullout	2 x 4 SP 3 x 5.25 in. plates	Showed reduction in connection tensile capacity with an increase in applied moment

Table 3 continued.

Reference	Subject of testing	Type of test (loading)	Failure	Joint description	Remarks
Groom (1989)	Tensile	Tensile	-	2 x 4 SP 3 x 4 in. plates 60 joints	Addition of an epoxy resin to the tooth-wood interface increases resistance to tooth withdrawal and increases initial stiffness by 90%
Kirk et al. (1989)	Tensile joints	Compression	Plate buckling	2 x 4 SP 4 types of plates	Evaluated the effect of gap size on joint serviceability
McAlister (1989) configurations	Four CSA 3 plate types	Tensile are the same for all these framing	- composite lumber	2 x 4 SP LVL[4] and slip, and ultimate load of the joint	Initial deflection, load at critical materials
Bodig and Farquhar (1988)	Tensile	Tensile	-	2 x 4 DF[5] and E. spruce[6] 3 x 4 in. plates 120 joints	Behavior at accelerated strain rates
Stern (1988)	Tensile joints	Tensile; ASTM D1761, E489 and E 767	-	14 series of tests	Tested plates with three teeth per hole; 42% more effective and 55% more efficient
Lau (1987)	Shear test Heel joints (30°)	Vertical loads	Tooth withdrawal, plate buckling	138 x 235 mm spruce and lodgepole pine different size plates	Test results were compared with SAT[7]; the model can predict yield load and joint stiffness at low slip
McCarthy and Wolfe (1987)	Standard and nonstandard splice	Tensile	Tooth withdrawal	2 x 4 SP 3 x 5 in. plates	Determined nonlinear model parameters; no effect of MOE[8] on parameter values
Palka (1985)	Splice joints	Ramp, tension, creep tests	-	2 x 4 lumber	Short, long term
Palka (1984)	Tensile	Load parallel and perpendicular to grain	-	-	Wood density was most important in determining strength

Hayashi and Sasaki (1982)	Splice joint	Tensile	Tooth withdrawal, plate failure	40 x 90 mm hemlock 16 plate types	Linear relationship between strength and specific gravity for tooth withdrawal cases
Hayashi et al. (1980)	Butt joint	Cyclic tension loading	Tooth pullout, Tooth shearing	40 x 30 mm	1.07 Hz frequency
Suddarth et al. (1979)	Splice joint	Tensile	-	322 joists, SP, SPF[9], DF	Coefficient of variation = 10-15%; 2 x 4 lumber, 3 x 3 in. plate, SG[10] is related to strength and stiffness of connections
Tokuda et al. (1979a)	Splice joints and others	Dead tension load	Tooth withdrawal, tension failure of plate, and shear failure along the grain	-	In Japanese
Tokuda et al. (1979b)	Splice joints and others	Repetitive tension load	Tension fatigue, withdrawal	-	In Japanese
Suddarth and Percival (1972)	Heel, peak, and lower chord web	Tensile	-	-	Evaluated the bending and axial stiffness of the fictitious members in truss analog for analysis
Dudley (1966)	Metal plates	Tensile	-	width 4 1/16 in. to 5 3/16 in.	Determine efficiency of perforated plates to carry tension loads
Felton and Bartlett (1964)	Tension and shear joints	Tensile and compression to produce shear in plates	Plate failure, tooth withdrawal	2 x 4 DF 11 plate types	Load-deflection character, tension test gives realistic load-carrying capacity as compared to shear tests

[1] 2 x 4 = 1.5 x 3.5 in. (38 x 89 mm)
[2] SP = southern pine
[3] CSA = Canadian Standards Association
[4] LVL = laminated veneer lumber
[5] DF = Douglas-fir
[6] E. spruce = Engelmann spruce
[7] SAT = Structural Analysis of Trusses
[8] MOE = Modulus of Elasticity
[9] SPF = spruce-pine-fir
[10] SG = specific gravity

Table 4. Summary of literature on modeling of metal-plate-connected (MPC) joints.

Reference	Modeling	Technique	Results, remarks
Groom and Polensek (1992)	Mechanism of load transfer; load displacement trace and ultimate load	Beam on inelastic foundation and Runge-Kutta numerical analysis; destructive tests	Accurately predicted the load-displacement trace, ultimate load, and failure modes considering grain orientations and plate geometries
Gebremedhin and Crovella (1991)	Load distribution along the tooth array	Elastic foundation model	The load distribution along the tooth array was nonuniform; stiffness was very sensitive to modulus of the wood followed by the moment of inertia of the tooth
Crovella and Gebremedhin (1990)	Axial stiffness	Finite element and elastic foundation models; destructive tests	Finite element model overpredicted stiffness values; elastic foundation model predicted stiffness similar to experimental results
Cramer et al. (1990)	Tensile and bending of splice joints	Nonlinear, plane stress finite element, includes wood contact, steel plate, and tooth-wood interface	Computed internal deformation, stress conditions, and ultimate strength; showed that current design assumptions represent unrealistic approximations of behavior for connections involving larger plates; predicted bending behavior using data from tension tests
Heard et al. (1988)	Performance of tension splice with MPC joints wider than lumber and stress distribution	Model 1: Adjusted connector plate net section method Model 2: Transformed section method; destructive tests	Variation in the width of the chord material and changes in connector plate width and length significantly affect the ultimate tension load of blocked splices; wood block contributes to the transfer of load
Reynolds (1988)	Stiffness behavior of MPC wood truss joints	Finite element model using "interface elements"; includes gaps, plate-wood interactions, and contact; specialized shear test and ridge joints tests	On the basis of comparisons with test results, the program accurately predicts connection behavior; the load at which contact occurs between members appears to be the most important factor in accurately predicting displacements

Palka (1985)	Short- and long-term behavior of splice joint in tension	Conventional elastic model using a complex nonlinear equation and a simple bilinear model to estimate the secant moduli of metal teeth; a conventional four-parameter linear viscoelastic spring and dash-pot model for creep	The proposed model is able to answer many practical "what if" questions for truss-plate joints in static tension; the agreement between measured and predicted creep values was excellent for most specimens
Triche (1984)	Force-displacement relationship of tension joints in bending	Modified Foschi's (1979) model and SAT; Canadian standard tests and bending tests	Demonstrated that Foschi's model can describe the mechanical behavior of MPC joints; slightly modified SAT[1] to predict behavior of connection under applied moments
Noguchi (1980)	Maximum bending moments of butt joints in pure bending	Four models; Elastic yield of wood member, tensile yield of plate connector, and plastic; bending tests	Plastic model gave the most unbiased estimates of the moment capacity and correlated well with experimental values; maximum bending moment of a joint is insensitive to variations in wood member strength
Beineke and Suddarth (1979)	Analytical approach to predict joint behavior under axial load and empirical approach to obtain joint stiffness	Analytical discrete and continuous models; empirical approach used test data	Analytical approach was not able to predict behavior accurately; used empirical approach to obtain joint stiffness from test data of shortest and longest plates
Foschi (1979)	A method of analysis of MPC joints	Includes plate orientation, nonlinear load-slip characteristics, actual shape of connected areas, plate buckling, plate yielding, and gaps	Method deals with the connections as with any other part of the structure; avoids need to define equivalent springs or fictitious members; allows estimation of ultimate load
Misra and Esmay (1966)	Stresses in a MPC joint under uniaxial tension	Discrete approach of difference equation; continuous approach of principle of minimum complementary energy; and experimental investigation using photo stress and strain gauges	Theoretical investigation showed stresses in the metal plate are not uniform; experimental investigation showed sharp stress gradients in the metal plate

[1]SAT = Structural Analysis of Trusses

Most of the early work focused on testing and modeling of tensile connections under axial (tensile) loads to determine strength and stiffness, as well as on studying the effects of different variables on the behavior of the connections. In recent years, the focus has shifted somewhat to other connections (such as heel, web) under a variety of loading conditions. Also, more emphasis is being placed on testing actual connections under in-service loading conditions to determine their behavior. Quaile and Keenan (1979) were the first to emphasize the need for testing actual truss connections to determine their structural characteristics and failure modes. Since then, Gupta (1990) and Vatovec *et al.* (1995) have tested different actual MPC joints under a variety of loading conditions.

The number of variables that influence the performance of MPC joints makes it difficult to determine the behavior of connections by either testing or modeling. Quaile and Keenan (1979) listed the following factors that may affect the strength properties of connections: orientation of plate and wood, end and edge distance, size of plate, method of installation, species and specific gravity of wood, wood moisture content, sampling, and elapsed time between assembly and test. McLain (1983) listed the following additional variables that influence the behavior of MPC joints: the properties of the plate such as tensile strength, shear strength, aspect ratio, net section characteristics at various angles within the plane of the plate, and row effects similar to other multiple fastener joints. This diversity of variables is one reason that there is no single standard test method to determine the behavior of these connections. Quaile and Keenan (1979) emphasized that a standard test method is needed to obtain results directly relevant to truss design. Testing of actual connections under in-service loading conditions has some potential to be used as a standard test procedure for connections as diverse as MPC joints.

