LOAD-SLIP CHARACTERISTICS OF METAL PLATE CONNECTED WOOD JOINTS TESTED IN TENSION AND SHEAR

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ABSTRACT

Thirty-six metal plate connected wood joints were tested in tension and shear to failure to determine their strength and stiffness characteristics and failure modes. Twenty-one of the joints were tested in tension, and the rest were tested in shear. Test specimens included the four Canadian standard orientations and intermediate orientations of 30, 45, and 60°. For the joints tested in tension, failure was by plate shear for the 0°, by tooth withdrawal for the 30 and 45°, and by wood failure for the 60 and 90° orientations. For the joints tested in shear, failure was consistently by tooth withdrawal for the 0, 30, and 45°, and by plate shear for the 60 and 90° orientations.

A 2-parameter nonlinear model characterized the P-Δ curve quite well. When characterizing the P-Δ curve, the entire curve extending from zero to the ultimate load was used. The stiffness values for the intermediate angles were calculated from the stiffness values of the standard orientations using a Hankinson-type formula.

Keywords: Load-slip, metal plate, wood joint, stiffness, strength, modeling.

INTRODUCTION

Sophisticated computer programs such as SOLVER (Gebremedhin 1986), PPSA II (Suddarth and Wolfe 1984), and SAT (Varoglu 1984) have been developed for modeling wood structures. The applicability and usefulness of these programs would be expanded if truss joint models can be incorporated into these programs. To improve the design of metal plate connected trusses and make them more economical and reliable, more information about metal plate connected joint performance is needed. Data vital to this understanding include the determination of the load-displacement relationship, strength, stiffness values, and mode of failure of these joints.

Properties of lumber such as modulus of elasticity, moisture content, specific gravity, angle of grain, and properties of the metal connector plate such as size, thickness, tooth length, tooth density, configuration, and yield strength affect the performance of truss joints. Conducting experimental investigation on each and possible combinations of these properties would be costly and time-consuming. A theoretical model that would predict the load-displacement relationship and stiffness of truss joints would alleviate the necessity to conduct

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extensive testing of every type of joint. The model should be validated by experimental data.

The present study includes analysis of load-deformation of truss joints tested in shear and in tension. The configurations of the joints tested are shown in Fig. 1.

Objectives

The objectives of this study were to:

1) determine experimentally the strength and stiffness values of metal plate connected wood joints tested in tension and shear,
2) understand the behavior of the joints through their failure modes when subjected to tension or shear loads, and
3) develop models that would predict the load-deformation (P-Δ) relationships and stiffness values for the joints tested.

LITERATURE REVIEW

Several investigators have studied the mechanics of metal plate connected truss joints. Foschi (1977) developed a three-parameter nonlinear model that correctly characterized the P-Δ curves of metal plate connected truss joints. To use Foschi's model, one must fit parameter values to the P-Δ curve obtained experimentally. McCarthy and Little (1988) assessed the sensitivity of Foschi's model parameters to different parameter determination methods. They reported that alternative determination methods may produce a variance up to 70% among the same parameters. The validity of their conclusion should be confirmed by comparison with other data sets obtained from conducting similar joint tests. Currently, no standard exists for method of analysis such as determining the parameter values from test results. For example, Foschi set one of the three parameters to equal to zero (Foschi 1977); Triche and Suddarth (1988), and McCarthy and Little (1988) determined the parameters by fitting the P-Δ curve up to the critical slip (=0.015 inch); but McCarthy and Wolfe (1987) considered the data curve up to the ultimate load. Also no standard exists as to whether or not the data for replicates should be averaged to generate a mean load-slip curve. Lau (1987) and McCarthy and Little (1988) averaged the data for replicates, but McCarthy and Wolfe (1987) did not.

Because of the number of variables that affect joint performance, future research effort should probably focus on several areas. Of fundamental importance is confirmation of the appropriateness of current testing methods for metal plate connected joints. The ASTM Standard D 1761 (American Society for Testing and Materials 1985) includes only one standard joint configuration. This standard may not be sufficient for collecting data for joint stiffness for all fasteners. The Canadian Standard, CSA S347 (Canadian Standards Association 1980), includes four standard configurations of plate and wood grain to load orientations. These orientations simulate actual truss joint action under axial loading conditions. Triche and Suddarth (1988) extended the finite element model originally developed by Foschi (1977) to include determination of allowable load per tooth. The finite element model has been incorporated in PPSA II and provides a new engineering design tool that can support the expansion of wood truss and frame applications. Recently, Gupta and Gebremedhin (1990) have developed a novel computer-controlled testing apparatus and methods for testing metal plate connected truss joints. The system provides flexibility to test different joints such as tension splice joint, heel joint, and web at the bottom chord joint subjected to axial, bending, or combined axial and bending loading conditions.

