WOOD FRAME SHEAR WALLS INCORPORATING METAL PLATE CONNECTED FRAMEWORK

By

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DEDICATION

This work is dedicated to my amazing wife Gina. She is the joy in my life and my driving force behind all that I do. I would never have been able to complete this without her love and support.

CHAPTER 1

INTRODUCTION

Research was conducted in order to determine the effects of Metal Plate Connectors, MPC's, used for framework connections in conventional shear walls. Walls of various configurations, listed in Table 1.1, were laterally loaded in a test frame used to isolate shear wall behavior. Four variables were investigated through the course of this research. The four variables were MPC size, framing member stiffness, sheathing thickness, and wall length. Shear wall behavior characteristics were measured and compared for walls with end-nailed connected framework and MPC connected framework. Conclusions were drawn based on load versus displacement graphs, visual observations and calculated behavior characteristics.

Shear walls are the primary lateral load resisting element in light frame structures commonly used in residential and wood frame construction. Shear walls are composed of dimensional lumber framing overlaid with sheathing. Shear walls are considered to act as deep cantilevered beams. Although shear walls contain much framework, only sheathing and its connection to the framework are considered to resist lateral load, load acting parallel to the length of the wall. Lateral loads are developed from wind and earthquakes. As such, as a shear wall is laterally loaded, the studs rotate as rigid bodies and the framework distorts as a parallelogram without bending the frame members. Since the framework is not forced to bend, the framework bending stiffness is not employed. This is due to flexible end-nailed connections between studs and struts. The sheathing rotates as a rigid body. Nails connecting the sheathing are deformed between the rotating studs and the rotating sheathing. Due to the differential displacement between the sheathing and framework, the nails will either withdraw from the frame or pull through the sheathing as the wall continues to deflect toward failure.

The objective of this research was to utilize the bending stiffness and strength of the framing members to improve a wall's resistance to lateral loads. Metal plate connectors, MPCs, were selected as a framing connection alternative for this research. MPCs can vary by size, shape, gage, and tooth pattern. The first MPC was created in 1952, and since that time they have been used extensively in wood frame construction.

MPCs are light gage steel plates with sharp protruding teeth formed by punching holes in the plate. The MPCs are pressed into the ends of two or more wood members to form a semi-rigid moment resistant connection.

MPCs were introduced as a connection for prefabricated trusses. Prior to MPCs, truss construction was done using the stick-framing method. Each truss was built, lifted into place, and secured by hand. MPCs allow for trusses to be prefabricated to specification, transported to the job site, and lifted into place as a component. Manual truss construction was exchanged for component installation.

Component use in residential and commercial construction is advantageous to architects, engineers, and builders. Architects design roof trusses for different appearances and functions based upon client needs. Before MPCs were made available to architects, only simple stick frame trusses were available. Now architects can draw on 75 different forms of trusses (Callahan, 1994). Engineers optimize strength and available space in a building by structurally designing roof and floor trusses. This process is done rapidly through computer software. After MPCs were introduced, builders no longer had to construct their own trusses. Trusses can be fabricated at a factory. The prefabricated trusses are better quality and can be transported to the jobsite. Builders save money on materials and labor required to construct trusses by using prefabricated engineered components. Components are prefabricated substructures that can be directly connected to the main structure with no manual alteration. Shear walls constructed with similar technology as roof trusses could easily fit into the component fabrication industry.

The motivation behind this research is to evaluate a new shear wall construction technique. There are several reasons for needing a new shear wall. Every year many lives are lost due to building destruction in lateral loading events such as tornados, hurricanes and earthquakes. Billions of dollars are spent every year repairing or replacing buildings damaged in these events. A stronger more durable shear wall would help mitigate the damaging effects of lateral loading events by saving lives and reducing the cost of repair. The construction industry could profit from a shear wall that can increase strength and durability of a structure without raising cost. A shear wall component that could be prefabricated would benefit engineers, architects, builders, and building owners. The use of structural components is cost effective.

Components are also specifically engineered and built under factory conditions with quality control guidelines. When a component of a structure can be lifted into place and secured, time and money are saved since the component was not built manually by skilled workers on the job site. The overall benefit of component construction to the owner is they have a structure with custom engineered and better built components at less cost.

The specific goal of this research was to experimentally determine whether conventional shear walls are improved by making framing connections with MPCs. This was accomplished by conducting tests on walls built with MPCs and comparing results with conventionally fabricated walls. The tests are separated into groups to isolate four variables. Each wall group was similar. The first group had walls built with different size MPCs. The size of the MPC, a measure of MPC teeth embedded into the framing members, will govern stiffness of a framing connection. The second group had walls built with MPCs and three different grades of lumber. Lumber grade represents wood density and stiffness. Higher grade lumber will result in stiffer framing connections and greater bending stiffness in the framework members. The third group investigated MPC-connected walls with three different sheathing thicknesses. Sheathing is the lateral load resisting component in conventional shear walls. The interaction of sheathing with MPCs was measured. All walls in the last group were built the same with the exception of wall length. Walls of 4 different lengths were tested. Monotonic load tests were conducted to collect load versus displacement data used to compare strength, stiffness and energy dissipation. Strength, stiffness and energy dissipation are the basis for comparison of this research. In addition to research conducted on various shear wall configurations, this study will identify different internal behaviors of MPC-connected shear walls that add to lateral load resistance, such as framework joints, stud bending, sheathing and its connections, and sheathing friction.

Table 1.1 lists the different wall configurations tested through this research. The first column is the name of the test set. The second column is the type of framework connection used on the wall. The third column is the grade of lumber used to frame the wall. In the column, the term DFL stands for the Douglas Fir Larch and the term SYP stands for Southern Yellow Pine. The fourth column is the thickness of sheathing used to connect the wall where the term OSB stands for Oriented Strand Board. The fifth column is the length of the wall and the last column is the number of replications of the given configuration.

TABLE 1.1. TEST SPECIMEN CONFIGURATIONS

Test Set	Framework Connection	Framing Grade	OSB Sheathing Thickness (IN)	Wall Length (FT)	Number of Replications
Framing Connector Tests	End Nails	DFL No. 2	None	4	5
	3X4 MPC	DFL No. 2	None	4	5
	4X4 MPC	DFL No. 2	None	4	5
	4X5 MPC	DFL No. 2	None	4	5
	5X5 MPC	DFL No. 2	None	4	5
	5X6 MPC	DFL No. 2	None	4	5
	6X6 MPC	DFL No. 2	None	4	5
	6X7 MPC	DFL No. 2	None	4	5
	End Nails	DFL No. 2	7/16	4	5
	3X4 MPC	DFL No. 2	7/16	4	5
	4X5 MPC	DFL No. 2	7/16	4	5
	5X6 MPC	DFL No. 2	7/16	4	5
	6X7 MPC	DFL No. 2	7/16	4	5
Framing Member Stiffness Tests	End Nails	SYP No. 1	None	4	5
	End Nails	DFL No. 2	None	4	5
	End Nails	DFL No. 3	None	4	5
	5X6 MPC	SYP No. 1	None	4	5
	5X6 MPC	DFL No. 2	None	4	5
	5X6 MPC	DFL No. 3	None	4	5

TABLE 1.1 CONTINUED

Sheathing Thickness Tests	End Nails	DFL No. 2	1/4	4	5
	End Nails	DFL No. 2	7/16	4	5
	End Nails	DFL No. 2	5/8	4	5
	5X6 MPC	DFL No. 2	1/4	4	5
	5X6 MPC	DFL No. 2	7/16	4	5
	5X6 MPC	DFL No. 2	5/8	4	5
Wall Length Tests	End Nails	DFL No. 2	None	4	3
	5X6 MPC	DFL No. 2	None	4	3
	End Nails	DFL No. 2	7/16	4	3
	5X6 MPC	DFL No. 2	7/16	4	3
	End Nails	DFL No. 2	None	8	3
	5X6 MPC	DFL No. 2	None	8	3
	End Nails	DFL No. 2	7/16	8	3
	5X6 MPC	DFL No. 2	7/16	8	3
	End Nails	DFL No. 2	None	12	3
	5X6 MPC	DFL No. 2	None	12	3
	End Nails	DFL No. 2	7/16	12	3
	5X6 MPC	DFL No. 2	7/16	12	3
	End Nails	DFL No. 2	None	16	3
	5X6 MPC	DFL No. 2	None	16	3
	End Nails	DFL No. 2	7/16	16	3
	5X6 MPC	DFL No. 2	7/16	16	3

CHAPTER 2

BACKGROUND

This research was conducted to observe the behavior of shear walls with MPC-connected framing members. It is important to understand the design and behavior of conventional wood frame shear walls in addition to models used to determine behavior of shear walls and MPC connections. Through an understanding of conventional shear wall and MPC behavior, models for combined behavior can be developed.

2 1 Conventional Shear Wall Composition

Shear walls are composed of dimensional lumber framing and structural sheathing. The framing plays two roles: It provides resistance to vertical loads and supports the sheathing. The wood framework composition consists of studs, chords, and struts. Studs are vertical members within the wall's interior that are spaced evenly throughout the wall length. A typical value for stud spacing is 16-in. on center. Chords are exterior studs but have a different function as explained later. Struts are horizontal members at the top and bottom of the wall. Chords and top struts are made of two 2 x 4 pieces of lumber face-nailed to form a single member. Since studs and chords are perpendicular to the struts, they are connected by either end-nailed or toe-nailed connections. Neither of these connections produces any rigidity in the joint. The framework is rigidly connected to the foundation to prevent wall horizontal translation and overturning moment by some form of mechanical fastener. Sheathing is attached to the framework to provide resistance to lateral forces. Nails are driven through the sheathing into the framework for attachment. Figure 2.1 illustrates conventional shear wall configuration.

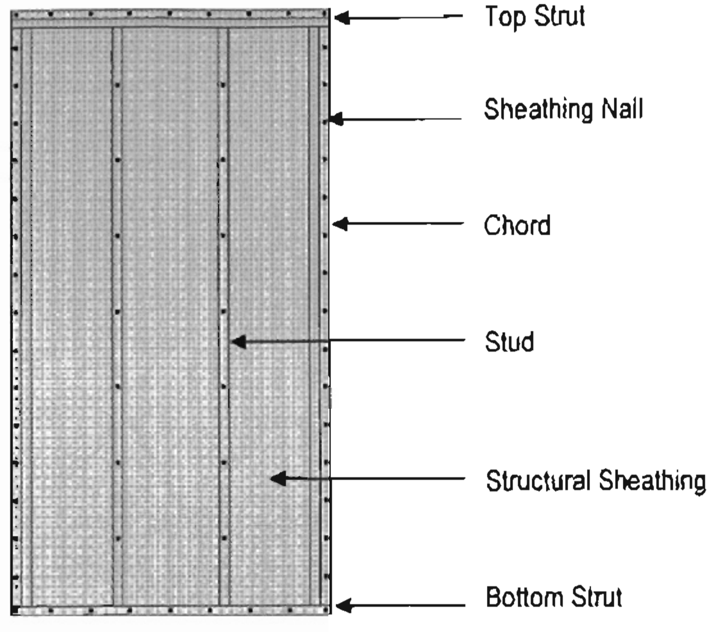

Figure 2.1. Conventional Shear Wall Configuration

2.2 Shear Wall Behavior

A shear wall behaves as a deep cantilevered beam when subjected to lateral forces. However, members of the shear wall begin to slip and move in relation to one another under increasing lateral load. As the wall racks, the sheathing rotates as a rigid body and the framework distorts as a parallelogram. The framework does not bend because there is no joint rigidity in the framework. The sheathing to framework nails are stressed due to the relative displacement between the sheathing and framework. The nails distort by bending and either withdraw from the framework or pull through the sheathing as load increases to the wall's capacity. The nails distort until the framework and sheathing are no longer rigidly attached and load resistance is lost. Figure 2.2 illustrates the racking behavior of conventional shear walls.

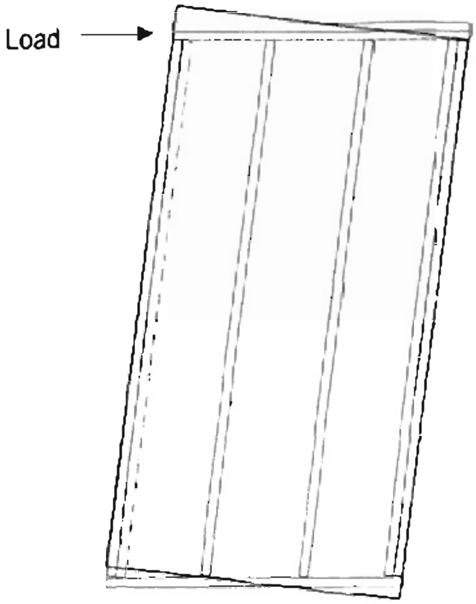

Figure 2.2. Racking Shear Wall

2.3 Shear Wall Design

Shear walls are designed as deep cantilever beams. As lateral load is applied to the wall, flexural tension and compression are developed. Tension is resisted by one chord and a mechanical tie-down to prevent uplift. Compression is resisted by the opposite chord. These are the only components that are considered when designing for flexural tension and compression. Studs and chords must also be designed to resist vertical loads. The cross section and spacing of the studs are typically governed by vertical loads and construction convenience. Struts are designed as a part of the horizontal diaphragm design. Shear forces developed in the wall can be accounted for by one of two methods, both of which are presented by Breyer, Fridley, and Cobeen (1999). The methods are identical unless the wall contains an opening. The segmented shear wall design method calculates the unit shear force on the wall by dividing the total lateral load applied by the length of full height wall. The sheathing type, grade and thickness along with a nailing schedule required to resist the lateral load can be selected from a table. If the wall contains an opening, the wall is separated into smaller wall segments. Wall segments with full height sheathing are considered alone and wall segments without full sheathing for the height of the wall are neglected. For instance, the sheathing above and below a window is disregarded as part of the shear resisting system. The shear force applied to the entire wall is divided by the length of the fully sheathed segments and distributed to the fully sheathed wall segments. The unit shear force is the total lateral load on the wall divided by the total length of fully sheathed wall segments. The designer can then go to a table to determine the appropriate sheathing type, grade, thickness and nail schedule. Each wall segment is assumed to act independently. Therefore, chords and tie-downs must be designed for each wall segment. The perforated shear wall design method is similar to segmented shear wall design with two exceptions. First, the wall is considered to act as a whole, including fully and partially sheathed wall segments. The resistance of a shear wall with no openings is determined. Then the resistance provided by the full height sheathing is multiplied by an opening adjustment factor. This factor is taken from a table based the on ratio of the height of the opening in the wall to the total wall height and ratio of wall length with full height sheathing to total wall length. The opening adjustment factor increases the required resistance from the sheathing over a wall with the same configuration designed by the segmented wall method. Since the wall is considered to act as a single unit, tie-downs and chords are only designed for the ends of the wall. According to Breyer, Fridley, and Cobeen (1999), the perforated design method will always calculate a lesser allowable shear wall capacity than the segmented shear wall design method. Therefore, the designer may trade tie-down anchors for increased sheathing nails, grade, or thickness. This is an economic issue to be weighed by the designer. Moment capacity due to shear wall framework is in no way considered a lateral force resisting component in shear wall design for either method. The end-nailed framework joint connections are flexible and will not prevent the framework from resisting moment.

2.4 Shear Wall Research

The majority of wood frame shear wall research has revolved around calculating strength capacity. Wall strength is derived from sheathing but is controlled by failure of the sheathing nails. Tuomi and McCutcheon (1978) developed a method of shear wall strength calculation based on the load distortion relationship of sheathing nails. Their method assumed a linear load distortion relationship of a single nail, parallelogram distortion of the frame, rigid body rotation of the sheathing, and nails are evenly spaced and symmetrically placed about the sheathing center. The total racking strength of the wall is the racking strength of one panel multiplied by the number of panels attached plus "the contribution of the frame itself" (Tuomi and

McCutcheon. 1978). This contribution was assumed to be 450 lbs for an 8 ft x 8 ft wall with two pieces of plywood sheathing. It is stated that these contributions are due to "friction of the sheathing sliding over the framework and other relatively minor considerations" (Tuomi and McCutcheon. 1978). Shear wall tests produced results in good agreement with the calculated racking strength.

Easley, Foomani and Dodds (1982), derived formulas for shear wall initial linear stiffness and nonlinear shear strain of wood frame shear walls. Wall stiffness was considered a function of nail lateral stiffness. This required a set of three equations be developed based on nail behavior. The behavior of a single nail connecting plywood sheathing to a piece of dimensional lumber was found to be initially linear elastic followed by a nonlinear region. As load is increased to capacity, the behavior becomes linear again. This behavior is depicted in Figure 2.3 where the letter A indicates a transition between linear elastic and the nonlinear behavior and B indicates a transition to linear behavior.

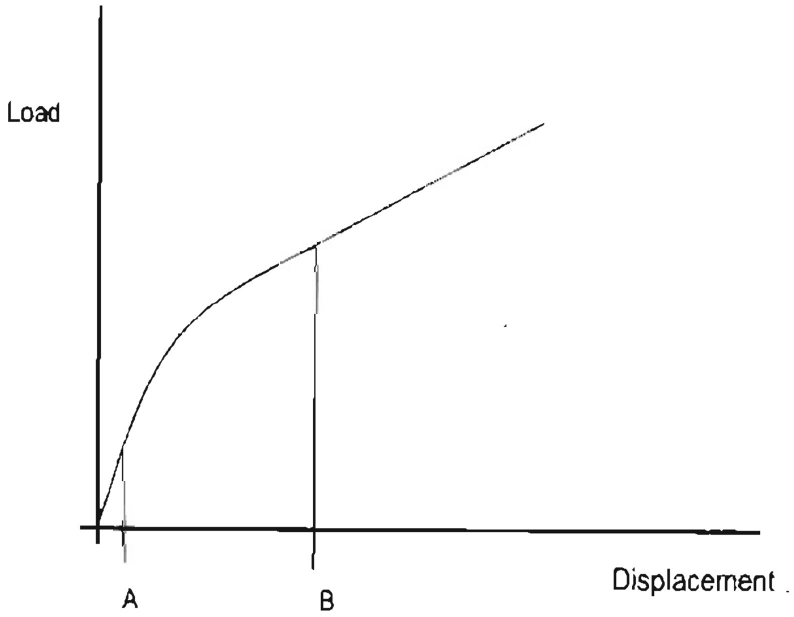

Figure 2.3. Single Nail Load Displacement Behavior

Each segment of load displacement behavior was used to produce an equation for shear strain of the wall. These equations were used to plot lateral load per length of wall versus shear strain. These plots were compared to actual wall data and a finite element analysis for the walls. Easley, Foomani and Dodds (1982) concluded that the equations for shear strain were "accurate to a degree usually acceptable in engineering practice." The graphed load versus shear strain results closely matched the form of the graphed data for the load versus displacement of a single nail, depicted in Figure 2.3. Figure 2.4 illustrates the value of shear wall shear strain, γ. Stiffness due to the frame itself was not taken into account by this method and parallelogram frame distortion was assumed.

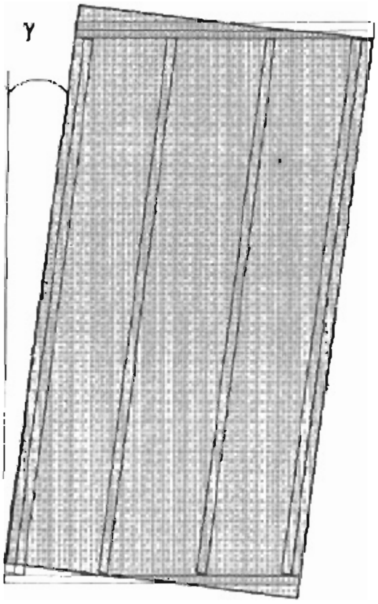

Figure 2 4. Shear Wall Shear Strain

Sugiyama and Matsumoto (1994) developed an empirical equation for calculating racking strength of walls. This equation was the basis for the perforated shear wall method mentioned before. Other shear wall research was devoted to validating the perforated shear wall design method. A specific example is the research conducted by Dolan and Johnson. Dolan and Johnson (1997) statically tested walls that were 40 ft in length and 8 ft tall. Five walls were tested, each with different sheathing coverage; one was fully sheathed and the others had holes for doors and windows or just had segments of unsheathed framing. Dolan and Johnson validated the perforated shear wall design method and found that the "strength predictions were conservative throughout the range of interstory drifts up to capacity." (1997)

According to Breyer, Fridley, and Cobeen (1999), the perforated shear wall design is the preferred design method because the expense of shear walls is driven up by the number of mechanical tie-downs required to resist overturning moment. The perforated shear wall design requires only two tie-downs per wall whereas the segmented wall design method could require any number of tie-downs. The National Association of Home Builders (1998), NAHB, conducted research on the perforated shear wall method to determine its validity by testing walls with varying base restraints and framing. This investigation concluded that the perforated shear wall method predicted wall racking strength conservatively by 10 percent. Two of the test specimens in the NAHB research were 20 ft long x 8 ft tall with three 4 ft x 4 ft windows. The three windows were centered in height and had fully sheathed segments that were two ft wide on either side of each window. One wall was anchored with moment tie-downs connected to the exterior studs and had nailed frame connections. The other wall did not employ moment tie-downs but did have MPCs connected to the wall and window corners in addition to nailed framing connections. The MPCs were 3-in. x 6-in. and pressed into the frame with a mallet. Shear restraints for the walls were identical. The NAHB reported that the wall with MPC connections showed much improvement over the wall with tie-downs. Maximum strength capacity, initial stiffness, and energy dissipation increased by 40, 38, and 68 percent for the MPC-connected wall.

2.5 MPC Design

Metal plate connected truss design is governed by two documents. The metal plate connections are designed according to the National Design Standard for Metal Plate Connected Wood Truss Construction produced by the Truss Plate Institute (2002). The wood truss members are designed according to the National Design Specification for Wood Construction (1997).

2.6 MPC Research

A truss is defined by flexible pinned connections and loads applied only to joints. Although called "trusses," wood frame trusses experience load along the length of their members and have semi-rigid connections. Member loadings cause flexure and semi-rigid joints transfer bending from member to member. Since bending moment is present in truss connections, research has been conducted to determine behavior of the semi-rigid connections. Noguchi's (1980), research investigated bending moments in MPC-connected butt joints, a joint made by splicing two members together with MPCs. This joint is commonly found in the tension chord of the truss when member lengths required are longer than readily available lumber. Noguchi suggested several possible flexural behaviors of the connection. Experimental tests were compared with models of moment behavior. Noguchi's fully plastic behavior model was determined to be the most accurate and was suggested to be used for design purposes. This model assumes all wood material in compression and all steel material in tension has yielded.

MPC connections have two failure states in tension: net section and tooth withdrawal failure. Net section failure occurs when the steel plate material yields and ruptures. Tooth withdrawal failures are a separation of the MPC and the wood member. MPC teeth pull out of the wood and the connection fails. O'Regan, Woeste, and Lewis (1998) tested splice joints under tension and several different degrees of flexure to determine net section capacity under combined bending and tension. The test specimens were built with plate lengths long enough to ensure the connection would not fail due to tooth withdrawal. The splice joints were pulled in tension loaded concentrically or with one of three eccentricities. The moment in the splice joint at failure was calculated by multiplying tensile force at failure by the eccentricity of the load. Three theoretical models were developed to predict the moment capacity of the splice joints. Each model was for flexural behavior which produces counteracting tensile and compressive forces. The MPC is assumed to resist tensile stresses developed and the wood is assumed to resist compressive stresses. The model that most closely fit the experimental data was derived by assuming plastic steel behavior and elastic wood behavior. The plastic steel elastic wood model was used to derive a design method for net section capacity of splice joints. Research on splice joints was continued by O'Regan, Woeste, and Brakeman (1998) to determine the required length of MPC to ensure a net section failure. This was done by equating the "average ultimate steel net section capacity" to the "average ultimate tooth withdrawal capacity" (O'Regan, Woeste, and Brakeman. 1998). By using the derived equation for minimum length of plate, splice joints can be governed by net section failure.

2.7 Background Conclusions

Conventional shear wall design has a common theme regardless of the method selected for design; sheathing alone resists lateral load. Rigid stud rotation is a common assumption for conventional shear wall research and can be verified visually. Each research conducted on methods of calculating lateral load capacity of shear walls has been proven valid with no consideration to lateral load resistance of framework. The idea for this research, to improve conventional shear walls with the addition of MPCs to the framework joints, stems from the fact that framework does not contribute lateral load resistance to the conventional shear wall. The research conducted by the NAHB proves that wall strength and stiffness are increased with just a few framework joints connected with MPC connections. This research will determine how much strength, stiffness, and energy dissipation will increase if all framework joints are connected with MPCs.

The MPC research reviewed demonstrates the failure states that would be similar to those occurring in MPCs used to connect shear wall framework. Research on MPC-connected right angle joint connections under bending, axial load, and shear has yet to be published. It is likely that if MPC failure were to govern lateral load capacity of shear walls, either tooth withdrawal or net section failures would be found as the failure states.

CHAPTER 3

TESTING AND ANALYSIS

The data acquisition and analysis chapter outlines the steps used to gain information on the behavior of shear walls connected with metal plate connectors. The testing procedure for this study follows ASTM E72-98, Standard Test Methods of Conducting Strength Tests of Panels for Building Construction, as a guideline. The difference between the test procedure used for this research and that recommended by ASTM E72-98 includes the load history and the size of the test specimens. ASTM E72-98 recommends that walls should be loaded until 3.5 Kips of lateral load capacity may be measured. The wall should then be unloaded and loaded again to 7.5 Kips and again to 10 Kips. Some walls in these tests could not produce the ASTM required 3.5 Kips of lateral load capacity and therefore, the loading procedure was changed to a single monotonic load test until the top of the wall deflected 5 in. with respect to the bottom of the wall. The maximum stroke of the actuator used for the tests was 5 in. ASTM E72-98 also recommended that test specimens be 8 ft long by 8 ft tall. These tests Investigated many test specimens with many replications and it was uneconomical to use 8 ft wall lengths for the majority of the tests. The majority of walls were 4 ft to efficiently investigate many variables. Data was collected in order to define MPC-connected shear wall behavior and compare it to conventional shear wall behavior. The process of collecting data began with fabricating the test specimens and attaching them to a test frame built to isolate racking behavior. Data, the relative displacements of the wall and the corresponding load to force the displacement, were then acquired from the wall under loading. These data were plotted to form load-displacement histories. The load displacement histories were used to calculate values of strength, stiffness, and energy dissipation. Wall data were analyzed by comparing the calculated values and load displacement histories of each wall. The process was completed by determining the moisture content of each framing member in each wall.

3.1 Test Specimen Fabrication

Test specimen fabrication had three steps. First, each member of the framework was cut to size and tested for bending stiffness. Second, the framework of the test specimen was connected by nails or MPC. Third, if sheathed wall behavior was to be recorded, sheathing was attached. Finally, all walls were set aside for a seven day waiting period. Each wall was constructed precisely following these four steps to limit variability of wall behavior.

3.1.1 Member Production and Material Properties

The experimental procedure began with fabrication of the walls. The wall components were fastened together with nails or nails and MPCs. All framing members for each wall, 2 x 4 dimensional lumber, were cut to exact lengths to allow a precise fit of the wall. The framework members are named studs, chords and struts. Studs are the interior vertical framing members of the wall. Chords are the vertical framing members on the outside edge of the wall. Struts, also known as plates, are horizontal members at the top and bottom edges of the walls. Each stud and chord was cut to 91.5-in. long and each strut was cut to 4, 8, 12, or 16 feet long, depending upon the wall length tested. Figure 3.1 illustrates the framework found in a typical shear wall that does not contain openings. In Figure 3.1, the short hash marks represent framing nails. This figure also shows the name and orientation of each framing member.

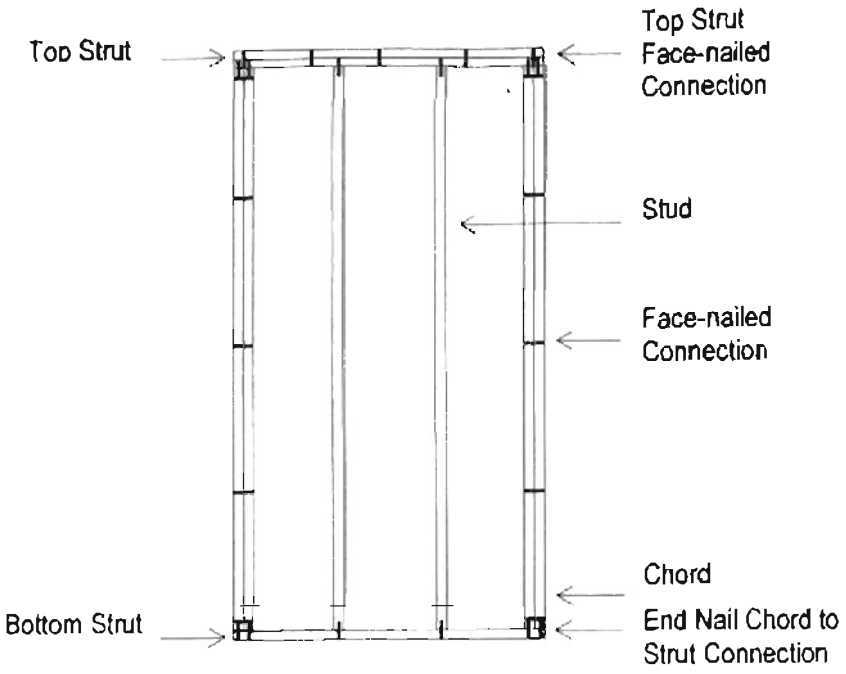

Figure 3.1. Framework Nails

The struts were directly connected to the test frame by bolts to resist shear at the plane between the top and bottom of the wall and the test frame and therefore contain holes. Holes were drilled into the centerline of the struts, and spaced at 16-in. on center. 5/8 in. diameter bolts were used; therefore 11/16-in. diameter holes were drilled to accommodate the 5/8 in. bolts.

After cutting the framework members, the weak axis bending stiffness of each piece was measured for data comparisons after the tests were conducted. Each framework member in a shear wall bends about its weak axis. The weak axis bending stiffness was determined by setting each wood member in its flat wise orientation across a 3 ft simple span and measuring the deflection of the wood member when a 50-lb weight was set on the member at midspan. Then the deflection was used to calculate stiffness. Equation 3.1. is the equation for deflection of a simply supported elastic member which was used to determine the bending stiffness.

$$\Delta = \frac{PL^3}{48EI} \tag{3.1}$$

The term Δ is the deflection measured from a digital dial gage. The span, L, was equal to 3 ft. The load, P, was 50 lbs. The 3 ft span and 50 lb load were selected so that the bending stiffness tests could be easily conducted by hand. The bending stiffness, EI, was determined and recorded for later use. Figure 3.2 illustrates the apparatus used for acquiring the bending stiffness of the framing members. This picture shows a 2 x 4 placed across a 3 ft span and loaded with a 50 lb weight. A dial gage was placed directly below the weight to measure the initial and final deflection of the 2 x 4.

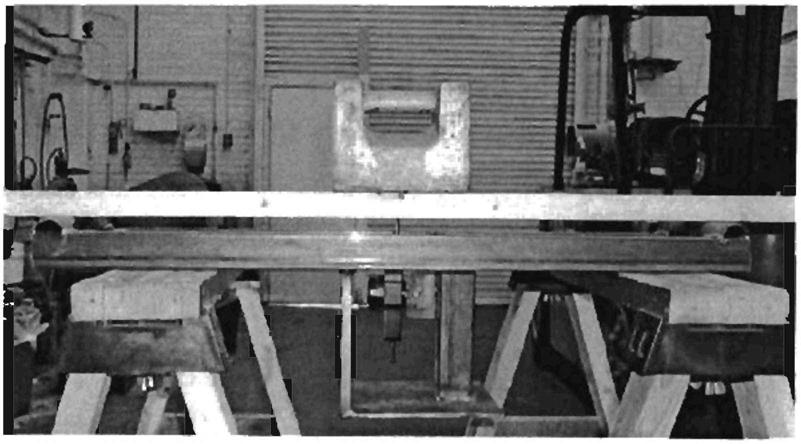

Figure 3.2. Bending Stiffness Measurement

3.1.2 Framework Connection

Each frame had an exact geometrical configuration. Studs and chords were spaced at 16-in. on center, positioned parallel to one another and perpendicular to struts. To ensure the wall frames were identical, a jig made of steel tubing was fabricated to hold the frame during construction. The jig stiffness was sufficient to bend the wood frame members toward the steel tubing when they were clamped to the jig. This ensured that crooked or twisted wood members were pulled into place rather than the jig bending to conform to the framework. Figure 3.2 shows the jig with loose members placed into the jig before connection.

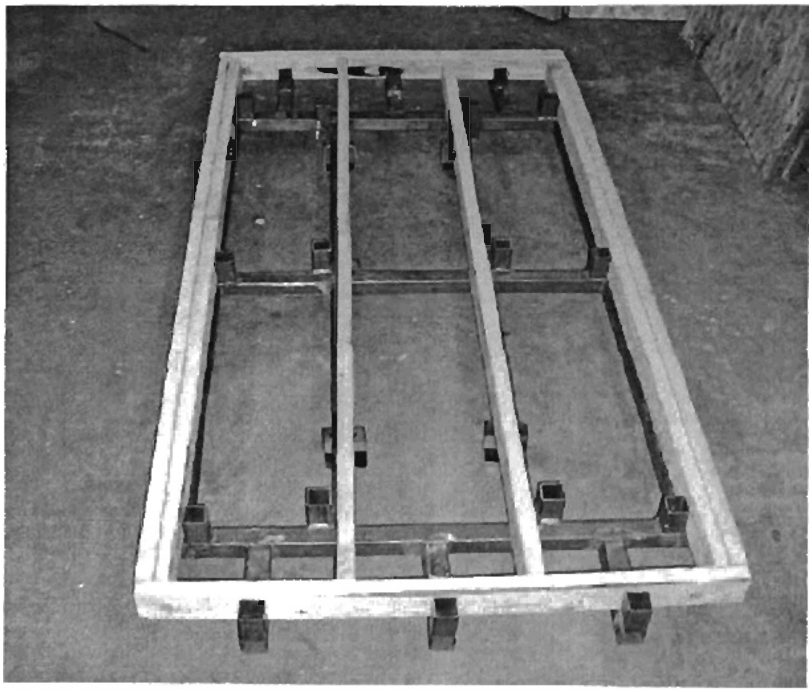

Figure 3.3. Wall Fabrication Jig

After the struts and studs were clamped to the jig and verified for proper placement, the frame members were connected together. Nailed walls were started by nailing the chords together with 3-1/2-in. 16d nails spaced at 24-in. Nails were driven with a pneumatic nail gun. The chords and top strut were double 2 x 4 specimens, which means that two 2 x 4 pieces of lumber were face-nailed to approximately form a 4 x 4 member. The struts were end-nailed to the ends of the studs and chords with two 3-1/2-in. 16d nails driven through the strut into the end of each stud and chord. The nails forming the double strut were driven last so that nails connecting the double strut to the studs and chords could be driven. The first piece of the double strut was connected with two nails driven into the ends of the studs and chords, and then the second piece was face-nailed to ensure enough length of nail was driven into the studs and chords. The double strut was connected with 3-1/2-in. 16d nails at every 12-in.