Modeling of MPC joints to predict their behavior (e.g., stiffness, strength) is even more challenging than testing. The finite element method seems the best alternative to model a joint that is highly irregular in shape, is subjected to a complex set of loading conditions, and probably has the most complex behavior among all wood connectors. Almost all past modeling efforts predicted the behavior of one particular configuration of MPC joints (mostly the tensile connection) under one particular loading condition (generally axial tensile force). A model is needed that could predict design loads for a variety of connections under different loading conditions. Vatovec *et al.* (1995) used a commercially available finite element program to predict behavior of different types of MPC joints under in-service loading conditions.

Reliability-Based Design

Reliability-based design is an alternative approach that is probably more effective than allowable stress design in the analysis of MPC wood trusses (Showalter and Grundahl 1991). McLain (1986) emphasized the need to develop probabilistic distributions for the strength of connections. He pointed out that connection resistance is generally less variable than resistance of the joined members. Gupta *et al.* (1992) showed that properties for some of the MPC joints in a truss could be characterized by a normal distribution. In the fall of 1987, a consortium representing wood products industries such as lumber, glulam, trusses, and I-joists began developing load and resistance factor design (LRFD) procedures for wood structures based on reliability theory (Pollock 1989). The goal was to complete an LRFD specification in early 1994. The section on MPC joints was to be developed by an engineer-manufacturer task group and is almost complete (AFPA 1995). The LRFD specification is currently out for public review and not yet approved by code agencies. Showalter and Grundahl (1991) compared MPC joint design (lateral resistance, shear and tension strengths) using LRFD procedures with a design in accordance with TPI (1995). They concluded that the TPI procedure required larger cross sections, which indicates possible overdesign, and therefore increased cost.

Yates (1987, 1989) and Bulleit and Yates (1988) developed a stochastic finite element program for the probabilistic analysis of MPC trusses that computes the first four statistical moments for the nodal displacements, member forces, and maximum interior moments for the "beam-column" members. Predicted deflections agreed very well with the actual values. Lam and Varoglu (1988) found that accidental misplacement of truss plates affected truss reliability and reduced the allowable truss span by 2 ft. Gizejowski and Mansell (1991) described a computer program that is used to carry out reliability analysis of typical domestic roof trusses. Parameswar and Mansell (1989) devised a method to arrive at the partial safety factors applied to the forces at MPC joints. This was based on a global reliability index for the design. Gupta and Gebremedhin (1992) determined reliability of MPC wood trusses using probabilistic strength characteristics of members and stiffness characteristics of semirigid joints. Based on lognormal load and resistance distributions, the reliability of a truss with three different joint assumptions (pinned, rigid, and semirigid) was obtained, along with the probabilities of failure.

Dynamic and Cyclic Testing

Very little information is available on the dynamic and cyclic behavior of MPC joints. Sletteland *et al.* (1977) conducted experiments on the fatigue life of MPC tensile joints. They showed that failure was initiated by teeth fatigue, which caused some teeth to shear off at the roots and then the remaining teeth to withdraw. Several Japanese researchers (Hayashi 1978; Hayashi *et al.* 1979, 1980, 1983; Hayashi and Sasaki 1981, 1984) have conducted studies on MPC tensile joints under tension-only, tension-compression, and flexural loads. Tokuda *et al.* (1979b) studied the behavior of MPC joints under repetitive tensile forces. Whittington (1986) tested a model of a prestressed bridge using metal connector plates and dimension lumber under static and cyclic loads; he concluded, without giving any specific figures, that truss plates are much stronger than recommended by manufacturers. More recently, Dagher *et al.* (1991) conducted extensive fatigue testing of MPC tensile joints at several different load levels (percentages of static ultimate load). They reported that ultimate failure is always due to tooth withdrawal, even if failure was initiated by metal fatigue. Leivo (1991) has also conducted tests to determine changes in stiffness of MPC joints due to dynamic loads. Emerson and Fridley (1994) tested tensile joints under cyclic loading, and Kent *et al*. (1995) tested MPC tensile and heel joints under seismic and cyclic loads to evaluate their behavior.

Moisture Cycling and Creep

Both the TPI (1995) and NDS (AFPA 1991) recommend a 20 percent reduction in the strength of MPC joints when used under wet conditions. This reduction is based on tests of light-frame MPC wood trusses that were fabricated at 19 percent moisture content (MC) and tested at 6 percent MC (Radcliffe and Sliker 1964). Wilkinson (1966) conducted tests on MPC joints at various MC and showed a decrease in axial strength with increase in MC. Aplin (1973) and Wight (1977) also conducted tests on MPC joints and showed a reduction in strength and stiffness due to moisture cycling.

Tokuda (1986) studied mechanical properties of laminated veneer lumber (LVL) and lumber connections under variable moisture conditions. He found that mechanical properties of LVL connections were less affected by specific changes in environmental conditions than were those of lumber connections. Sliker and Radcliffe (1965) studied deflection and creep characteristics of trussed rafters with metal connector plates. They showed that trusses exhibited distinct creep patterns and the major part of the creep was considered to occur at interactions between the fasteners (metal connector plates) and the wood.

Tokuda *et al*. (1979a) examined the behavior of MPC tensile joints under long-term tension loading. They showed that the static strength of specimens that experienced a creep test was not significantly different from the static strength of a virgin specimen. Leicester *et al*. (1979) tested MPC joints at high constant-load levels. Palka (1988) investigated short-term and long-term behavior of MPC tensile joints in uniaxial tension to develop creep models. In a pilot study, Soltis and Shea (1988) obtained time-to-failure and creep data for constant-loaded MPC joints. Percival and Suddarth (1988) conducted long-term (10 years) creep tests on parallel chord trusses. They did not observe any significant strength or stiffness losses over the 10-year period.

Recently, Groom (1994) quantified the effect of moisture cycling on the mechanical properties of MPC joints. He also evaluated the possibility of retarding the degenerative effects of moisture cycling by applying an adhesive to the teeth of the truss plate immediately before assembly.

Other Uses

With the popularity and satisfactory performance of metal connector plates in wooden trusses, they are finding new structural and nonstructural applications. Recently, several researchers (Whittington 1986; Dagher *et al*. 1991) have looked into ways of using metal connector plates in timber bridges. Dagher *et al*. (1991) studied the fatigue behavior of metal connector plates to investigate the feasibility of incorporating them in timber bridges.

Traditionally, metal connector plates have been used with visually graded lumber in trusses. With machine stress rated (MSR) lumber becoming more popular, more trusses are built with MSR lumber and with metal connector plates used as fastening devices. Keenan *et al*. (1985) studied the behavior of truss plate and metal web joints in MSR lumber trusses. Tokuda (1984) studied the feasibility of using LVL in MPC trusses and demonstrated that there was little difference in stiffness and strength between lumber joints and LVL joints. Also, the mechanical properties of LVL joints were affected less by changes in moisture content than were those of lumber joints. Emanuel *et al*. (1987) investigated the behavior of MPC double 4 by 2 beams. They concluded that the plates effectively transferred the interface shear between the two members to produce a highly efficient composite member.

Metal connector plates may also be used to reinforce pallets, thus allowing for longer service life or the use of additional or less desirable wood species in pallet manufacturing (McLain 1992; NWPCA 1994). Matlock (1992a, 1992b) patented a special metal connector plate that is used as an antisplitting device for wood crossties.

Researchers are still developing new plates to improve the behavior of MPC joints and for other special uses. Poutanen (1993) proposed a new metal connector plate with two projecting teeth per hole and a row of peripheral teeth (Fig. 11 in Stern 1992). Stern (1992) recently improved this new design by adding prongs or teeth that protrude from both faces of the plate (Fig. 7 in Stern 1992). Stern *et al*. (1995) recently tested this design in a solid-lattice plate bridge girder with continuous metal connector plates between the lumber members, both chord and diagonals.

Because fabrication is easy and forces are transferred efficiently with metal connector plates, they are being used in several applications other than MPC trusses. Use of metal connector plates in timber bridges seems to be quite promising, but environmental effects will need careful study and consideration.

Inspection and Repair

Although MPC trusses are one of the most widely used structural systems, structural deficiencies are commonly encountered during inspection. Klein and Kristie (1988) listed several structural deficiencies, ranging from design deficiencies to damage occurring during service. Among the most common problems are mislocation and partial embedment of connector plates (Klein 1991). To rectify some of the problems associated with metal connector plates and trusses, Grossthanner *et al*. (1991, 1992) outlined a method of inspecting MPC wood trusses. In a case study, Smulski (1993) found that excessive heat and moisture could cause the metal plates in old trusses to loosen their grip. Kagan (1993) reported from three case studies that the major cause for the collapse of MPC trusses during installation, erection, or in-service is inadequate temporary or permanent bracing.

Treatment, Weathering, and Preservatives

Percival and Suddarth (1971) studied the influence of fire-retardant treatment on stiffness and strength of MPC joints. Laidlaw and Cox (1983) studied the effect of preservatives on the corrosion of metal connector plates. They reported that joints made from wood treated with CCA (chromated copper arsenate) lost some strength after 2 to 3 years, whereas joints made from wood treated with organic solvent lost no strength over 4 years. Oliva *et al.* (1988) showed that the capacity and stiffness of joints made with creosote-treated wood either stayed the same or increased compared with joints made with untreated wood. McAlister (1990) found that weathering and accelerated aging reduced the load capacity of MPC joints.