Consideration must be given to the moment-carrying capacity of a truss joint. It may not be appropriate to assume that a joint is pinned. Massé and Salinas (1988) reported that the best representation of an actual truss joint is to assume that it is semi-rigid. They concluded that traditional design methods over-design the top chords and under-design the bottom chords. Maragechi and Itani (1984) tested tension splice joints in pure axial tension, pure shear, and pure bending to obtain

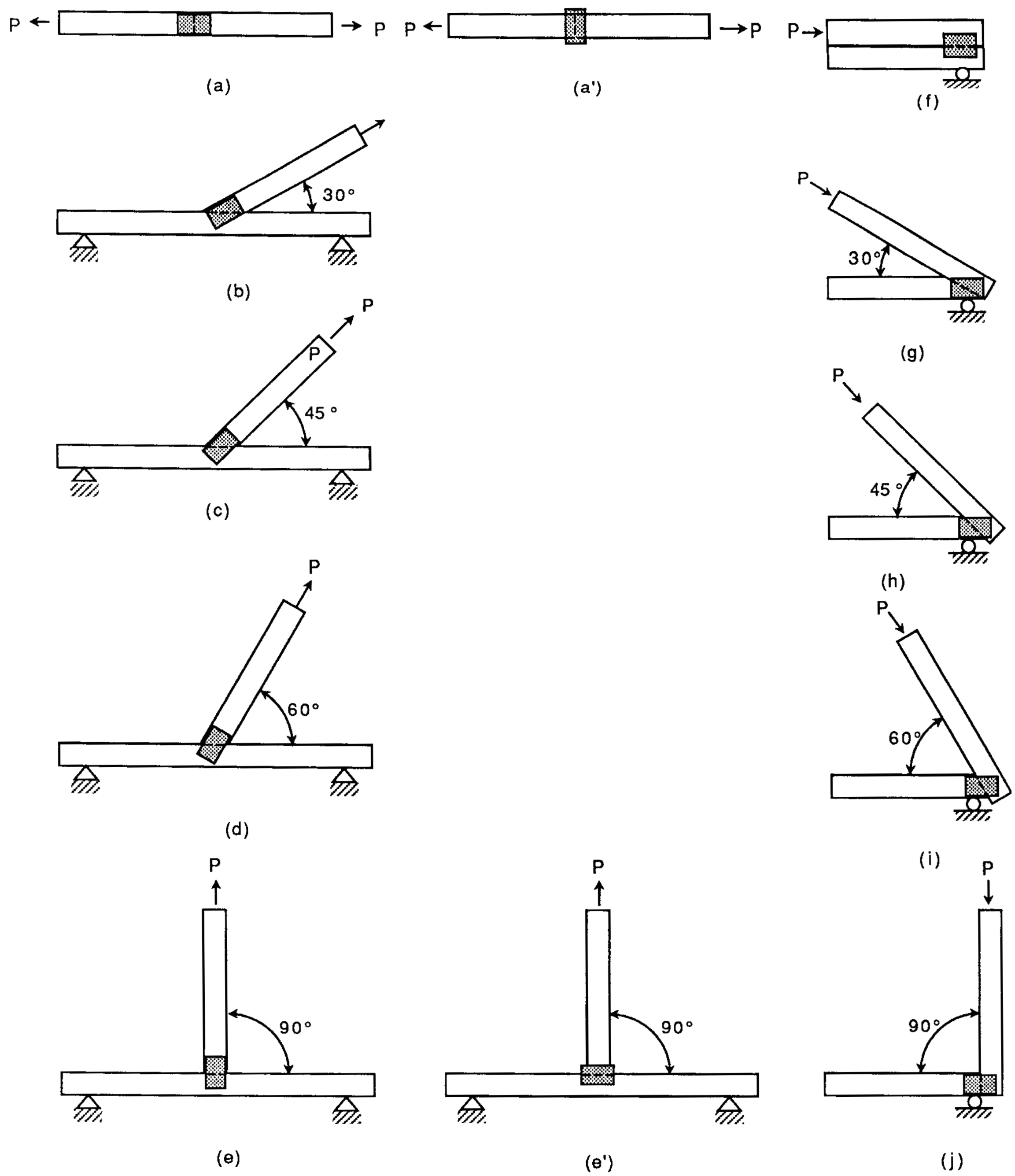

FIG. 1. Joint orientations. Joints (a) to (e') were tested in tension, and (f) to (j) were tested in shear.

stiffnesses for truss joints. They reported that axial and rotational stiffnesses had appreciable influences on member end forces, while shear stiffness had little effect.

The orientation of the metal connector plate affects the mode of failure of joints. McMartin et al. (1984) reported that improving designs of heel joints resulted in a 40% increase in the load carrying capacity of trusses. Sheppard (1969) tested heel joints fabricated using six different sizes of metal connector plates. The most common mode of failure of the joints was tooth withdrawal.

MATERIALS AND METHODS

Material and fabrication

All lumber used for this study was purchased from a local lumber yard and was No. 2 Southern Yellow Pine KD 15. The modulus of elasticity (MOE) and moisture content (MC) of each specimen were determined prior to fabrication of the joints. To determine the MOE, the 8-ft-long piece was placed flatwise and simply supported 6 ft apart. Dead weight was applied at the center in increments of 10 lb (up to 50 lb). Deflection was measured at midspan by a linear variable differential transducer (LVDT) and was recorded by a computer.

The moisture content of each piece was determined according to the ASTM D 2016-74, Method A (ASTM 1974). In this procedure, a 1-inch cross section was cut from each piece of lumber and weighed. All of the specimens were then placed in an oven and heated at 103 ± 2 C temperature for approximately 24 h until they reached a constant weight. Upon removal from the oven, the specimens were weighed immediately and the MC was calculated. The specific gravity (SG) of the specimens was not determined.

The metal connector plates were procured from an industry metal connector plate manufacturer. The specifications of the connector plates are given in Table 1.