Walls composed of framework connected with metal plate connectors, MPCs, used only some of the framing nails mentioned before. The chords and double strut members were face-nailed, but the walls did not use stud to strut or strut to chord end-nail connections. The end-nailed connections were replaced with MPCs. The MPC connections were fabricated following the National Design Standard for Metal Plate Connected Wood Truss Construction, TPI 1-2001, issued October 19, 2001, as a guideline. The framing members were clamped together to prevent gaps in excess of 1/16-in. between the framing members. The jig and clamps were used to close gaps between wood members. The MPCs were pressed into each side of the wood framing using an Eagle Metal Products Field Repair Press. The MPCs were pressed flush to the wood to eliminate embedment gaps. Each MPC was pressed into the frame at a specific orientation and placement. In the corners of the wall, chord MPCs were positioned to allow outside MPC edges to remain flush with outside wall edges. Stud MPCs were positioned to allow the outside MPC edge to remain flush with the strut and the MPC center was centered with the stud. All MPCs were placed in the same orientation so that tooth slots ran parallel to the studs. This orientation provided the greatest tooth holding strengths for the joint configurations. MPC positioning and orientation were selected prior to testing and maintained throughout the test duration. Figure 3.3. illustrates an MPC connection in shear wall framework. The figure shows an MPC used to connect the corner framework of a sheathed wall.

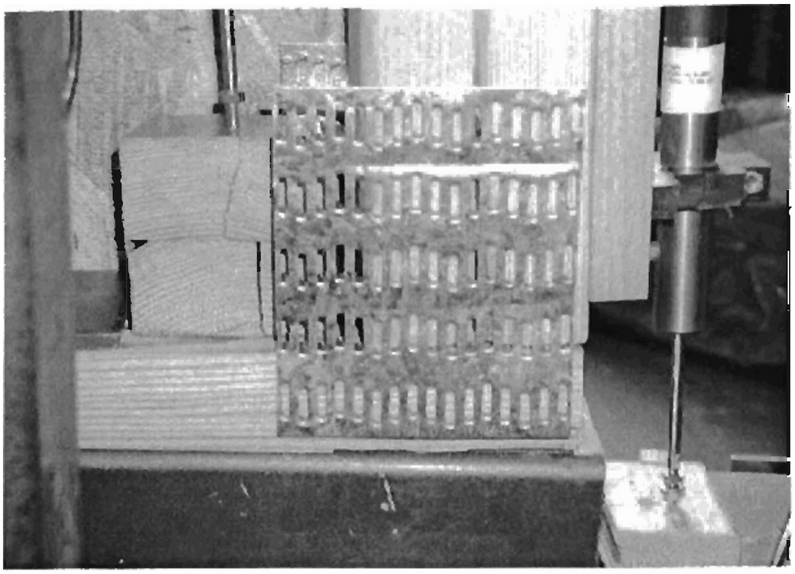

Figure 3.4. MPC Connection

The MPC selected for the test was the Wave™ Metal Connector Plate for Wood Trusses produced by Alpine Engineered Products, Inc. Full specifications for this MPC can be found in ES Report ER-5352 from ICBO Evaluation Service, Inc. Table 3.1 presents connection information for wall construction.

TABLE 3.1. WALL CONNECTION AND ANCHORAGE

Connection	Description	Number and Type of Connector	Spacing
Framing	Top Strut to Top Strut—Face-nailed	16d	12-in. on center
	Top / Bottom Strut to Stud End-nailed	2-16d	per stud
	Chord (Stud to Stud) Face-nailed	2-16d	24-in. on center
Sheathing	Edge	8d	6-in. on center
	Field	8d	12-in. on center
Bolts	Wall Anchorage	A307 - 5/8 in. diameter	16-in. on center
MPC	Wave™ Plate, Pair Per Stud, Size Specified for Test Set		

3.1.3 Sheathing Attachment

After all framing nails and/or MPCs were in place, sheathing was placed on top of the frame for connection. Each piece of sheathing was nailed with 8d sheathing nails at 6-in. around all outside edges of the sheathing and at every 12-in. to studs located within the field of sheathing. Figure 3.3. illustrates the nail placement used to attach the sheathing.

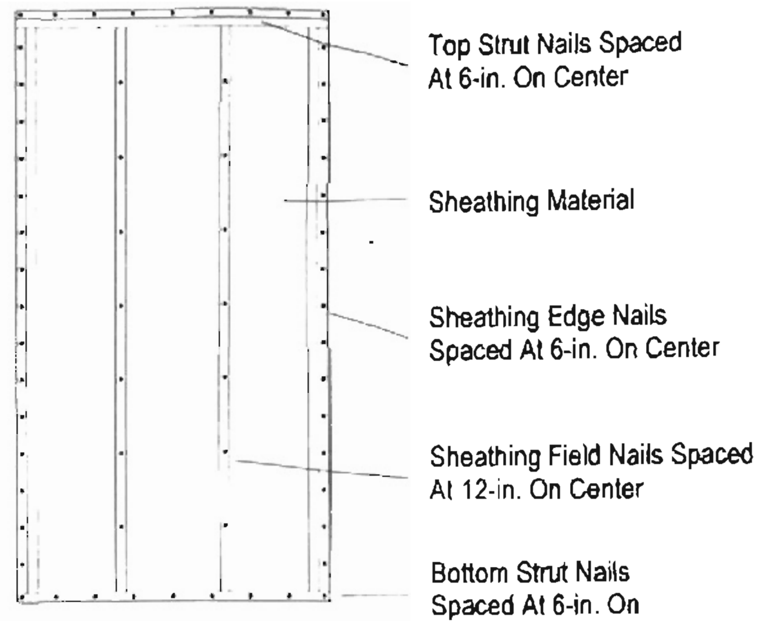

Figure 3.5. Sheathing Nails

3.1.4 Material Conditioning

ASTM D 1761 specifies that wood should be kiln- or air-dried for the wood to reach moisture equilibrium. The wood for this study was purchased kiln-dried from a local lumber yard. However, some of the wood was transported in wet conditions and therefore had high moisture contents prior to testing. The wood was allowed to dry within the testing laboratory before the walls were fabricated. TPI 1-2001 stipulates that trusses connected with MPCs are to be set aside for seven days before to obtain typical strength of connections. MPC connections are at their greatest strength immediately after fabrication. When MPCs are pressed into wood members, wood material is pressed tightly against the steel material as the teeth enter the wood. The 7-day period allows the wood material to relax which releases pressure between the wood and metal contact surface. The 7-day waiting period is sufficient to reduce the connection strength to the in-service connection strength. All walls in this study were tested seven days after fabrication.

3.2 Test Specimen Loading

After the 7-day waiting period the walls were tested in a frame designed to isolate racking behavior in the wall. The walls were attached to the test frame and loading tube with 5/8-in. A 307 bolts. Three to twelve bolts were used to attach the walls to both the loading tube and the test frame depending upon the length of the wall. The top bolts attach the loading tube to the double top strut. An MTS 22-kip actuator was used to move the loading tube. The 5/8 in. bolts resisted the translation of the wall, but a moment was developed by the lateral load. Unrestrained, this moment would cause the wall to potentially rotate and overturn as a rigid body or result in a premature tension failure of the connection between the chord in tension and the bottom strut. The overturning moment was resisted by all-thread ties attached to the wall and test frame at the actuator side. Friction was reduced from the tie by placing a roller between the tie and loading tube pushing the wall. The sheathed walls were only sheathed on one side. Out-of-plane braces were employed to prevent out-of-plane bending resulting from the asymmetric section. Figure 3.1 illustrates the placement of all braces and bolts used to restrain the wall.

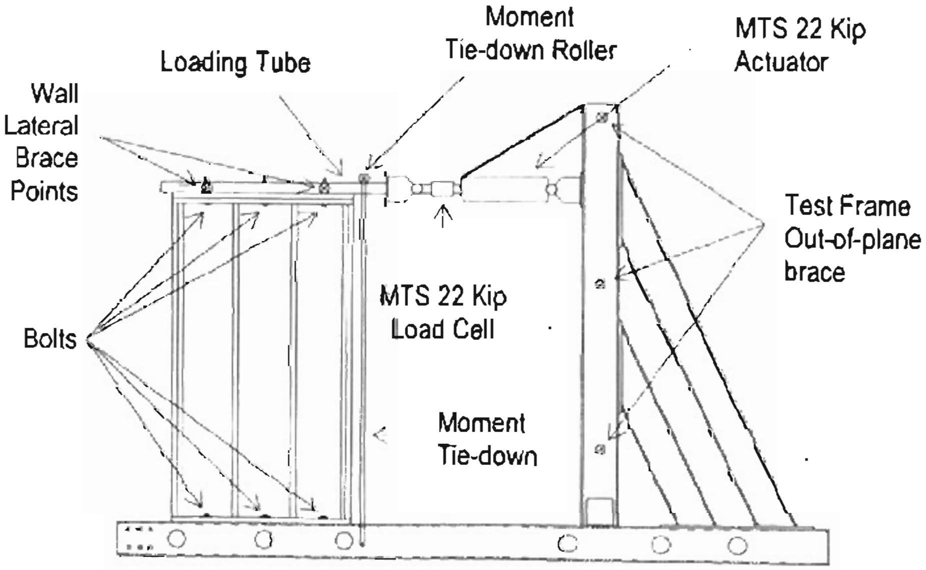

Figure 3.6. Wall Anchorage and Restraint

3.3 Data Acquisition

The data collected in wall tests for comparison were a series of six relative displacements of each wall. Each relative displacement in a series was paired with a corresponding lateral load which was used to plot load-displacement curves. Data acquisition was accomplished through placing linear variable displacement transducers (LVDTs) at specific points on the wall, controlled deflection of the wall, and monitoring the lateral load applied to the wall.

3.3.1 LVDT Placement

Six LVDTs were used to collect the displacement history of the walls during testing. The first LVDT recorded tension chord uplift. The second LVDT recorded tension chord and bottom strut separation. The difference in recordings from the first two LVDTs was used to determine the uplift of the bottom strut under the tension chord. The third LVDT recorded compression deformation between the compression chord and the bottom strut. The fourth LVDT recorded downward movement of the compression chord. The difference in recordings for the third and fourth LVDTs was used to determine the crushing of the bottom strut below the compression chord. The remaining LVDTs recorded horizontal wall movement. The fifth LVDT was located at the bottom of the wall to measure slip between the bottom strut and the test frame. The sixth LVDT was located at the top of the wall to measured horizontal displacement of the top MPC. Figure 3.2 demonstrates the LVDT placement. Although six LVDTs were used for data acquisition, only two were used for calculations of wall behavior comparison in this study. The two LVDT's used for this study were the LVDT that measured horizontal movement of the top of the wall and the LVDT that measured horizontal movement of the wall bottom. Vertical displacements were found to be extremely small and therefore of little importance. The load displacement behavior of the walls was evaluated using the relative displacement between the top and bottom of the wall.

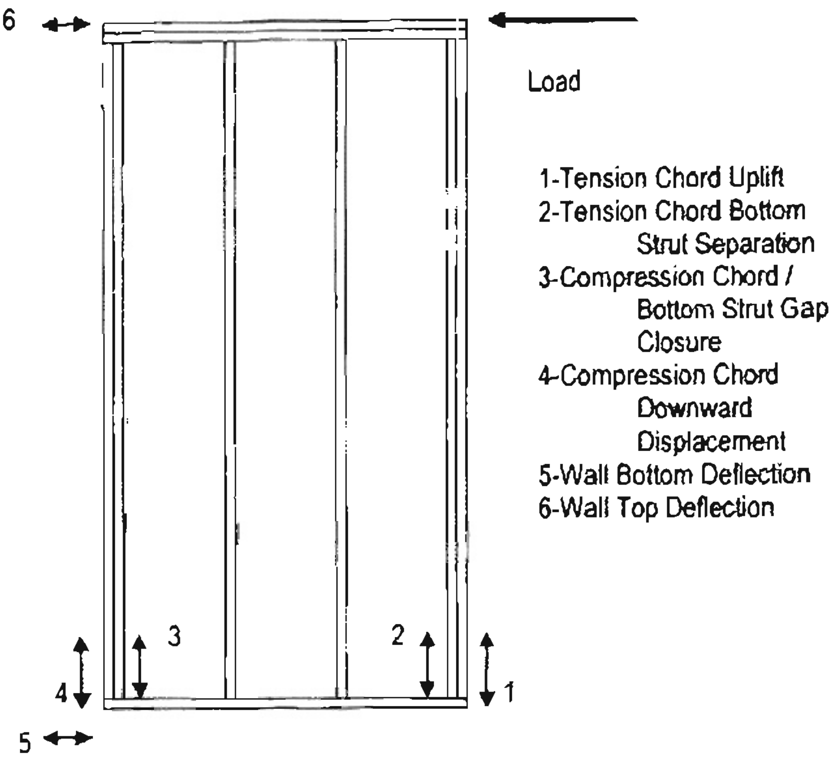

Figure 3.7. LVDT Placement

The walls were loaded monotonically under displacement control. The actuator controller was programmed to load the wall under displacement control at a rate of 0.5-in. per minute for a displacement of 5-in. An MTS 22-kip load cell was placed between the wall and the actuator to record the load on the wall at any given time. The load cell and LVDT measurements were recorded via a DAQP-16 data acquisition card produced by Quatech. Analog signals are input into the card and output as digital signals. The digital signals were recorded via a Dasylab data acquisition program. Dasylab was used to record the displacement of each LVDT and the load on the wall at 2-second intervals and store the data. The digital signals were later imported into Microsoft Excel for analysis.

3.4 Data Analysis

Several characteristic values were calculated and tabulated for comparing wall behavior. Three values for strength, two for stiffness, and one for energy dissipation were used for comparing relative wall behaviors.

3.4.1 Strength Characteristic Values

Three strength values were used for the comparison—maximum load, load at 4-in. drift, and design load. Maximum load was defined as peak loading or strength capacity, followed by a consistent drop in load as deflection continued. Some walls in this test were too ductile to fail within the 5-in. drift. For these walls, a load at 4-in. drift was found and recorded because the maximum strength capacity could not be determined. The method and equations for determining the design load is a detailed process that can be found in the ICBO Evaluation Service Report AC130 Acceptance Criteria for Prefabricated Wood Shear Panels and the 2000 International Building Code. The ICBO report method is specified for cyclic tests and was altered to fit the monotonic tests for this study. Step 1 was to determine δ_x, the maximum inelastic response displacement. The value δ_x is the smaller of the inelastic drift limit as defined in IBC Table 1617.3 or the displacement at the strength limit state. The IBC defines δ_x as $0.025h_{sx}$ or 2.5% of the wall height. 2.5% of the wall height is 2.4-in. for 8-ft walls. Displacement at the strength limit state is the displacement at the maximum load, as defined before. For walls that reach a maximum load before a 2.4-in. drift, δ_x is the drift at maximum load. For walls that reach a maximum load before a 2.4-in. drift, δ_x is 2.4-in. The next step was to determine C_d which is defined as the deflection amplification factor in the IBC. C_d can be found in IBC Table 1617.6 and was determined to be 4 for the walls in this study since the shear walls in this study can be used to resist both lateral loads and gravity. The third step was to find the occupancy importance factor, I_E, in IBC Section 1616.2. The occupancy Importance factor was determined to be 1.0 for this study. The design load is then calculated as the load corresponding to the deflection δ_{xe} on the load displacement histories for the walls. Equation 3.2 can be used to calculate the deflection δ_{xe}

$$\delta_{xe} = \frac{\delta_x I_E}{C_d} \tag{3.2}$$

The ICBO report also gives a factor of safety if the data collected will be used for design. The values obtained from the experiments were not used for design therefore no factor of safety was applied. The factor of safety is a constant and the lack of one does not interfere with a comparison of characteristic values. Figure 3.7 illustrates the maximum load, load at 4in drift, and design load values. The figure shows two load-displacement histories, A and B. History A represents a wall that fails within a 5-in. drift. History B represents a wall that does not fail within a 5-in. drift.

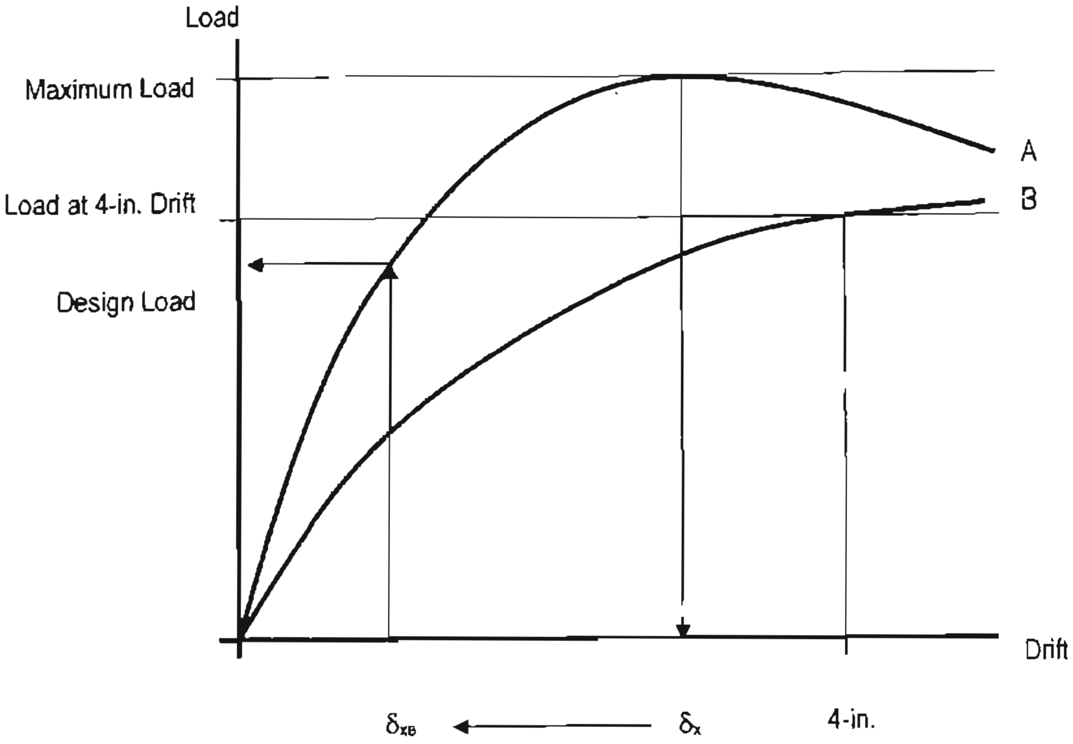

Figure 3.8. Strength Characteristic Values

3.4.2 Stiffness Characteristic Values

Two stiffness values were calculated. One value is for walls with a known maximum load and the other is for walls that were too ductile to show a failure within a 5-in. drift. The Technical Coordinating Committee on Masonry Research states that stiffness for shear walls shall be taken as the secant stiffness of the load-displacement history at 40% of the maximum load. For walls that do not reach a maximum load, a constant reference point was needed for comparison. This point was selected to be a 1-in. drift. The secant stiffness at 1-in. drift was also found for walls that fail to facilitate comparison. Figure 3.8. illustrates the stiffness at 40% of maximum load and stiffness at 1-in. drift. The figure shows two load displacement histories. History A fails within a 5-in. drift and B does not. The slope of line 1 is the secant stiffness of wall A at 40 percent of maximum load. The slope of line 2 is the secant stiffness of wall A at 1-in. drift. The slope of line 3 is the secant stiffness of wall B at 1-in. drift.

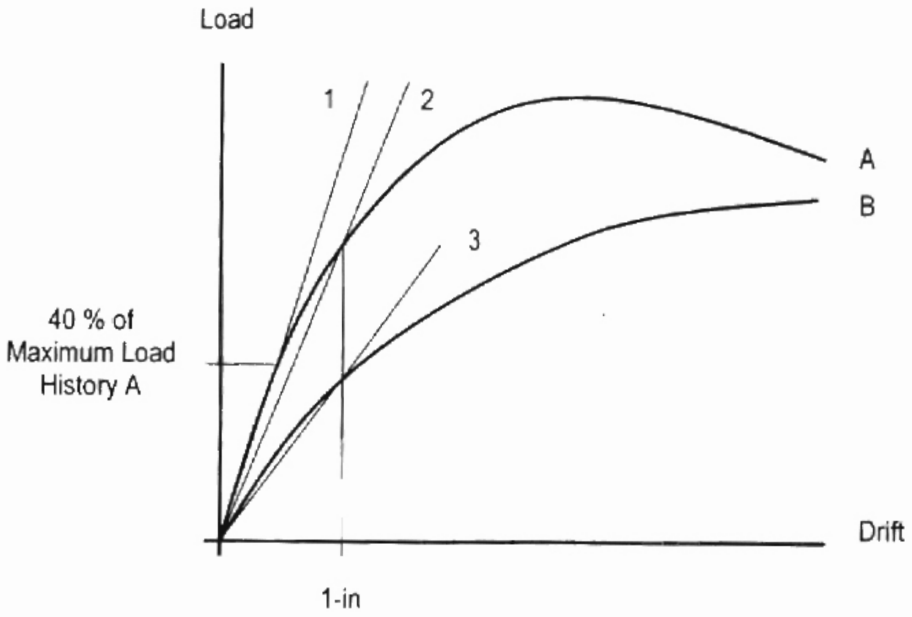

Figure 3.9. Stiffness Characteristic Values

3.4.3 Energy Dissipation Characteristic Value

Energy dissipation during wall loading was calculated as the area under the load displacement curve. It was calculated by numerical integration of the area beneath the curve from 0 to 4-in. drift. This was done for all walls regardless of whether a maximum load was reached.

3.5 Framework Moisture Data Collection

The final task to complete the testing for the walls was to measure the moisture content of each wall. This was accomplished using a Wagner Inspector Proline L606 moisture meter. The moisture content of each framework member was recorded for use in relative wall comparisons.

CHAPTER 4

FRAMING CONNECTOR TESTS

Walls with various framework connections were the first walls investigated. Bare frames and sheathed walls were fabricated with nailed and MPC-connected framework connections. First, bare frames were tested to determine MPC-connected frame behavior and to compare this behavior with end nail-connected frames. Also, sheathed walls were fabricated with end nail and MPC connections. These walls were tested to determine MPC connection behavior when sheathing is employed and to compare this behavior to end-nailed sheathed wall behavior. The focus of these tests is an evaluation of the moment resistance provided by MPC connections of the framing members.

4.1 Framework Connector Test Description

All walls in the framing connector tests were 4 ft long and all framing members were DFL No. 2 2x4 visually graded dimensional lumber. Walls in this test were either bare frames (unsheathed framework) or sheathed frames. Seven MPC sizes (3x4, 4x4, 4x5, 5x5, 5x6, 6x6, 6x7) were used to evaluate the performance of MPCs as moment resistant connections in bare frames and rectangular MPCs (3x4, 4x5, 5x6, 6x7) were used to evaluate the ability of MPCs to increase the performance of sheathed shear walls. The first number in the MPC size designation was MPC length perpendicular to the studs and the second was MPC length parallel to the studs. All MPCs were placed on the frame with tooth slots parallel to the studs. MPC orientation can greatly affect MPC connection behavior. A single orientation was selected to exclude extra variables introduced by MPC orientation. End-nailed bare and sheathed frames were also tested so the MPC frames and sheathed walls could be compared to a conventional construction benchmark. Five replications were fabricated and tested for each wall configuration.

Three behavior characteristics were calculated from the wall load-displacement histories for bare frames and five values were calculated for sheathed frames. The bare frames load-displacement histories did not show a peak load. Since a peak load is required to calculate the maximum load, design load, and stiffness at 40% of maximum load, the characteristics calculated for bare frames were load at 4-in. deflection, stiffness at 1-in. deflection, and energy dissipation at 4-in. deflection. The five behavior characteristics evaluated for sheathed frames were maximum load, design load, stiffness at 1-in. drift, stiffness at 40% of maximum load, and energy dissipation at 4-in. drift.

4.2 Framing Connector Test Results

4.2.1 End-nailed Bare Frames

The first frames tested were end-nailed bare frames. Figure 4.1 shows the load-displacement history for the five end-nailed bare frames.

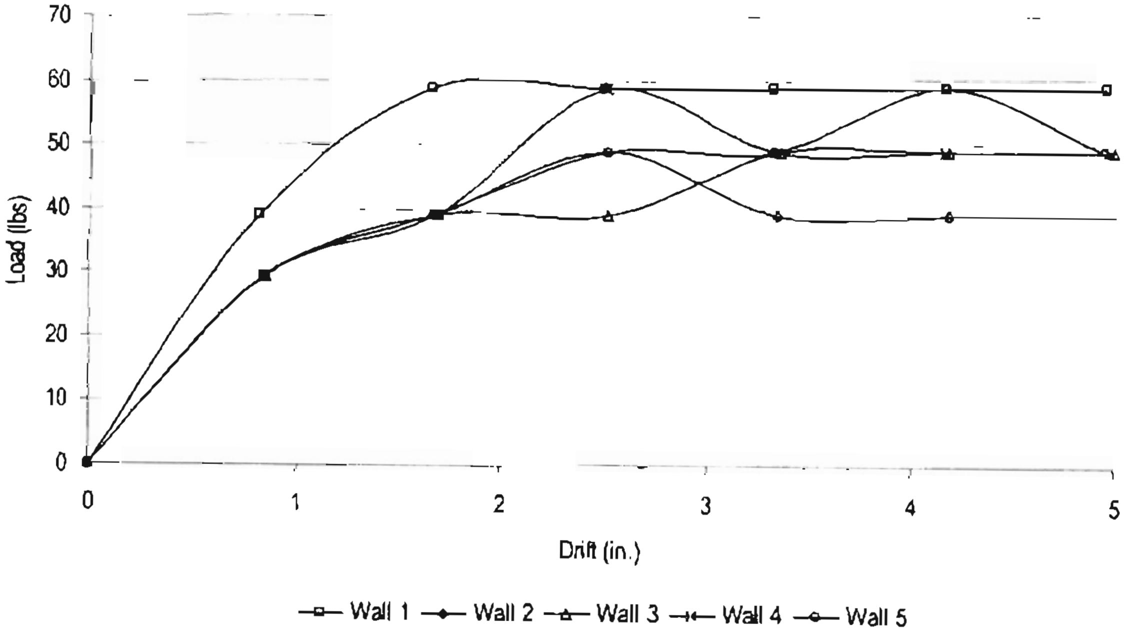

Figure 4.1. Load-Displacement Histories of End-Nailed Bare Frame Walls

The average maximum load for end-nailed bare frames was 56 lbs. The average stiffness at 1-in. deflection for end-nailed bare frames was 37 lbs/in. The average energy dissipation for end-nailed bare frames was 0.16 K-in. The end-nailed bare frames load-displacement history shows the behavior expected from a simple end-nailed frame. During testing, end-nailed bare frames were observed to rack without bending the studs. The wall became a collapsible mechanism that resisted very little lateral load. There is no connection rigidity and thus the walls rack under small loads. Strength and stiffness are developed by nail bending and withdrawal from the studs in the frame connections. Wall ductility, as seen by the load-displacement history, was consistent with steel nail ductile failure.

4.2.2 MPC-Connected Bare Frames

The moment resistant behavior of framework connected by MPCs was evaluated through experimental testing of unsheathed frames. The behavior was evaluated for a variety of MPC plate sizes and compared to end-nailed frame behavior. Table 4.1 presents average values for load at 4-in. drift, stiffness at 1-in. drift, and energy dissipation and average increases in the three characteristic values of behavior relative to end-nailed bare frame behavior for each MPC size. Load-displacement histories for each MPC-connected bare frame are presented in Figures 4.2 through 4.10.

TABLE 4.1. FRAMING CONNECTOR TEST TABULATED VALUES AND AVERAGE INCREASES FOR MPC-CONNECTED BARE FRAMES

Connection	Load at 4-in. Drift (lbs)	Load at 4-in. Drift (% Increase)	Stiffness at 1-in. Drift (lbs/in.)	Stiffness at 1-in. Drift (% Increase)	Energy Dissipation at 4-in. Drift (Kip-in.)	Energy Dissipation at 4-in. Drift (% Increase)
End-nailed	56		37		0.16	
3 x 4 MPC	162	187	78	112	0.42	164
4 x 4 MPC	168	197	74	100	0.42	163
4 x 5 MPC	254	350	113	205	0.64	297
5 x 5 MPC	287	407	115	211	0.68	326
5 x 6 MPC	327	478	121	228	0.77	379
6 x 6 MPC	332	486	119	222	0.75	366
6 x 7 MPC	373	559	131	255	0.85	428

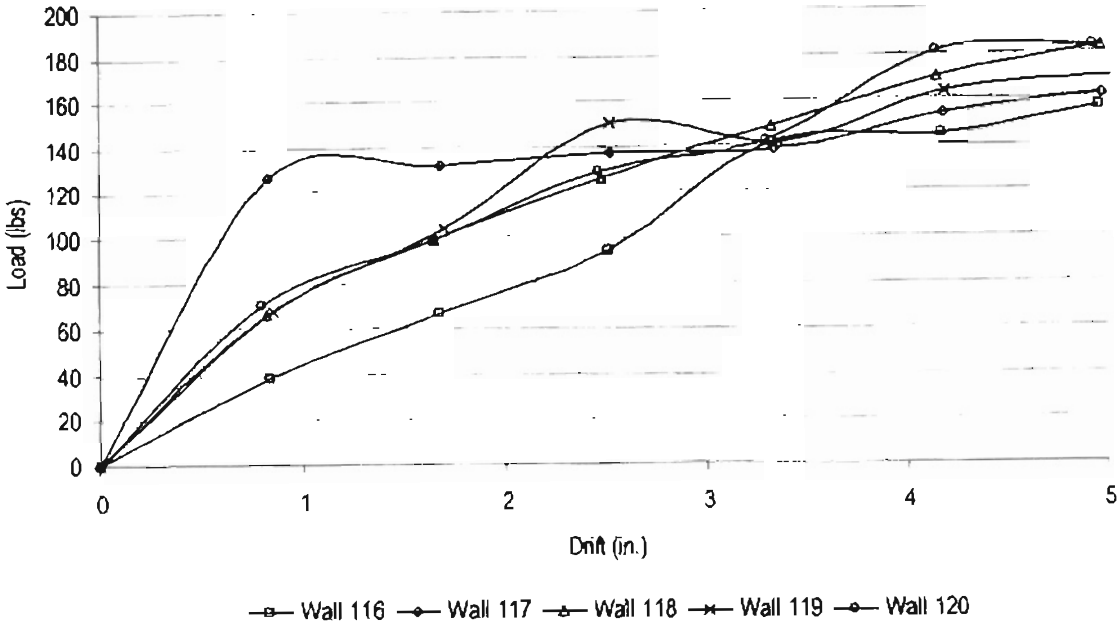

Figure 4.2. 3x4 MPC-Connected Bare Frames Load-Displacement Histories

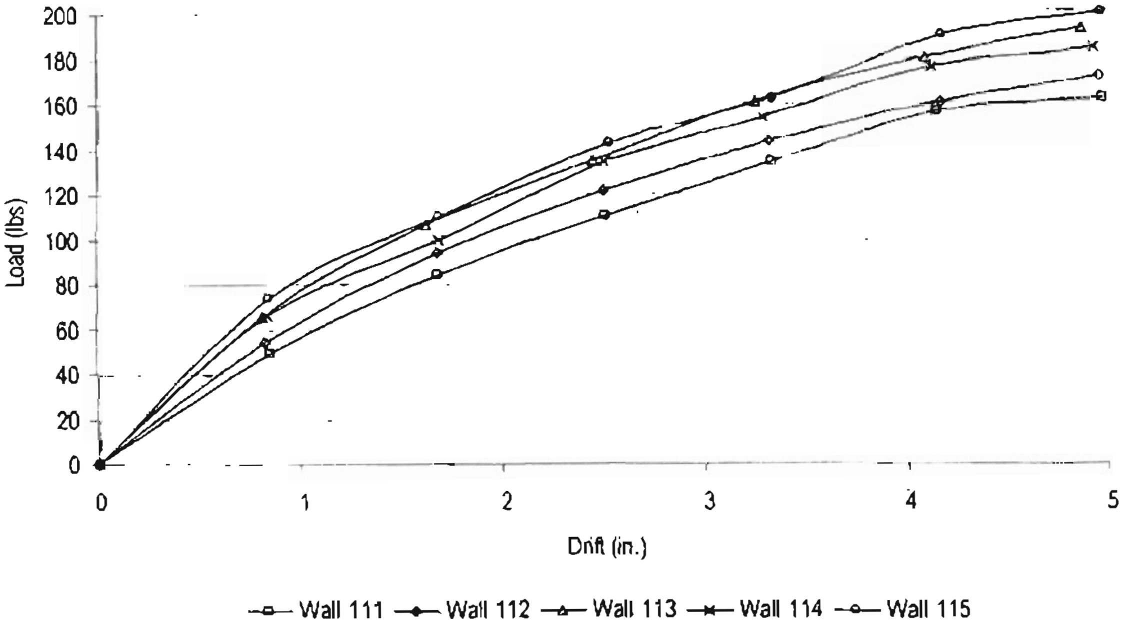

Figure 4.3. 4x4 MPC-Connected Bare Frames Load-Displacement Histories

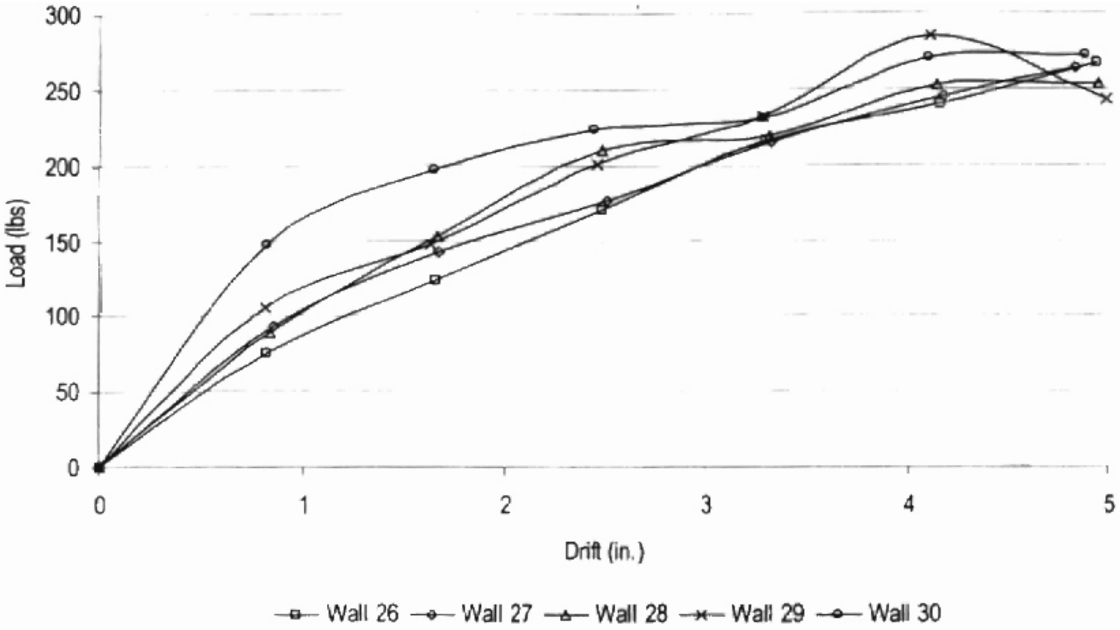

Figure 4.4. 4x5 MPC-Connected Bare Frames Load-Displacement Histories

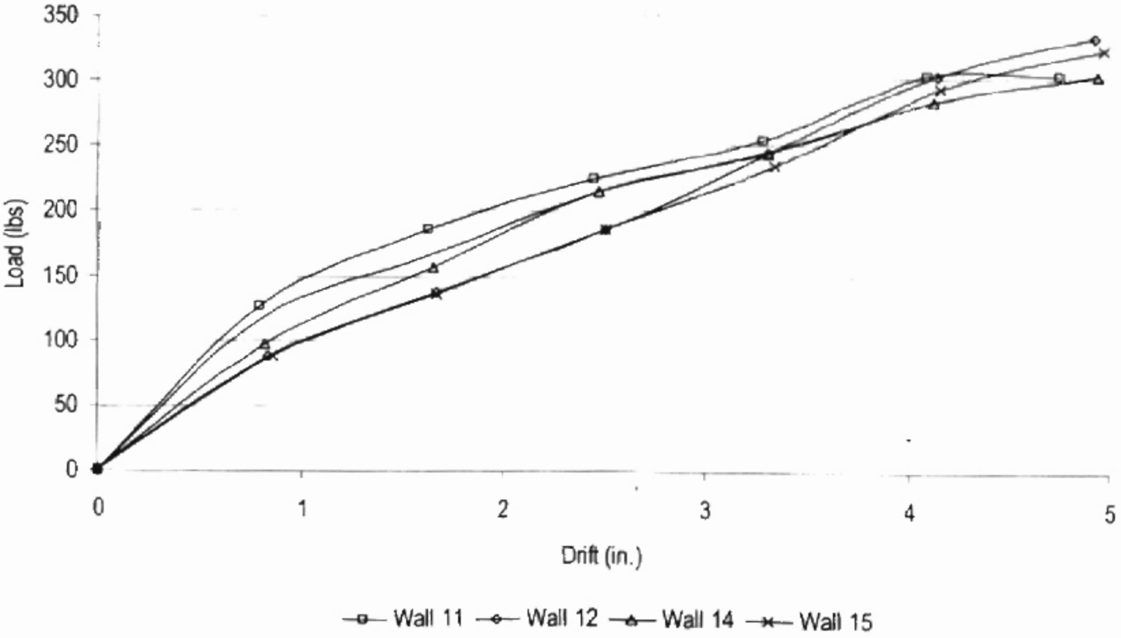

Figure 4.5 5x5 MPC-Connected Bare Frames Load-Displacement Histories

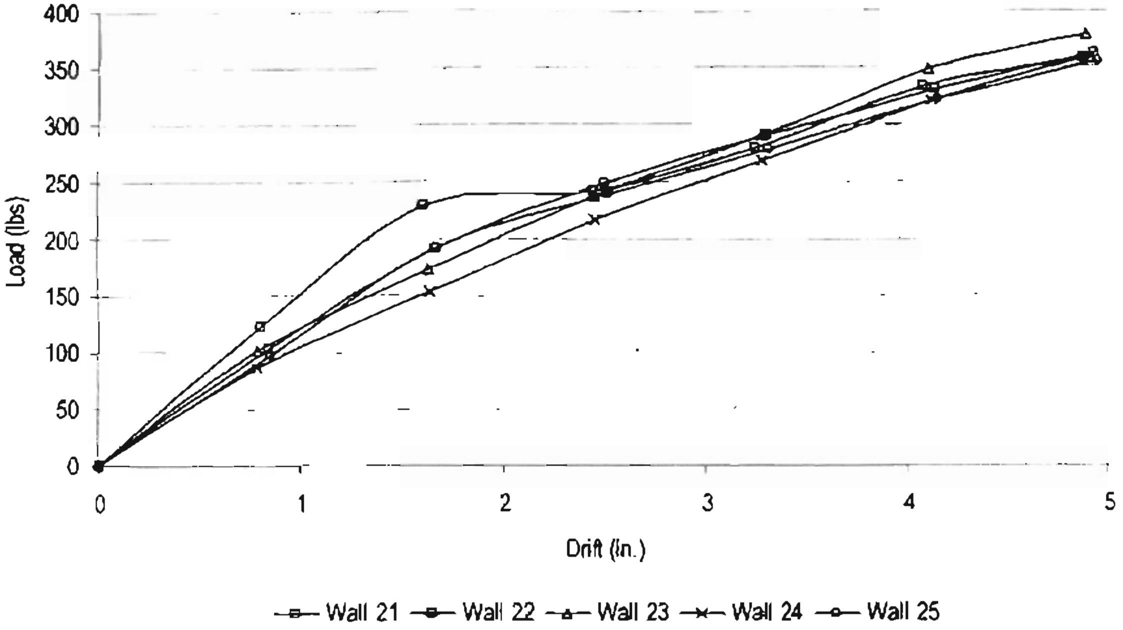

Figure 4.6. 5x6 MPC-Connected Bare Frames Load-Displacement Histories

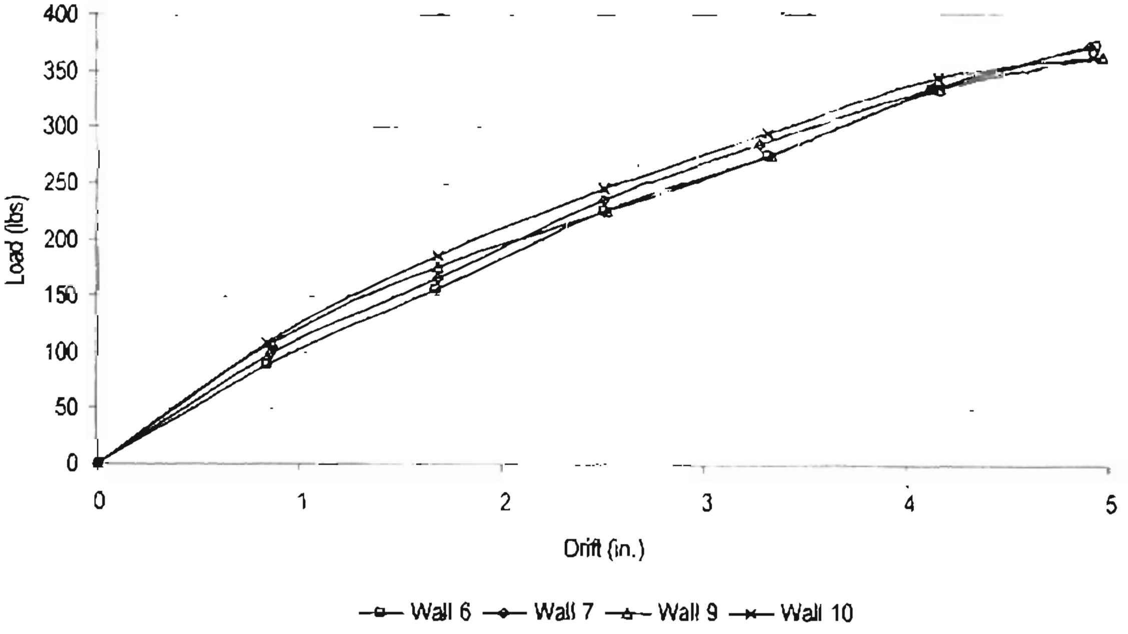

Figure 4.7. 6x6 MPC-Connected Bare Frames Load-Displacement Histories

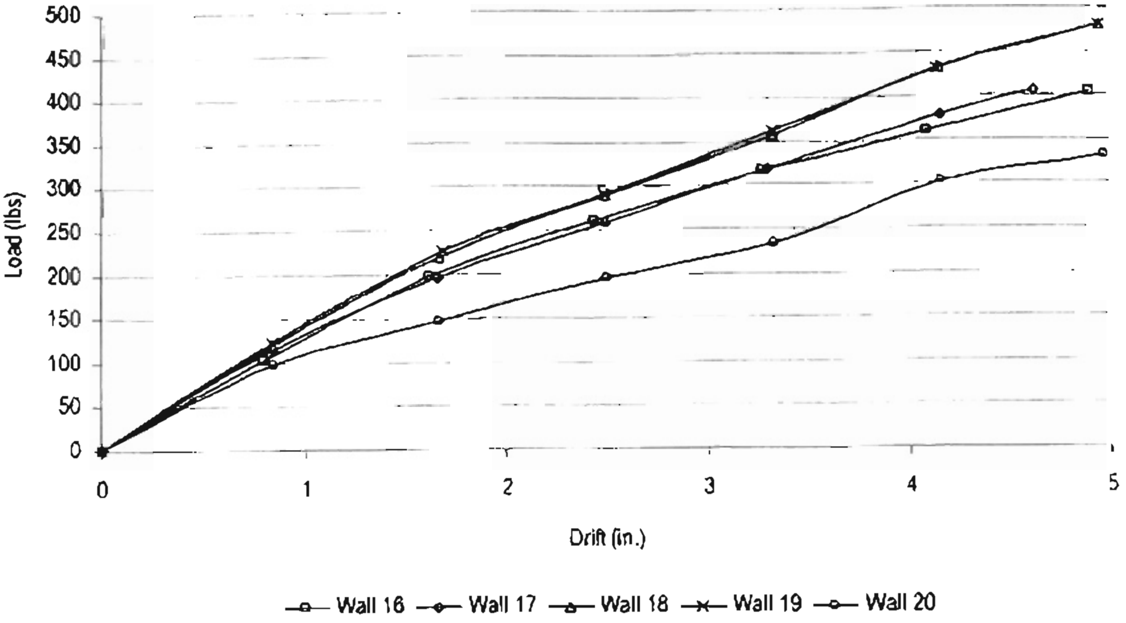

Figure 4.8. 6x7 MPC-Connected Bare Frames Load-Displacement Histories

The MPC-connected bare frame behavior as represented by strength, stiffness, and energy dissipation greatly exceeded the behavior of end-nailed bare frames. The load-displacement histories show the relative behavior of bare frames connected with MPCs to frames connected with end nails. They also show that by increasing MPC size, the frame structural performance also increases. This is logical because MPC connections are stiffer and stronger in tension when more MPC teeth are embedded into wood. In other words larger MPC sizes equal greater MPC stiffness and tooth embedment areas. Flexural rigidity increases with MPC tooth embedment and plate stiffness.

Observing MPC-connected bare frames after loading shows there is some connection rigidity. The studs are bent in double curvature. The wall frame is no longer a collapsible mechanism but a moment resistant frame, which explains the enhancement in strength, stiffness, and energy dissipation. Figure 4.11 illustrates a portion of a bare frame connected with MPCs.

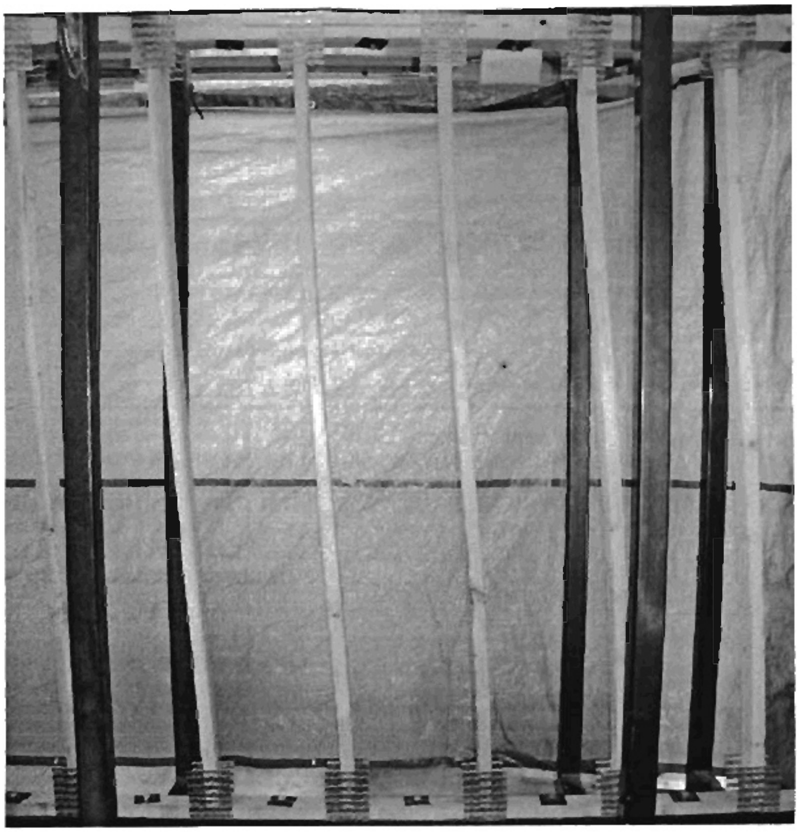

Figure 4.9. Stud Bending in an MPC-Connected Bare Frame

Close inspection of an MPC-connection within a bare frame under loading provides further insight into the MPC connection flexural behavior. The compression side of an MPC buckles about the weak axis. Then, compression is resisted by the wood material of the framework within the connection. The resulting tension force is resisted by the MPC. The maximum flexural strength of the connection is commonly controlled by either net section failure of the MPC in tension or the withdrawal of the MPC teeth from the wood material. The failure mechanism for the MPC frame connections was found to be tooth withdrawal in the strut. Net section failure was not visible in any tested MPC frame connections.

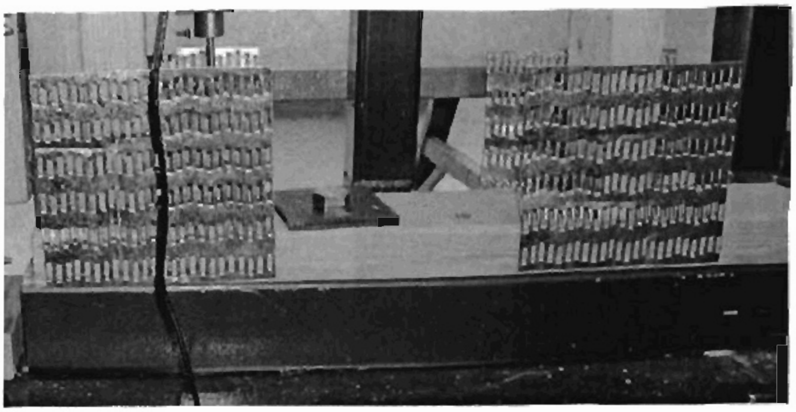

Figure 4.10. MPC Connection Behavior

One other notable observation made in the MPC-connected bare frame tests was that rectangular MPCs performed similarly to square MPCs with the same length. Therefore, the square MPCs were eliminated from the sheathed wall tests because the rectangular plates behaved similarly.

4.2.3 Sheathed Frames

Sheathed frames were tested to determine if MPCs affect sheathed wall behavior in terms of additional lateral resistance. Load displacement histories for sheathed frames were used to evaluate the performance of sheathed walls containing frames connected with MPCs. Five characteristic values were used to represent and compare sheathed frame behavior. These characteristic values were maximum load, design load, stiffness at 1-in. drift, stiffness at 40% of maximum load, and energy dissipation at 4-in. drift. Table 4.2 presents averages of the five characteristic values for each sheathed frame type and the average increase for all behavior for MPC-connected sheathed frames with respect to the characteristic values determined for end-nailed sheathed frames. Figure 4.11 presents the load-displacement histories for sheathed walls with end nail-connected framework. Figures 12 through 15 present the load-displacement histories for sheathed walls with MPC connected framework.

TABLE 4.2. FRAMING CONNECTOR TEST BEHAVIOR CHARACTERISTICS AND INCREASES FOR MPC-CONNECTED SHEATHED FRAMES

Connection MPC	Maximum Load (lbs)	(% Increase)	Design Load (lbs)	(% Increase)	Stiffness at 40% of Maximum Load (lb/in.)	(% Increase)	Stiffness at 1-in. Drift (lb/in.)	(% Increase)	Energy Dissipation at 4-in. Drift (K-in.)	(% Increase)
End-nailed	2406		1117		2014		1642		8.01	
3 x 4 MPC	2995	24	1241	11	2104	4	1742	6	8.81	10
4 x 5 MPC	3232	34	1315	18	2189	9	1915	17	9.30	16
5 x 6 MPC	3495	45	1308	17	2114	5	1868	14	9.84	23
6 x 7 MPC	3460	44	1412	26	2454	22	1964	20	9.90	24

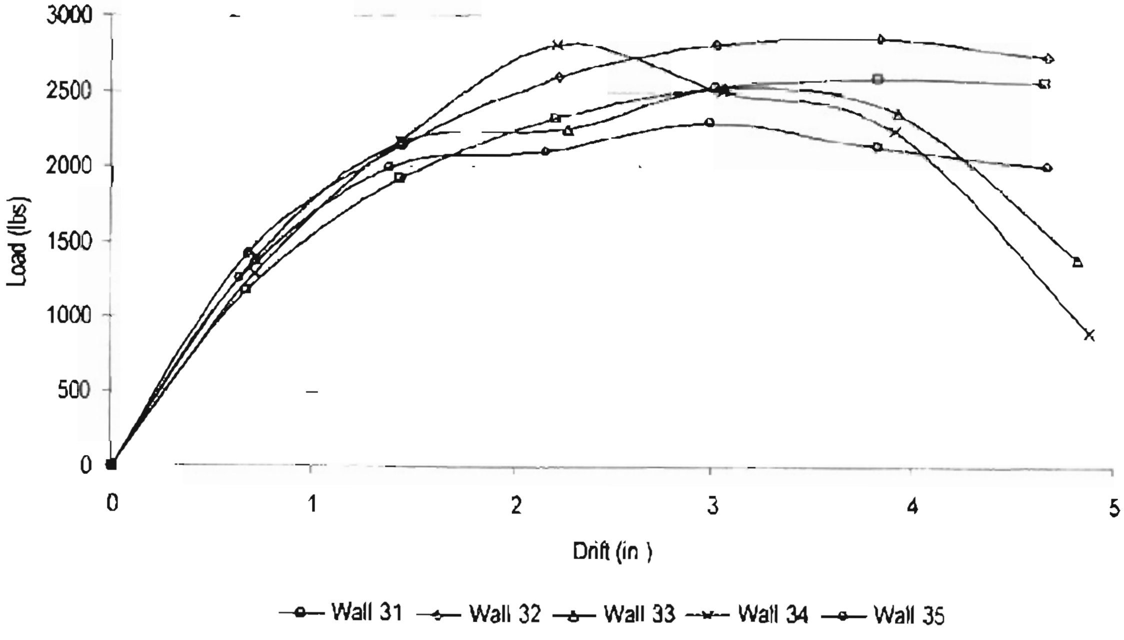

Figure 4.11. End Nail-Connected Sheathed Frames Load-Displacement Histories

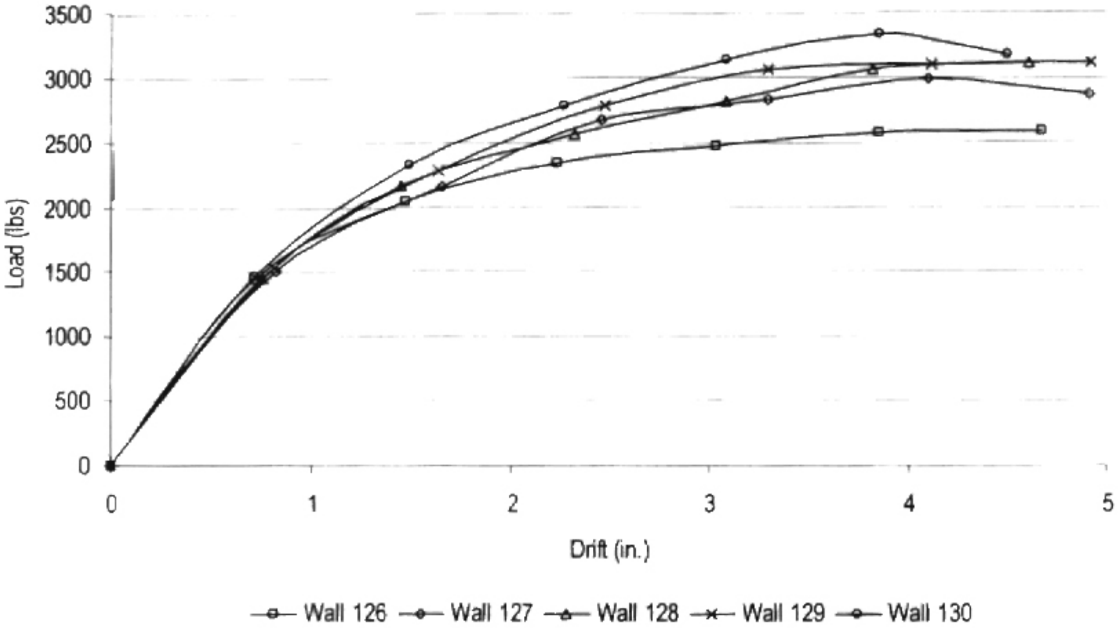

Figure 4.12. 3x4 MPC-Connected Sheathed Frames Load-Displacement Histories

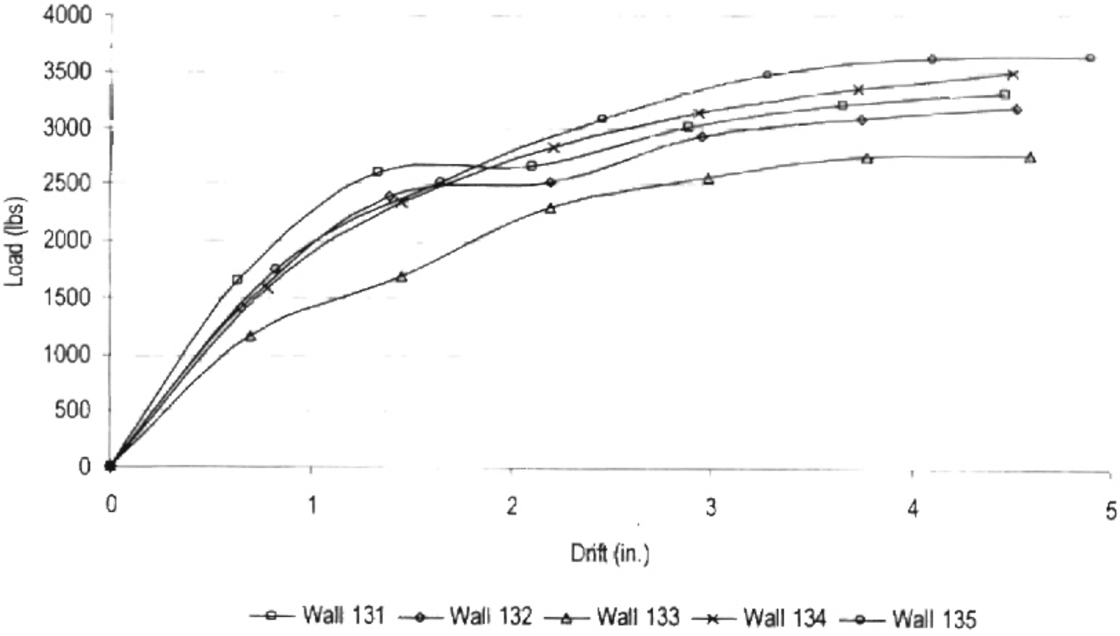

Figure 4.13. 4x5 MPC-Connected Sheathed Frames Load-Displacement Histories

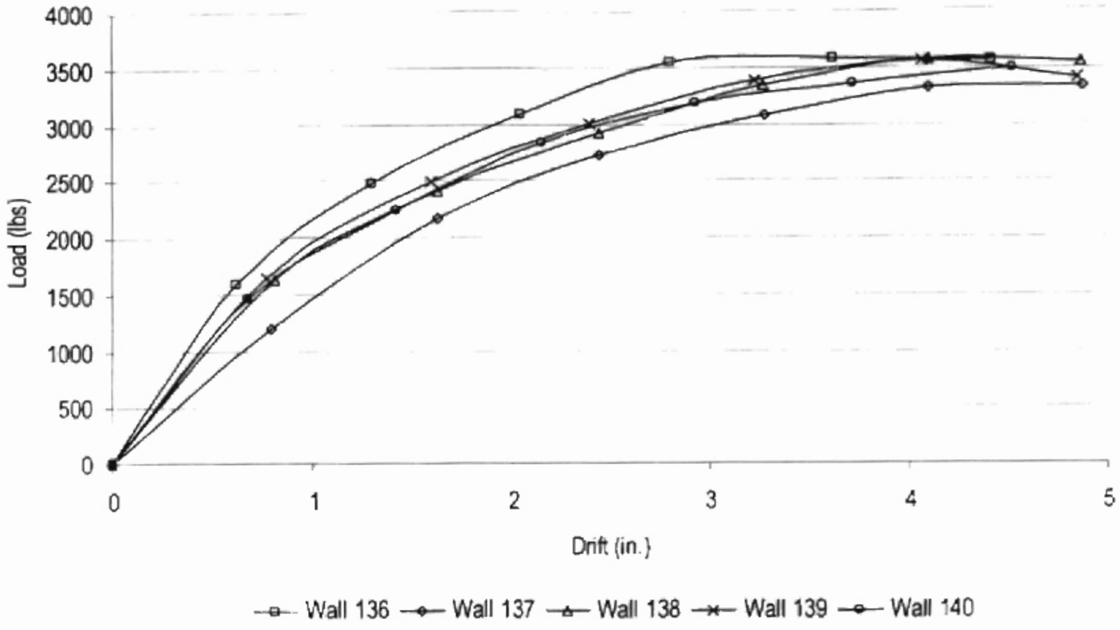

Figure 4.14. 5x6 MPC-Connected Sheathed Frames Load-Displacement Histories

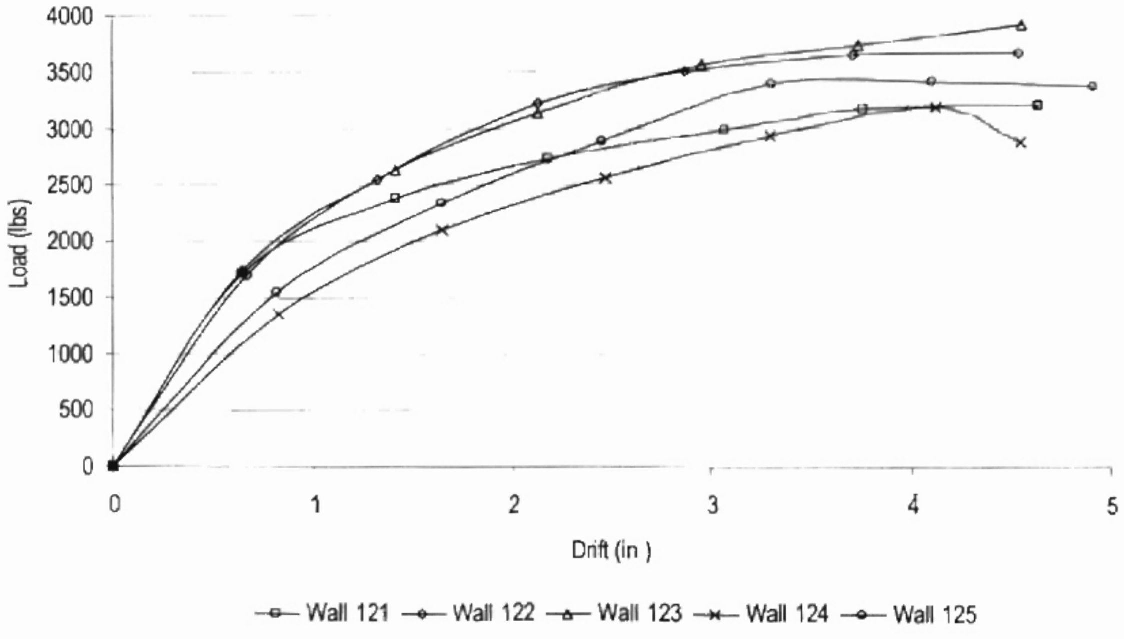

Figure 4.15. 6x7 MPC-Connected Sheathed Frames Load-Displacement Histories

The load-displacement histories for sheathed walls in addition to the characteristic values for wall behavior demonstrate that MPC-connected walls are stronger, stiffer, and dissipate more energy than walls connected with end nails alone. Maximum load and energy dissipation increase as plate size is increased. One puzzling result is the behavior characteristics for stiffness at 1-in. drift, stiffness at 40% of maximum load, and the design load are more greatly enhanced by the addition of 4x5 MPCs than by 5x6 MPCs. This discrepancy in the data is intuitively incorrect and is accounted for by test variability discussed later in the chapter.

The end nail-connected sheathed walls yield and lose a significant amount of stiffness before the MPC-connected walls yield and therefore have a lower maximum load. However, the design load of end nail and MPC-connected sheathed walls is calculated within a range of deflection in which the stiffness of the MPC-connected sheathed walls is only slightly greater than the stiffness of the end nail-connected walls. Therefore, the design loads do not have as great an increase as maximum loads when MPCs are used to connect sheathed wall framework. Maximum load of the sheathed walls increased 24 to 44% when MPCs were used to connect the sheathed wall framework whereas design load only increased 11 to 26%.

Energy dissipation at 4-in. drift increased 10 to 24% when MPCs, in place of end nails, were used to connect the framework of sheathed walls. Figure 4.11 shows two end-nailed sheathed frames failing at approximately 3-in. deflection at which the load capacity fell significantly. No MPC-connected sheathed frames experienced such a failure, which demonstrates that MPC-connected sheathed frames fail in a more ductile fashion than end-nailed sheathed frames. If the walls could be tested with a system that allowed more than 5-in. drift, energy dissipation increases would be much greater.

Another conclusion may be drawn by comparing load-displacement behavior of bare frames and sheathed walls. The MPC-connected sheathed frame maximum load was increased 24 to 45% with respect to the maximum load of sheathed walls with end-nailed connections. MPC-connected bare frame load at 4-in. drift increased 187 to 559% with respect to the load at 4-in. drift of end-nailed bare frames. Stiffness at 1-in. drift and energy dissipation at 4-in. drift also increased more for bare frames rather than sheathed walls. Therefore, sheathing and its connection to the framework are still the primary shear force and moment resisting elements in a sheathed shear wall.

4.2.4 Bending Stiffness and Moisture Content

The bending stiffness and moisture content of each framing member was measured. Table 4.3 lists the average bending stiffness and moisture content of the wall framing members for each bare frame. Also listed in the table are the coefficients of variation for these bending stiffness and moisture content. Table 4.4 presents the average bending stiffness and moisture content along with coefficients of variation of the wall framing members for each sheathed wall.

The range of average bending stiffness for the walls in the framing connector tests was 1.31 E+06 lb-in.^{2} to 1.75 E+06 lb-in.^{2}. The National Design Specification for Wood Construction lists the average modulus of elasticity for all DFL No. 2 lumber as 1.6 E+06 psi. The modulus of elasticity multiplied by the weak axis moment of inertia for a perfect 2x4 section is 1.57E+06 lbs-in.^{2}. The National Design Standard for Wood Construction also states that the coefficient of variability for the modulus of elasticity of visually graded lumber is 25%. The results for bending stiffness of the wall members fall within a reasonable range. The moisture content measurements however do not. The average moisture contents for all walls in the framing connector tests fall between 10.9 and 19.9%. The coefficients of variation of moisture contents for the walls are as high as 40%. Moisture content adversely affects the tests conducted in this study. The tooth holding properties are weakened as a result of high moisture content. High moisture content makes wood softer. When MPCs are in tension, they bear against the soft wood. The soft wood allows the MPC tooth to deflect and rotate more which weakens the tooth and further weakens the wood material surrounding the nail which subsequently facilitates tooth withdrawal.

If all variability other than the bending stiffness and moisture content of the framing members was removed from the experimental tests, walls with a combination of the highest bending stiffness and lowest moisture content would resist the most lateral load and be the stiffest. Similarly, walls with a combination of the lowest bending stiffness and highest moisture content would be the weakest and most flexible. Results were collected for 65 walls in the framing connector tests. Of the 65 walls, 2 had the highest average bending stiffness and lowest average moisture content in their respective tests sets. Wall 10 in the 6x6

MPC-connected bare frame test had an average bending stiffness of 1.60E+06 lb-in.^{2} and an average moisture content of 13.33%. Wall 140 in the 5x6 MPC-connected sheathed wall test set had an average bending stiffness of 1.53E+06 lb-in.^{2} and a moisture content of 10.89%. If no other variability was introduced to the tests, these walls would be expected to be the strongest and stiffest walls in their respective test sets. All walls in the 6x6 MPC-connected bare frame load-displacement histories follow a very similar load-displacement path. Wall 10 is the strongest wall in the group but only by a very small margin. Wall 140 of the 5x6 MPC-connected sheathed wall test set follows a load-displacement path through the center of the results. Two walls had the lowest average bending stiffness and highest average moisture content in their test set. Wall 20 in the 6x7 MPC-connected bare frame test had an average bending stiffness of 1.31E+06 lb-in.^{2} and an average moisture content of 17.78%. Wall 138 in the 5x6 MPC-connected sheathed wall test set had an average bending stiffness of 1.37E+06 lb-in.^{2} and a moisture content of 13.11%. These walls should be the weakest and most flexible walls in their respective test sets if no other variability was introduced. Wall 20 was the weakest and most flexible wall in its test set after a drift of approximately 1-in. Wall 138 follows a load-displacement path through the center of the results of the 5x6 MPC-connected sheathed wall test set.

Some wall load displacement paths deviated from the trend defined by the other wall histories for the given test set. Walls 21, 136, 30, and 11 showed considerably stronger and stiffer load displacement paths in comparison to other walls in their respective tests sets. However, none of these walls had the highest average bending stiffness in their test sets. Only walls 30 and 11 had the lowest average moisture content and wall 11 had the lowest average bending stiffness for its test set. Walls 26, 20, 126, 133, 137, and 124 all showed considerably lower strength and stiffness for their common tests sets. Only wall 20 had the lowest average bending stiffness and highest average moisture content. Wall 133 had the highest average moisture content but only a midrange average bending stiffness. Wall 124 had the lowest average bending stiffness but only a midrange average moisture content. Wall 26 had the highest average bending stiffness and midrange average moisture content for its test set. Wall 137 had both midrange average bending stiffness and average moisture content.

4.3 Framing Connector Test Conclusions

Several conclusions may be drawn from the framing connector tests. First, MPCs benefit bare frames and sheathed walls alike, but sheathing is still the primary element in shear wall strength. This is evident in that sheathed walls did not benefit from MPCs nearly as much as bare frames did when connected by MPCs. Second, connection rigidity and strength increases with plate size. This is logical because the connection failures are governed by MPC stiffness and tooth withdrawal which is directly proportional to the size of the MPC and tooth embedment area, respectively. Larger MPC sizes increase the MPC stiffness and amount of tooth embedment area. Third, end nail-connected sheathed walls are initially less stiff and will yield under far less load than MPC-connected sheathed walls. The maximum load of an MPC-connected sheathed wall is much greater than the maximum load of an end nail-connected sheathed wall, but the design load of the MPC-connected sheathed wall is not much greater than that of an end nail-connected sheathed wall.

Framing connector tests are subject to variability. There is an inherent variability in wood construction that cannot be removed. Wood is an anisotropic, naturally grown material with grain, variable density, and defects. Also, it is improbable that any two MPC connections can be fabricated alike. Therefore experimental tests of wood construction will always show variability. High and various moisture contents also add to test variability. Moisture content affects tooth holding properties of the MPC connection which adds further variability to the experimental test results.

TABLE 4.3. FRAMING CONNECTOR TEST BENDING STIFFNESS
AND MOISTURE CONTENT OF BARE FRAMES

Tests Set	Wall	Average EI (lb-in.^{2})	COV EI	Average MC	COV MC
End-Nailed Bare Frames	1	1.62E+06	0.27	11.89	0.08
	2	1.43E+06	0.17	12.00	0.32
	3	1.61E+06	0.20	13.67	0.33
	4	1.61E+06	0.19	13.56	0.14
	5	1.48E+06	0.20	13.22	0.14
3x4 MPC-Connected Bare Frames	116	1.62E+06	0.18	13.56	0.18
	117	1.41E+06	0.30	14.22	0.35
	118	1.54E+06	0.20	12.56	0.16
	119	1.51E+06	0.16	16.33	0.29
	120	1.50E+06	0.24	18.33	0.40
4x4 MPC-Connected Bare Frames	111	1.68E+06	0.23	13.78	0.17
	112	1.50E+06	0.18	14.33	0.35
	113	1.75E+06	0.22	16.56	0.33
	114	1.62E+06	0.23	14.11	0.29
	115	1.71E+06	0.19	11.78	0.10
4x5 MPC-Connected Bare Frames	26	1.58E+06	0.18	16.78	0.29
	27	1.53E+06	0.17	17.11	0.32
	28	1.47E+06	0.16	15.56	0.30
	29	1.44E+06	0.14	15.11	0.29
	30	1.46E+06	0.26	13.56	0.15
5x5 MPC-Connected Bare Frames	11	1.42E+06	0.15	14.67	0.25
	12	1.55E+06	0.17	16.11	0.14
	13	1.54E+06	0.21	15.22	0.15
	14	1.58E+06	0.21	18.33	0.25
	15	1.63E+06	0.29	18.00	0.31
5x6 MPC-Connected Bare Frames	21	1.43E+06	0.22	18.22	0.38
	22	1.68E+06	0.29	15.44	0.32
	23	1.69E+06	0.27	19.89	0.28
	24	1.38E+06	0.37	15.33	0.34
	25	1.59E+06	0.18	15.33	0.22
6x6 MPC-Connected Bare Frames	6	1.34E+06	0.24	14.22	0.14
	7	1.48E+06	0.24	18.44	0.37
	8	1.35E+06	0.18	13.33	0.14
	9	1.56E+06	0.23	13.78	0.12
	10	1.60E+06	0.17	13.33	0.11
6x7MPC-Connected Bare Frames	16	1.49E+06	0.32	14.56	0.15
	17	1.41E+06	0.20	16.78	0.40
	18	1.62E+06	0.12	16.22	0.26
	19	1.69E+06	0.19	15.89	0.35
	20	1.31E+06	0.20	17.78	0.41

TABLE 4.4. FRAMING CONNECTOR TEST BENDING STIFFNESS AND MOISTURE CONTENT OF SHEATHED WALLS

Test Set	Wall	Average EI (lb-in.^{2})	COV EI	Average MC	COV MC
3x4 MPC-Connected Walls With 7/16-in. Sheathing	126	1.45E+06	0.22	13.33	0.18
	127	1.54E+06	0.16	12.89	0.15
	128	1.55E+06	0.22	13.67	0.28
	129	1.56E+06	0.26	12.22	0.14
	130	1.46E+06	0.20	11.89	0.11
4x5 MPC-Connected Walls With 7/16-in. Sheathing	131	1.40E+06	0.15	11.78	0.11
	132	1.47E+06	0.27	13.00	0.25
	133	1.43E+06	0.28	13.22	0.08
	134	1.44E+06	0.26	12.44	0.11
	135	1.64E+06	0.25	12.00	0.13
5x6 MPC-Connected Walls With 7/16-in. Sheathing	136	1.42E+06	0.27	12.11	0.16
	137	1.47E+06	0.17	12.33	0.12
	138	1.37E+06	0.16	13.11	0.22
	139	1.47E+06	0.26	13.11	0.23
	140	1.53E+06	0.14	10.89	0.15
6x7 MPC-Connected Walls With 7/16-in. Sheathing	121	1.64E+06	0.33	12.44	0.14
	122	1.66E+06	0.23	13.78	0.21
	123	1.72E+06	0.13	15.56	0.31
	124	1.62E+06	0.12	13.89	0.13
	125	1.68E+06	0.12	13.11	0.16
End-nailed Walls With 7/16-in. Sheathing	31	1.42E+06	0.23	15.33	0.40
	32	1.65E+06	0.26	15.00	0.38
	33	1.43E+06	0.22	14.56	0.29
	34	1.42E+06	0.18	17.22	0.27
	35	1.50E+06	0.27	16.11	0.26

CHAPTER 5

FRAMING MEMBER STIFFNESS TESTS

Conventional shear walls employ an end-nailed frame covered with sheathing, which is attached with sheathing nails. The sheathing provides stiffness to the wall while the frame resists gravity loads and supports the sheathing. As the wall racks due to lateral loads, the framing distorts as a parallelogram while the sheathing rotates as a rigid body with deformation occurring in the end-nailed connection between the sheathing and the frame. There is no framework bending and therefore no racking resistance is provided by the frame. By connecting the framework with semi-rigid MPC connections, it was expected that the frame would provide racking resistance to the wall. The semi-rigid connections would resist moment and provide frame bending stiffness. Framing member stiffness tests were used to investigate MPC-connected bare frame behavior and the changes in this behavior when the framing member stiffness is changed. The bending stiffness of wood is correlated to the wood grade. Therefore, three grades of wood framing members were used to provide a wide variety of bending stiffness.

5.1 Framing Member Stiffness Test Description

Three grades of lumber from two species of wood were used for frame construction. The stiffest grade was Southern Pine No. 1 (SYP No. 1). The other two grades are Douglas Fir-Larch, DFL, Nos. 2 and 3. A lower grading number indicates clearer wood with fewer defects. All framework is visually graded dimensional lumber. Wood members are visually inspected for defects that adversely effect wood strength and stiffness. Defects such as knots, splits, and wane grow naturally in wood and are the basis for wood grading. After each member is sawn to size it is graded to give designers strength and stiffness values with which to work.

Six bare frame sets each containing five replications were constructed with one of the lumber grades and were either MPC or end nail-connected. The names for the sets are No. 1 Nailed, No. 1 MPC-connected, No. 2 Nailed, No. 2 MPC-connected, No. 3 Nailed, and No. 3 MPC-connected. Each bare frame was 4 ft long and no frames were sheathed.

5.2 Framing Member Stiffness Test Results

5.2.1 Wall Tests

Two LVDTs were used to measure the lateral frame top displacement relative to the frame bottom. This relative displacement was plotted versus the coinciding load to force the relative displacement. These plots are the load- displacement histories. The load-displacement histories for the framing member tests are presented in Figures 5.1 through 5.6.

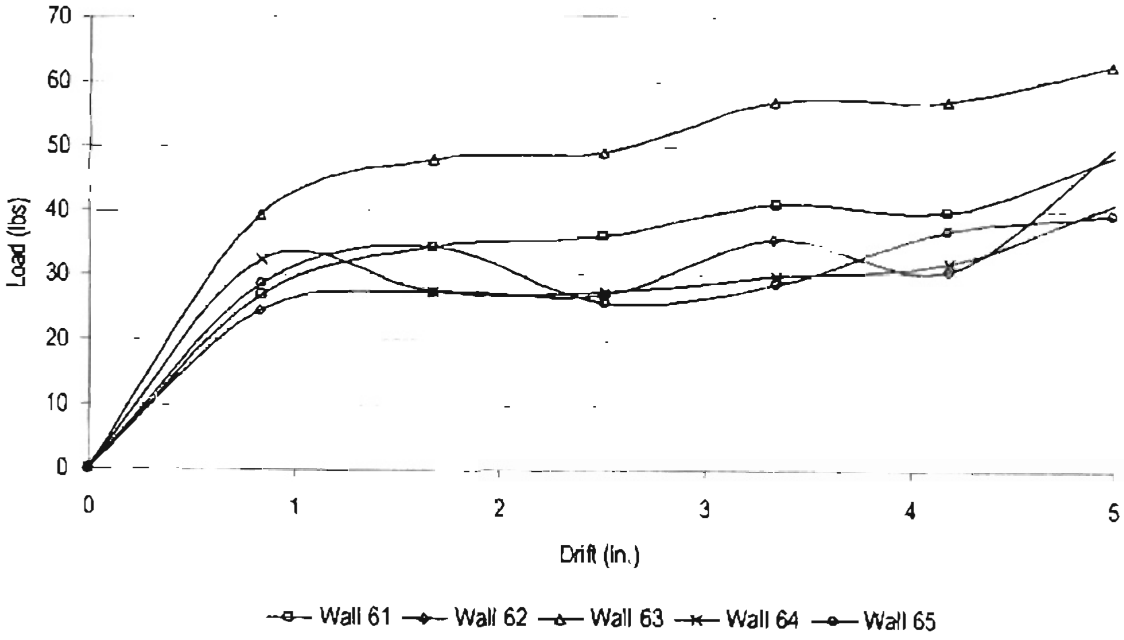

Figure 5.1. No. 1 End-nailed Load-Displacement Histories

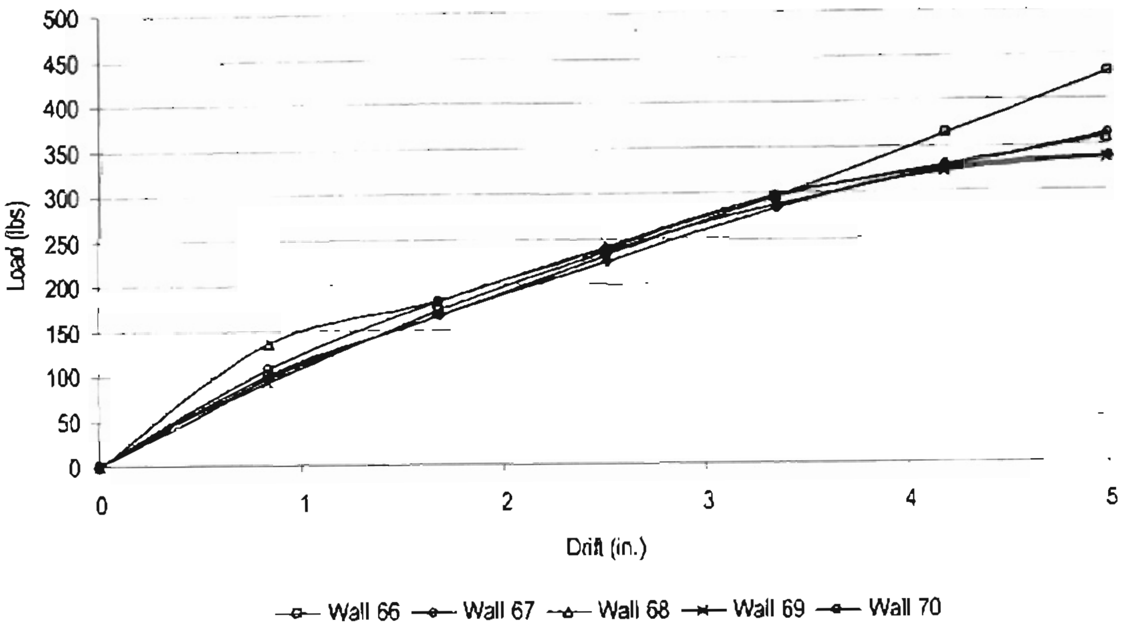

Figure 5.2. No.1 MPC-Connected Load Displacement Histories

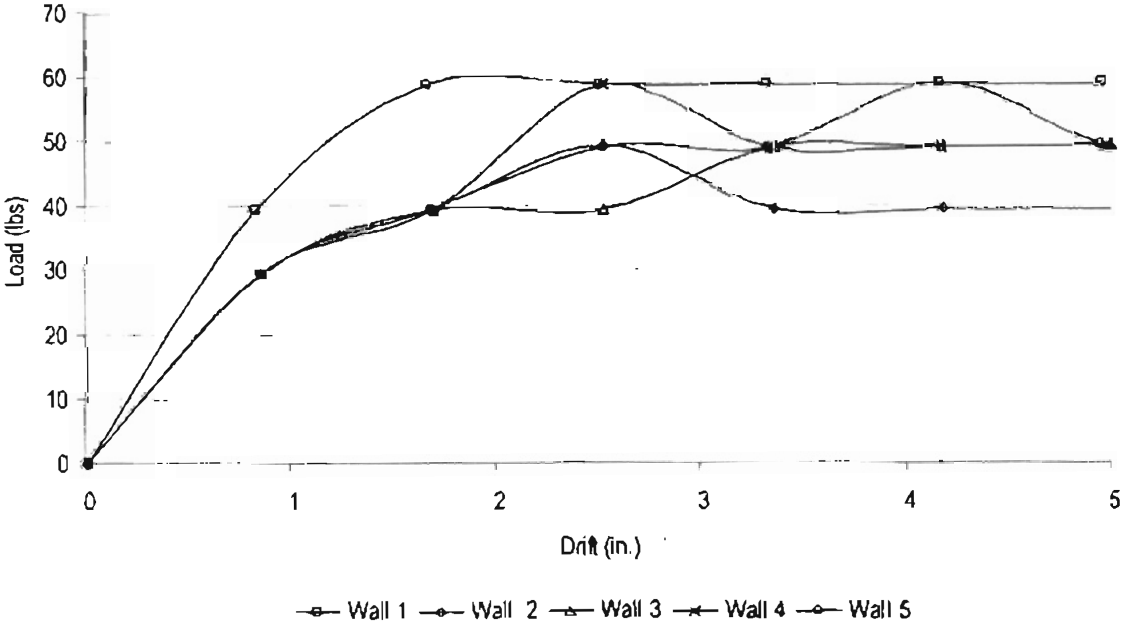

Figure 5.3. No. 2 End-nailed Load-Displacement Histories

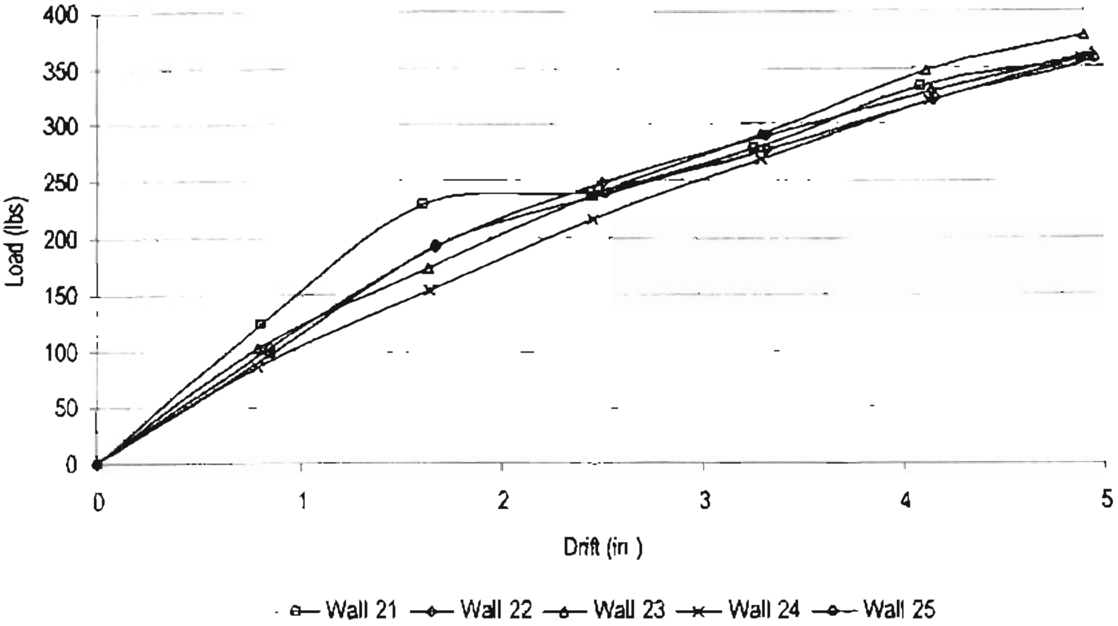

Figure 5.4. No. 2 MPC-Connected Load-Displacement Histories

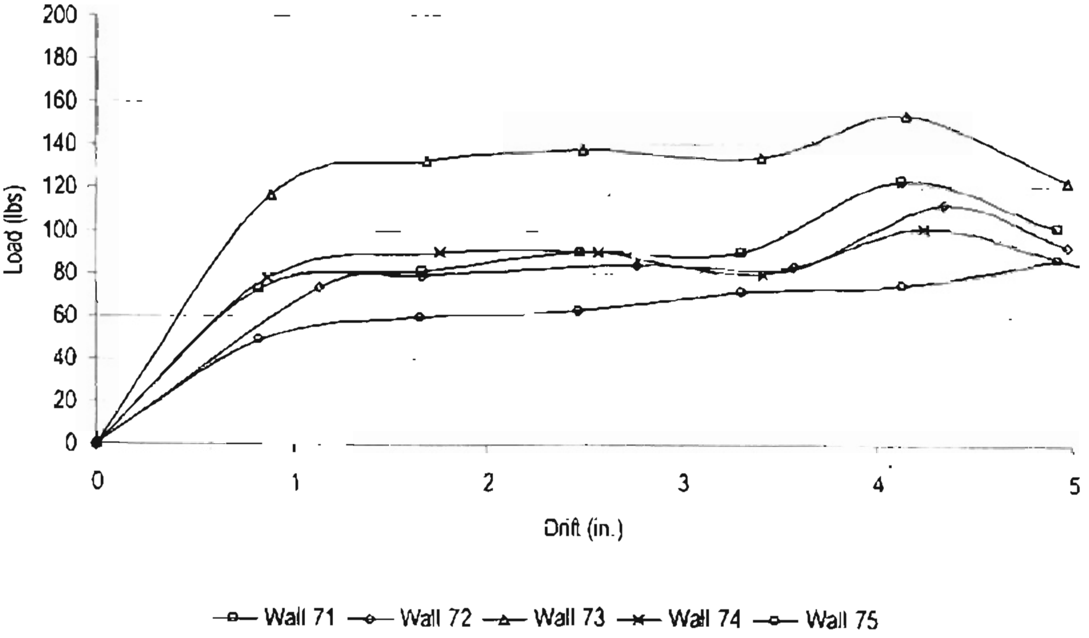

Figure 5.5. No. 3 End-nailed Load-Displacement Histories

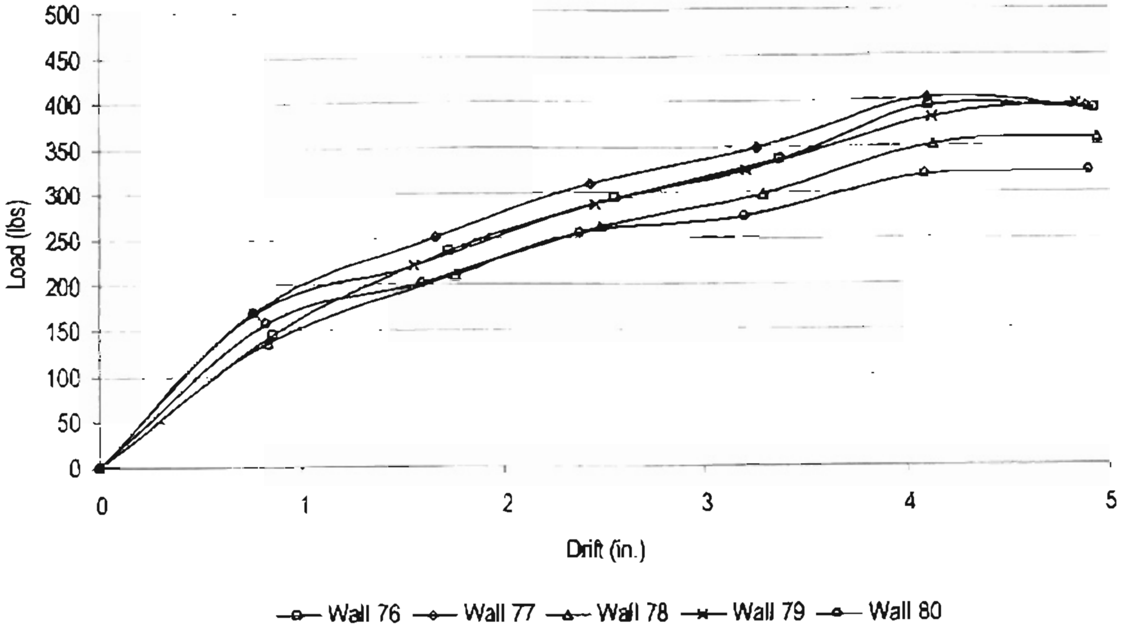

Figure 5.6. No. 3 MPC-Connected Load-Displacement Histories

By examining the load-displacement histories for each frame set it was first observed that none of the frames reached failure. The frames constructed for this test were neither very strong nor stiff in comparison to conventional 4 ft end-nailed sheathed walls. The end-nailed frame strength was controlled by nail bending. The MPC-connected wall strength was provided by the bending stiffness of the framework and MPC moment resistance. The load-displacement histories indicate a ductile behavior. This is logical because the frame is controlled by connections made of steel, a ductile material.

Visual observations of the walls showed that each MPC-connected wall behaved as moment resistant frames with soft joints. One could easily observe bending of the studs during loading. The MPC connections forced the studs to stay in contact with the struts and allowed less end rotation than end-nailed connections as shown in Figure 5.7. End-nailed wall studs could be seen to rotate as rigid bodies rocking on edge. The end-nailed connections separated as shown in Figure 5.8. MPCs provided much more rigidity both visually and in the acquired load-displacement behavior.

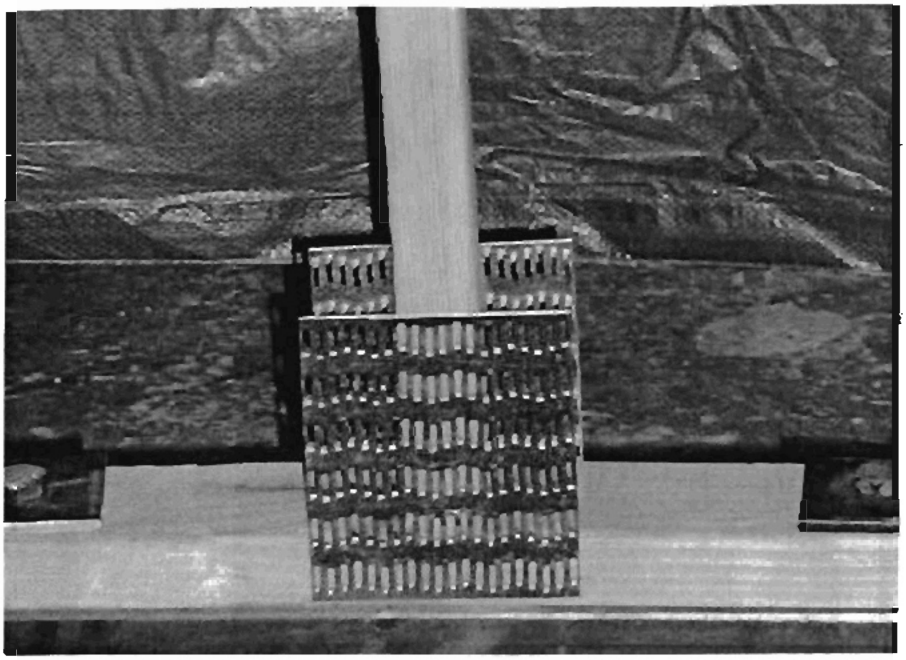

Figure 5.7. MPC Connection During Loading

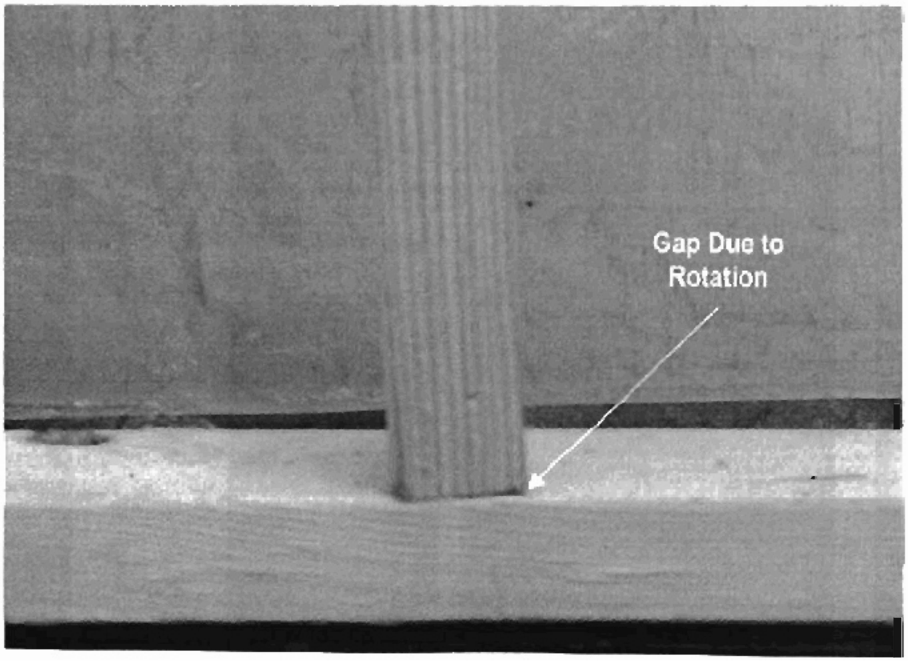

Figure 5.8. End Nail Connection During Loading

Three characteristic values were calculated numerically to compare frame behavior. These values are load at 4-in. drift, stiffness at 1-in. drift, and energy dissipation at 4-in. drift as defined in chapter 3. Averages of these values are shown in Table 5.1.

TABLE 5.1. FRAMING MEMBER STIFFNESS TEST BEHAVIOR CHARACTERISTICS

Wall Set	Load at 4-in. Drift (lbs)	Stiffness at 1-in. Drift (lbs/in.)	Energy Dissipation at 4-in. Drift (K-in.)
No. 1 Nailed	36	32	0.13
No. 1 MPC-Connected	322	123	0.76
No. 2 Nailed	56	37	0.16
No. 2 MPC-Connected	327	121	0.77
No. 3 Nailed	109	76	0.34
No. 3 MPC-Connected	357	166	0.93

The results from the framing member stiffness tests show that MPC-connected frames performed better than end-nailed frames as before. Using MPCs to connect the framing members increased the average load at 4-in. drift by 249 to 285 lbs. Average stiffness increased 85 to 90 lbs/in. and average energy dissipation increased 0.59 to 0.63 K-in. However, there was no explicit evidence that racking resistance is increased by increasing bending stiffness of the framing members. The frames composed of No. 1 SYP and No. 2 DFL behaved similarly. The No. 3 DFL frames resisted approximately 30 more lbs of lateral force, were stiffer by approximately 40 lbs/in., and dissipated approximately 0.16 K-ins. more energy than the No. 1 SYP and No. 2 DFL frames. The No. 1 and No. 2 walls behaved similarly.

5.2.2 Bending Stiffness, Moisture Content, and Tooth Holding Properties

Load-displacement histories and the subsequent behavior characteristics (strength, stiffness, and energy dissipation data) from framing member stiffness tests showed results which contradict intuition. Variability in wood properties (bending stiffness, moisture content, and tooth holding properties) were investigated to determine their influence on test results. Since framing member bending stiffness is not employed in end-nailed bare frames, only the effects of bending stiffness, moisture content, and tooth holding properties of the members within MPC-connected bare frames were investigated.

5.2.2.1 Bending Stiffness

Bending stiffness was determined experimentally via static load-displacement tests. Table 5.2 presents the average bending stiffness with the corresponding Coefficient of Variation, COV, for all framing members connected with MPCs. Also listed are the design values for each lumber grade as specified in the 1997 NDS. The Modulus of Elasticity values for from the NDS are multiplied by a weak axis moment of inertia for a perfect 2x4 cross section, 0.984 in^4.

TABLE 5.2. AVERAGE BENDING STIFFNESS

Framing Grade	Bending Stiffness EI (lb-in.^{2})	COV
SYP No. 1 As Tested	1.73E+06	0.29
SYP No. 1 NDS Design Value	1.67E+06	0.25
DFL No. 2 As Tested	1.55E+06	0.27
DFL No. 2 NDS Design Value	1.57E+06	0.25
DFL No. 3 As Tested	1.52E+06	0.28
DFL No. 3 NDS Design Value	1.38E+06	0.25

The member stiffness data presented in Table 5.2 contain several points of interest. First, only the No. 2 frames had members with a lower average bending stiffness, 1.55E+06 lb-in.^{2}, than the design value specified by the NDS, 1.57E+06 lb-in.^{2}. The No.1 frames had an average bending stiffness, 1.73E+06 lb-in.^{2}, which was higher than specified by the NDS, 1.67E+06 lb-in.^{2}. The No. 3 frames also had a higher average bending stiffness, 1.52E+06 lb-in.^{2}, than specified by the NDS, 1.38E+06 lb-in.^{2}. Second, the COVs for the all three framing grades used were similar. The COV of 25% for the NDS values comes from the 1997 NDS. The NDS states that the COV for visually inspected sawn lumber is 25% and that this value was determined by field experience and tests. Therefore, since the COVs for the lumber employed in the framing member stiffness tests are similar to those recommended by the NDS, the variability of the lumber used for the tests was within reason. Last, the average stiffness of the No. 3 frames were much higher than specified by the NDS, an increase of 0.13E+06 lb-in.^{2}. The No. 1 frames average bending stiffness was only 0.06E+06 lb-in.^{2} greater than the NDS specified. The results of bending stiffness alone suggest that the No. 1 grade frames should perform better with regards to strength, stiffness, and energy dissipation than the No. 2 or No. 3 grade frames. However, as previously stated, this was not the case.

5.2.2.2 Moisture Content

Wood moisture content affects connection properties and therefore must also be considered. Table 5.3 presents the average moisture content for the framing members in each test set.

TABLE 5.3. AVERAGE MOISTURE CONTENT FOR TEST SET LUMBER GRADE

Framing Grade	Moisture Content	COV.
SYP No. 1	11.5	0.13
DFL No. 2	16.8	0.32
DFL No. 3	11.9	0.12

The moisture contents were within reason for No. 1 and No. 3 framing members with 11.5% and 11.9% respectively. They also had low COVs at 0.13 and 0.12. The No. 2 members had higher and more variable moisture content with an average of 16.8% and a COV of 0.32. High moisture contents adversely affect the tooth holding properties of wood. This may explain why No. 2 grade frames were more flexible and weaker than the No. 3 grade frames. From the results of moisture content alone, it would be expected that the No. 3 walls would perform similarly or slightly better than the No. 2 walls in regards to strength and stiffness. It would also be expected that the No. 1 walls would perform better than the No. 2 and No. 3 walls.

5.2.2.3 Combined Bending Stiffness and Moisture Content

Another aspect of the bending stiffness and moisture content tests that must be investigated is the performance of a single wall within its particular test set. A wall with a combination of relatively high bending stiffness and low moisture content for its given test set should perform better than the other walls in its set with combinations of lower stiffness and higher moisture content. The opposite should also be true. Walls with a combination relatively low stiffness and high moisture should perform poorly with respect to the other walls within the set. Table 5.4 presents the bending stiffness and moisture contents of each MPC-connected frame.

TABLE 5.4. FRAMING MEMBER STIFFNESS TEST BENDING STIFFNESS AND MOISTURE CONTENT

Wall Set	Wall Number	Average EI (lb-in.^{2})	EI COV	Average Moisture Content	Moisture Content COV
5x6 MPC-Connected Bare Frames With No 1. Framing	66	1.92E+06	0.19	12%	0.15
	67	1.41E+06	0.43	11%	0.09
	68	1.84E+06	0.31	12%	0.14
	69	1.77E+06	0.28	12%	0.10
	70	1.71E+06	0.24	11%	0.13
5x6 MPC-Connected Bare Frames With No. 2. Framing	21	1.43E+06	0.22	18%	0.38
	22	1.68E+06	0.29	15%	0.32
	23	1.69E+06	0.27	20%	0.28
	24	1.38E+06	0.37	15%	0.34
	25	1.59E+06	0.18	15%	0.22
5x6 MPC-Connected Bare Frames With No. 3. Framing	76	1.61E+06	0.24	11%	0.13
	77	1.70E+06	0.28	12%	0.07
	78	1.25E+06	0.39	12%	0.08
	79	1.38E+06	0.16	12%	0.16
	80	1.68E+06	0.25	12%	0.13

The MPC-connected frames with No. 1 SYP had members with variable average stiffness. Frame 66 had an average bending stiffness of 1.92E+06 lb-in.^{2}, the highest for this test set. Frame 67 had an average bending stiffness of 1.41E+06 lb-in.^{2}, the lowest for its test set. The load-displacement history presented in Figure 5.2 shows that all walls in this test set behave very similarly despite the variability in bending stiffness.

The MPC-connected frames fabricated with No. 2 DFL had members with variable average stiffness and variable average moisture content. Frame 22 had nearly the highest average bending stiffness, 1.68E+06 lb-in.^{2}, and frame 21 has the nearly the lowest, 1.43E+06 lb-in.^{2}. Frames 22 and 21 had average moisture contents of 15 and 18%. No wall in this group has a combination of highest average stiffness and lowest average moisture or lowest average stiffness and highest average moisture but these walls are the best representatives. Despite frame 26 having lower stiffness and higher moisture than frame 27, it was initially stronger and stiffer as can be seen in the load-displacement history presented in Figure 5.3.

The MPC-connected frame fabricated with No. 3 DFL had members with relatively average stiffness and relatively constant moisture content. Frame 77 has the highest average bending stiffness, 1.70E+06 lb-in.^{2}, and wall 78 has the lowest, 1.25E+06 lb-in.^{2}. Frame 77 is shown in the load displacement history presented in Figure 5.5 to be the stiffest and strongest initially and wall 78 is the weakest and most flexible initially.

5.2.2.4 Tooth Holding Properties

As walls failed, neither MPC net section tensile nor MPC shear failures were seen. Joints were failing in tensile tooth withdrawal. Tooth withdrawal failures were noticed to occur in the struts. Therefore, tooth holding properties greatly affected the rigidity of the MPC connections. ES Report ER-5352 (2001) lists the tensile tooth holding design capacity of the Wave™ metal connector plate per square inch of plate embedment area for various connection geometries. MPC teeth slots ran perpendicular to the grain of the struts and parallel to the gain of the studs. This orientation is defined as an AE orientation in the ES Report. For this orientation, SYP has a capacity of 163 lbs per square in. of plate embedment area for tensile tooth withdrawal. The Douglas fir only has 145 lbs of capacity per square inch for tensile tooth withdrawal. Therefore, barring all other variability, MPC-connected frames with SYP No.1 framing should have been the strongest, stiffest, and most ductile.

5.3 Framing Member Stiffness Test Conclusion

The results of the framing member tests are inconclusive. The load displacement histories and numerical values for strength, stiffness, and energy dissipation show that walls constructed with No. 3 framing performed the best. The results of the bending stiffness and moisture content tests contradict this and show that if bending stiffness and moisture content affect frame performance, the No. 1 frames should perform best. Also, the results of the individual frames compared to the other frames in-their respective test set show that only two of six walls performed the best or the worst when having a corresponding combination of high average bending stiffness and low average moisture content or low average bending stiffness and high average moisture content respectively. The tooth holding properties for SYP lumber are greater than those of DFL lumber; therefore the No. 1 framed walls should have been the strongest, stiffest, and most ductile.

There are several possible explanations for the contradicting results in the framing member tests. First, two different species of wood were used. DFL No. 1 lumber was expensive and difficult to obtain and thus was replaced with SYP lumber for one set of tests. The tooth holding properties of MPCs for DFL are different than those of SYP. Therefore, the DFL frame connections are weaker than the SYP frame connections. Although it is a fact that the SYP frame connections are the strongest and stiffest, the test results contradicted this. This contradiction is seen through the behavior characteristics when comparing the No. 3 DFL frames to the No. 1 SYP frames. The No. 3 DFL frames were stronger and stiffer than the No. 1 SYP frames. Although the variability in wood species is present and should be removed, it is likely not the variability that skewed the test results in light of the contradiction in behavior compared to tooth holding properties. Second, variability is introduced inherently in wood construction. One example of this is the framing width. Studs and struts that must be connected are not always the same width. This leaves gaps between the wood and MPC so that MPC teeth are not fully driven into the wood material. Also, wood is an anisotropic material therefore MPC connections can not possibly be made the exact same way. Variability also comes from the defects in wood material. Voids in the wood such as wane and splits can be in the MPC embedment area. Therefore MPC embedment areas vary from connection to connection. Third, out-of-plane bracing was used to ensure walls racked in plane. This out-of-plane bracing was applied in a way which the amount of friction applied with the out-of-plane bracing could not be controlled. The possible friction force may have had influence on walls that resist relatively small lateral forces. Fourth, there was a lack of control of the moisture content of the framing members prior to frame construction and testing. Moisture content affects the framing member stiffness tests in two ways. The modulus of elasticity and therefore the framing member stiffness is inversely proportional to moisture content. Stiffness is lost when moisture content rises. Also, the wood in the embedment area of the MPCs softens when moisture is added and therefore decreases the tooth holding properties of the MPCs.

The framing member stiffness tests showed that MPC-connected bare frames were stronger and stiffer and dissipated more energy than end-nailed bare frames. However, the results are inconclusive as to the effects of changing the lumber grade and therefore the bending stiffness used in construction. It was determined that because of the use of two species of wood, the inherent variability of wood and construction with MPC plates, friction from the wall out-of-plane braces resisting load, and the lack of control of moisture contents for framing members, the framing member stiffness tests showed no changes in wall behavior that could be directly attributed to changes in framing grade. It is recommended that these tests be conducted again with slight modifications. First, testing should use one species of wood in which three grades can be obtained. Second, testing should be conducted on sheathed frames to determine if changes in framing grade effect sheathed walls. Third, environmental conditions of the lumber should be controlled and measured to obtain uniform moisture content. Finally, the walls should be laterally braced in such a way as to control and fix the amount of frictional force developed.

CHAPTER 6

SHEATHED WALL TESTS

Lateral load tests were conducted with frames sheathed with oriented strand board to determine the effects of MPC framework connections in sheathed walls. The behavior of sheathed walls with nail-connected framework and MPC-connected framework were evaluated and compared. As stated in Chapter 4, structural sheathing and its associated connections are the primary element for lateral load resistance. When a conventional shear wall is laterally loaded, sheathing rotates as a rigid body as the framework distorts as a parallelogram. Since sheathing deflects into a different configuration than the frame, nails connecting the two are forced to bend and pull through the sheathing or out of the framework. Sheathing will resist racking force until the sheathing nails can no longer rigidly connect the sheathing to the frame. By increasing the sheathing thickness, walls can resist much more lateral load because sheathing is stronger, stiffer, and thicker, and more force is required to pull sheathing nails through the sheathing. Several sheathing products are available for wall construction; however, only one type was selected to limit variability. The sheathing type selected was Oriented Strand Board (OSB) due to its wide availability and use. OSB is produced by laying rectangular wood strands in layers with the wood grain running in a single direction. Three or more layers are laid so stands run perpendicular to one another and are bonded with adhesive under heat and pressure.

6.1 Test Description

Three OSB thicknesses were used for these tests to determine the influence of MPC connectors on shear wall behavior when sheathing stiffness is altered. The three thicknesses were 1/4-in., 7/16-in., and 5/8 in. All walls in this test were 4 ft long by 8 ft tall, constructed with DFL No. 2 visually graded dimensional lumber framing members connected with either end nails or 5 x 6 MPCs. Five replications were fabricated and tested for each test set.

6.2 Test Results

6.2.1 Sheathed Walls

The moment resistant behavior of framework connected by 5x6 MPCs and sheathed with 1/4, 7/16, and 5/8 in. thick OSB was evaluated through experimental testing and then compared to walls with the same sheathing but end-nailed connected framework. Figures 6.1 through 6.6 present the load-displacement histories for the walls investigated in the sheathed wall tests.

Figure 6.1 presents the load displacement histories for the 1/4-in. sheathed end-nailed walls. The 1/4-in. OSB is weak and the sheathing material near the sheathing nail is easily destroyed during the process of driving nails with a pneumatic nail gun. Two walls in this set were constructed with overdriven sheathing nails and showed very little stiffness and strength. Since the cause of early failure of the walls was easily detected, the results were not presented as they would not represent a conventional wall.

Five characteristic values were calculated from load displacement history data to compare behavior characteristics of the sheathed end-nailed and 5x6 MPC-connected walls. The five behavior characteristic values were maximum load, design load, stiffness at 40% of maximum load, stiffness at 1-in. drift, and energy dissipation at 4-in. drift. These values are presented in Table 6.1. Table 6.2 lists the percent increase calculated by using the 5x6 MPCs to connect the framework instead of end-nailed connections.

The results in Table 6.1 show that by increasing sheathing thickness, wall strength, stiffness and energy dissipation were increased. The walls also performed better in regards to strength, stiffness and energy dissipation when MPCs rather than end nails were used to connect the wall framework.

From Table 6.2, the average maximum load for the sheathed and MPC-connected walls rises and falls as sheathing thickness is increased. In Chapter 4, it was determined that the average load at 4-in. drift of bare frame walls was increased greatly when MPCs were used to connect the framework. Since 1/4-in. sheathing is the thinnest and weakest sheathing used in these tests, it is conceivable that the average maximum load of the 1/4-in. sheathed walls should increase the most when MPCs are used to connect the framework. However, the results of Table 6.2 show that the average maximum load increases the least for 1/4 in. sheathed walls. The sheathing nail connections were investigated to determine the cause of this disagreement. Many of the sheathing nails are driven through MPCs in order to connect the sheathing to the framework for walls with MPC-connected framework. The nails driven through MPCs are done so along the top and bottom edges of the sheathing and therefore are the nails that do the most work to resist sheathing rotation. This can be seen in Figure 2.2. Since the MPC is between the sheathing and the framework, the behavior of the nailed connection is different than if no MPC were present.

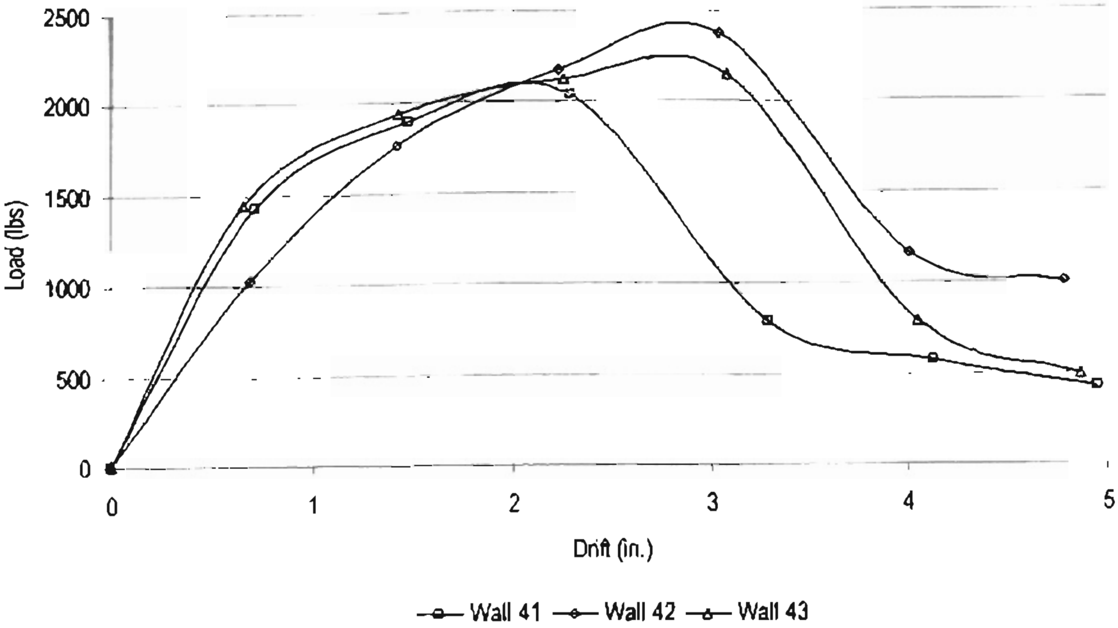

Figure 6.1. Load-Displacement Histories for 1/4-in. Sheathed End-nailed Walls

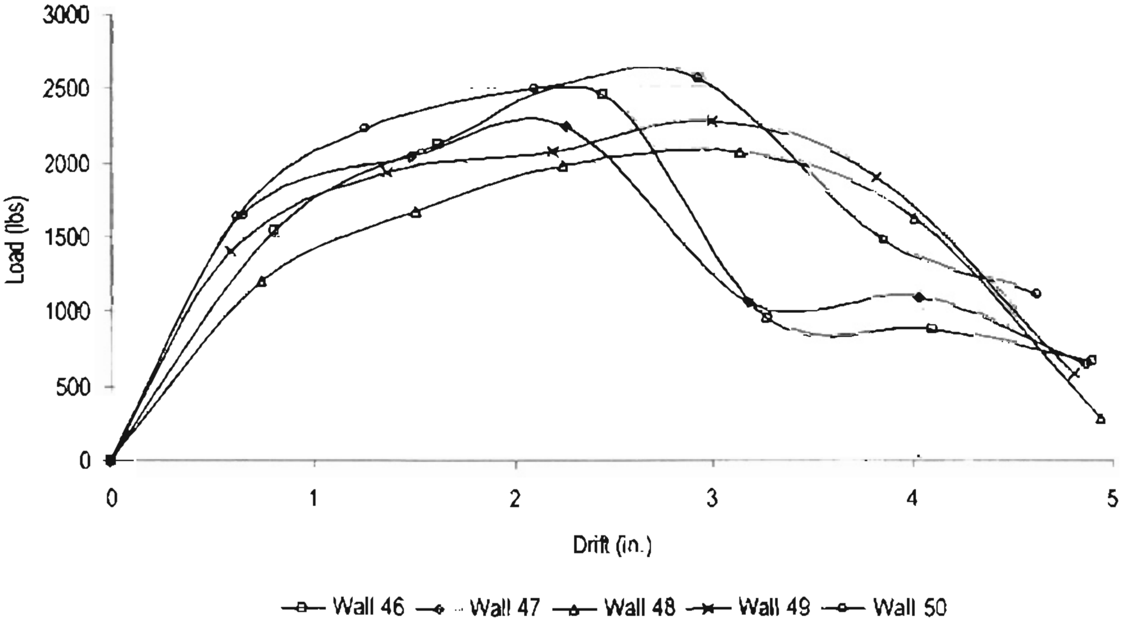

Figure 6.2. Load-Displacement Histories for 1/4-in. Sheathed MPC-Connected Walls

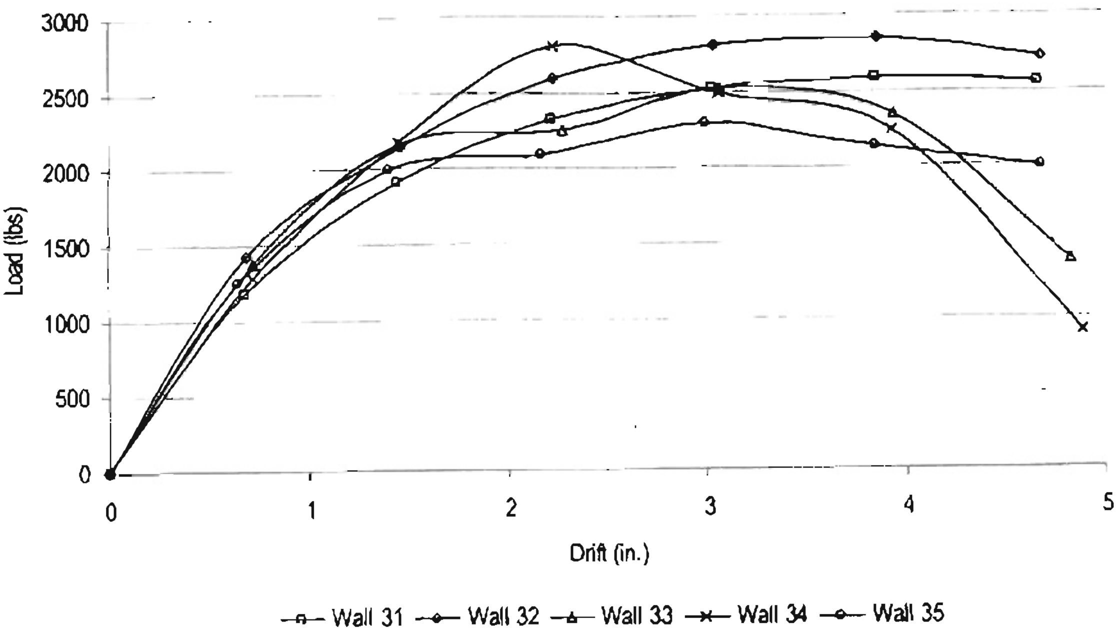

Figure 6.3. Load-Displacement Histories for 7/16-in. Sheathed End-nailed Walls

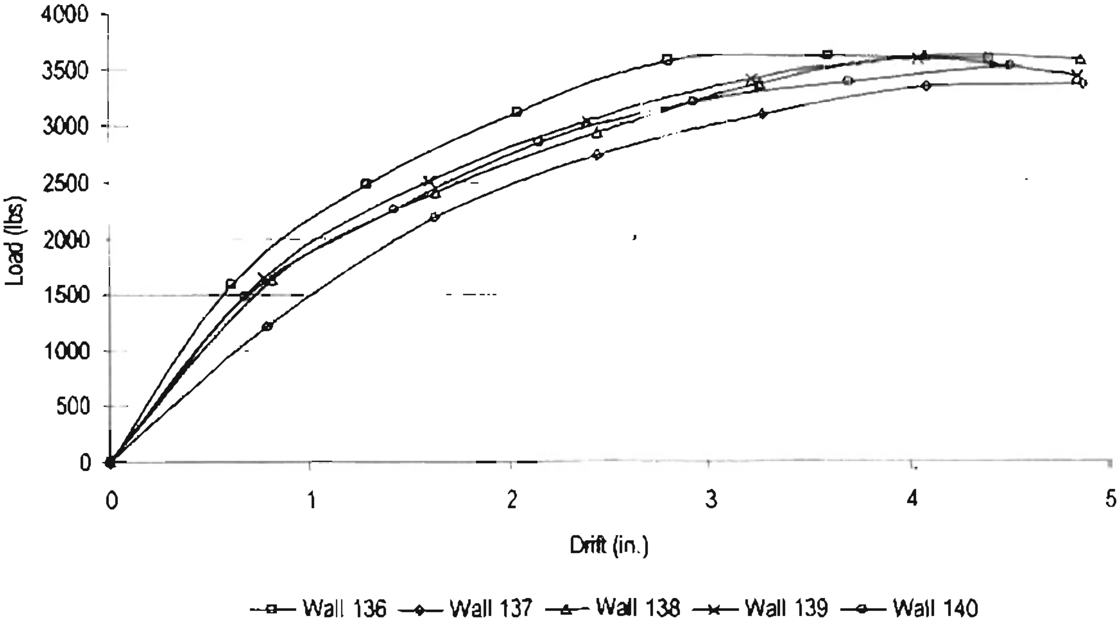

Figure 6.4. Load-Displacement Histories for 7/16-in. Sheathed MPC-Connected Walls

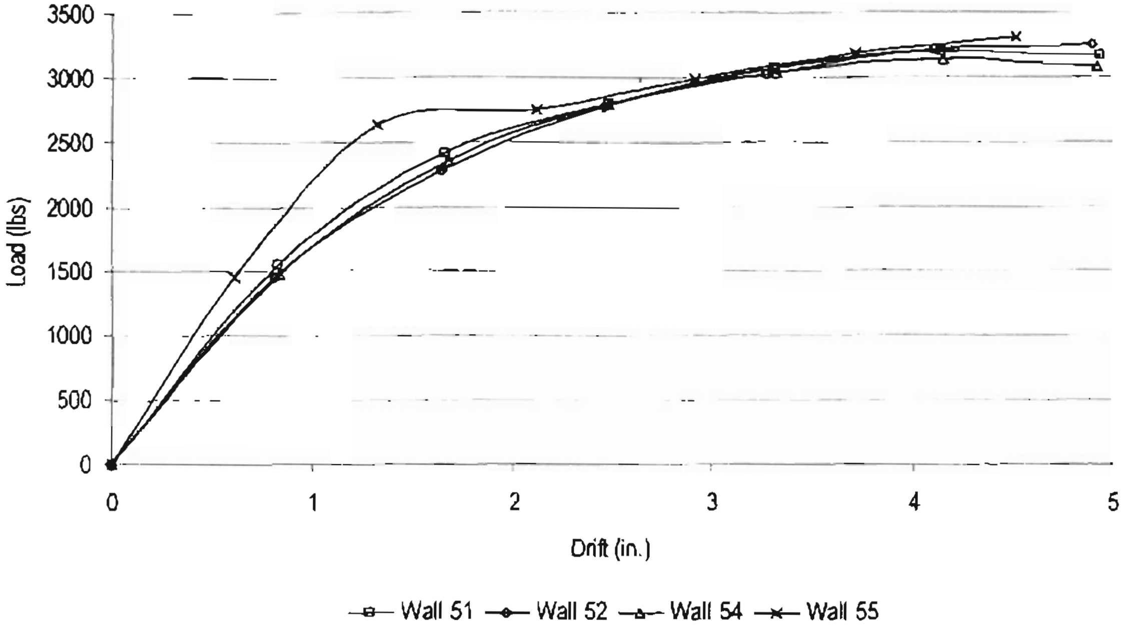

Figure 6.5. Load-Displacement Histories for 5/8-in. Sheathed End-nailed Walls

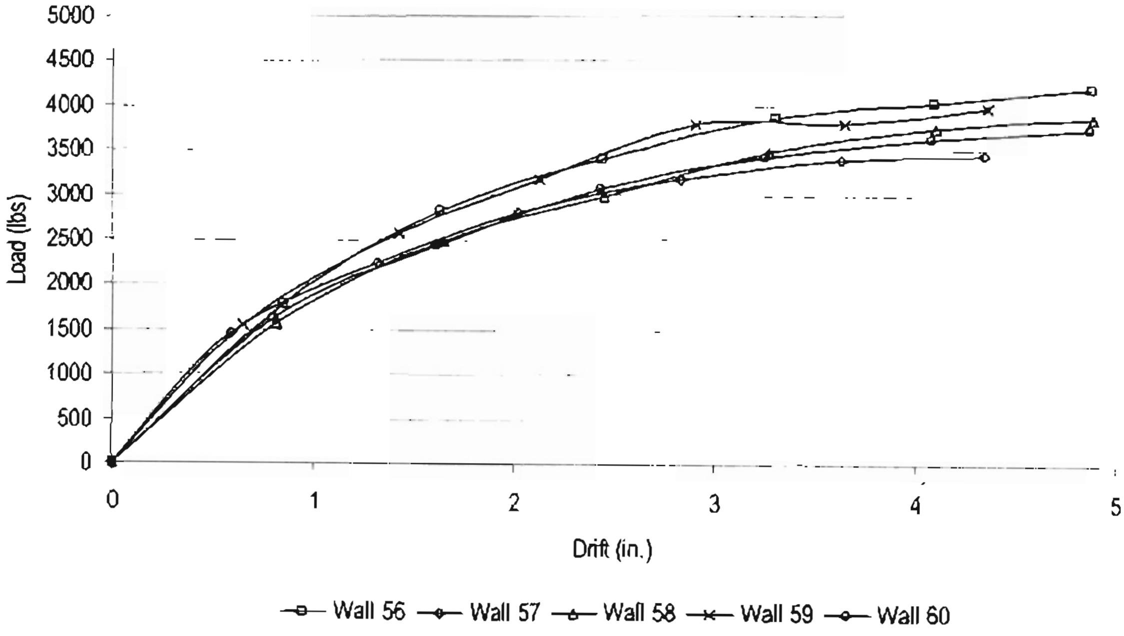

Figure 6.6. Load-Displacement Histories for 5/8-in. Sheathed MPC-Connected Walls

TABLE 6.1. SHEATHED WALL TEST RESULTS

OSB Connection	Maximum Load (lbs)	Design Load (lbs)	Stiffness at 40% of Maximum Load (lbs/in.)	Stiffness at 1-in. Drift (lbs/in.)	Energy Dissipation at 4-in. Drift (K-in.)
1/4-in. Nail	2259	1069	2169	1598	6.37
1/4-in. Plate	2335	1369	3163	1795	7.07
7/16-in. Nail	2718	1117	2014	1642	8.01
7/16-in. Plate	3636	1308	2114	1868	9.84
5/8 in. Nail	3246	1252	2097	1893	9.28
5/8 in. Plate	3862	1285	2158	1951	10.21

TABLE 6.2. SHEATHED WALL TEST BEHAVIOR INCREASES

Connection	Maximum Load	Design Load	Stiffness at 40% of Maximum Load	Stiffness at 1-in. Drift	Energy Dissipation at 4-in. Drift
1/4-in. OSB	3%	28%	44%	12%	11%
7/16-in. OSB	34%	17%	5%	14%	23%
5/8 in. OSB	19%	3%	3%	3%	10%

Table 6.3 lists the nail capacity of an 8d sheathing nail which is 2-3/8 in. long with a 0.113-in. diameter connecting the three thicknesses of sheathing to a DFL framing member calculated from the National Design Specification for Wood Construction, 1997. The six possible failure modes for the nail are presented. Figure 6.7 illustrates these failure modes. Mode Im represents crushing of the main member. Mode Is represents crushing of the side member. Mode II represents nail rotation. Mode IIIm represents the formation of a plastic hinge in the nail and crushing of the main member. Mode IIIs represents plastic hinge formation in the nail and crushing of the side member. Mode IV represents the formation of two plastic hinges in the nail. For the application of shear walls, the sheathing is always the side member and the framing is always the main member

TABLE 6.3. SHEATHING NAIL FAILURE MODE

Failure Mode	1/4-in. OSB	5/8 in. OSB	7/16-in. OSB
Im	507	462	417
Is	59	104	149
II	175	155	139
IIIm	174	159	145
IIIs	51	56	65
IV	72	72	72

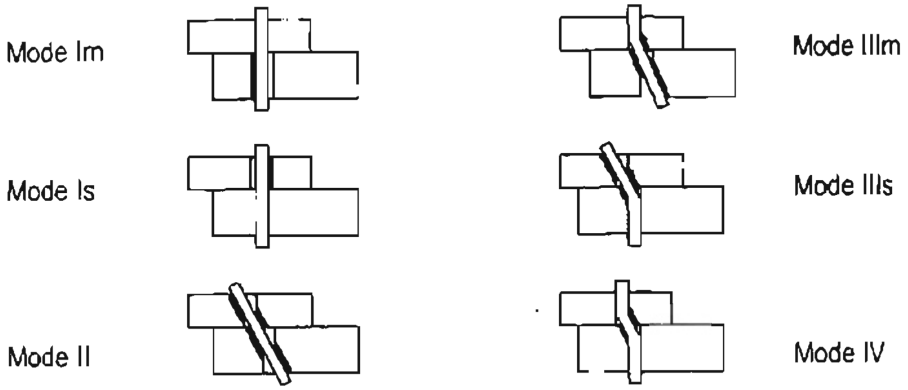

Figure 6.7. Nail Connection Failure Modes

From Table 6.3, the failure mode for nails connecting the 1/4-in. OSB to the framework of an end nail-connected wall is IIIs with a lateral capacity of 51 lbs. If a MPC were placed between the main and side members the capacity of the IIIs failure mode would increase in capacity since the MPC would resist the crushing of the main member (see Figure 6.7). The capacity before failure could increase from 51 to 59 lbs and remain in the IIIs failure mode but it cannot exceed 59 lbs because the failure mode would change to Is which is not affected by addition of the plate. The capacity of the connection most used to resist sheathing rotation can only increase slightly for the 1/4-in. sheathed MPC-connected walls. It must also be noted that the behavior of nails that do not pass through MPCs do not change.

The added load capacity of the MPCs and bending framework acting independent of the sheathing must also be considered. The average maximum load at 4-in. drift for 5x6 MPC-connected bare frames was 327 lbs and this load was not reached until the wall had drifted 4-inches. The average maximum load at 4-in. drift for end nail-connected bare frame was 56 lbs. This suggests that MPCs only slightly increase the lateral load capacity, 271 lbs, by forcing the framework to bend and slightly increase the lateral load capacity of the wall by increasing the capacity of the sheathing nails for the 1/4-in. sheathed walls. This must also be investigated for the walls with thicker sheathing.

Table 6.2 shows that the average maximum load is increased by 34% for 7/16-in. sheathed walls by using MPC connections. Table 6.3 shows that the corner nail capacity can be increased by nearly double before the sheathing nail failure mode is limited to an Is failure. The Is failure mode is not effected by the MPC like the IIIs and IV failure modes are. The combination of the added capacity of the sheathing nails for 7/16-in. sheathed MPC-connected walls, which is conceivably twice the capacity of the sheathing nails in the 1/4-in. sheathed MPC-connected walls, with the lateral load capacity from the semi-rigid framework could greatly increase the average maximum load of the 7/16-in. sheathed MPC-connected walls. The failure modes of the sheathing nails passing through MPC connections should be studied to determine the capacity of the sheathing nails

The average maximum load of the 5/8 in. sheathed walls increased 19% with the addition of MPC connections which was more than for 1/4-in. sheathed walls but less than for 7/16-in. sheathed walls. Again, to change the failure modes of the sheathing nails passing through MPC plates, the capacity of the nail must increase by nearly double to reach a failure mode than is not affected by the MPC. Still, the failure modes of sheathing nails passing through MPCs must be studied in greater detail to define this behavior.

It was stated earlier that the maximum load for 1/4-in sheathed walls was barely increased by the addition of MPC connections. However, the average stiffness at 40% of maximum load was increased tremendously in addition to average design load. Average stiffness at 40% of maximum load of 1/4-in. sheathed walls increased 44%, the greatest for any of the sheathing thicknesses. Table 6.1 shows that the average stiffness at 40% of maximum load is far greater than the average stiffness at 1-in. of drift, and Figure 6.2 shows that initial stiffness is high and decreases as the wall top continues to drift. Therefore, stiffness at 40% of maximum load is recorded at a drift smaller than 1-in. The 1/4-in. sheathing is the most flexible sheathing used in these tests. It is likely that since it is the most flexible, it benefits the most from the addition of MPC connections. As sheathing thickness and stiffness was increased, the relative benefit of MPC connections was expected to decrease. Thick sheathing with great stiffness will likely overshadow the effects of MPC connections on stiffness. Although the effects are possibly overshadowed, the 7/16-in. and 5/8 in. sheathed walls did increase in average stiffness at 40% of maximum load slightly, 5% and 3% when MPC connections were used.

Increase in design load is a direct reflection of increase in initial stiffness. Since the 1/4-in. sheathed MPC-connected walls had the greatest increase in average stiffness at 40% of maximum load they also had the greatest increase in average design load. Since the increase in average stiffness at 40% of maximum dropped as sheathing thickness increased, the increase in average design load also dropped as sheathing thickness increased. Increases in average stiffness at 1-in. drift and average energy dissipation rose and fell in the same manner as average maximum load. These values are probably also effected by the failure modes of the sheathing nails therefore they will not be discussed in detail.

Interesting results were found when comparing an end-nailed wall with thicker sheathing to an MPC-connected wall with one size thinner sheathing. MPC-connected 4-ft walls with 1/4-in. OSB failed suddenly in comparison to end-nailed walls with 7/16-in. OSB. Therefore, the average maximum load and energy dissipation were lower, but the MPC-connected wall had a greater design load and stiffness. MPC-connected walls with 7/16-in. OSB, on average, produced slightly greater maximum loads, design loads, and energy dissipation than end-nailed walls with 5/8-in. OSB; and stiffness at 1-in. was only a percent lower. Table 6.3 lists increases in strength, stiffness, and energy dissipation for MPC-connected sheathed walls over end nail-connected walls with one size thicker sheathing. The most important detail to notice is that although the behavior of sheathed walls with MPC connections cannot be completely defined at this time, all behavioral characteristics increased when sheathed wall frameworks were connected with MPCs.

6.2.2 Bending Stiffness and Moisture Content

The bending stiffness and moisture content of each framing member in each wall were measured because the stiffness of the entire wall is dependent upon the stiffness of the individual framework members and the stiffness of the MPC connections is adversely affected by excessive moisture content. These values are averaged for each wall in the MPC-connected test sets and listed in Table 6.4. The coefficients of variability, COV, are also listed for each measurement.

TABLE 6.4. BEHAVIOR INCREASES FOR WALLS WITH MPCS AND THINNER OSB OVER END-NAILED-CONNECTIONS AND THICKER OSB

Connection	Maximum Load	Design Load	Stiffness at 40% of Maximum Load	Stiffness at 1-in.	Energy Dissipation at 4-in. Drift
1/4-in. OSB MPC-Connected Over 7/16-in. OSB Nailed	-14%	23%	55%	9%	-12%
7/16-in. OSB MPC-Connected Over 5/8 in. OSB Nailed	12%	4%	1%	-1%	6%

TABLE 6.4. BENDING STIFFNESS AND MOISTURE CONTENT OF FRAMING MEMBERS IN SHEATHED WALL TESTS

Tests Set	Wall	Average EI (lb-in.^{2})	COV EI	Average MC	COV MC
5x6 MPC-Connected Walls With 1/4-in. OSB	46	1.47E+06	0.17	12.8	0.07
	47	1.78E+06	0.67	11.6	0.09
	48	1.36E+06	0.20	12.2	0.15
	49	1.65E+06	0.22	14.2	0.10
	50	1.38E+06	0.18	14.2	0.13
5x6 MPC-Connected Walls With 7/16 OSB	136	1.42E+06	0.27	12.1	0.16
	137	1.47E+06	0.17	12.3	0.12
	138	1.37E+06	0.16	13.1	0.22
	139	1.47E+06	0.26	13.1	0.23
	140	1.53E+06	0.14	10.8	0.15
5x6 MPC-Connected Walls With 5/8. OSB	56	1.67E+06	0.14	11.33	0.19
	57	1.70E+06	0.17	11.00	0.16
	58	1.48E+06	0.26	12.22	0.26
	59	1.66E+06	0.18	12.67	0.26
	60	1.48E+06	0.22	11.22	0.19

The walls in the MPC-connected 1/4-in. sheathed wall tests set developed similar load-displacement paths but wall but wall 48 proved to be the least strong and stiff. However, wall 48 did not have the lowest average bending stiffness or the highest average moisture content for its test set as might be expected. Walls 136 and 137 were the strongest and stiffest and weakest and most flexible walls, respectively, in the MPC-connected 7/16-in. sheathed wall test set. Wall 136 did not have the highest average bending stiffness or lowest average moisture content nor did wall 137 have the lowest average bending stiffness or highest average moisture content. All of the walls in the MPC-connected 5/8 in. sheathing performed very similarly despite having high COVs for both bending stiffness and moisture content.

The results of the bending stiffness and moisture content tests for the framing members used in sheathed wall tests are inconclusive. Although the bending stiffness and moisture content of the members should affect lateral load resistance, the results of the bending stiffness and moisture content tests do not suggest this to be true.

6.3 Sheathed Wall Test Conclusions

MPCs were found to enhance structural characteristics for walls sheathed with 1/4, 7/16, and 5/8 in. OSB. In fact, the MPC framing connections resulted in the 1/4-in. sheathed walls being stiffer and producing a greater design load than 7/16-in. sheathed walls with end-nailed framework. Similarly, the 7/16-in. sheathed walls with MPC-connected framework were as strong and stiff and dissipate as much energy as 5/8 in. sheathed walls with end-nailed framework.

Sheathed wall tests should be continued for more comparisons of MPC-connected sheathed wall behavior to end nail-connected sheathed wall behavior. Careful fabrication should be conducted to ensure sheathing nails are driven flush with the OSB surface and the moisture content of the framing members should be strictly controlled to ensure all members have the same or at least very similar moisture contents. In addition to these changes, wall lengths should be varied to determine if MPC-connected walls with thinner sheathing still perform better than end-nailed walls with thicker sheathing for different length walls. Also, the sheathing nail behavior and failure modes should be investigated. A single nail test of the lateral load resistance for connections of sheathing to framing members with MPCs attached should be conducted. The behavior and mode of failure should be developed and compared against the equations for nail lateral load capacity. The connections with MPCs sandwiched between the framing member and the sheathing will be used many times in walls incorporating MPC connections. Research on the behavior of this subsystem should prove beneficial. The results of these tests could then be reexamined for more insight into the changes in shear wall behavior due to varying sheathing thickness and MPC connections.

CHAPTER 7

WALL LENGTH TESTS

MPC-connected wall behavior was observed and compared to end nail-connected walls and MPCs were shown to enhance wall performance. However, all previous tests were conducted with 4 ft walls. Wall length tests were used to determine how walls with MPC-connected frames behave in comparison to walls with end-nailed frames for walls 4 ft long and longer.

7.1 Test Description

All walls with bare and sheathed frames in wall length tests were composed of DFL No. 2 framing. Each framing member was 2 x 4 visually graded dimensional lumber. Sheathed walls were fabricated with 7/16-in. OSB. A single MPC size, 5 x 6, was used for frame connections of the MPC-connected walls that were built in four lengths: 4, 8, 12, and 16 ft. The 4-ft wall configurations were built in five replications; all other configurations were built in three replications.

7.2 Test Results

7.2.1 Bare Frames

The behavior of bare frames that were 8 ft tall with lengths of 4, 8, 12, and 16 ft were evaluated through experimental testing. Figures 7.1 through 7.8 present load-displacement histories for each bare frame wall set. The load-displacement histories for bare frames were used to calculate the behavior characteristics presented in Table 7.1. Table 7.1 presents the average strength, stiffness, and energy dissipation for bare frame wall sets.

The values listed in Table 7.1 show that strength, stiffness, and energy dissipation are all increased by the addition of MPC connections and by increasing wall length. It was concluded earlier that MPC connections enhanced the behavior characteristics of bare frames. As walls are fabricated with greater lengths, more MPC connections or end nails are required and each connection contributes to the lateral load resistance.

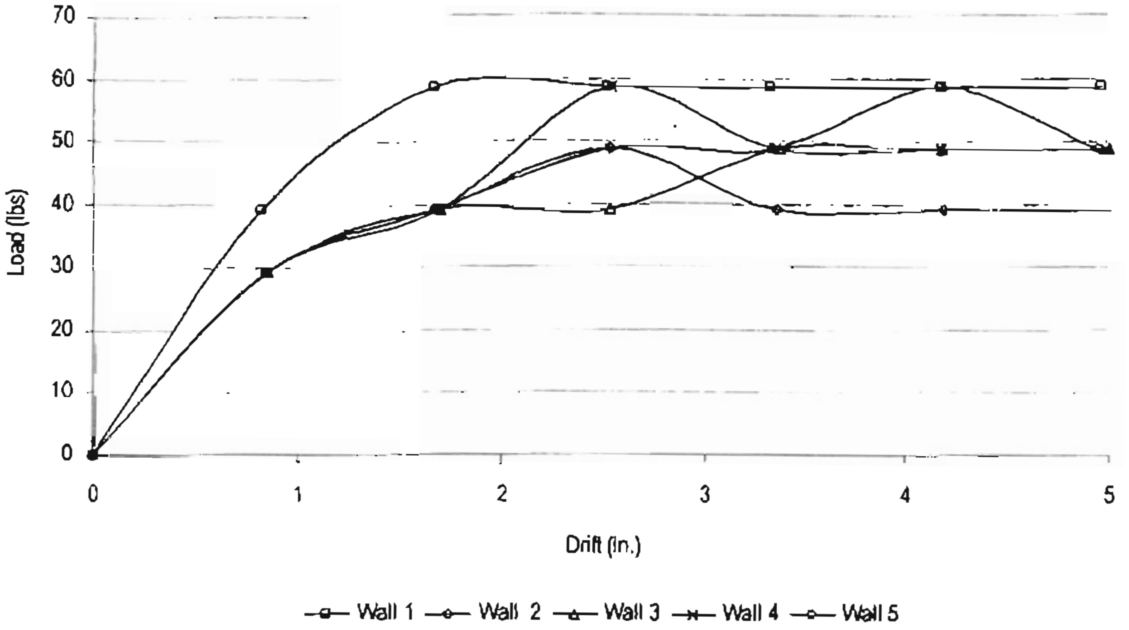

Figure 7.1. 4-ft End-nailed Wall Load-Displacement Histories

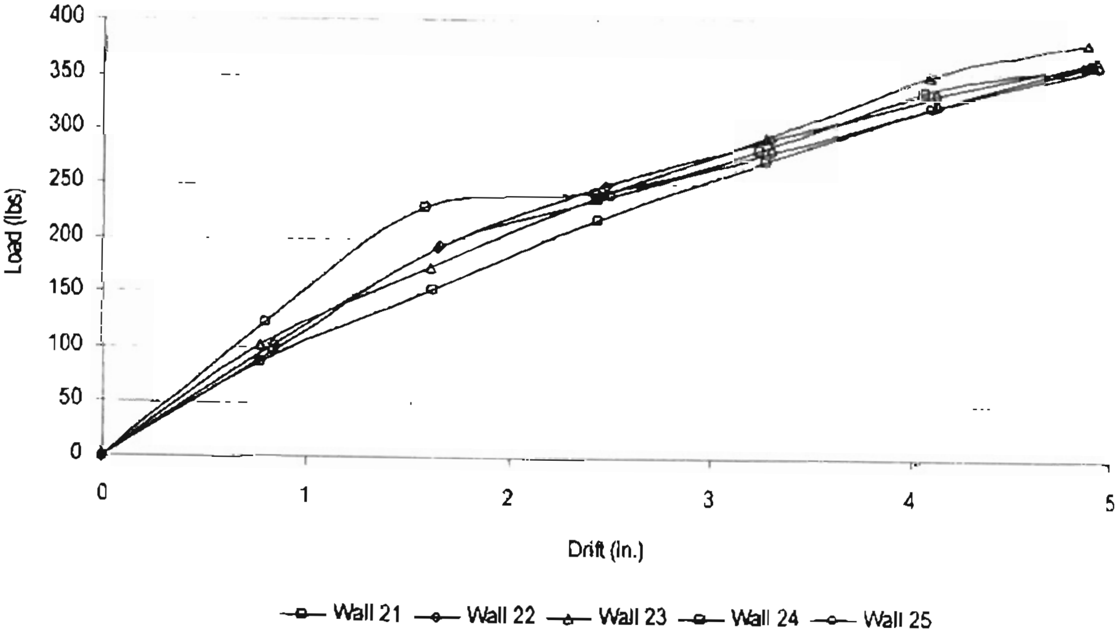

Figure 7.2. 4-ft MPC-Connected Wall Load-Displacement Histories

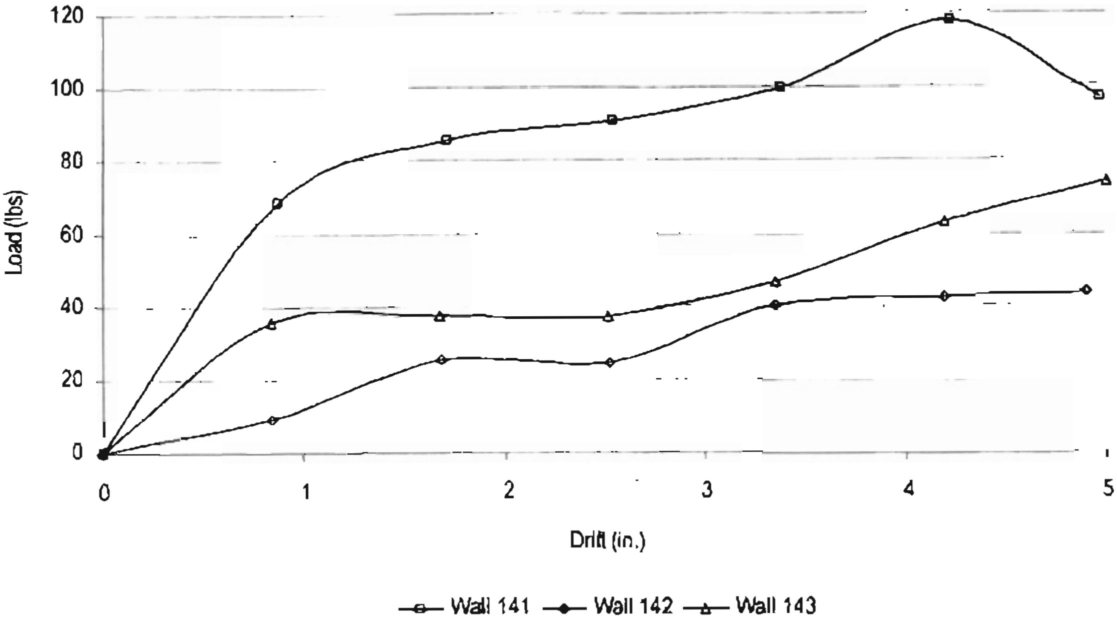

Figure 7.3. 8-ft End-nailed Wall Load-Displacement Histories

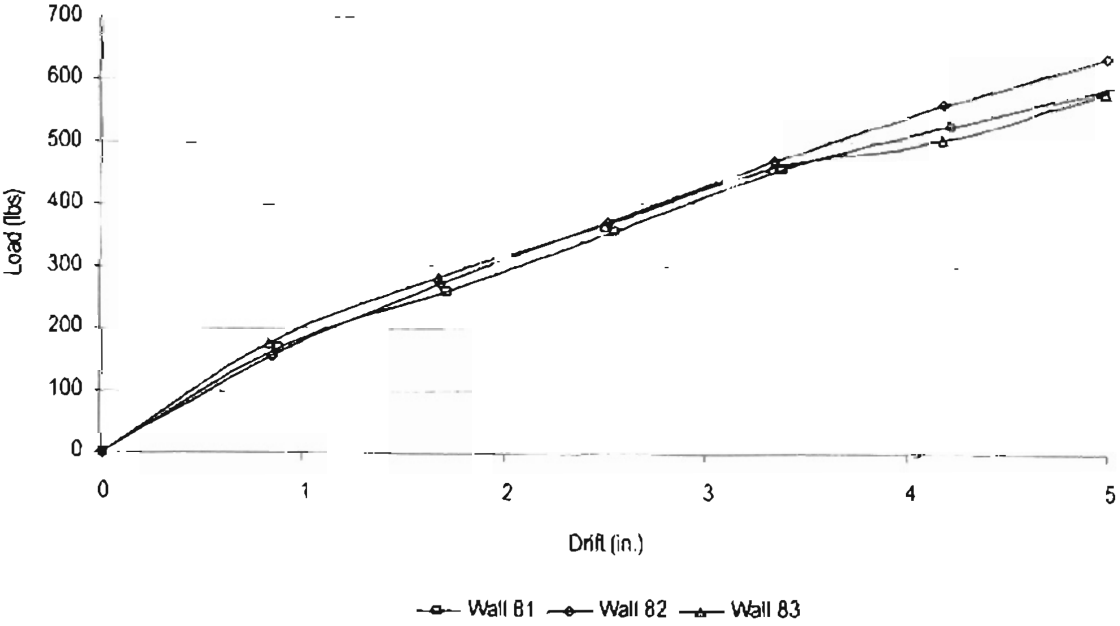

Figure 7.4. 8-ft MPC-Connected Wall Load-Displacement Histories

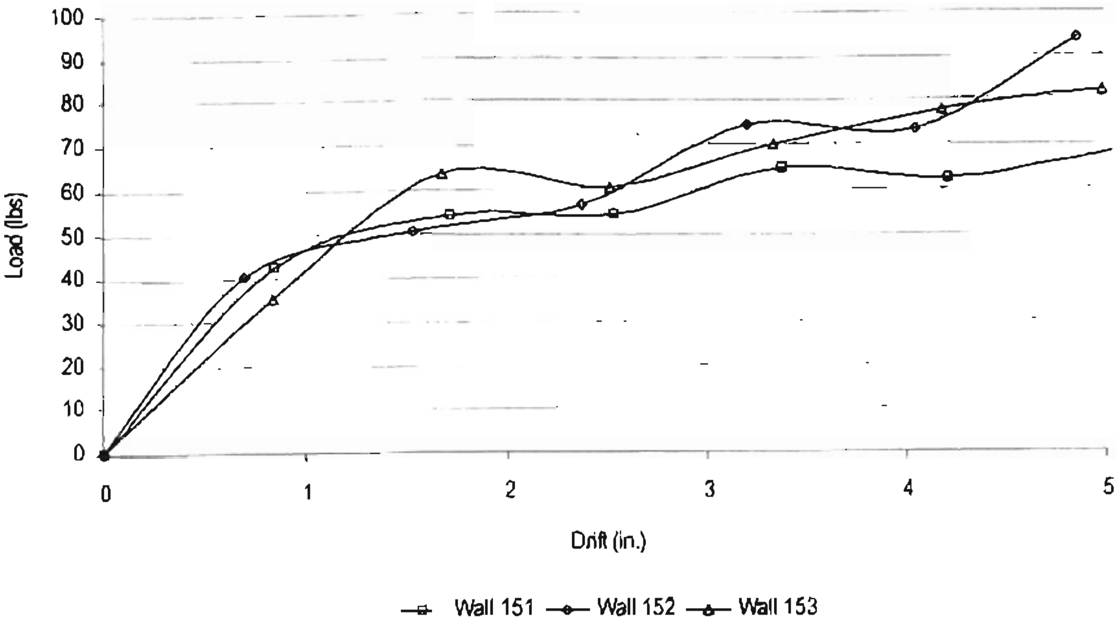

Figure 7.5. 12-ft End-nailed Wall Load-Displacement Histories

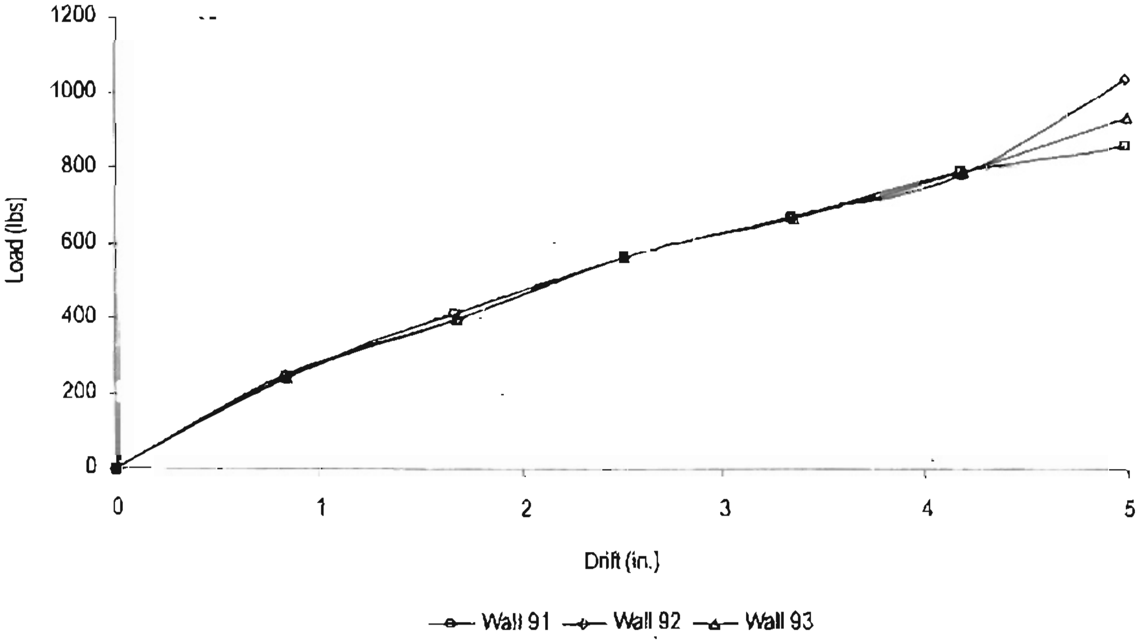

Figure 7.6. 12-ft MPC-Connected Wall Load-Displacement Histories

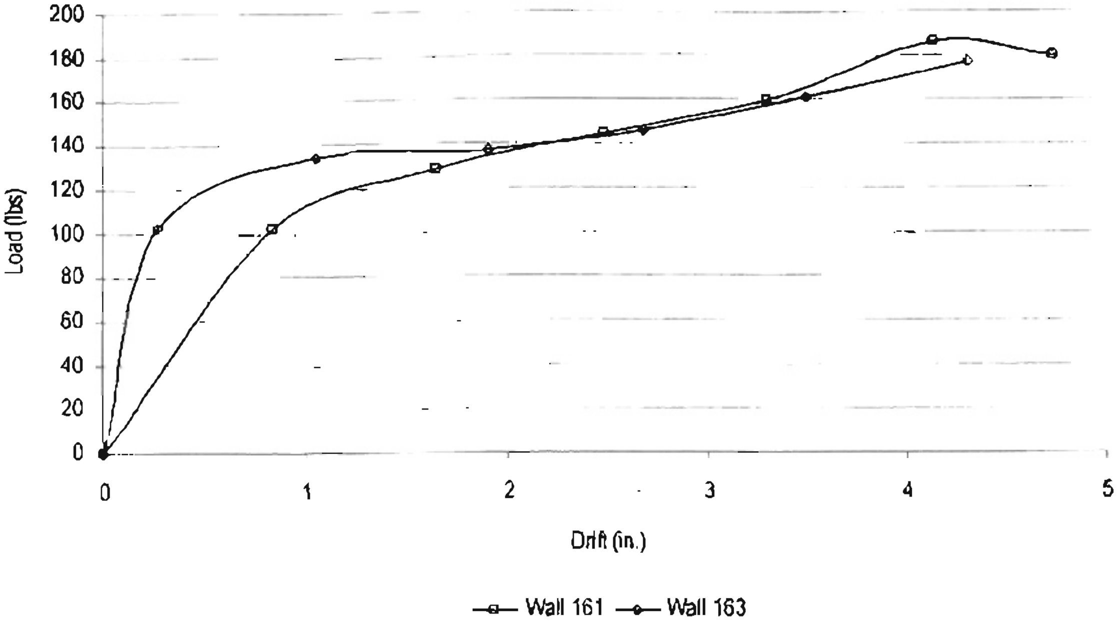

Figure 7.7. 16-ft End-nailed Wall Load-Displacement Histories

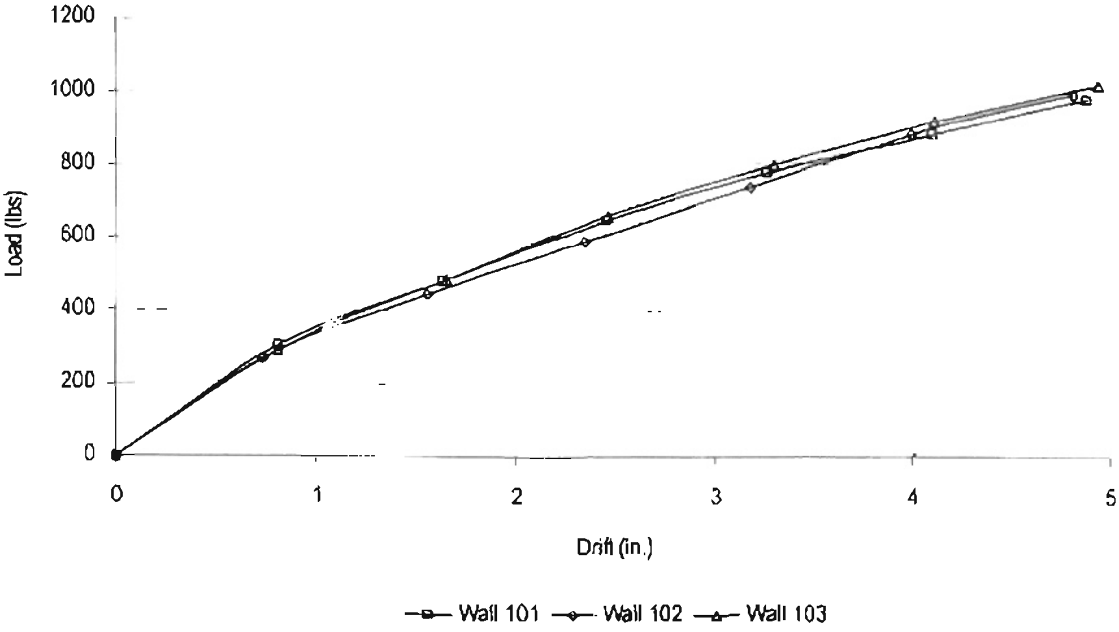

Figure 7.8. 16-ft MPC-Connected Wall Load-Displacement Histories

TABLE 7.1. WALL LENGTH TEST BARE FRAME STRENGTH, STIFFNESS, AND ENERGY DISSIPATION

Length/Connection	Load at 4-in. Drift (lbs)	Stiffness at 1-in. Drift (lbs/in.)	Energy Dissipation at 4-in. Drift (K-in.)
4-ft End-nailed	56	37	0.16
4-ft MPC-Connected	327	121	0.77
8-ft End-nailed	79	42	0.19
8-ft MPC-Connected	509	176	1.18
12-ft End-nailed	71	48	0.22
12-ft MPC-Connected	757	277	1.77
16-ft End-nailed	176	119	0.53
16-ft MPC-Connected	879	341	2.10

Table 7.1 indicates that bare frame performance is a function of wall length or how many connections are used to connect the framework. As the number of connections increases, the behavior characteristics of the bare frames are enhanced more. This is true for both end-nailed and MPC connections.

7.2.2 Sheathed Walls

The behavior of 8 ft tall sheathed frames with lengths of 4, 8, 12, and 16 ft was evaluated through experimental testing. Figures 7.9 through 7.16 present load-displacement histories for each sheathed wall set. The load-displacement histories of the sheathed walls sets indicate each wall followed a load-displacement path similar to that of other walls within its set with the exception of wall 84 of the 8-ft sheathed wall set. Even then, wall 84 followed a similar path but only reached higher loads.

Each of the following tables shows an average for the given value for each wall set. This is followed by the coefficient of variation and the percent increase for that value for MPC-connected walls versus end-nailed walls of the same length. Tables 7.2 through 7.6 show average maximum load, stiffness at 40% of maximum load, stiffness at 1-in. drift, and energy dissipation at 4-in. drift for each wall set.

The results listed in Tables 7.2 through 7.6 show conflicting data. The average maximum load and average energy dissipation at 4-in. drift for each wall length were increased by connecting the framework with MPCs. However, average design load and stiffness did not always increase for each wall length when connecting framework with MPCs.

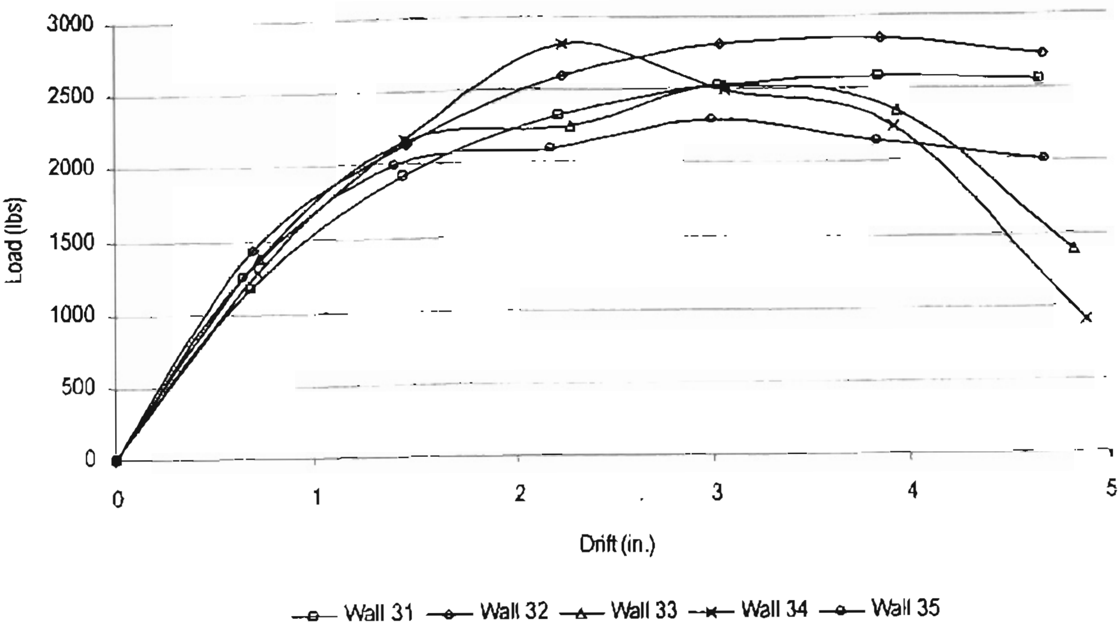

Figure 7.9. End-nailed Sheathed Load-Displacement Histories for 4-ft Sheathed Walls

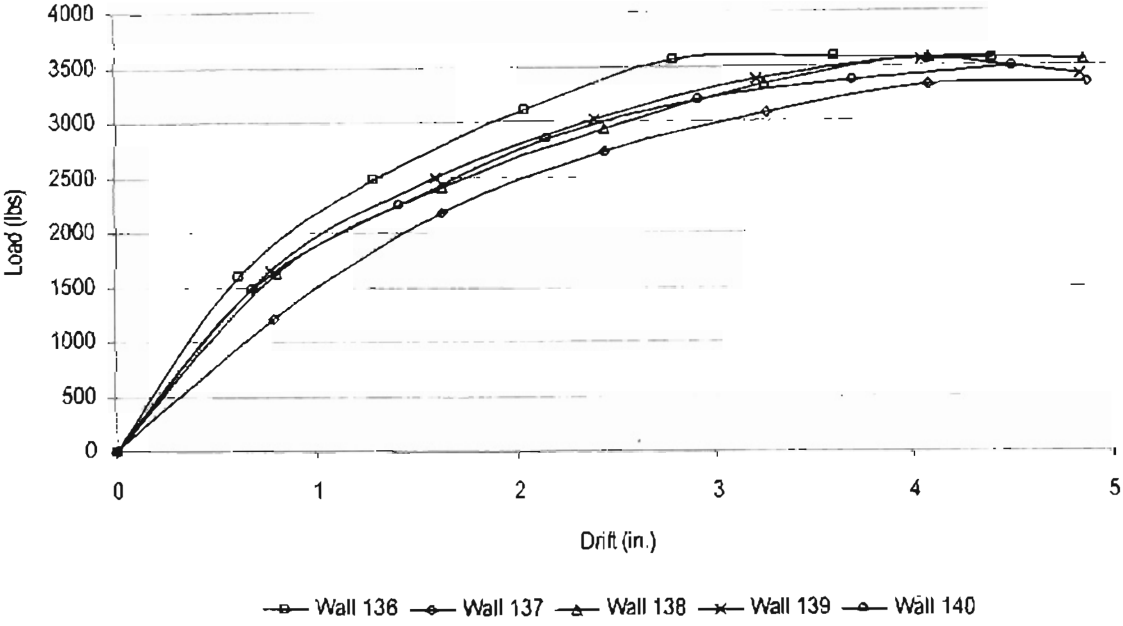

Figure 7.10. MPC-Connected Sheathed Load-Displacement Histories for 4-ft Sheathed Walls

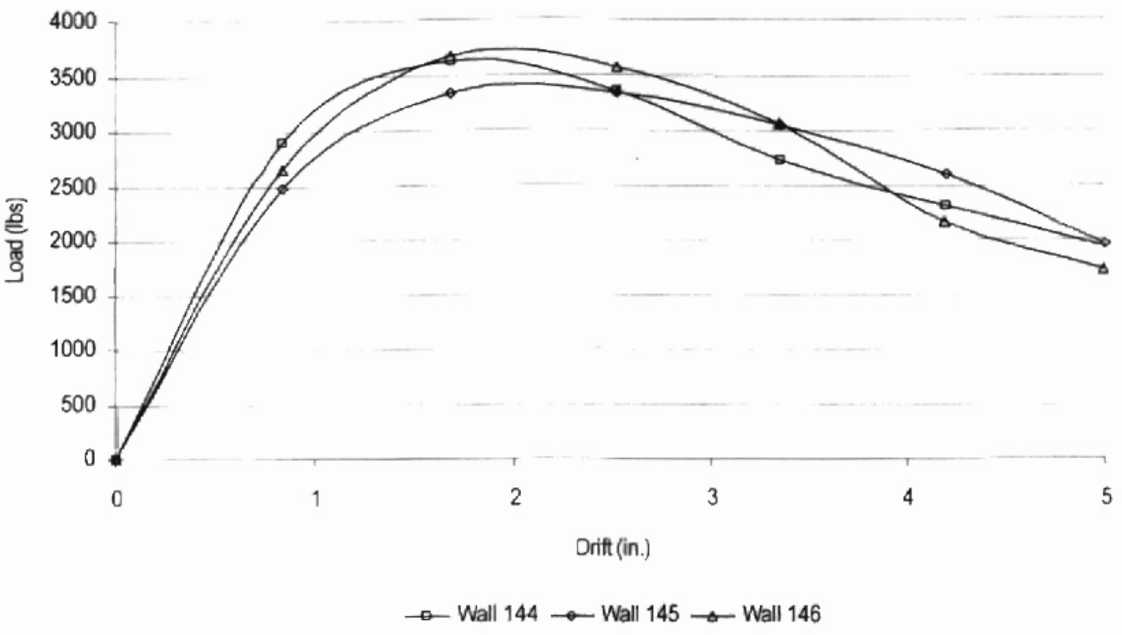

Figure 7.11. End-nailed Sheathed Load-Displacement Histories for 8-ft Sheathed Walls

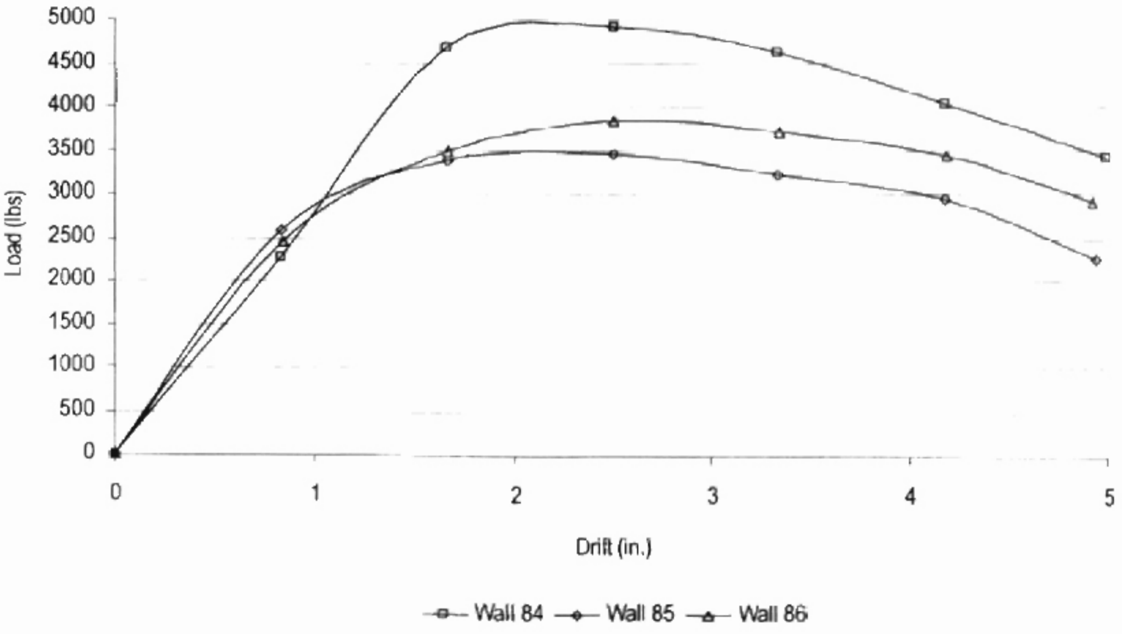

Figure 7.12. MPC-Connected Sheathed Load-Displacement Histories for 8-ft Sheathed Walls

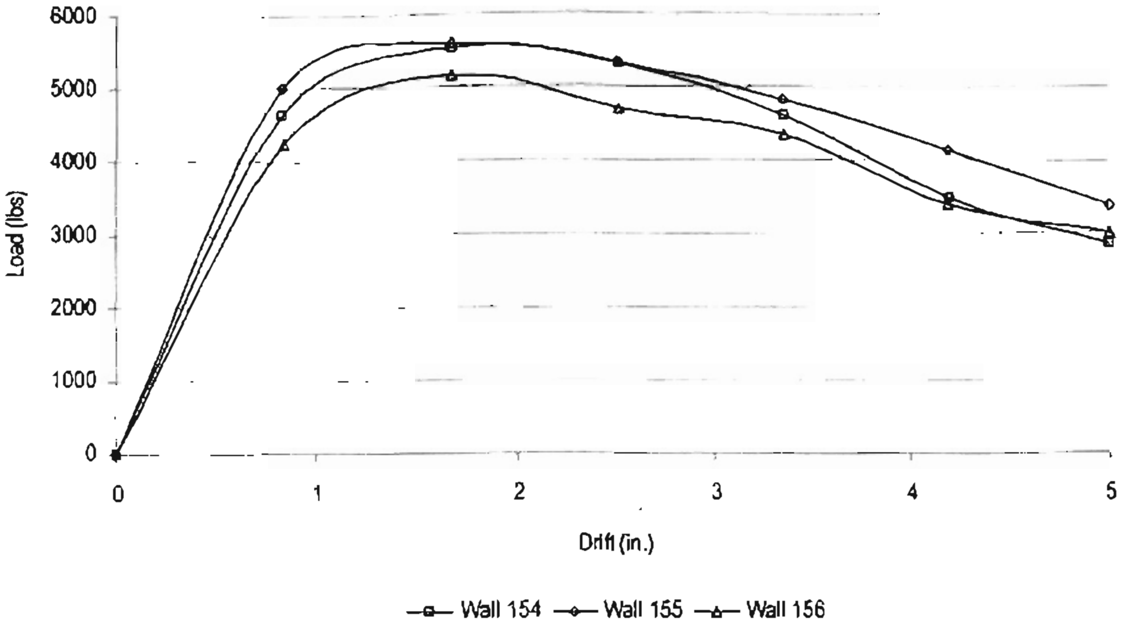

Figure 7.13. End-nailed Sheathed Load-Displacement Histories for 12-ft Sheathed Walls

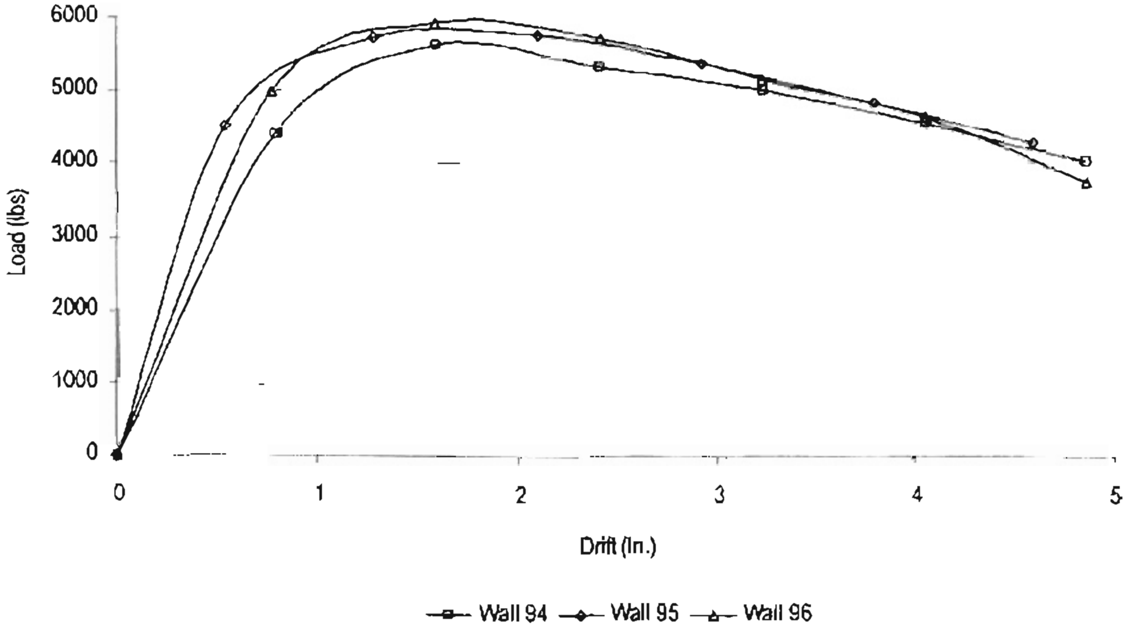

Figure 7.14. MPC-Connected Sheathed Load-Displacement Histories for 12-ft Sheathed Walls

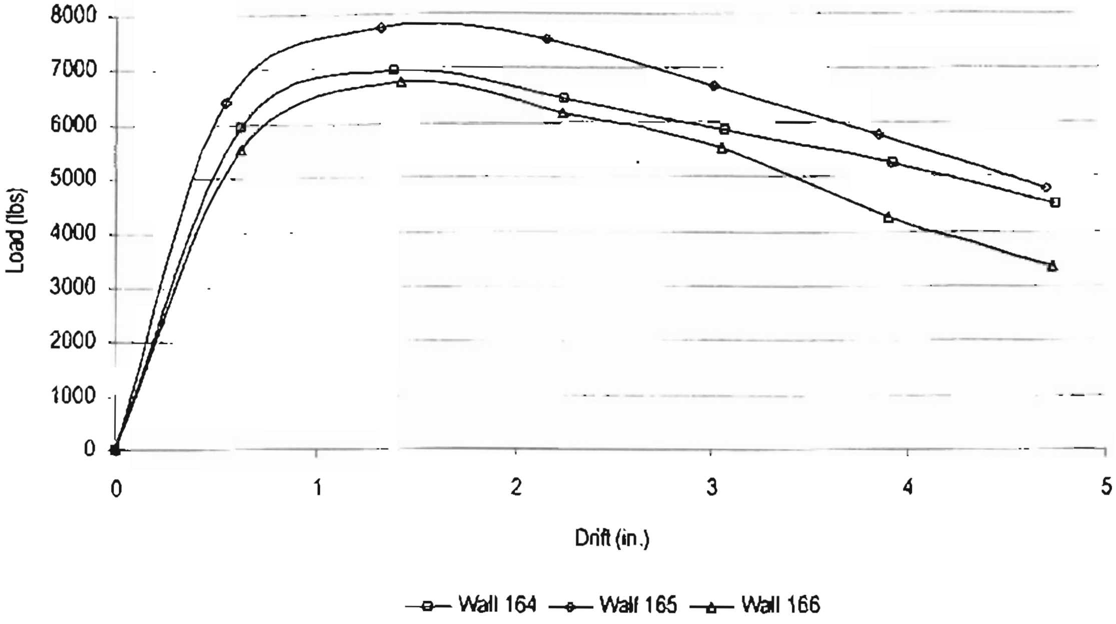

Figure 7.15. End-nailed Sheathed Load-Displacement Histories for 16-ft Sheathed Walls

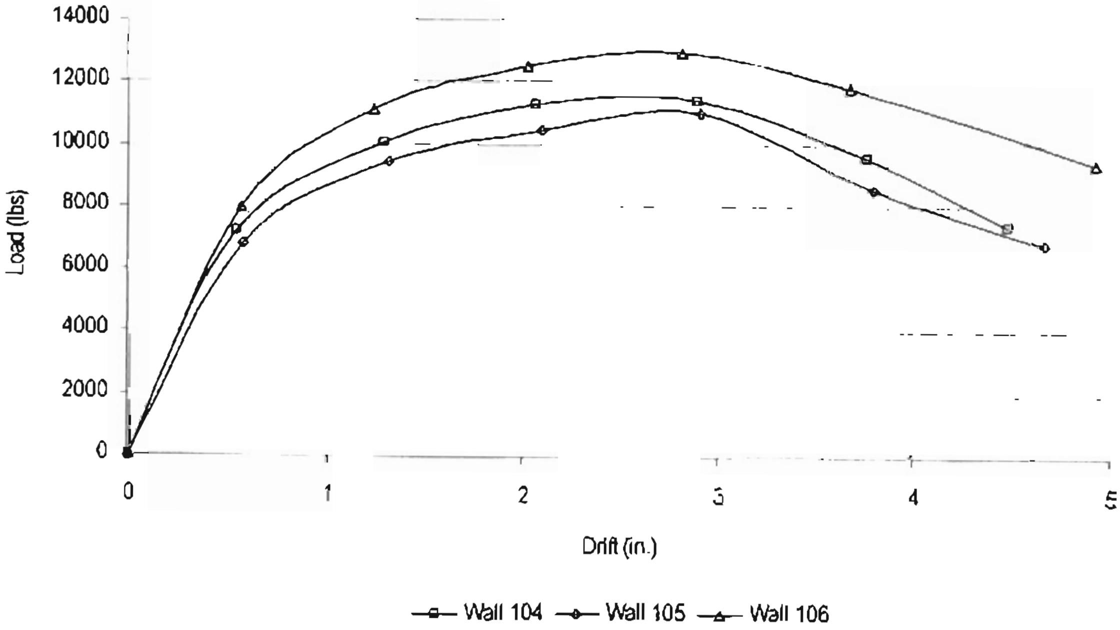

Figure 7.16. MPC-Connected Sheathed Load-Displacement Histories for 16-ft Sheathed Walls

Another conflict in the test results for long MPC-connected sheathed shear walls is found when looking at the tendencies for percent increases for a given characteristic value. Looking at the average maximum load, it is noticed that the 4 ft sheathed walls average maximum load increased by 34% when MPCs were used to connect the framework.

The 8, 12, and 16 ft walls average maximum loads increased by 13, 7, and 63% respectively when framework was connected by MPCs. The characteristic values for design load and energy dissipation follow the same tendency. It is illogical to believe shear wall performance falls gradually as wall length increases followed by a peak increase in performance when wall length reaches 16 ft. When looking at stiffness at 40% of maximum load and stiffness at 1-in. drift, there seems to be no definitive pattern for the way some wall lengths were stiffer when MPCs were used as framework connections and some were not.

7.2.3 Bending Stiffness and Moisture Content

The bending stiffness and moisture content of each framing member used to fabricate the walls in the wall length tests was measured. Wall framework stiffness is governed by the bending stiffness of its individual members and MPC connection stiffness is adversely affected by increases in moisture content. Table 7.7 lists the average bending stiffness and moisture content for the framing members found in each test set. Also listed in the table are the coefficients of variation, COV, for the listed bending stiffness and moisture contents. Each test set for each wall length had very similar average bending stiffness. Moisture contents for each test set for a given length were within 2.5% of each other. Average bending stiffness and moisture contents were relatively close and the COV for the bending stiffness is reasonable for visually graded lumber, however the COVs for the moisture content were extremely high.

Table 7.3 lists average bending stiffness and average moisture contents found in framing members for each wall within the sheathed wall test sets. Also listed in the table are the coefficients of variation for the listed bending stiffness and moisture contents. The load-displacement histories show that walls 136, 84, 165, and 106 were the strongest and stiffest walls in their respective test sets. However, none of these walls had the highest average bending stiffness in their test sets and only wall 84 had the lowest average moisture content for its test set. Walls 137, 156, and 94 were the weakest and least stiff walls in their respective test sets. None of these walls had the lowest average bending stiffness or highest average moisture content for their given test sets. Bending stiffness and moisture content of the individual frame members must affect the lateral resistance of the wall. However, the tests for members of the wall length tests do not suggest this to be true.

TABLE 7.2. WALL LENGTH TEST SHEATHED WALL MAXIMUM LOAD

Length/Connection	Maximum Load (lbs)	Maximum Load COV	Increase for MPC vs. End-nailed Connection
4 ft End-nailed	2718	0.06	34%
4 ft MPC-Connected	3636	0.05	
8 ft End-nailed	3601	0.05	13%
8 ft MPC-Connected	4077	0.19	
12 ft End-nailed	5431	0.04	7%
12 ft MPC-Connected	5807	0.02	
16 ft End-nailed	7231	0.08	63%
16 ft MPC-Connected	11766	0.08	

TABLE 7.3. WALL LENGTH TEST SHEATHED WALL DESIGN LOAD

Length/Connection	Design Load (lbs)	Design Load COV	Increase for MPC vs. End-nailed Connection
4 ft End-nailed	1117	0.08	17%
4 ft MPC-Connected	1308	0.12	
8 ft End-nailed	1659	0.13	10%
8 ft MPC-Connected	1820	0.07	
12 ft End-nailed	3340	0.24	8%
12 ft MPC-Connected	3609	0.11	
16 ft End-nailed	4975	0.15	51%
16 ft MPC-Connected	7531	0.09	

TABLE 7.4. WALL LENGTH TEST SHEATHED WALL STIFFNESS AT 40% OF MAXIMUM LOAD

Length/Connection	Stiffness at 40% Maximum Load (lbs/in.)	Stiffness at 40% Maximum Load COV	Increase for MPC vs. End-nailed Connection
4 ft End-nailed	2014	0.11	5%
4 ft MPC-Connected	2114	0.18	
8 ft End-nailed	4024	0.14	-19%
8 ft MPC-Connected	3269	0.14	
12 ft End-nailed	5846	0.45	72%
12 ft MPC-Connected	10038	0.24	
16 ft End-nailed	28680	0.42	-27%
16 ft MPC-Connected	20855	0.11	

TABLE 7.5. WALL LENGTH TEST SHEATHED WALL STIFFNESS AT 1-IN. DRIFT

Length/Connection	Stiffness at 1-in. Drift (lbs/in.)	Stiffness at 1-in. Drift COV	Increase for MPC vs. End-nailed Connection
4 ft End-nailed	1642	0.05	14%
4 ft MPC-Connected	1868	0.12	
8 ft End-nailed	3001	0.06	-7%
8 ft MPC-Connected	2785	0.02	
12 ft End-nailed	4514	0.13	17%
12 ft MPC-Connected	5275	0.07	
16 ft End-nailed	7529	0.24	23%
16 ft MPC-Connected	9266	0.10	

TABLE 7.6. WALL LENGTH TEST SHEATHED WALL ENERGY DISSIPATION AT 4-IN. DRIFT

Length/Connection	Energy Dissipation at 4-in. Drift (K-in.)	Energy Dissipation at 4-in. Drift COV	Increase for MPC vs. End-nailed Connection
4 ft End-nailed	8.0	0.06	23%
4 ft MPC-Connected	9.8	0.08	
8 ft End-nailed	11.4	0.03	13%
8 ft MPC-Connected	12.9	0.15	
12 ft End-nailed	17.2	0.05	14%
12 ft MPC-Connected	19.5	0.05	
16 ft End-nailed	24.1	0.10	60%
16 ft MPC-Connected	38.7	0.08	

TABLE 7.7. WALL LENGTH TEST SHEATHED WALL TEST SET BENDING STIFFNESS AND MOISTURE CONTENT

Tests Set	Average EI (lb-in.^{2})	COV EI	Average MC	COV MC
4 ft End-nailed and Sheathed	1.48E+06	0.24	15.6	0.31
4 ft MPC-Connected and Sheathed	1.45E+06	0.20	12.3	0.19
8 ft End-nailed and Sheathed	1.67E+06	0.24	11.6	0.19
8 ft MPC-Connected and Sheathed	1.76E+06	0.40	11.6	0.20
12 ft End-nailed and Sheathed	1.43E+06	0.22	13.7	0.25
12 ft MPC-Connected and Sheathed	1.45E+06	0.24	10.9	0.14
16 ft End-nailed and Sheathed	1.72E+06	0.25	11.2	0.13
16 ft MPC-Connected and Sheathed	1.72E+06	0.32	11.9	0.17

TABLE 7.8. WALL LENGTH TEST SHEATHED WALL BENDING STIFFNESS AND MOISTURE CONTENT

Tests Set	Wall	Average EI (lb-in.^{2})	COV EI	Average MC	COV MC
4 ft End-nailed Walls With 7/16-in. Sheathing	31	1.42E+06	2.32E-01	15.3	0.40
	32	1.65E+06	2.61E-01	15.0	0.38
	33	1.43E+06	2.18E-01	14.5	0.29
	34	1.42E+06	1.85E-01	17.2	0.27
	35	1.50E+06	2.75E-01	16.1	0.26
4 ft 5x6 MPC-Connected Walls With 7/16-in. Sheathing	136	1.42E+06	2.70E-01	12.1	0.16
	137	1.47E+06	1.71E-01	12.3	0.12
	138	1.37E+06	1.57E-01	13.1	0.22
	139	1.47E+06	2.59E-01	13.1	0.23
	140	1.53E+06	1.37E-01	10.8	0.15
8 ft End-nailed Walls With 7/16-in. Sheathing	144	1.62E+06	1.87E-01	12.4	0.23
	145	1.67E+06	2.21E-01	11.1	0.19
	146	1.73E+06	3.11E-01	11.4	0.13
8 ft 5x6 MPC-Connected Walls With 7/16-in. Sheathing	84	1.82E+06	2.78E-01	10.9	0.22
	85	1.54E+06	1.68E-01	11.6	0.18
	86	1.92E+06	5.67E-01	12.4	0.19
12 ft End-nailed Walls With 7/16-in. Sheathing	154	1.33E+06	2.08E-01	12.2	0.25
	155	1.49E+06	2.11E-01	15.1	0.30
	156	1.58E+06	2.02E-01	13.6	0.15
12 ft 5x6 MPC-Connected Walls With 7/16-in. Sheathing	94	1.43E+06	1.67E-01	10.5	0.18
	95	1.48E+06	3.40E-01	11.3	0.13
	96	1.37E+06	1.85E-01	10.8	0.12
16 ft End-nailed Walls With 7/16-in. Sheathing	164	1.70E+06	1.94E-01	11.3	0.12
	165	1.73E+06	2.25E-01	11.2	0.15
	166	1.79E+06	3.17E-01	11.0	0.12
16 ft 5x6 MPC-Connected Walls With 7/16-in. Sheathing	104	1.80E+06	4.11E-01	12.3	0.17
	105	1.65E+06	2.74E-01	11.5	0.15
	106	1.44E+06	2.31E-01	11.1	0.19

7.3 Wall Length Test Conclusions

Wall length tests were used to determine how walls with MPC-connected frames behave in comparison to walls with end-nailed frames for walls 4 ft long and longer. Walls with MPC end nail connected framework that were 4 ft in length were tested and observed for behavior characteristics and it was determined that MPCs enhanced wall performance with respect to strength, stiffness and energy dissipation. The results of wall length tests were expected to demonstrate whether this behavior remained for varying wall length and find a discernable tendency in the changes in behavior as wall length was increased.

Bare frame results showed that strength, stiffness and energy dissipation were increased by connecting framework with MPCs rather than nails and by increasing wall length for both MPC-connected and end nail-connected framework walls. Walls of greater lengths require a greater number of connectors, nails or MPCs. Bare frame performance was found to be a function of wall length or how many connections are used to connect the framework. As the number of connections increases, the behavior characteristics of the bare frames are enhanced more. This is true for both end-nailed and MPC connections.

Sheathed wall results, however, did not show a discernable tendency for changes in wall behavior. There was no recognizable tendency for percent increases in strength, stiffness, or energy dissipation behavior for sheathed walls with lengths greater than 4 ft. It is conceivable that percent increases would become smaller as walls are lengthened. This would indicate that sheathing governs the behavior. Since a longer wall requires more sheathing, strength increases derived from MPC connections would diminish in comparison to strength increases derived from sheathing. If the percent increase fell to zero as the wall became longer, it would be evident that MPC connections would not alter shear wall behavior. Then long MPC-connected shear walls would behave as long end nail-connected shear walls. It would have been conceivable to see percent increases in wall behavior be constant over the increasing wall length, which would indicate that wider walls acted as several 4-ft wall panels. Also, if percent increases in wall behavior had risen as walls were lengthened, there would be evidence of a moment resistant system in which sheathing was no longer the sole source of lateral load resistance.

The reason for the indiscernible tendency for wall behavior is believed to be an exceedingly flexible test frame. Two test frame problems appeared visually during the test process for the 8, 12, and 16 ft sheathed walls. First, the wall foundation was not rigid enough to prevent bending under the moment imposed by the tension-compression couple of the wall. As the wall was pushed, the loaded side of the wall bent the foundation tube upwards off of the ground. The moment imposed by the lateral load was not adequately designed for deflection and thus the foundation tube bent. Second, as the foundation tube deflected, out-of-plane braces were slightly lifted from their supports and no longer acted as out-of-plane bracing. Many efforts were made to stop deformation of the test frame, but they were evidently not enough. Flexural deformation of the test frame foundation is believed to be why there is no logical tendency in the percent increases of characteristic values for long sheathed walls.

The results of the bending stiffness and moisture content tests for the framing members used in wall length tests walls are also inconclusive. These results are not affected by the flexibility of the frame but it is possible that the inherent variability of wood masked the effects of member bending stiffness and moisture content.

Results of the wall length test proved that bare frame performance was enhanced greatly by the addition of MPC connections and the enhancements increased as walls were built longer. However, no conclusions can be made as to the behavior of long sheathed walls. The test frame was under-designed for the loads imposed on it. In order to develop reasonable data wall length tests should be conducted again with three changes. The wall foundation should be more rigid to control test frame deflection that may skew test results The out-of-plane bracing of the walls should be applied in such a way as to have control over the amount of friction applied to the wall and the out-of-plane braces should be fixed rigidly to the foundation. The last change is to sort and condition all framing material to similar moisture content before testing the bending stiffness.

CHAPTER 8

SUMMARY AND RECOMMENDATIONS OF SHEAR WALL RESEARCH

Through the course of this research, over 140 walls were fabricated, tested, and analyzed to investigate the behavioral differences between bare frames and sheathed walls with and without MPC connections. The test process included measuring bending stiffness and moisture content for each framing member, constructing walls to fit precise configurations, and monotonically testing the walls for load-displacement data collection. Four specific variables were investigated including the affects of the size of MPCs used for framing connections on sheathed and unsheathed 4 ft walls, changes in lumber grade for MPC-connected sheathed and unsheathed walls, changes in sheathing thickness for MPC-connected walls, and changes in wall length of MPC-connected sheathed and unsheathed walls.

8.1 Shear Wall Test Summary

8.1.1 Framing Connector Tests

MPCs benefit bare frames and sheathed walls alike, but sheathing is still the primary element in shear wall strength. In other word, sheathing provides the greatest contribution to lateral load resistance. It is evident in that sheathed walls did not benefit from MPCs nearly as much as bare frames because the structural attributes measured for sheathed walls did not increase nearly as much as they did for bare frames. However, the benefit of connecting sheathed framework with MPCs is not insignificant. The maximum load capacity of a 4 ft wall sheathed with 7/16-in. OSB increased 45% when 5x6 MPCs were used to connect the framework. Wall stiffness at 1-in. drift and wall stiffness at 4-in. drift increased 14 and 23%, respectively, as well. Design load, a reflection of the increase in initial stiffness, increased 17% due to the use of 5x6 MPCs rather than end nails for framework connections. Energy dissipation at 4-in. drift also increased 23% due to the use of 5x6 MPCs. The use of MPCs changes the load-displacement path of the shear wall. The MPC-connected walls are stiffer and the end nail-connected walls will yield at a lower drift or load than MPC-connected walls.

8.1.2 Framing Member Stiffness Tests

The framing member stiffness tests showed that MPC-connected bare frames were stronger and stiffer and dissipated more energy than end-nailed bare frames just as the MPC size test had shown. However, the results are inconclusive as to the effects of changing the lumber grade used in construction.

Variability was added to the test results in several aspects. First, two different species of wood were used. DFL No. 1 lumber was replaced with SYP lumber for one set of tests. The tooth holding properties of MPCs for DFL are different than those of SYP. Therefore, the DFL frame connections are weaker than the SYP frame connections. Although it is a fact that the SYP frame connections are the strongest and stiffest, the test results contradicted this. This contradiction is seen through the calculated behavior characteristics when comparing the No. 3 DFL frames to the No. 1 SYP frames. The No. 3 DFL frames were stronger and stiffer than the No. 1 SYP frames. Although the variability in wood species is present and should be removed, it is likely not the variability that skewed the test results in light of the contradiction in behavior compared to tooth holding properties. Second, variability in the tested systems is inherently in wood construction. One example of this is the framing width. Studs and struts that must be connected are not always the same width. This leaves gaps between the wood of the thinner member connected and MPC so that MPC teeth are not fully driven into the wood material. Also, wood is an anisotropic material therefore MPC connections are not identical from test to test. Variability also comes from the defects in wood material. Voids in the wood can be present in the MPC embedment area. Therefore MPC embedment areas vary from connection to connection. Third, out-of-plane bracing was used to ensure walls racked in plane. This out-of-plane bracing was applied in a way which the amount of friction applied with the out-of-plane bracing could not be controlled. Fourth, there was a lack of control of the moisture content of the framing members prior to wall construction and testing. High moisture content adversely affects MPC connection stiffness.

It was determined that because of the use of two species of wood, the inherent variability of wood and construction with MPC plates, friction from the wall out-of-plane braces resisting load, and variability in moisture contents for framing members, the framing member stiffness tests showed no changes in wall behavior that could be directly attributed to changes in framing grade.

8.1.3 Sheathed Wall Tests

MPCs were found to enhance structural characteristics for walls sheathed with 1/4, 7/16, and 5/8 in. OSB. In fact, the MPCs enhanced the 1/4-in. sheathed walls to be stiffer and produce a greater design load than end nail-connected 7/16-in. sheathed walls. Similarly, the MPC-connected 7/16-in. sheathed walls were enhanced to be as strong and stiff and dissipate as much energy as end nail-connected 5/8 in. sheathed walls.

The average maximum load for the sheathed and MPC-connected walls was found to increase and then decrease as the sheathing thickness is increased. The sheathing nail connections were suspected to be the cause of this discrepancy. Many of the sheathing nails are driven through MPCs in order to connect the sheathing to the framework for walls with MPC-connected framework. The nails that are driven through MPCs are done so along the top and bottom edges of the sheathing and therefore are the nails that do the most work to resist sheathing rotation. Since the MPC is between the sheathing and the framework, the behavior of the nailed connection is different than if no MPC were present. The failure mode for nails connecting the 1/4-in. OSB to the framework of an end nail-connected wall is IIIs with a lateral capacity of 51 lbs. If a MPC were placed between the main and side members the capacity of the IIIs failure mode would increase in capacity since the MPC would resist the crushing of the main member. The capacity before failure could increase from 51 to 59 lbs for a single sheathing nail and remain in the IIIS failure mode but it can not exceed 59 lbs because the failure mode would change to Is which is not affected by the addition of the plate. The capacity of the nails most used to resist sheathing rotation can only increase slightly for the

1/4-in. sheathed MPC-connected walls. It must also be noted that the behavior of nails that do not pass through MPCs do not change. The added load capacity of the MPCs and bending framework acting independent of the sheathing must also be considered. The average maximum load at 4-in. drift for a 5x6 MPC-connected bare frame was 327 lbs and this load was not reached until the wall had drifted 4-inches. This suggests that MPCs only slightly increase the lateral load capacity by forcing the framework to bend and slightly increase the lateral load capacity of the wall by increasing the capacity of the sheathing nails for the 1/4-in. sheathed walls. The average maximum load is increased by 34% for 7/16-in. sheathed walls by using MPC connections and corner nail capacity can be increased by nearly double before the sheathing nail failure mode is limited to an Is failure. The combination of the added capacity of the sheathing nails for 7/16-in. sheathed MPC-connected walls, which is conceivably twice the capacity of the sheathing nails in the 1/4-in. sheathed MPC-connected walls, with the lateral load capacity from the semi-rigid framework, could greatly increase the average maximum load of the 7/16-in. sheathed MPC-connected walls. The average maximum load of the 5/8 in. sheathed walls increased 19% with the addition of MPC connections which was more than for 1/4-in. sheathed walls but less than for 7/16-in. sheathed walls. Again, to change the failure modes of the sheathing nails passing through MPC plates, the capacity of the nail must increase by nearly double to reach a failure mode than is not affected by the MPC.

It was previously stated that the maximum load for 1/4-in sheathed walls was barely increased by the addition of MPC connections. However, the average stiffness at 40% of maximum load was increased tremendously in addition to average design load. The 1/4-in. sheathing is the most flexible sheathing used in these tests. It is likely that since it is the most flexible, it benefits the most from the addition of MPC connections. This is also likely true for the opposite. Thick sheathing with great stiffness will likely overshadow the effects of MPC connections on stiffness. Although the effects of adding MPC connections are possibly overshadowed, the 7/16-in. and 5/8 in. sheathed walls did increase in average stiffness at 40% of maximum load slightly when MPC connections were used.

Increase in design load is a direct reflection of increase in initial stiffness. Since the 1/4-in. sheathed MPC-connected walls had the greatest increase in average stiffness at 40% of maximum load they also had the greatest increase in average design load. Since the increase in average stiffness at 40% of maximum dropped as sheathing thickness increased, the increase in average design load also dropped as sheathing thickness increased. Increases in average stiffness at 1-in. drift and average energy dissipation rose and fell in the same manner as average maximum load. These values are probably also affected by the failure modes of the sheathing nails.

8.1.4 Wall Length Tests

Strength, stiffness, and energy dissipation were all increased by the addition of MPC connections and by increasing wall length of the bare frames. As walls are fabricated with greater lengths, more MPC connections or end nails are required and each connection contributes to the lateral load resistance, therefore bare frame performance is a function of wall length or how many connections are used to connect the framework. As the number of connections increases, the behavior characteristics of the bare frames are enhanced more. This is true for both end-nailed and MPC connections.

The long sheathed wall results showed conflicting data. The average maximum load and average energy dissipation at 4-in. drift for each wall length were increased by connecting the framework with MPCs. However, average design load and stiffness did not always increase for each wall length when connecting framework with MPCs. Another conflict was found in the test results for long MPC-connected sheathed shear walls when looking at the tendencies for percent increases for a given characteristic value. Looking at the average maximum load, it is noticed that the 4 ft sheathed walls average maximum load increased by 34% when MPC were used to connect the framework. The 8, 12, and 16 ft walls average maximum loads increased by 13, 7, and 63% respectively when framework was connected by MPCs. The characteristic values for design load and energy dissipation follow the same tendency. It is illogical to believe shear wall performance falls gradually as wall length increases followed by a peak increase in performance when wall length reaches 16 ft. When looking at stiffness at 40% of maximum load and stiffness at 1-in. drift, there seems to be no logical reason for the way some wall lengths were stiffer when MPC were used as framework connections and some were not.

There are a few reasons to believe the wall length tests were limited by an exceedingly flexible test frame. First, there was no recognizable tendency for percent increases. Second, two test frame problems appeared visually during the test process for the 8, 12, and 16 ft sheathed walls. The wall foundation tube deflected due to moment imposed on it through the shear wall and the out-of-plane bracing was lifted and allowed to rigidly rotate until it no longer eliminated out of plane bending of the shear wall. No conclusions were made as to the behavior of long sheathed walls. The test frame was under designed for the loads imposed on it.

8.1.5 Bending Stiffness and Moisture Content

The results of the bending stiffness and moisture content tests for the framing members used in all four different tests are inconclusive. There was not enough control over the moisture content of the framing members which directly affects tooth holding properties of the MPCs. Also, it is believed that the inherent variability of wood construction and wood material were to great for the conducted tests to attribute any changes in wall behavior directly to the bending stiffness and moisture content of the framing members.

8.2 Recommendations

8.2.1 Improved Test Procedures

The results of the wall length tests were affected by the lack of stiffness of the tests frame. The foundation of the test frame must be stiffened. The foundation tube of the test frame underwent flexural deformation as the 8, 12, and 16 ft sheathed walls were loaded therefore skewing the results for these walls. Since the test frame deformed, the out-of-plane braces were lifted and allowed to rigidly rotate. This rotation kept the out-of-plane braces from working and allowed the sheathed walls to bend out of plane. The wall length tests for sheathed walls should be conducted again when the frame foundation is stiffened to where it isolates racking behavior of all walls tested.

There must be more control over the moisture content of the framing members. High moisture content adversely affects the tooth holding properties of the MPC plates. Lumber for framing members should be purchased kiln dried and plastic wrapped. As the lumber arrives at the testing laboratory, it should be placed in enclosed environmental conditions in an attempt to attain low and similar moisture contents for all framing members. After the walls are constructed, they should be placed back into the controlled environmental conditions until testing.

A single species of wood should be acquired for the framing members. The tooth holding properties of the MPCs vary depending on wood species.

The variability inherent in wood construction can not be removed but variability due to an exceedingly flexible test frame, poor control of moisture content, and the use of two species of wood for framing members can. Framing member stiffness tests and the wall length tests for the 8, 12, and 16 ft sheathed walls should be conducted again after these variability are removed.

8.2.2 Continued Research

Since walls constructed with MPC connections proved stronger, stiffer, and more ductile than conventional shear walls, deriving a model to predict the behavior of the MPC-connected shear walls is essential. In order to develop a model of behavior for the MPC connected shear walls, the internal behaviors of the wall must be identified and defined. Four internal behaviors contribute to racking load resistance. The behaviors are from sheathing nails, chord and stud bending, MPC connection rotation, and resistance from friction.

8.2.2.1 Sheathing Nail Contribution to Lateral Load Resistance

The first lateral load resistant behavior possessed by MPC-connected shear walls is that of the sheathing nails. Adding MPCs to the sheathed frames did not increase strength of the sheathed frames nearly as much as the addition of MPC connections to bare frames. Therefore, sheathing and sheathing nails provide the greatest contribution to lateral force resistance. Tuomi and McCutchen determined the contribution of sheathing nails by equating internal energy of the sheathing nails and the external energy from the racking force traveling through a displacement equal to the wall drift. (1978) Tuomi's model assumed a linear load to distortion relationship of the nails and no bending of the studs. The assumption of linear load versus distortion of the nails is true for small deflections and it greatly simplifies calculation of the internal energy produced by the nails. This model found nail distortion by finding the difference in panel and framework distortions. Internal energy, I, of the nails could then be calculated by the equation 8.1.

$$I = \frac{k\delta^2}{2} \tag{8.1}$$

The value k is the linear load distortion ratio and δ is the total displacement between nail position in the frame and nail position in the sheathing. The Pythagorean Theorem can be used to replace δ^2, the square of the total length of distortion, with the square of the horizontal displacement, δ_x^2, plus the square of the vertical displacement, δ_y^2. Tuomi and McCutcheon's model was greatly simplified by using this approach. However, Tuomi and McCutcheon assume no bending of the studs which is not the case for MPC-connected walls. Horizontal deflection of the studs is a function of end moments applied to the studs by the MPCs and sheathing nail forces on the studs. It should be noted that nail forces on the studs is a function of deflection of the studs. It is likely a good assumption that vertical displacement of the studs is 0. Rotation and translation of the sheathing must also be defined. The center of the sheathing remains centered with the series of studs in which it is attached and rotates an angle equal to the inverse tangent of the overall deflection of the top of the framework divided by the height of the wall. Although translation and rotation of the panel will vary slightly for wall to wall, this assumption is reasonable and will greatly simplify calculations of the total nail distortion. The assumptions for vertical frame and panel distortions seem reasonable and can be verified through observation of the wall during loading. Therefore, to determine the contribution of the nails against lateral load, two items must be identified. The load distortion ratio of the nails used for these tests with the same grades of framing and OSB must be determined through simple tests outlined by ASTM. The second is to determine deflection of the studs. No observation was made from the results of these tests that suggest a method for determining horizontal displacement of the studs and chords.

It was also determined that the sheathing nails driven through MPC connections have different failure modes than the sheathing nails connecting sheathing and framework only. The nails driven through MPCs are found in regions were sheathing nails work the most to prevent sheathing rotation. The presence of an

MPC between the framing and the sheathing can increase the capacity of the nailed connection depending upon the thickness of the sheathing. The failure modes of the sheathing nails driven through MPC plates must be determined and if a linear relationship for load versus nail distortion is used for an MPC-connected sheathed shear wall model, the linear constant, k (See equation 8.1), must be determined.

8.2.2.2 Vertical Beam Contribution to Lateral Load Resistance

The second lateral load resistant behavior possessed by MPC-connected shear walls is bending of the studs and chords. The studs and chords may be viewed as vertical beams. For a wall with two or more pieces of sheathing, four different vertical beams are found. The first is the tension chord that has a single row of closely spaced nails because the edge of a piece of sheathing is attached to it. Nails are closely spaced at the edges of sheathing material because the edges of the sheathing displace the most due to panel rotation. The MPC connections attaching this member to the rest of the frame are different from the other connection location; therefore, it is affected by a specific set of unique bending moments. The chords are composed of two 2 x 4 members that are face-nailed and connected with MPCs at the ends. Therefore, the moment of inertia for the tension chord is greater than that of the studs. The second is a stud attached to the interior of a piece of sheathing. The nails for this member are positioned at greater spacing than the chords. This member also has a unique set of end moments due to the MPCs on each end. The moment of inertia for this member is that of a single 2 x 4 subjected to flat wise bending. The third is a stud that is attached to the edges of two pieces of sheathing. This member will contain two rows of nails spaced closely because two pieces of sheathing are attached to it. The nail spacing in this stud will be the same as in the chords. This member's end moments will have the same characteristics of the stud within the interior of the sheathing. The moment of inertia for this member is that of a single 2 x 4 subjected to flat wise bending. The last vertical beam is the compression chord. It differs only from the tension chord in that it has different end moment characteristics. Figure 8.1 illustrates the four different vertical beams that contribute to lateral load resistance. The figure shows a typical 8 ft wall with two pieces of sheathing and MPC connections at all corners.

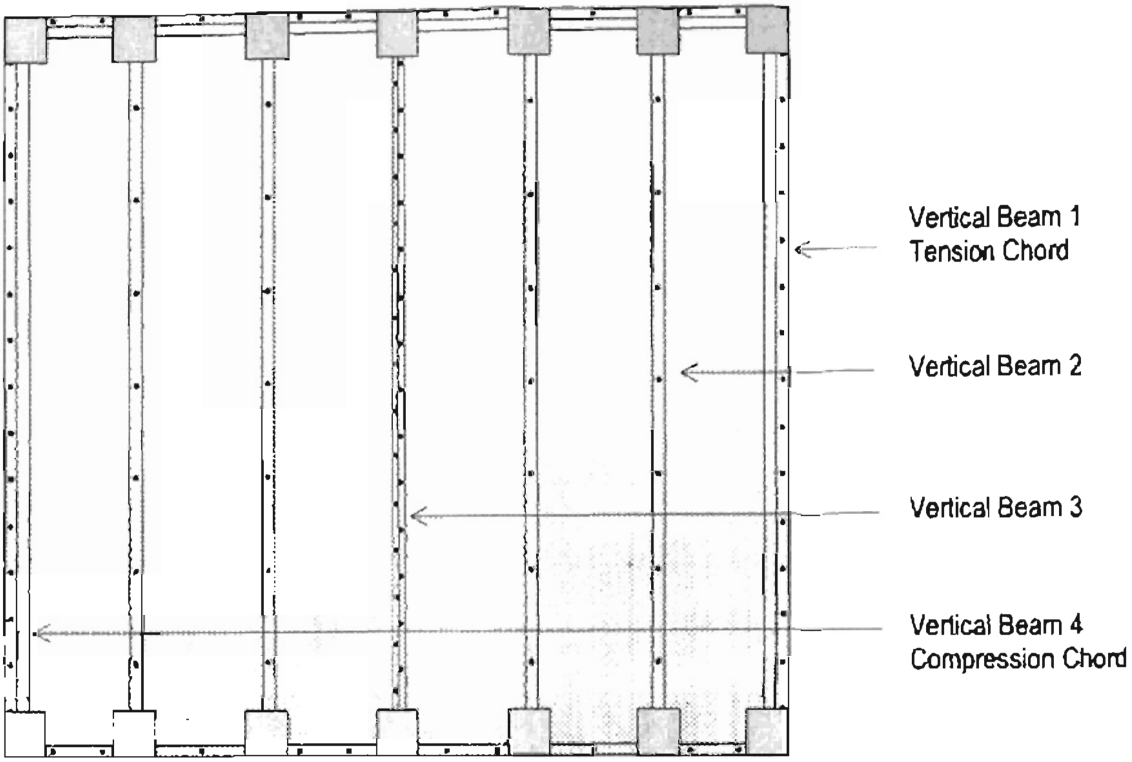

Figure 8.1. Vertical Lateral Load Resisting Beams

The moment of inertia for the chords must be determined. The chords are composed of two face-nailed 2 x 4s that are also connected by MPCs at the ends. The MPC connections at the ends likely force the chords to act as a composite member or nearly composite, but this should be verified through testing.