Industry Associations

TPI was formed in the early 1960s in order to develop uniform design criteria that are acceptable to the various code agencies [e.g., FHA (Federal Housing Authority), ICBO (International Conference of Building Officials), and BOCA (Building Officials and Code Administrators)] (Juriet 1962; Meeks 1979a). Through their several Technical Advisory Committees, TPI has developed an industry standard for designing, manufacturing, and erecting MPC trusses. The Wood Truss Council of America is another national trade association that provides a united voice for truss manufacturers (Callahan 1993). Several industry-wide publications help disseminate information about MPC trusses (e.g., *Journal of Light Construction, Lumberman, Woodwords*).

Software to Analyze MPC Trusses

The program most widely used by plate and truss manufacturers is Purdue Plane Structures Analyzer (PPSA) (Triche and Suddarth 1988), which incorporates a nonlinear plate element originally developed by Foschi (1977). The original PPSA (Suddarth 1972) was used by Woeste (1975) for a Monte Carlo simulation study of a king post truss, in which joint flexibility was included as a stochastic variable. Varoglu (1984) developed Structural Analysis of Trusses, a program that is a research tool for characterizing the statistical distribution of stiffness and strength of MPC roof trusses. Gebremedhin (1986) developed a structural analysis program (called SOLVER) as an educational tool for analyzing a variety of structural systems. Gupta (1990) developed SIMRED (SIMulate REsistance Distribution) to generate the resistance distribution of MPC trusses. SIMRED takes into account semirigid connection behavior and probabilistic material characteristics of members and joints. There are many proprietary programs offered by the metal connector plate industry to clients.

Current Research

Researchers at several universities are studying various aspects of MPC trusses. The Departments of Forest Products and Civil Engineering at Oregon State University (OSU) are currently conducting static and dynamic testing of several types of MPC joints in order to understand their behavior and improve their design. Kenneth Fridley at Washington State University is testing MPC tensile joints under cyclic loading to examine their response to wind. Bo Kasal at North Carolina State University and researchers at OSU are examining biaxial characteristics of metal connector plates to develop design criteria for truss plates subjected to multiaxial loads. Kifle Gebremedhin at Cornell University is working to include semirigid behavior of joints into the analysis and design of MPC trusses. Frank Woeste at Virginia Polytechnic Institute and State University is characterizing steel properties in an in-grade study to form a database for truss research. Ron Wolfe at the Forest Products Laboratory, Madison, Wisconsin, is examining the state of stress in metal plates in a connection. The following researchers are studying various other aspects of MPC joints: Les Groom, USDA Southern Forest Experiment Station, Pineville, Louisiana; Habib Dagher, Department of Civil Engineering, University of Maine; Mike Triche, Department of Civil Engineering, University of Alabama at Tuscaloosa; Steve Cramer, Department of Civil Engineering, University of Wisconsin at Madison.

Research Needs

Only a few works in the literature elaborate on the research needed on wood structures, and specific portions of them have concentrated on wood connections (ASCE 1979, 1983, 1986). Table 5 lists some of the research needs identified by ASCE (1986).

Some work has been done in the area of theoretical modeling of MPC joints, but the information is fragmented and directed towards specific problems only. Wolfe (1990) and Gupta (1990) emphasized the need for a database on the strength and stiffness of MPC joints; such a database does not exist currently. Wolfe *et al*. (1991) and Gupta (1990) developed testing apparatus and methods that have a potential to be used in standard testing procedures, but the development of standard testing methods has not received much attention in general. Environmental effects on MPC joints have been studied in some works that concentrated on the long-term behavior of the trusses (i.e., Sletteland *et al*. 1977; Wilkinson 1978; Tokuda *et al*. 1979a), but, again, no information that could be used in standard design methods has been gained. There also is not much com-

Table 5. Partial list of research needs for structural wood joints. (Source: ASCE 1986)

Topic	Need Description
Theoretical modeling	Develop and verify procedures for predicting strength, stiffness, and damping capacity
Database	Develop probability density functions of structural properties
Testing methods	Develop standard testing methods
Environmental effects	Determine effects of heating or cooling, humidity, load duration, dynamic loading, and preservative treatment
Stress concentration	Determine the effect of joints on stress concentrations in wood members
Product improvements	Develop and evaluate more efficient joints (among subsystems and for moment transfer)

pleted research in the area of stress concentrations in MPC joints.

A recent international workshop on wood connectors (FPS 1993) resulted in a list of research priorities for developing global standards for wood connectors. The same list can also be used as research needs for MPC joints. Some of the research areas that apply to MPC joints and still need attention are the following:

1. Testing methods for actual truss joints (e.g., heel, web, crown) under in-service loads (e.g., combined loading, multiaxial loading)
2. Energy absorption characteristics, especially with regard to seismic and similar extreme events, ductility, and cyclic loading
3. Creep, moisture cycling, and load duration effects
4. Durability
5. Stress concentration effects
6. Uniform database on connection properties

Efforts are underway at OSU in the first two areas. Load duration effects from the third area will also be quantified as part of the research to evaluate the dynamic behavior of MPC joints. Another important factor that often is not considered by the designers because of insufficient information is the variability in materials, fabrication, erection, environmental conditions, performance, and design.

Summary and Conclusions

This publication has presented an overview of current research on MPC joints in wood trusses. The literature search was primarily of U.S. sources, with some effort to obtain literature from other parts of the world. An enormous amount of important information has been amassed by studies on testing procedures and theoretical models. Among the many attributes that must be considered in modeling and analysis of joints and trusses are the effect of load angle, wood-plate orientation, size, thickness, stiffness of steel plates, and specific gravity of wood on the strength of the joints, as well as the effect of the gap closure between members, tooth damage or length, and tooth layout on the overall joint performance.

Extensive research has been done on tension joints in trusses; some has been done on heel connections, but very little has been done on web and other connections. Researchers have devoted considerable effort to understanding tensile joints under axial loading. However, experience suggests that even tensile joints are subjected to combined loadings because of eccentricities.

The behavior of a simple MPC joint is very complex and influenced by many variables, including plate properties, joint geometry, and the natural variability of wood. An integrated approach, as used by Foschi (1977), that considers the material behavior and interactions of wood and plate and that is simple but sufficiently accurate for designing joints should be developed. A standard method for studying the long-term behavior of MPC joints should be developed and used in design. One possible option would be to use a time-temperature superposition principle for developing long-term data from relatively short-term tests. Failure modes of the truss joints should be characterized. Work on dynamic behavior and environmental effects on the joints is also needed.

Literature Cited

AASHEIM, E. 1991. Design of trusses. Proceedings International Timber Engineering Conference V1:1.89-1.96.

AFPA. 1991. National Design Specification for Wood Construction. American Forest and Paper Association, Washington, D.C. 125 p.

AFPA. 1995. Manual of Wood Construction: Metal Plate Connected Wood Truss Guidelines. Load and Resistance Factor Design - Supplement and Guidelines (Committee review draft - January 1995). American Forest and Paper Association and American Wood Council, Washington, D.C.

AITC. 1985. Timber Construction Manual. Third edition. American Institute of Timber Construction. John Wiley & Sons, Inc., New York. 836 p.

ANSYS®. 1992. ANSYS® 5.0a. Finite-Element Analysis Software. ANSYS®, Houston, Pennsylvania.

APLIN, E.N. 1973. Factors affecting the stiffness and strength of metal plate connector joints. Eastern Forest Products Laboratory, Ottawa, Ontario, Canada. Information Report OP-X-57.

ASCE. 1979. Important research needs in wood as a structural material. Journal of Structural Engineering 105(ST10):2069-2089.

ASCE. 1983. Structural wood research: state-of-the-art and research needs. American Society of Civil Engineers, New York.

ASCE. 1986. Structural wood research needs. Journal of Structural Engineering 112(ST9):2155-2165.

ASTM. 1991a. Standard test methods of tension testing of metallic materials. E 8-91:578-597, American Society for Testing and Materials, Philadelphia, Pennsylvania.

ASTM. 1991b. Standard test method for tensile strength properties of steel truss plates. E 489-81:441-444, American Society for Testing and Materials, Philadelphia, Pennsylvania.

ASTM. 1991c. Standard test method for shear resistance of steel truss plates. E 767-80:645-649, American Society for Testing and Materials, Philadelphia, Pennsylvania.

ASTM. 1991d. Standard test methods for mechanical fasteners in wood. D 1761-88:297-308, American Society for Testing and Materials, Philadelphia, Pennsylvania.

BEINEKE, L.A., and S.K. SUDDARTH. 1979. Modeling joints made with light-gage metal connector plates. Forest Products Journal 29(8):39-45.

BENJAMIN, S., and D.R. BOHNHOFF. 1990. Increasing the moment capacity of truss plates. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 904528.

BODIG, J., and B. FARQUHAR. 1988. Behavior of mechanical joints of wood at accelerated strain rates. Proceedings, International Conference on Timber Engineering 2:455-463.

BRYNILDSEN, O. 1979. Structural models for trussed rafters. Norsk Treteknisk Institute, Oslo, Norway.

BULLEIT, W.M., and J.L. YATES. 1988. Stochastic finite element analysis of metal plate connected wood trusses. Proceedings, International Conference on Timber Engineering 1:125-131.

CALLAHAN, E.E. 1993. Metal plate connected wood truss handbook. Wood Truss Council of America, Madison, Wisconsin.

CARLSON, D.O. 1991. Automated Builder - Dictionary/Encyclopedia of Industrialized Housing. P.O. Box 120, Carpinteria, California.

CRAMER, S.M., D. SHRESTHA, and W.B. FOHRELL. 1990. Theoretical consideration of metal-plate-connected wood-splice joints. Journal of Structural Engineering 116:3458-3474.

CROVELLA, P.L., and K.G. GEBREMEDHIN. 1990. Analysis of light frame wood truss tension joint stiffness. Forest Products Journal 40(4):41-47.

CSA. 1980. Method of test for evaluation of truss plates used in lumber joints. S347-M1980. Canadian Standards Association, Rexdale, Ontario, Canada. (Reaffirmed in 1992)

CSA. 1989. Engineering design in wood (Limit States Design). CAN/CSA-086.1-M89. Canadian Standards Association, Rexdale, Ontario, Canada. pp. 186-190.

CWC. 1990. Wood Design Manual. Canadian Wood Council, Ottawa, Ontario, Canada. pp. 289-296.

CWC. 1991. Introduction to Design in Wood. Canadian Wood Council, Ottawa, Ontario, Canada. pp. 203-206.

DAGHER, H.J., V. CACCESE, Y. HSU, R.W. WOLFE, and M.A. RITTER. 1991. Feasibility of metal connector plates in timber bridges: fatigue study. Department of Civil Engineering, University of Maine, Orono, Maine.

DOLAN, J.D. 1993. Proposed test method for dynamic properties of connections assembled with mechanical fasteners. CIB-W18[1], Paper No. 26-7-1.

DUDLEY, H.T. 1966. Determination of net section properties of metal truss plates. Forest Products Journal 16(5):48-49.

EMANUEL, J.H., C.M. NEWHOUSE, and D.B. BRAKEMAN. 1987. Investigation of metal-plate-connected double 4 by 2 beams. Forest Products Journal 37(11/12):75-79.

EMERSON, R., and K.J. FRIDELY. 1994. Cyclic loading of truss plate connections. Technical Forum Presentation. Forest Products Society, Madison, Wisconsin.

FELTON, K.E., and H.D. BARTLETT. 1964. Punched-metal truss plates used in timber joints. Transactions of the ASAE 7:159-163.

FOSCHI, R.O. 1977. Analysis of wood diaphragms and trusses. Part II: Truss-plate connection. Canadian Journal of Civil Engineering 4:353-362.

FOSCHI, R.O. 1979. Truss plate modelling in the analysis of trusses. Proceedings, Metal Plate Wood Truss Conference. P-79-28. Forest Products Society, Madison, Wisconsin.

FPS. 1979. Proceedings, Metal Plate Wood Truss Conference. Forest Products Society, Madison, Wisconsin. 259 p.

GEBREMEDHIN, K.G. 1986. SOLVER - an interactive structures analyzer for microcomputers. Journal of Applied Engineering in Agriculture 2(1):10-13.

GEBREMEDHIN, K.G., and P.L. CROVELLA. 1991. Load distribution of metal plate connectors of tension joints in wood trusses. Transactions of the ASAE 34:281-287.

GEBREMEDHIN, K.G., M.C. JORGENSEN, and C.B. WOELFEL. 1992. Load-slip characteristics of metal plate connected wood joints tested in tension and shear. Wood and Fiber Science 24:118-132.

GIZEJOWSKI, M.A., and M.G. MANSELL. 1991. Stability and reliability of semi-rigid timber trusses. Proceedings, International Timber Engineering Conference 2:2.375-2.382.

GROOM, L.H. 1989. Effect of adhesive applied to the tooth-wood interface on metal-plate connections loaded in tension. Forest Products Journal 41(4):33-35.

GROOM, L.H. 1994. Effect of moisture cycling on truss-plate joint behavior. Forest Products Journal 44(1):21-29.

GROOM, L.H., and A. POLENSEK. 1992. Nonlinear modeling of truss-plate joints. Journal of Structural Engineering 118:2514-2531.

GROSSTHANNER, O.A., D.B. BRAKEMAN, and N.D. WOOD. 1991. Metal-plate-connected wood truss inspection: Part I. Wood Design Focus 2(4):17-19.

GROSSTHANNER, O.A., D.B. BRAKEMAN, and N.D. WOOD. 1992. Metal-plate-connected wood truss inspection: Part II. Wood Design Focus 3(1):4-6.

GUPTA, R. 1990. Reliability analysis of semirigidly connected metal plate residential wood trusses. Ph.D. dissertation. Cornell University, Ithaca, New York. 169 p.

GUPTA, R. 1994. Metal-plate connected tension joints under different loading conditions. Wood and Fiber Science 26:212-222.

GUPTA, R., and K.G. GEBREMEDHIN. 1990. Destructive testing of metal-plate-connected wood truss joints. Journal of Structural Engineering 116:1971-1982.

GUPTA, R., and K.G. GEBREMEDHIN. 1992. Resistance distributions of a metal-plate-connected wood truss. Forest Products Journal 42(7/8):11-16.

GUPTA, R., K.G. GEBREMEDHIN, and J.R. COOKE. 1992. Analysis of metal-plate-connected wood trusses with semi-rigid joints. Transactions of the ASAE 35:1011-1018.

HATA, M., K. KOMATSU, and H. SASAKI. 1977. Structural analysis of wood shelf as a semi-rigid jointed frame. Mokuzai Gakkaishi 23:434-439.

HAYASHI, T. 1978. Strain distribution in metal plate connectors. Master's thesis. Kyoto University, Kyoto, Japan.

HAYASHI, T., M. MASUDA, and H. SASAKI. 1979. Rotating bending fatigue properties of timber butt-joints with metal plate connectors. Journal, Society of Materials Science, Japan 28(310):623-628.

HAYASHI, T., and H. SASAKI. 1981. Time dependence on fatigue strength of timber butt-joints with metal plate connectors. Journal, Society of Materials Science, Japan 30(334):697-702.

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HAYASHI, T., and H. SASAKI. 1982. Static tensile strength of wood butt joints with metal plate connectors. Bulletin of the Wood Research Institute, Kyoto University 68:22-36.

HAYASHI, T., and H. SASAKI. 1984. Fatigue damage of wood butt-joints with metal plate connectors. Journal, Japan Wood Research Society 30:23-31.

HAYASHI, T., H. SASAKI, and T. FUYUKI. 1983. Effect of butt-joint gap on fatigue properties of laminated veneer lumber (LVL) with metal plate connectors. Journal, Japan Wood Research Society 29:663-669.

HAYASHI, T., H. SASAKI, and M. MASUDA. 1980. Fatigue properties of wood butt joints with metal plate connectors. Forest Products Journal 30(2):49-54.

HEARD, L.R., S.G. WINISTORFER, and O.A GROSSTHANNER. 1988. Analysis of metal plate connected high capacity tension splices for wood trusses. Proceedings, International Conference on Timber Engineering 2:149-162.

HOYLE, R.J., and F.E. WOESTE. 1989. Wood Technology in the Design of Structures. Fifth edition. Iowa State University Press, Ames, Iowa. 394 p.

ICBO. 1988. Uniform building code. International Conference of Building Officials, Whittier, California.

ISO. 1990. Timber structures — testing of unilateral punched metal plate fasteners and joints. Standard 8969. International Standards Organization, Geneva, Switzerland.

JUREIT, J.C. 1962. Truss plate connectors in present use. Proceedings, Symposium on Fastenings for Wood in House Construction. USDA Forest Service, Forest Product Laboratory, Madison, Wisconsin. FPL No. 2241. 38 p.

KAGAN, H.A. 1993. Common causes of collapse of metal-plate-connected wood roof trusses. Journal of Performance of Constructed Facilities 7:225-234.

KEENAN, F.J., M.M. LEPPER, A.T. QUAILE, and E.N. APLIN. 1985. Behaviour of truss plate and metal web joints in machine-stress-related lumber trusses. Canadian Journal of Civil Engineering 12:700-716.

KENT, S.M., R. GUPTA, and T.H., MILLER. 1995. Dynamic effects on metal-plate-connected wood truss joints. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 954458.

KIRK, L.S., T.E. MCLAIN, and F.E. WOESTE. 1989. Effect of gap size on performance of metal plated joints in compression. Wood and Fiber Science 21:274-288.

KLEIN, G.J. 1991. Mechanical connections: the weak link in light-frame wood constructions. In Proceedings, Mechanical Fasteners Plenary Session. Forest Products Society, Madison, Wisconsin.