TABLE 1. *Metal plate connector specifications.*

Plate size (inch)	3 × 5
Plate thickness (gauge)	20
Tooth density (teeth/sq. in.)	8
Tooth length (inch)	3/8
Teeth configuration	In-line
Modulus of elasticity (psi)	29.5×10^6
Yield strength (psi)	36×10^3

Joint fabrication and testing procedures

A total of 36 joints were fabricated and tested. These joints consisted of the four Canadian Standard orientations and three intermediate (30, 45, and 60°) orientations tested in tension, and five orientations (0, 30, 45, 60, and 90°) tested in shear. Each joint was replicated three times. All configurations are shown in Fig. 1.

Each joint was fabricated from a single piece of lumber cut in half and rejoined together by metal connector plates. This procedure would minimize variations in MOE, SG, and MC between the connected pieces. A hydraulic press was used to stamp the metal connector plates to the lumber. Unlike common practice in truss fabrication, only one plate was pressed at a time. Testing was conducted using a recently developed testing frame apparatus. The test frame was laid out horizontally and was bolted to the floor to restrict any movement. Each joint specimen was held in place by and loaded on this test frame. The test frame with a heel joint in place is shown in Fig. 2. The joints were kept at room temperature for 7 days prior to testing.

The load was applied through a hydraulic cylinder. A calibrated force transducer attached to the hydraulic cylinder measured the applied force. The cylinder was actuated by a single variable volume hydraulic pump and was restrained by the test frame to exert pressure on the joint. A proportional solenoid pressure control valve was the "heart" of the hydraulic system, permitting close control of the pressure in the cylinder. Joint slip was measured using LVDTs. The applied force was monitored and recorded by an IBM-PC/XT computer. The analog signals from the load cell and LVDTs were amplified using a signal conditioning unit and then converted into digital signals by an analog to digital (A/D) converter to be recorded by the computer.

The joint specimen was placed in the testing apparatus, and a tensile load (tension test) or a compressive load (shear test) was applied. In each case, the load was applied in a manner such that joint displacement was in the plane of the load. The following steps describe the loading procedure: