# Chapter 1 – Introduction

## 1.1 – Background and Description of Problem

Single-shear connections are by far the most common type of joint found in wood and timber structures. In such an assembly, two members are held together through the combination of lateral and withdrawal resistance provided by dowel-type connectors (nails, bolts, screws, etc.) which are oriented such that their axes run perpendicular to the interface plane between the two members. Their prevalence is largely owing to two factors: 1) the low cost of materials involved, and 2) the ease with which these materials may be employed in construction. Some prime examples of where these connections are typically employed in construction are:

- Connections between sheathing and framing members such those found between oriented strand board (OSB) and 2x4 wall studs.
- Connections between the framing members themselves such as those used to mechanically laminate the individual members of a built-up column.
- Connections between framing members and metal plates such as those existing between joist hangers and the girders to which they are attached.

For the most part, these examples characterize connections found in light-frame (wood frame) residential or commercial construction (Figure 1.1). The predominant loading component applied to this type of joint is often perpendicular to the dowel axis. In such cases, connections are said to be laterally-loaded.

Though common, single-shear laterally-loaded connections often represent the most critical points in a building from a structural standpoint. For wood structures, the vast majority of failures brought about by extreme loading conditions are initiated in the connections (Foliente 1998). This is due to the fact that laterally-loaded dowel-type connections are relatively inefficient at transferring loads from one member to another in terms of member size (Schreyer et. al. 2001). In other words, stresses are concentrated within the dowel or materials immediately surrounding the dowel such that they will reach said material's ultimate strength long before the main and side members reach their respective ultimate tensile or compressive strengths. These connections may therefore be thought of as stress-flow bottlenecks. The fact that single-shear connections represent a structure's most critical points, however, actually serves as an advantage in that it helps to isolate the mechanism of failure in such a system. Furthermore, nearly all of the ductility of a wood structure comes from its connections. Thus, a structure's ability to dissipate energy from dynamic loading depends mainly upon how its connections behave under such loading conditions.

Figure 1.1: Light-frame structure under construction.

Due to the combination of their prevalence and the fact that they often represent the most critical points within a structure, proper design of laterally-loaded single-shear connections is crucial to the integrity and stability of wood frame structures.

Over the past four decades, structural design procedures for reinforced concrete and steel have made the shift from ASD to *strength design* involving *load and resistance factors* (LRFD). In LRFD, one factor is applied to each side of the design inequality. These are: 1) the load factor, which is assigned to each respective loading type, and 2) the resistance factor, which is assigned to adjust the theoretical strength of a member or connection to its design value. Each factor accounts for the inherent variability of the term to which it is applied (Boresi et al, 1993). Strength design has several advantages over ASD. Through application of LRFD, a structure may be designed such that a certain probability of failure is not exceeded, thereby giving it an assumed *reliability*. Additionally, a design procedure based upon strength – or the condition of impending failure – provides greater insight into the actual mechanism of failure itself. This, in turn, allows for the design of structures with calculated amounts of ductility. Thus, strength design is especially advantageous in applications where the controlling loads are cyclic or dynamic.

Current techniques for design of laterally-loaded wood or timber connections in the United States follow the provisions of the *National Design Specification for Wood Construction* (NDS-97) (1997a). The NDS® provides equations for calculation of nominal lateral design values as well as tabulated values for various connection geometries and wood species (i.e. material strengths). These design values represent allowable loads with no consideration given to the connection's actual capacity. The aforementioned equations – the *general dowel equations* – are derived from the yield theory, which, as is discussed in Chapter 2, has been proven to accurately model the mechanics of a connection *at small deflections*. Thus, the general dowel equations may be used to accurately predict the resistance a connection will afford at its yield point.

The numerous studies that have validated the yield model typically involved experimental connection testing, followed by statistical comparison of test results to values calculated using said model. Due to the fact that these studies were conducted to investigate the validity of the model at *yield*, most of the connection tests were only run up to or just beyond that point. Thus, connection load-deflection behavior between yield and capacity (i.e. maximum resistance) is largely unknown; as is the validity of the general dowel equations for predicting the capacity of a connection. If deemed valid, these equations would make capacity-based design of laterally-loaded connections in wood possible.

This thesis presents research that was conducted in an effort to make capacity-based design possible for laterally-loaded connections in wood. Extensive experimental testing was conducted to develop physical data on the behavior of these connections between yield and failure. Based upon this, the accuracy of the yield model for predicting connection resistance at capacity was investigated.

## 1.2 – Objectives

The objectives of this research are: 1) Develop physical data on the behavior and mechanics of nailed and bolted single-shear laterally-loaded connections up to and beyond capacity, and 2) using this data, quantify the safety factors and over-strengths of design values currently stipulated by the NDS® and LRFD *Manual for Engineered Wood Construction* on a capacity-basis.

## 1.3 – Significance

Benefits gained from the development of data on laterally-loaded connection behavior up to and beyond capacity (i.e., the first objective) would include enhanced insight into the response characteristics a wood or timber structure exhibits when loaded to failure. An additional benefit derived from the experimental data is the quantification of various parameters characteristic of these connections. Some of these parameters, including equivalent energy yield, capacity, resistance and deflection at failure, and ductility ratio have not been quantified in previous studies for the particular configurations tested, and thus serve as new and possibly valuable information.

By determining the safety factors and over-strengths of a wide array of laterally-loaded connection configurations (i.e., the second objective), any trends that may exist with respect to geometry or material property test variables will be discovered. This, in turn, will further the establishment of a knowledge base upon which a capacity-based (as well as reliability-based) design technique for laterally-loaded wood connections may be implemented.

## 1.4 – Thesis Overview

Chapter 2 is a brief review of past studies that have resulted in advancements of knowledge in the field of laterally-loaded connections in wood. A concise historical review of connection design, as well as a discussion of current design practice is also presented in this chapter. Chapter 3 contains a thorough description of experimental materials used as well as methods followed in the experimental phase of this research. Materials, specimens, equipment, and testing procedures are all discussed in this chapter. In Chapter 4, test results are presented and discussed. A description of patterns, trends, and noteworthy observations is given in Chapter 4. Finally, a summary is given and conclusions, with reference to the objectives stated in Section 1.2, are presented in Chapter 5.

As with most experimental studies, the appendices of this thesis contain detailed information primarily made up of tabulated and plotted test results. Appendix A contains the plotted load-deflection curves recorded for each connection test. Appendix B presents tabulated program output from the data analysis program written specifically for analysis of raw data generated in this study. Tabulated values for all connection tests are included here, organized by set. Appendix C presents a tabulated comparison of connection resistance values obtained from test results to those calculated using equations for the yield model for each connection. Also included in these tables are values such as the moisture content, specific gravity, and embedment strength of each member of each connection.