KLEIN, G.J., and R.J. KRISTIE. 1988. Inspection and repair of plate-connected wood trusses. Proceedings, International Conference on Timber Engineering 1:449-459.

LAIDLAW, R.A., and R.N. COX. 1983. The effect of preservatives on the corrosion of galvanised metal plate fasteners in timber. Part I: Effect on joint strength and the significance for trusses rafter roofs. International Journal of Wood Preservation 3(2):51-60.

LAM, F., and E. VAROGLU. 1988. Effect of truss plate placement and sizing on the short term reliability of trusses. Proceedings, International Timber Engineering Conference 1:132-135.

LAU, P.W.C. 1987. Factors affecting the behaviour and modelling of toothed metal-plate joints. Canadian Journal of Civil Engineering 14:183-195.

LEICESTER, R.H., G.F. REARDON, and K.B. SCHUSTER. 1979. Toothed-plate connector joints subjected to long duration loads. *In* 19th Forest Products Research Conference. CSIRO, Melbourne, Australia.

LEIVO, M. 1991. On the stiffness changes in nail plate trusses. Technical Research Centre of Finland, Espoo, Finland. Publication No. 80.

MARAGHECHI, K., and R. ITANI. 1984. Influence of truss plate connectors on the analysis of light frame structures. Wood and Fiber Science 16:306-322.

MASSE, D.I., and J.J. SALINAS. 1988. Analysis of timber trusses using semi-rigid joints. Canadian Agricultural Engineering 30:111-124.

MATLOCK, G.E. 1992a. Nail end plate for wooden ties. U.S. Patent No. 5116179.

MATLOCK, G.E. 1992b. Special metal connector plates, an anti-splitting device for railroad ties. CIB-W18A/TG6.

MCALISTER, R.H. 1989. Interaction between truss plate design and type of truss framing. Forest Products Journal 39(7/8):17-24.

MCALISTER, R.H. 1990. Tensile loading characteristics of truss plate joints after weathering and accelerated aging. Forest Products Journal 40(2):9-15.

MCALISTER, R.H., and T.D. FOUST. 1992. Load/deflection parameters for metal-plate connectors in yellow-poplar and sweetgum structural lumber. Forest Products Journal 42(3):60-64.

MCCARTHY, M., and R.W. WOLFE. 1987. Assessment of truss plate performance model applied to southern pine truss joints. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. Research Paper FPL-RP-483. 13 p.

MCLAIN, T.E. 1983. Mechanical fastening of structural wood members — design and research status. P. 31-70 *in* Proceedings, Structural Wood Research — State-of-the-Art and Research Needs. American Society of Civil Engineers, New York.

MCLAIN, T.E. 1986. Resistance distribution - connections. *In* Reliability Based Wood Symposium (unpublished). Purdue Wood Research Laboratory, Purdue University, West Lafayette, Indiana.

MCLAIN, T.E. 1992. Repair and reinforcement of wood pallets with metal connector plates. CIB-W18A/TG6.

MEEKS, J.E. 1979a. Industrial profile of the metal plate connected wood truss industry. P. 3-5 in Proceedings, Metal Plate Wood Truss Conference. Forest Products Society, Madison,Wisconsin.

MEEKS, J.E. 1979b. U.S. and Canadian design methodology. P. 114-116 *in* Proceedings, Metal Plate Wood Truss Conference. Forest Products Society, Madison, Wisconsin.

MISRA, R.D., and M.L. ESMAY. 1966. Stress distribution in the punched metal plate of a timber joint. Transactions of the ASAE 9:839-842, 845.

NIELSEN, J., and A. RATHKJEN. 1994. Laterally loaded nail-plates. University of Aalborg, Aalborg, Denmark. Structural Design Paper No.1.

NOGUCHI, M. 1980. Ultimate resisting moment of butt joints with plate connectors stressed in pure bending. Wood Science 12(3):168-175.

NWPCA. 1994. Uniform voluntary standard for wood pallets. National Wood Pallet and Container Association, Arlington, Virginia.

OLIVA, M.G., L. KRAHN, M. MCCARTHY, and M. RITTER. 1988. Behavior of metal-plate connected joints in creosote treated wood: a pilot study. Forest Products Journal 38(7/8):76-80.

PALKA, L.C. 1984. Effect of wood density on truss-plate joint strength. Report to the Scientific Council of British Columbia No. 50-69-569. Forintek Canada Corporation, Vancouver, B.C., Canada.

PALKA, L.C. 1985. Prediction of short and long term behavior of truss-plate joints in tension. Forintek Canada Corporation, Vancouver, B.C., Canada. Special Publication No. SP-27.

PALKA, L.C. 1988. Exploratory study of short-term and long-term behaviour of truss-plate joints in tension under ambient laboratory conditions. Forintek Canada Corporation, Vancouver, B.C., Canada.

PARAMESWAR, H.C., and M.G. MANSELL. 1989. Limit state design of nail plate joints in timber trusses. Proceedings, Pacific Timber Engineering Conference 1:151-154.

PATTON-MALLORY, M. 1986. Strength of mechanically fastened wood connections. P. 92-95 in Proceedings, Current Topics *in* Forest Research: Emphasis on Contributions by Women Scientists. USDA Forest Service, Asheville, North Carolina. General Technical Report SE-46.

PERCIVAL, D.H., and S.K. Suddarth. 1971. An investigation of the mechanical characteristics of truss plates on fire-retardant treated wood. Forest Products Journal 21(1):17-22.

PERCIVAL, D.H., and S.K. SUDDARTH. 1988. Long term tests of 4 x 2 parallel chord metal plate connected wood trusses. Proceedings, International Timber Engineering Conference 1:475-481.

POLLOCK, D.G., Jr. 1989. Reliability based design for wood construction. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 89-4501.

POUTANEN, T.T. 1993. Connector plates, connector plate joints and connector plate structures. U.S. Patent No. 5234279.

QUAILE, A.T., and F.J. KEENAN, 1979. Truss plate testing in Canada: test procedures and factors affecting strength properties. P. 105-113 in Proceedings, Metal Plate Wood Truss Conference. Forest Products Society, Madison, Wisconsin.

RADCLIFFE, B., and A. SLIKER. 1964. Effect of variables on trussed rafters. Michigan State University Agriculture Experiment Station, East Lansing, Michigan. Research Report No. 21.

REYNOLDS, G.M. 1988. Analysis and testing of toothed metal plate wood truss connections. M.S. thesis. Michigan Technological University, Houghton, Michigan.

RILEM/CIB-3TT. 1982. Testing methods for joints with mechanical fasteners in load-bearing timber structures, ANNEX A - punched metal plate fasteners. Materiaux et Constructions 15(88):31-41.

SASAKI, Y., S. MIURA, and T. TAKEMURA. 1988. Non-linear analysis of a semi rigid jointed metal-plate wood truss. Journal, Japan Wood Research Society 34(2):120-125.

SASAKI, Y., and T. TAKEMURA. 1990. Non-linear analysis of metal plate wood trusses. Proceedings, International Timber Engineering Conference 3:701-708.

SHOWALTER, J.H., Jr., and K.H. GRUNDAHL. 1991. Metal plate connected wood truss design by LRFD. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE paper No. 91-4539.

SLETTELAND, N.T., G.L. PRATT, and R.T. SCHULER. 1977. Fatigue life of metal connector plates. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 77-4037.

SLIKER, A., and B. RADCLIFFE. 1965. Deflection and creep characteristics of trussed rafters with metal plate fasteners. Forest Products Journal 15(11):473-479.

SMULSKI, S. 1993. Flat truss failure. Journal of Light Construction (October):38-39.

SOLTIS, L.A., and R.M. SHEA. 1988. Duration-of-load effect on toothed metal-plate connections. Proceedings, International Conference on Timber Engineering 2:499-503.

STAHL, D.C., R.W. WOLF, S.M. CRAMER, and D. MCDONALD. 1994. Strength and stiffness of large-gap metal-plate wood connections. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. Research Paper FPL-RP-535. 9 p.

STERN, E.G. 1988. Truss plate with plurality of teeth stamped from same plate hole. Proceedings, International Conference on Timber Engineering 1:274-280.

STERN, E.G. 1992. 35 years of experience with certain types of connectors used for the assembly of wood structures and their components. Forest Products Journal 42(11/12):33-45.

STERN, E.G., J.D. DOLAN, and S. SUGAR. 1995. Bridge plate girder assembled with continuous double-sided metal connector plates. CIB-W18A/TG6.

SUDDARTH, S.K. 1963. A detailed study of a W truss with metal gusset plates. Agricultural Experiment Station, Purdue University, West Lafayette, Indiana. Research Progress Report 50.

SUDDARTH, S.K. 1972. A computerized wood engineering system: Purdue plane structures analyzer. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. Research Paper FPL-168. 50 p.

SUDDARTH, S.K., and D.H. PERCIVAL. 1972. Increasing the application efficiency of performance tests with analytic procedures. National Bureau of Standards. Special Publication 361.

SUDDARTH, S.K., D.H. PERCIVAL, and Q.B. COMUS. 1979. Variability in tension performance of metal plate connectors. P. 98-104 *in* Proceedings, Metal Plate Wood Truss Conference, Forest Products Society, Madison, Wisconsin.

TOKUDA, M. 1984. The feasibility of laminated veneer lumber for metal-plate connected joints. Mokuzai Gakkaishi 30:139-147.

TOKUDA, M. 1986. Mechanical properties of nailed joints and metal-plate connected joints under various environmental conditions. University of Tokyo, Tokyo, Japan. Bulletin of the Tokyo University Forests No. 75.

TOKUDA, M., M. TAKESHITA, and H. SUGIYAMA. 1979a. Creep behavior of metal plate connector joints subjected to tension force. Journal, Japan Wood Research Society 25:399-407.

TOKUDA, M., M. TAKESHITA, and H. SUGIYAMA. 1979b. The behavior of metal plate connector joints subjected to repetitive tension force. Journal, Japan Wood Research Society 25:408-413.

TPI. 1995. National design standard for metal-plate-connected wood truss construction. ANSI/TPI 1-1995. Truss Plate Institute, Madison, Wisconsin.

TPIC. 1988. Truss design procedures and specifications for light metal plate connected wood trusses. Truss Plate Institute of Canada.

TRICHE, M.H. 1984. Analysis and design of metal plate connections. M.Sc. thesis. Purdue University, West Lafayette, Indiana.

TRICHE, M.H. 1991. Eccentricities in metal-plate-connected joints. *In* Proceedings, Mechanical Fasteners Plenary Session. Forest Products Society, Madison, Wisconsin.

TRICHE, M.H., and S.K. SUDDARTH. 1988. Advanced design of metal plate connector joints. Forest Products Journal 38(9):7-12.

UBC. 1994. Light metal plate connected wood truss design. Section 2343, 2. International Council of Building Officials, Whittier, California.

UEAtc. 1994. Assessment of light weight metal-plate-connectors in wood construction and assembly. M.O.A.T. 16. European Union of Agreement, Paris, France.

VAROGLU, E. 1984. Structural analysis of trusses and roof truss systems. Project 02-50-68-582. Forintek Canada Corporation, Vancouver, B.C., Canada.

VATOVEC, M., R. GUPTA, and T.H. MILLER. 1995. Finite element modeling of metal-plate-connected joints in wood trusses. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 954586. 20 p.

WHITTINGTON, I.L. 1986. Truss plate behaviour in a prestressed integrated bridge deck. Final Year Project (ES400). University of Western Ontario, London, Canada.

WIGHT, M. 1977. Moisture content effect on strength of truss plate connector joints. Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada.

WILKINSON, T.L. 1966. Moisture cycling trussed rafter joints. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. Research Paper FPL 67. 38 p.

WILKINSON, T.L. 1978. Longtime performance of trussed rafters with different connection systems: 10-year evaluation. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. Research Paper FPL 204. 23 p.

WOESTE, F.E. 1975. Truss reliability as related to variability in modulus of elasticity of the constituent members. Ph.D. thesis. Purdue University, West Lafayette, Indiana.

WOLFE, R.W. 1990. Metal-plate connections loaded in combined bending and tension. Forest Products Journal 40(9):17-23.

WOLFE, R.W., M. HALL, and D. LYLES. 1991. Test apparatus for simulating interactive loads on metal plate wood connections. Journal of Testing and Evaluation 19:421-428.

YATES, J.L. 1987. Stochastic finite element analysis of metal plate connected wood trusses. M.S. thesis. Michigan Technological University, Houghton, Michigan.

YATES, J.L. 1989. Probabilistic analysis of metal plate connected wood trusses. Ph.D. dissertation. Michigan Technological University, Houghton, Michigan.

Other Relevant Literature

Aasheim, E. 1992. Further discussion on the design of nail plates. CIB-W18A[1].

Aasheim, E. 1993. Test of nail plates subjected to moment. CIB-W18, Paper No. 26-14-1.

Aasheim, E., and K.H. Solli. 1990. Proposal for design code for nail plates. CIB-W18, Paper No. 23-7-1.

Arbek, T. 1973. The effect of time on strength of truss plate joints. Civil Engineering Department, Carleton University, Ottawa, Ontario, Canada.

ASCE. 1988. Load and resistance factor design for engineered wood construction. A pre-standard report. American Society of Civil Engineers, New York.

Aune, P. 1970. Investigations on strength and stiffness of joints made with hydro-nail truss plates. Acta Polytechnica Scandinavica Ci 67.

Baird, J.A., and E.C. Ozelton. 1984. Timber Designers' Manual. Granada Technical Books, London, England. 624 p.

Blas, H.J., J. Ehlbeck, and M. Schlager. 1993. Characteristic strength of tooth-plate connector joints. Holz als Roh- und Werkstoff 51:395-399.

Bovim, N.I., and E. Aasheim. 1985. The strength of nail plates. CIB-W18A, Paper No. 18-7-6.

Breyer, D.E. 1993. Design of Wood Structures. McGraw-Hill, Inc., New York. 538 p.

Bulleit, W.M., and J.L. Yates. 1989. Stochastic behavior of metal plate connected wood trusses. Proceedings, Second Pacific Timber Engineering Conference 2:89-94.

Bulleit, W.M., and J.L. Yates. 1991. Probabilistic analysis of wood trusses. Journal of Structural Engineering 117:3008–3025.

Byerly, M.S., F.E. Woeste, and A.L. DeBonis. 1982. Nail laminated posts with metal plated joints. Transactions of the ASAE 25:441-444.

Cramer, S.M., D. Shrestha, and P.V. Mtenga. 1993. Computation of member forces in metal plate connected wood trusses. Structural Engineering Review 5:209-217.

[1]CIB-W18A is the International Council for Building Research Studies and Documentation, Working Commission W18-Timber Structures. (Address: General Secretariat, Postbox 20704, 3001 JA Rotterdam, The Netherlands. Phone: +31 10 411 0240 FAX: +31 10 4334372)

Dumovsky, A.M., and L.M. Kovalchuk. 1992. State of the art and outlook for use of metal connector plates in timber structures for small houses. CIB-W18A/TG6.

Dzida, F. 1979. Stress concentrations around splice joints in tension members. B.Sc. Forestry thesis. Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada.

Edlund, G. 1971. Splicing of timber joints with nail plates. Swedish Institute for Building Research, Stockholm, Sweden. Report R40.

Edlund, G. 1973. Nail plates as connectors in trusses. Swedish Institute for Building Research, Stockholm, Sweden. Report R52.

Edlund, G. 1974. Example of dimensioning structures assembled with nail plates. Swedish Institute for Building Research, Stockholm, Sweden. Report B,296 TT B:54.

Egerup, A.R. 1979. Design of metal plate connected wood trusses. CIB-W18A, Paper No. 11-14-1.

Egerup, A.R. 1979. European practice and future development in the design of metal plate connected wood trusses. Proceedings, Metal Plate Wood Truss Conference. P-79-28. Forest Products Society, Madison, Wisconsin.

Ehlbeck, J., and R. Gorlacher. 1984. Shear connections with nail plates. Bauen mit Holz 9:587-591.

Engestom, D., R. Kliger, and G. Johansson. 1994. Timber joints-philosophy and tests. Proceedings, Pacific Timber Engineering Conference 2:701-708.

Feldborg, T., and M. Johansen. 1981. Wood trussed rafters design, strength and stiffness tests on joints under short-term loading. Deflection of W-trussed rafters under long-term loading. Danish Building Research Institute, Hoersholm, Denmark.

FPS. 1993. Proceedings, International Workshop on Wood Connectors. Forest Products Society, Madison, Wisconsin. 148 p.

Galligan, W.L., D.W. Green, D.S. Gromala, and J.H. Haskell. 1980. Evaluation of lumber properties in the United States and their application to structural research. Forest Products Journal 30(10):45-50.

Groom, L.H. 1988. Experimental verification and nonlinear modeling of truss-plate joints by Runge-Kutta numerical methods. Ph.D. thesis. Oregon State University, Corvallis, Oregon. 202 p.

Grossthanner, O.A. 1992. Fabrication and erection of trusses assembled with metal connector plates. CIB-W18A/TG6.

Gupta, R. 1993. Testing metal-plate connected wood truss joints. CIB-W18 Meeting, Paper No. 26-14-5.

Gupta, R., and K.G. Gebremedhin. 1988. An experimental investigation to determine the strength of tension splice joints. Proceedings, International Conference on Timber Engineering 1:257-265.

Gupta, R., and K.G. Gebremedhin. 1988. Strength and stiffness of metal plate connected tension splice wood truss joints. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 88-4008.

Gupta, R., and K.G. Gebremedhin. 1990. Semirigid analysis of metal plate connected wood trusses. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 90-4527.

Gupta, R., K.G. Gebremedhin, and M.D. Grigoriu. 1991. Probabilistic characterization of strength of metal plate connected wood truss joints. Transactions of the ASAE 35:1286-1290.

Gurfinkel, G. 1973. Wood Engineering. Southern Forest Products Association, New Orleans, Louisiana. 537 p.

Hayward, R.M. 1977. Tensile strength of extended truss plate connectors. B.Sc. Forestry thesis. Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada.

Hoyle, R.J., W.L. Galligan, and J.H. Haskell. 1979. Characterizing lumber properties for truss research. P. 32-64 *in* Proceedings, Metal Plate Wood Truss Conference. Forest Products Society, Madison, Wisconsin.

Inlow, D.N., D.L. Wheat, and D.W. Fowler. 1988. Joint behavior of metal-plate connected wood trusses. Department of Research, Civil Engineering Department, University of Texas, Austin, Texas.

ITPA. 1990. ITPA Technical Handbook. International Truss Plate Association, Rowlands Castle, Hampshire, England.

Källsner, B. 1980. Design of joints with nail plates — the heel joint. CIB-W18A, Paper No. 13-7-5.

Källsner, B. 1981. The effect of support eccentricity on the design of W and WW trusses with nail plate connectors. CIB-W18A, Paper No. 14-7-5.

Källsner, B., and Y. Kangas. 1991. Theoretical and experimental tension and shear capacity of nail plate connections. CIB-W18A, Paper No. 24-7-1.

Kamiya, F., M. Kawai, Y. Hayayama, and K. Okada. 1988. Calculation method for stress and deflection of a metal-plated wood truss I. Experiment with a parallel-chord truss. Journal, Japan Wood Research Society 34:326-332.

Kanaya, N. 1983. Mechanical properties of timber joints with metal plate connectors. Journal, Society of Materials Science, Japan 32(359):922-928.

Kangas, J. 1985. A detailed testing method for nail plate joints. CIB-W18A, Paper No. 18-7-4.

Kangas, J. 1985. Principles for design values of nail-plates in Finland. CIB-W18A, Paper No. 18-7-5.

Kangas, J. 1991. Anchorage capacity of nail plate. CIB-W18A, Paper No. 24-7-3.

Kangas, J. 1992. Latest proposals and drafts for EUROCODE 5 in designing and testing of nail plate joints. CIB-W18A/TG6.

Kangas, J., and A. Kevarinmäki. 1992. Design values of anchorage strength of nail plate joints by 2-curve method and interpolation. CIB-W18A, Paper No. 25-14-2.

Karacabeyli, E., E. Varoglu, C. Lum, and L. Olson. 1990. Structural performance of punched metal plated glulam trusses. Proceedings, International Timber Engineering Conference 3:693-700.

Karlsson, P. 1980. Effect of moisture variation on strength and stiffness of nail-plate joint. Tampere University of Technology, Tampere, Finland.

Kauranen, P. 1979. Study of stiffness of nail-plate joint. Tampere University of Technology, Tampere, Finland.

Keenan, F.J. 1978. Design of truss plate joints. CIB-W18A, Paper No. 9-7-1.

Keenan, F.J., P. Dubelsten, T. Klajnerman, and B. Kyokong. 1983. Strength interactions of finger joints and truss plate joints in light wood trusses. Canadian Journal of Civil Engineering 10:466-480.

Keskkula, T. 1991. Durability of nail plate trusses in agricultural buildings. In Proceedings, SEPA Seminar on Stiffness of the Nail Plate Trusses. Tallinn, Estonia.

Kevarinmäki, A. 1991. Capacity of support areas reinforced with nail plates in trussed rafters. In Proceedings, SEPA Seminar on Stiffness of the Nail Plate Trusses. Tallinn, Estonia.

Kevarinmäki, A. 1991. Mechanical behaviour of nail plate joint — Part I: Mechanical behaviour of tooth. Helsinki University of Technology, Espoo, Finland.

Kevarinmäki, A., and J. Kangas. 1992. Moment anchorage capacity and rotational stiffness of nail plates in shear tests. CIB-W18A, Paper No. 25-14-1.

Kevarinmäki, A., and J. Kangas. 1993. Rotational stiffness of nail plates in movement anchorage. CIB-W18A, Paper No. 26-14-3.

King, C.G., and D.L. Wheat. 1988. Deflection and member behavior of metal plate connected parallel chord wood trusses. Proceedings, International Timber Engineering Conference 1:482-497.

Klein, G. 1992. Effect of partial embedment on the strength of plate-connected joints. Presentation to Truss Plate Institute Technical Advisory Committee, Truss Plate Institute, Madison, Wisconsin.

Kocher, G.L. 1986. An experimental investigation of buckling in the unsupported regions of metal connector plates as used in parallel-chord wood truss joints. M.S. thesis. Marquette University, Milwaukee, Wisconsin. 247 p.

Komatsu, K. 1989. Behaviour of nailed timber joints with steel side plates. Proceedings, Second Pacific Timber Engineering Conference 2:89-94.

Kovalchuck, L.M. 1992. Experiences with metal connector plates in the Commonwealth of Independent States. CIB-W18A/TG6.

Laidlaw, R.A., and L.C. Pinion. 1977. Metal plate fasteners in trussed rafters treated with preservatives or flame retardants-corrosive risks. Building Research Establishment, Stratford, England. BRE Information Sheet IS11/77.

Lau, P.W.C. 1977. The effect of specific gravity on the strength of truss plate joints. Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada.

Lee, J.N. 1994. Determination of multiaxial strength of truss plate using orthotropic strength theory. M.S. thesis. Department of Wood and Paper Science, North Carolina State University, Raleigh, North Carolina.

Leivo, M. 1983. Test loading of nail plate trusses. Tampere University of Technology, Tampere, Finland.

Lewis, S. 1994. Truss testing: the continual search for knowledge and economical performance. Good Connnections. Alpine Engineered Products, Inc., Pompano Beach, Florida.

Lewis, S., and S. Triche. 1994. Metal plate connected wood trusses in highway bridges. Proceedings, Pacific Timber Engineering Conference 3:59-68.

Lhuede, E.P. 1990. A reappraisal of nailed timber joints. P. 361-365 in Proceedings, Second National Structural Engineering Conference Institution of Australian Engineers, Adelaide, Australia.

Lhuede, E.P., and H.O. Breitinger. 1989. Load capacities of punched nail plates in wood with defects. Proceedings, Second Pacific Timber Engineering Conference 2:83-88.

Litze, H. 1992. Metal connector plate usage in industrial buildings on the European Continent. CIB-W18A/TG6.

Lum, C., and E. Varoglu. 1988. Testing and analysis of parallel chord trusses. Proceedings, International Timber Engineering Conference 1:460-466.

Ma, L.K.K. 1977. Overpressing and underpressing effects on strength of truss plate connector joints. B.Sc. Forestry thesis. Faculty of Forestry, University Of Toronto, Toronto, Ontario, Canada.

Mackenzie, C., and R. McNamara. 1994. Basic working loads for truss plate connections in *Pinus elliotti* (slash pine). Proceedings, Pacific Timber Engineering Conference 2:370-378.

McAlister, R.H. 1986. Performance of truss plate joints in structural flakeboard and southern pine dimension lumber. Forest Products Journal 36(3):41-43.

McCarthy, M., and J.K. Little. 1988. Sensitivity of truss plate model parameters to parameter determination methods. Forest Products Journal 38(5):63-67.

McLain, T.E. 1992. Design of metal plate connected wood trusses in the U.S.A. CIB-W18A/TG6.

Mironov, V.G. 1991. Deformation of nail plate trusses under short and long term loads. *In* Proceedings, SEPA Seminar on Stiffness of the Nail Plate Trusses. Tallinn, Estonia.

Mironov, V.G. 1992. Metal connector plate design in timber construction in the Commonwealth of Independent States. Proceedings, CIB-W18A/TG6.

Möhler, K. 1977. Testing of integral nail plates as timber joints. Proceedings, CIB-W18A, Paper No. 7-7-1.

Möhler, K. 1981. Derivation of the allowable load in case of nail-plate joints perpendicular to grain. Proceedings, CIB-W18A, Paper No. 14-7-6.

Mortensen, N., S. Kloch, and J. Nielsen. 1994. Punched metal plate fasteners and steel gussets for movement resistant joints in timber. Proceedings, Pacific Timber Engineering Conference 2:1-8.

Njoto, I., and I. Salim 1978. Tensile strength of eccentric roof truss tension splice. Civil Engineering and Applied Mechanics Department, McGill University, Montreal, Quebec, Canada.

Norén, B. 1979. Design of joints with nail plates. Proceedings, CIB-W18A, Paper No. 12-7-3.

Norén, B. 1980. Design of joints with nail plates — calculation of slip. CIB-W18A, Paper No. 13-7-4.

Norén, B. 1981. Design of joints with nail plates (Second edition). CIB-W18A, Paper No. 14-7-1.

Norén, B. 1981. Wood failure in joints with nail plates. CIB-W18A, Paper No. 14-7-4.

Norén, B. 1986. Design of joints with nail plates — principles. CIB-W18A, Paper No. 19-7-7.

Norén, B. 1986. Shear tests for nail plates. CIB-W18A, Paper No. 19-7-8.

Ozola, L. 1991. Changes in deformations of nail plate trusses. In Proceedings, SEPA Seminar on Stiffness of the Nail Plate Trusses. Tallinn, Estonia.

Palka, L.C. 1983. Effect of load duration upon timber fasteners: load-slip characteristics of toothed truss-plate joints in static tension. Prediction of load-slip characteristics of timber joints made with metal plate connectors. Development of an economical test system for automatic measurements and recording of long-term slip in timber joints. Forintek Canada Corporation, Vancouver, B.C., Canada.

Palka, L.C. 1986. Creep and load duration of truss-plate joints in tension. In Proceedings, Meeting of the International Union of Forestry Research Organizations, Ljubljiana, Yugoslavia.

Palka, L.C. 1988. Effect of long-term constant loads on truss-plate joints in tension under ambient laboratory conditions. Proceedings, International Conference on Timber Engineering 2:489-498.

Palka, L.C. 1989. Review of an exploratory study of truss-plate joints in tension under ambient laboratory conditions. Forintek Canada Corporation, Vancouver, B.C., Canada.

Pienaar, F.R.P. 1984. Design of nailed plated joints in timber structures for strength and stiffness. National Timber Research Institute, Pretoria, South Africa. Report No. CSIR/SR/HOUT - 360. 14 p.

Piskunov, Y.V. 1992. Problems with building structures assembled with metal connector plates in northern and eastern regions of Russia. Proceedings, CIB-W18A/TG6.

Ploos van Amstel, H. 1990. Comparison of five models in creep prediction of joints with Menig plates: 13 years' creep data available. Stevin Laboratories, Delft, The Netherlands. Report 4-84-7.

Poutanen, T.T. 1986. Joint eccentricity in trussed rafters. Proceedings, CIB-W18A, Paper No. 19-14-3.

Poutanen, T.T. 1987. Some notes about testing nail plates subjected to moment load. CIB-W18A, Paper No. 20-14-1.

Poutanen, T.T. 1988. Eccentricity in a nail plate joint. Proceedings, International Conference on Timber Engineering 1:266-273.

Poutanen, T.T. 1988. Nail plate behavior under shear loads. CIB-W18.

Poutanen, T.T. 1989. Analysis of trusses with connector plate joints. Proceedings, Pacific Timber Engineering Conference 1:155-159.

Poutanen, T.T. 1994. Steel failure design in truss plate joints. CIB-W18.

Quaile, A.T. 1970. Static bending tests of truss plate joints. M.S. thesis. University of Toronto, Toronto, Ontario, Canada.

Reardon, G.F. 1966. Properties of joints in messmate stringybark formed by punched-tooth metal plate connectors. CSIRO, Melbourne, Australia. Laboratory Report No. 1.

Reece, P.O. 1982. The design of continuous members in timber trussed rafters with punched metal connector plates. CIB-W18A, Paper No. 15-14-9.

Riley, G.J., and K.G. Gebremedhin. 1992. Semi-rigid analysis of metal plate connected wood trusses. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 924064.

Riley, G.J., K.G. Gebremedhin, and R.N. White. 1993. Semi-rigid analysis of metal plate-connected wood trusses using fictitious members. Transactions of the ASAE 36:887-894.

Roald, B., and E. Aasheim. 1991. Fire testing of nail plate connected wood trusses. Proceedings, International Timber Engineering Conference 4.114-4.121.

Rodda, E. 1965. The analysis of trusses with semi-rigid joints. Ph.D. thesis. Purdue University, West Lafayette, Indiana.

Rogers, C.J., G.W. Smith, and R.F. Thomas. 1992. Developments in the use of metal nail plates, an Australian and South East Asian perspective. Proceedings, CIB-W18A/TG6.

Rogers, C.J., R.F. Thomas, and G.W. Smith. 1994. Nail plate reinforcement of bolted joints. Proceedings, Pacific Timber Engineering Conference 2:349-352.

SAA. 1988. Methods for the determination of basic working loads for metal fasteners for timber. AS A-188. Standards Association of Australia, Sydney, Australia.

Scott, K., R. Gupta, and T. Miller. 1995. Dynamic effects on metal-plate-connected wood truss joints. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 954458. 17 p.

Sheppard, I. 1969. An analytical and experimental investigation of contact area stress distribution and buckling strength of light gage punched metal heel plates for timber trusses. Ph.D. thesis. Michigan State University, East Lansing, Michigan.

Shrestha, D. 1992. Fire endurance modeling of metal-plate-connected wood trusses. Ph.D. thesis. University of Wisconsin, Madison, Wisconsin.

Skaggs, T.D., F.E. Woeste, J.D. Dolan, and J.R. Loferski. 1994. Safety factors for metal-plate-connected wood trusses: theoretical design versus specifications. Forest Products Journal 44(9):11-18.

Smith, G.W. 1992. Research support for the development of timber products utilizing nail plates. CIB-W18A/TG6.

Smith, G.W., R.F. Thomas, and C.J. Rogers. 1991. Innovative use of metal plate connectors for timber products. P. 171-176 *in* Proceedings, Innovation and Economics in Building Conference, Brisbane, Australia.

Stern, E.G. 1971. The heel joint of trussed rafters — a progress report. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Wood Research Laboratory Bulletin 101.

Stern, E.G. 1971. Plate-assembled trussed rafters with improved heel joints — a pilot study. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Wood Research Laboratory Bulletin 104.

Stern, E.G. 1992. ASTM standard test methods for performance of metal connector plates. Proceedings, CIB-W18A/TG6.

Stern, E.G. 1992. Design of nailed connections of timber structures in accordance with U.S. National Design Specification for Wood Construction. Proceedings, CIB-W18A/TG6.

Stern, E.G. 1992. Punched metal truss plates. CIB-W18A/TG6.

Stern, E.G. 1993. Definitions of terms and multi-language terminology to metal connector plates. Proceedings, CIB-W18A, Paper No. 26-7-3.

Stevens, R.F. 1995. Metal connector plates. Chapter 5 in Connectors Manual. American Society of Civil Engineers, New York.

Stone, M.F., and R.A. Eckert. 1984. New opportunities created for component industry with multiple parallel-chord truss design. Automation in Housing and Manufactured Home Dealer 21(10):36-38.

Suddarth, S.K., D.H. Percival, and Q.B. Comus. 1979. Testing and analysis of 4 x 2 parallel-chord metal-plate-connected trusses. Small Homes Council-Building Research Council, University of Illinois, Champaign-Urbana, Illinois. Research Report 81-1.

Suddarth, S.K., and R.W. Wolfe. 1984. Purdue plane structures analyzer II: a computerized wood engineering system. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. General Technical Report FPL-40. 38 p.

Sugiyama, H. 1972. Bending capacity of timber joints with metal-plate-connectors. Annual Meeting of Japan Wood Research Society.

TPI. 1980. Design specification of metal plate connected parallel chord wood trusses. PCT-80. Truss Plate Institute, Madison, Wisconsin.

TPI. 1989. Quality standard for metal plate connected wood trusses. QST-89. Truss Plate Institute, Madison, Wisconsin.

TPI. 1989. Recommended design specification for temporary bracing of metal plate connected wood trusses. DSB-89. Truss Plate Institute, Madison, Wisconsin.

TPI. 1991. Commentary and recommendations for handling, installing, and bracing metal plate connected wood trusses. HIB-91. Truss Plate Institute, Madison, Wisconsin.

Triche, M.H., M.A. Ritter, and S.L. Lewis. 1994. Design and field performance of a metal-plate-connected wood truss bridge. Proceedings, Structures Congress 2:1310-1315.

Van de Kuilen, J.W. 1994. Mechano-sorptive effects in toothed-plate and split-ring joints. Proceedings, Pacific Timber Engineering Conference 2:97-105.

Van der Put, T.A.C. 1984. Discussion on the design of nail plate connections. Proceedings, Pacific Timber Engineering Conference I:22-28.

Vatovec, M., R. Gupta, and T.H. Miller. 1994. Strength and stiffness of metal-plate-connected scissors truss joints. American Society of Agricultural Engineers, St. Joseph, Michigan. ASAE Paper No. 944550. 16 p.

Whale, L.R.J. 1992. State of the art in the field of metal connector plates and their use in building structures in the UK. CIB-W18A/TG6.

Whale, R.J. 1991. Eurocode 5 — joint design. Proceedings, International Timber Engineering Conference 1.97-1.106.

Williams, J., and G. Smith. 1994. Load transfer mechanisms in toothed nailplates. Proceedings, Pacific Timber Engineering Conference 2:106-112.

Wilson, F. 1978. The effect of time between assembly and testing on the strength of truss plate joints. Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada.

Woeste, F.E., A.L. DeBonis, T.E. McLain, and L.D. George. 1984. Strength of nail laminated columns with metal plated joints. Transactions of the ASAE 27(1):173-176.

Wolfe, R.W., T. LaBissoniere, and S.M. Cramer. 1988. Performance tests of light frame roof assemblies. Proceedings, International Timber Engineering Conference 2:3-11.

Wolfe, R.W., and D. McDonald. 1991. Performance of metal plate connectors. Conference on Environmental Impacts of Wood-Based Products and Processes: A Mandate for Change. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. (Poster Session, Abstract).

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