The behaviors of the sheathing nails in the beams and those of stud and chord bending go hand in hand. One can not be determined without specific information of the other. The interconnected behaviors of the nails and vertical beams must be studied in greater detail to develop a model for MPC-connected shear wall behavior.

8.2.2.3 MPC Contribution to Lateral Load Resistance

The third lateral load resistant behavior possessed by MPC-connected shear walls is from the MPCs. A wall with two or more pieces of sheathing contains six different connections. The first is the tension chord to top plate connection. The second is the tension chord to bottom plate connection. The third and fourth connections are located at the top and bottom of the studs. The fifth is the compression chord to top plate connection. The last is the compression chord to bottom plate connection. Each of these connections has a different amount of compression wood area and a tensile tooth holding area. Tests should be conducted to determine the moment curvature relationship for each of these joints. This information can be used to determine moments placed on the studs and horizontal deflections of the studs and chords. It may be possible to model these connections as rotational springs. Calculations of moment would become simpler if the rotational springs were considered to behave linearly. Figure 8.2 illustrates the same wall as Figure 8.1 but points out the 6 different MPC connections that contribute to lateral load resistance.

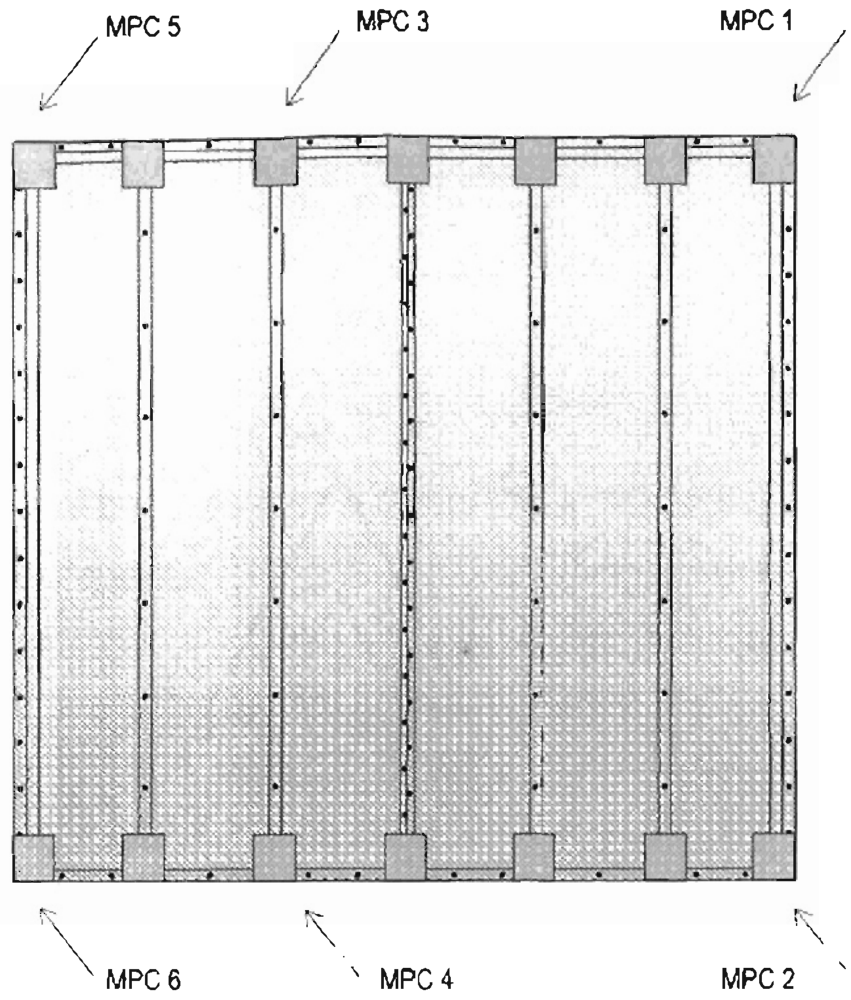

Figure 8.2. Lateral Load Resistant MPCs

8.2.2.4 Friction Contribution to Lateral Load Resistance

The fourth and final lateral load resistant behavior possessed by MPC-connected shear walls is friction, which can be found in two different parts of the wall. Friction occurs between the sheathing and framework where the normal force is delivered from the sheathing nails, and between sheathing edges. As the wall racks, sheathing rotates and comes in contact on its edges. To determine how much lateral resistance is developed from friction, a test should be conducted with as much friction eliminated as possible. This may be accomplished by covering OSB with a near frictionless material before attaching it to the frame. Conducting the same tests with friction removed should determine how much resistance is developed through friction.

The four components of lateral resistance must be investigated fully before constructing a model for estimating lateral resistance behavior. Bending of the horizontal beams and deflections of these beams must be modeled to determine bending resistance and forces applied through the sheathing nails. However, forces from the sheathing nails will affect how the beams will deform. The research of the lateral force resisting components provides a road to follow for the incorporation of MPC connections into wood frame shear wall construction. The results have proven that MPCs benefit the behavior of shear walls. The research of individual behaviors will identify how MPC-connected shear walls should be designed to be incorporated in wood frame construction.

8.3 Conclusions

The use of MPCs for the connections of shear wall framework proved beneficial. Strength, stiffness and energy dissipation was increased for all 4 ft wall configurations when nailed framework connections were exchanged with MPC connections. Although the benefits of using MPCs to connect shear wall framework are significant, they do not replace sheathing as the primary lateral load resisting component. MPCs were found to contribute to lateral load resistance in two ways. First, MPCs force the shear wall framework to undergo flexure. Second, MPCs change the failure mode of the sheathing nails driven through the MPC.

Several problems arose in shear wall testing that must be accounted for. Wood construction has inherent variability that must be controlled or minimized to gain a better understanding of MPC connected shear wall behavior. Framework members should be of a single species. The wood members must be conditioned to low and similar moisture contents. Variability was introduced to the shear wall tests that was not inherent and must be removed. A test frame must be constructed to isolate racking behavior for all walls tested. Out-of-plane bracing must be applied to the wall in such a way as to add only limited and controlled amounts of friction to the wall. The out-of-plane bracing must be rigid enough to resist any lateral movement. The variability mentioned before can mask the results of the tests and should be removed.

A theoretical model of shear wall behavior must be formed in order to define the behavior of shear walls with MPC connected framework. Four internal behaviors were identified that must be researched for development of the model. These include (a) sheathing nail lateral load resistance, (b) chord and stud moment resistance, (c) MPC connection stiffness, and (d) frictions between the framework and sheathing panel and between edges of sheathing panels.

APPENDIX A

INDIVIDUAL FRAMING MEMBER BENDING STIFFNESS AND MOISTURE CONTENT FOR ALL WALLS

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
1	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	2.39E+06	13
		1.69E+06	13
		9.38E+05	11
		1.49E+06	11
		1.37E+06	13
		1.75E+06	12
		1.15E+06	11
		1.88E+06	11
		1.88E+06	12
2	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.44E+06	11
		1.63E+06	11
		1.48E+06	12
		9.47E+05	9
		1.60E+06	12
		1.72E+06	22
		1.15E+06	11
		1.47E+06	10
		1.47E+06	10
3	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.74E+06	13
		2.25E+06	17
		1.67E+06	11
		1.28E+06	14
		1.30E+06	11
		1.39E+06	24
		1.94E+06	13
		1.46E+06	10
		1.46E+06	10

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
4	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.35E+06	14
		1.33E+06	14
		1.15E+06	12
		1.83E+06	16
		1.40E+06	17
		1.81E+06	13
		1.94E+06	12
		1.85E+06	11
		1.85E+06	13
5	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.35E+06	16
		1.75E+06	12
		1.78E+06	12
		1.76E+06	16
		1.56E+06	13
		1.69E+06	11
		1.23E+06	12
		1.09E+06	14
		1.09E+06	13
6	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X6 MPC NO SHEATHING	1.78E+06	18
		7.80E+05	15
		1.57E+06	14
		1.25E+06	14
		1.30E+06	15
		1.51E+06	14
		1.01E+06	12
		1.22E+06	11
		1.64E+06	15
7	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X6 MPC NO SHEATHING	1.69E+06	27
		1.23E+06	30
		1.37E+06	24
		1.32E+06	13
		1.00E+06	16
		1.26E+06	13
		1.85E+06	17
		2.16E+06	13
		1.43E+06	13

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
8	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X6 MPC NO SHEATHING	1.02E+06	15
		1.44E+06	16
		1.29E+06	12
		1.23E+06	14
		1.20E+06	15
		1.21E+06	14
		1.50E+06	11
		1.85E+06	11
		1.40E+06	12
9	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X6 MPC NO SHEATHING	1.85E+06	12
		1.30E+06	12
		1.57E+06	16
		1.04E+06	13
		2.19E+06	16
		1.22E+06	15
		1.59E+06	15
		1.79E+06	13
		1.47E+06	12
10	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X6 MPC NO SHEATHING	1.31E+06	15
		1.55E+06	11
		1.91E+06	14
		1.50E+06	11
		2.05E+06	14
		1.31E+06	13
		1.81E+06	14
		1.38E+06	13
		1.61E+06	15
11	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X5 MPC NO SHEATHING	1.68E+06	19
		1.33E+06	13
		1.35E+06	11
		1.50E+06	13
		1.34E+06	14
		1.66E+06	14
		1.42E+06	11
		1.53E+06	22
		9.59E+05	15

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
12	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X5 MPC NO SHEATHING	1.79E+06	19
		1.55E+06	17
		1.42E+06	12
		1.61E+06	17
		1.89E+06	18
		1.62E+06	17
		1.26E+06	17
		1.71E+06	13
		1.09E+06	15
13	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X5 MPC NO SHEATHING	1.32E+06	13
		2.08E+06	14
		1.60E+06	19
		1.95E+06	14
		1.24E+06	16
		1.61E+06	13
		1.28E+06	15
		1.63E+06	14
		1.12E+06	19
14	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X5 MPC NO SHEATHING	1.69E+06	16
		2.15E+06	18
		1.63E+06	13
		1.71E+06	22
		1.50E+06	13
		1.69E+06	26
		1.21E+06	20
		1.67E+06	22
		9.72E+05	15
15	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X5 MPC NO SHEATHING	1.93E+06	20
		1.17E+06	21
		1.53E+06	14
		2.10E+06	12
		1.35E+06	18
		1.38E+06	30
		1.59E+06	14
		1.10E+06	14
		2.53E+06	19

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
16	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 MPC NO SHEATHING	1.50E+06	11
		1.26E+06	14
		2.15E+06	15
		8.51E+05	15
		2.28E+06	19
		9.92E+05	15
		1.21E+06	15
		1.55E+06	13
		1.63E+06	14
17	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 MPC NO SHEATHING	1.25E+06	11
		1.68E+06	13
		1.22E+06	30
		1.67E+06	25
		1.13E+06	10
		9.74E+05	14
		1.59E+06	14
		1.41E+06	16
		1.79E+06	18
18	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 MPC NO SHEATHING	1.72E+06	14
		1.88E+06	15
		1.31E+06	13
		1.79E+06	17
		1.43E+06	12
		1.72E+06	13
		1.74E+06	21
		1.61E+06	25
		1.41E+06	16
19	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 MPC NO SHEATHING	1.76E+06	12
		1.98E+06	18
		1.77E+06	17
		1.44E+06	14
		1.85E+06	15
		1.69E+06	12
		1.71E+06	13
		2.03E+06	14
		9.78E+05	30

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
20	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 MPC NO SHEATHING	1.30E+06	17
		1.06E+06	10
		1.64E+06	12
		1.32E+06	22
		1.74E+06	28
		1.49E+06	12
		1.04E+06	13
		1.23E+06	30
		1.01E+06	16
21	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	1.09E+06	27
		1.30E+06	11
		1.74E+06	13
		1.64E+06	15
		1.37E+06	20
		1.14E+06	22
		1.29E+06	30
		1.29E+06	14
		2.06E+06	12
22	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	1.63E+06	12
		2.28E+06	18
		1.54E+06	18
		1.81E+06	14
		1.42E+06	13
		2.63E+06	12
		1.21E+06	27
		1.30E+06	14
		1.31E+06	11
23	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	1.99E+06	30
		2.14E+06	25
		1.61E+06	18
		1.17E+06	15
		2.25E+06	21
		2.16E+06	13
		1.16E+06	22
		1.45E+06	14
		1.25E+06	21

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
24	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	1.43E+06	14
		1.34E+06	15
		3.43E+05	12
		1.86E+06	18
		1.33E+06	15
		1.43E+06	13
		1.26E+06	28
		1.20E+06	10
		2.20E+06	13
25	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	1.94E+06	15
		1.36E+06	14
		1.45E+06	14
		1.85E+06	18
		1.08E+06	21
		1.52E+06	17
		1.76E+06	16
		1.48E+06	14
		1.85E+06	9
26	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 MPC NO SHEATHING	2.22E+06	19
		1.37E+06	28
		1.57E+06	14
		1.76E+06	14
		1.62E+06	16
		1.60E+06	16
		1.23E+06	19
		1.42E+06	12
		1.45E+06	13
27	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 MPC NO SHEATHING	1.41E+06	17
		1.08E+06	16
		2.03E+06	17
		1.64E+06	16
		1.66E+06	12
		1.53E+06	20
		1.40E+06	30
		1.65E+06	13
		1.38E+06	13

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
28	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 MPC NO SHEATHING	1.53E+06	12
		1.53E+06	14
		1.05E+06	10
		1.91E+06	16
		1.43E+06	12
		1.47E+06	20
		1.36E+06	25
		1.61E+06	17
		1.33E+06	14
29	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 MPC NO SHEATHING	1.56E+06	14
		1.15E+06	12
		1.33E+06	12
		1.22E+06	18
		1.51E+06	12
		1.82E+06	11
		1.52E+06	25
		1.54E+06	15
		1.35E+06	17
30	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 MPC NO SHEATHING	1.34E+06	12
		1.57E+06	13
		1.88E+06	17
		1.83E+06	14
		1.79E+06	17
		6.23E+05	12
		1.35E+06	12
		1.37E+06	12
		1.36E+06	13
31	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 7/16-in. SHEATHING	1.60E+06	13
		9.53E+05	30
		1.37E+06	13
		1.67E+06	13
		1.45E+06	12
		1.34E+06	20
		1.11E+06	10
		1.20E+06	14
		2.05E+06	13

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
32	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 7/16-in. SHEATHING	1.54E+06	5
		1.20E+06	15
		1.43E+06	26
		1.54E+06	14
		1.29E+06	11
		1.68E+06	13
		2.61E+06	15
		2.04E+06	18
		1.55E+06	18
33	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 7/16-in. SHEATHING	1.42E+06	16
		1.51E+06	11
		1.25E+06	13
		1.52E+06	24
		1.07E+06	11
		2.05E+06	11
		1.70E+06	18
		1.22E+06	14
		1.12E+06	13
34	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 7/16-in. SHEATHING	1.81E+06	17
		1.46E+06	17
		1.28E+06	21
		1.35E+06	18
		1.63E+06	27
		1.31E+06	14
		1.76E+06	16
		1.13E+06	11
		1.08E+06	14
35	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 7/16-in. SHEATHING	1.42E+06	14
		1.15E+06	24
		1.46E+06	10
		1.65E+06	13
		1.46E+06	17
		8.85E+05	15
		1.69E+06	14
		1.40E+06	18
		2.38E+06	20

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
41	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 1/4-in. SHEATHING	1.40E+06	14
		1.64E+06	12
		1.56E+06	15
		1.64E+06	21
		1.46E+06	24
		1.13E+06	12
		1.50E+06	13
		1.83E+06	10
		1.83E+06	12
42	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 1/4-in. SHEATHING	1.11E+06	13
		1.87E+06	13
		1.70E+06	12
		1.27E+06	19
		1.32E+06	16
		1.23E+06	17
		7.17E+05	16
		1.66E+06	12
		1.41E+06	12
43	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 1/4-in. SHEATHING	1.38E+06	17
		1.30E+06	13
		1.67E+06	18
		1.73E+06	15
		1.63E+06	20
		1.93E+06	12
		1.25E+06	13
		1.34E+06	22
		2.78E+06	12
44	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 1/4-in. SHEATHING	1.69E+06	
		1.79E+06	
		1.59E+06	
		1.64E+06	
		2.12E+06	
		1.58E+06	
		1.44E+06	
		1.68E+06	
		1.01E+06	

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
45	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 1/4-in. SHEATHING	1.56E+06	10
		1.58E+06	13
		1.55E+06	15
		1.56E+06	22
		1.60E+06	13
		1.65E+06	17
		1.49E+06	12
		2.20E+06	19
		1.67E+06	16
46	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 1/4-in. SHEATHING	1.43E+06	14
		1.17E+06	14
		1.29E+06	12
		1.44E+06	12
		1.91E+06	14
		1.24E+06	13
		1.82E+06	12
		1.45E+06	12
		1.46E+06	13
47	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 1/4-in. SHEATHING	1.50E+06	12
		8.84E+05	12
		4.86E+06	13
		1.72E+06	10
		1.46E+06	13
		1.63E+06	11
		1.57E+06	12
		1.00E+06	11
		1.39E+06	11
48	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 1/4-in. SHEATHING	1.88E+06	14
		1.35E+06	12
		1.09E+06	12
		1.68E+06	15
		1.38E+06	12
		1.42E+06	9
		1.11E+06	14
		1.27E+06	11
		1.06E+06	11

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
49	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 1/4-in. SHEATHING	1.56E+06	15
		2.21E+06	15
		2.23E+06	13
		1.27E+06	17
		1.63E+06	15
		1.68E+06	14
		1.16E+06	13
		1.61E+06	12
		1.56E+06	14
50	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 1/4-in. SHEATHING	1.02E+06	17
		1.74E+06	13
		1.56E+06	13
		1.10E+06	17
		1.57E+06	14
		1.56E+06	12
		1.28E+06	13
		1.34E+06	15
		1.21E+06	14
51	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 5/8-in. SHEATHING	1.48E+06	11
		1.63E+06	18
		1.94E+06	13
		1.97E+06	18
		1.11E+06	12
		2.51E+06	17
		1.76E+06	14
		1.32E+06	12
		2.27E+06	10
52	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 5/8-in. SHEATHING	2.31E+06	21
		1.36E+06	13
		1.60E+06	19
		1.81E+06	12
		9.98E+05	12
		1.83E+06	14
		1.53E+06	11
		1.72E+06	12
		1.50E+06	11

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
53	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 5/8-in. SHEATHING	1.21E+06	15
		1.50E+06	13
		1.32E+06	11
		1.81E+06	13
		9.36E+05	11
		1.94E+06	16
		1.13E+06	10
		1.48E+06	11
		1.58E+06	11
54	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 5/8-in. SHEATHING	2.05E+06	14
		1.38E+06	14
		1.48E+06	13
		1.44E+06	12
		2.15E+06	15
		1.61E+06	11
		2.03E+06	12
		1.61E+06	12
		1.46E+06	11
55	2X4 NO 2 DFL FRAMING 4 FT LENGTH NAILED FRAMING 5/8-in. SHEATHING	2.83E+06	17
		1.70E+06	15
		1.88E+06	13
		1.15E+06	17
		1.99E+06	27
		1.43E+06	16
		1.40E+06	9
		1.54E+06	16
		7.55E+05	11
56	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 5/8-in. SHEATHING	1.95E+06	14
		1.88E+06	13
		1.58E+06	14
		1.64E+06	9
		2.01E+06	13
		1.63E+06	10
		1.43E+06	10
		1.50E+06	9
		1.38E+06	10

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
57	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 5/8-in. SHEATHING	1.85E+06	12
		1.88E+06	12
		1.61E+06	9
		1.12E+06	12
		1.61E+06	9
		2.14E+06	10
		1.78E+06	14
		1.74E+06	9
		1.52E+06	12
58	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 5/8-in. SHEATHING	1.74E+06	13
		9.33E+05	13
		1.83E+06	11
		2.17E+06	11
		1.20E+06	11
		1.33E+06	20
		1.47E+06	12
		1.11E+06	10
		1.49E+06	9
59	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 5/8-in. SHEATHING	1.98E+06	10
		1.61E+06	12
		1.25E+06	18
		1.22E+06	9
		1.51E+06	13
		2.12E+06	9
		1.84E+06	17
		1.67E+06	14
		1.70E+06	12
60	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 MPC 5/8-in. SHEATHING	2.14E+06	12
		1.63E+06	12
		1.27E+06	11
		1.14E+06	11
		1.79E+06	16
		1.35E+06	10
		1.43E+06	9
		1.44E+06	9
		1.17E+06	11

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
61	2X4 NO 1 SYP FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.40E+06	12
		1.88E+06	10
		1.90E+06	11
		2.29E+06	13
		1.49E+06	10
		1.07E+06	12
		1.97E+06	13
		1.34E+06	10
		1.63E+06	11
62	2X4 NO 1 SYP FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	9.90E+05	13
		2.30E+06	11
		1.35E+06	10
		1.98E+06	13
		1.94E+06	12
		1.55E+06	11
		1.89E+06	11
		2.91E+06	13
		1.77E+06	12
63	2X4 NO 1 SYP FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.04E+06	12
		1.81E+06	10
		1.84E+06	15
		1.58E+06	12
		2.52E+06	14
		1.42E+06	12
		1.81E+06	9
		1.50E+06	10
		1.95E+06	11
64	2X4 NO 1 SYP FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	2.28E+06	11
		2.91E+06	10
		2.54E+06	12
		1.39E+06	10
		1.68E+06	14
		3.00E+06	10
		1.77E+06	9
		1.51E+06	10
		1.11E+06	11

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
65	2X4 NO 1 SYP FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	2.03E+06	13
		2.04E+06	10
		1.77E+06	9
		2.07E+06	11
		2.38E+06	10
		1.58E+06	11
		8.62E+05	9
		1.97E+06	12
		1.99E+06	11
66	2X4 NO 1 SYP FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	2.06E+06	12
		2.18E+06	10
		1.94E+06	14
		1.83E+06	12
		2.15E+06	14
		2.11E+06	12
		1.76E+06	9
		2.22E+06	10
		1.07E+06	11
67	2X4 NO 1 SYP FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	2.13E+06	12
		2.68E+05	12
		1.97E+06	10
		1.10E+06	11
		1.90E+06	10
		9.42E+05	13
		1.71E+06	11
		1.60E+06	11
		1.11E+06	10
68	2X4 NO 1 SYP FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	2.33E+06	14
		1.46E+06	12
		2.51E+06	14
		1.37E+06	10
		1.96E+06	13
		1.37E+06	13
		1.90E+06	11
		1.05E+06	9
		2.67E+06	12

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
69	2X4 NO 1 SYP FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	2.33E+06	12
		2.34E+06	12
		1.73E+06	12
		1.44E+06	12
		1.60E+06	14
		2.06E+06	10
		1.99E+06	11
		7.41E+05	12
		1.71E+06	10
70	2X4 NO 1 SYP FRAMING 4 FT LENGTH 5X6 MPC NO SHEATHING	1.39E+06	10
		1.65E+06	12
		2.31E+06	11
		1.71E+06	10
		2.31E+06	10
		1.56E+06	12
		1.92E+06	10
		1.19E+06	10
		1.31E+06	14
71	2X4 NO 3 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.73E+06	13
		1.29E+06	14
		1.85E+06	13
		1.59E+06	11
		1.54E+06	12
		5.65E+05	12
		1.32E+06	12
		7.85E+05	12
		1.42E+06	11
72	2X4 NO 3 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.78E+06	11
		1.32E+06	12
		1.04E+06	13
		1.43E+06	12
		1.55E+06	11
		1.32E+06	11
		8.90E+05	10
		1.25E+06	10
		1.72E+06	10

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
73	2X4 NO 3 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.31E+06	10
		1.33E+06	12
		1.39E+06	12
		2.47E+06	19
		1.45E+06	14
		1.03E+06	14
		1.03E+06	10
		1.23E+06	14
		7.88E+05	12
74	2X4 NO 3 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	1.64E+06	15
		1.14E+06	12
		2.02E+06	15
		1.83E+06	15
		1.11E+06	10
		9.60E+05	13
		1.72E+06	12
		2.25E+06	12
		9.03E+05	14
75	2X4 NO 3 DFL FRAMING 4 FT LENGTH NAILED FRAMING NO SHEATHING	2.09E+06	14
		1.31E+06	13
		1.31E+06	12
		1.61E+06	11
		3.86E+05	12
		1.35E+06	13
		1.03E+06	10
		8.88E+05	14
		6.79E+05	12
76	2X4 NO 3 DFL FRAMING 4 FT LENGTH 5X6 PLATE NO SHEATHING	1.91E+06	10
		2.04E+06	11
		1.26E+06	12
		1.98E+06	14
		1.40E+06	11
		2.00E+06	12
		1.33E+06	11
		1.04E+06	9
		1.49E+06	10

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
77	2X4 NO 3 DFL FRAMING 4 FT LENGTH 5X6 PLATE NO SHEATHING	1.92E+06	13
		1.95E+06	13
		1.05E+06	13
		1.86E+06	12
		1.29E+06	14
		2.67E+06	11
		1.45E+06	12
		1.50E+06	12
		1.60E+06	12
78	2X4 NO 3 DFL FRAMING 4 FT LENGTH 5X6 PLATE NO SHEATHING	1.31E+06	13
		1.28E+06	14
		2.11E+06	13
		4.46E+05	12
		1.15E+06	13
		1.68E+06	11
		1.42E+06	11
		1.11E+06	12
		7.09E+05	12
79	2X4 NO 3 DFL FRAMING 4 FT LENGTH 5X6 PLATE NO SHEATHING	1.53E+06	12
		9.57E+05	13
		1.23E+06	13
		1.32E+06	10
		1.65E+06	9
		1.59E+06	12
		1.39E+06	15
		1.25E+06	10
		1.54E+06	11
80	2X4 NO 3 DFL FRAMING 4 FT LENGTH 5X6 PLATE NO SHEATHING	2.22E+06	12
		1.86E+06	13
		1.44E+06	14
		1.90E+06	12
		8.90E+05	12
		2.00E+06	13
		1.79E+06	13
		1.24E+06	9
		1.82E+06	10

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
81	2X4 NO 2 DFL FRAMING 8 FT LENGTH 5X6 PLATE NO SHEATHING	1.59E+06	9
		2.22E+06	11
		2.22E+06	13
		1.51E+06	11
		1.42E+06	11
		1.14E+06	13
		1.66E+06	12
		1.11E+06	12
		1.04E+06	11
		1.37E+06	11
		1.01E+06	9
		9.49E+05	11
82	2X4 NO 2 DFL FRAMING 8 FT LENGTH 5X6 PLATE NO SHEATHING	1.89E+06	11
		1.56E+06	10
		3.16E+06	11
		1.49E+06	10
		1.07E+06	11
		1.58E+06	9
		1.28E+06	11
		1.30E+06	10
		1.37E+06	10
		1.53E+06	12
		1.68E+06	12
		1.32E+06	12
83	2X4 NO 2 DFL FRAMING 8 FT LENGTH 5X6 PLATE NO SHEATHING	1.45E+06	11
		1.81E+06	11
		1.23E+06	12
		1.51E+06	14
		1.88E+06	10
		1.28E+06	12
		1.83E+06	11
		1.56E+06	10
		1.06E+06	14
		1.29E+06	12
		1.26E+06	11
		1.19E+06	13

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
84	2X4 NO 2 DFL FRAMING 8 FT LENGTH 5X6 PLATE 7/16 SHEATHING	2.81E+06	10
		1.67E+06	9
		1.40E+06	10
		2.20E+06	10
		1.83E+06	11
		2.57E+06	13
		1.08E+06	17
		1.81E+06	13
		1.51E+06	9
		1.42E+06	9
		1.52E+06	10
		1.98E+06	10
85	2X4 NO 2 DFL FRAMING 8 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.48E+06	15
		1.81E+06	14
		1.75E+06	12
		1.37E+06	10
		1.43E+06	11
		1.32E+06	10
		1.36E+06	10
		1.81E+06	10
		1.92E+06	15
		1.74E+06	9
		1.29E+06	11
		1.13E+06	13
86	2X4 NO 2 DFL FRAMING 8 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.73E+06	17
		1.64E+06	12
		5.28E+06	10
		2.01E+06	16
		1.23E+06	12
		1.83E+06	10
		1.23E+06	9
		1.71E+06	14
		1.71E+06	13
		1.70E+06	12
		1.71E+06	13
		1.26E+06	11

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
91	2X4 NO 2 DFL FRAMING 12 FT LENGTH 5X6 PLATE NO SHEATHING	1.26E+06	10
		2.26E+06	10
		1.77E+06	12
		1.07E+06	10
		1.89E+06	9
		1.75E+06	10
		1.27E+06	11
		1.94E+06	12
		2.14E+06	9
		1.91E+06	10
		1.94E+06	9
		1.24E+06	10
		1.38E+06	10
		9.53E+05	11
		1.46E+06	12
92	2X4 NO 2 DFL FRAMING 12 FT LENGTH 5X6 PLATE NO SHEATHING	7.59E+05	10
		2.15E+06	8
		1.72E+06	10
		1.84E+06	10
		1.19E+06	13
		2.03E+06	11
		2.69E+06	12
		1.43E+06	10
		1.97E+06	11
		1.17E+06	10
		1.50E+06	10
		1.34E+06	10
		1.29E+06	9
		1.64E+06	11
		1.26E+06	12

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
93	2X4 NO 2 DFL FRAMING 12 FT LENGTH 5X6 PLATE NO SHEATHING	1.24E+06	8
		1.38E+06	11
		2.57E+06	11
		1.48E+06	11
		1.76E+06	14
		1.82E+06	9
		1.88E+06	10
		1.49E+06	12
		1.71E+06	10
		1.31E+06	10
		1.55E+06	10
		1.25E+06	11
		7.75E+05	10
		1.37E+06	10
		1.06E+06	10
94	2X4 NO 2 DFL FRAMING 12 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.20E+06	11
		1.75E+06	10
		1.59E+06	9
		1.56E+06	12
		1.35E+06	8
		1.14E+06	14
		1.46E+06	15
		1.22E+06	9
		1.05E+06	10
		1.91E+06	10
		1.25E+06	11
		1.66E+06	10
		1.46E+06	10
		1.37E+06	10
		1.48E+06	9

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
95	2X4 NO 2 DFL FRAMING 12 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.47E+06	12
		1.81E+06	12
		1.76E+06	11
		1.31E+06	12
		1.36E+06	13
		1.09E+06	13
		2.11E+06	12
		9.29E+05	13
		1.27E+06	9
		1.94E+06	11
		1.18E+06	9
		2.60E+06	13
		1.45E+06	10
		1.28E+06	11
		5.86E+05	9
96	2X4 NO 2 DFL FRAMING 12 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.17E+06	10
		1.98E+06	10
		1.17E+06	12
		1.46E+06	11
		1.09E+06	10
		1.64E+06	12
		1.47E+06	14
		1.29E+06	10
		1.08E+06	10
		1.45E+06	12
		1.32E+06	10
		1.23E+06	10
		1.68E+06	11
		1.34E+06	9
		1.14E+06	12

WAL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
101	2X4 NO 2 DFL FRAMING 16 FT LENGTH 5X6 PLATE NO SHEATHING	1.46E+06	11
		1.65E+06	10
		1.31E+06	9
		9.98E+05	12
		1.57E+06	8
		1.87E+06	13
		1.79E+06	16
		1.18E+06	9
		1.42E+06	11
		1.84E+06	11
		1.60E+06	11
		1.21E+06	9
		9.82E+05	9
		1.25E+06	9
		9.08E+05	12
		8.77E+05	11
		1.05E+06	9
		1.36E+06	14
102	2X4 NO 2 DFL FRAMING 16 FT LENGTH 5X6 PLATE NO SHEATHING	1.06E+06	12
		1.30E+06	12
		1.95E+06	13
		1.30E+06	12
		1.05E+06	11
		1.78E+06	10
		1.19E+06	12
		1.01E+06	9
		1.55E+06	13
		9.55E+05	12
		1.33E+06	14
		1.71E+06	15
		1.84E+06	12
		1.50E+06	11
		1.09E+06	11
		1.51E+06	12
		1.46E+06	14
		1.91E+06	15

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
103	2X4 NO 2 DFL FRAMING 16 FT LENGTH 5X6 PLATE NO SHEATHING	1.65E+06	11
		1.22E+06	12
		1.38E+06	10
		2.09E+06	10
		1.17E+06	9
		1.91E+06	12
		1.11E+06	13
		1.72E+06	11
		2.16E+06	16
		1.37E+06	9
		1.15E+06	12
		1.48E+06	10
		8.68E+05	10
		1.34E+06	13
		1.23E+06	11
		1.34E+06	11
		1.75E+06	10
		1.34E+06	13
104	2X4 NO 2 DFL FRAMING 16 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.92E+06	9
		1.14E+06	12
		3.86E+06	11
		1.33E+06	13
		1.22E+06	14
		2.38E+06	15
		1.42E+06	14
		1.38E+06	13
		2.98E+06	11
		1.12E+06	11
		2.38E+06	9
		1.57E+06	13
		2.24E+06	15
		1.69E+06	11
		1.10E+06	9
		1.64E+06	13
		1.87E+06	15
		1.16E+06	14

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
105	2X4 NO 2 DFL FRAMING 16 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.16E+06	10
		1.37E+06	10
		2.05E+06	13
		1.65E+06	10
		1.78E+06	12
		2.26E+06	9
		1.27E+06	11
		1.59E+06	11
		2.67E+06	12
		1.50E+06	15
		1.49E+06	12
		1.52E+06	12
		1.59E+06	14
		2.36E+06	12
		1.84E+06	12
		1.42E+06	8
		1.16E+06	12
		9.49E+05	12
106	2X4 NO 2 DFL FRAMING 16 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.74E+06	8
		1.50E+06	16
		1.94E+06	11
		1.11E+06	14
		1.62E+06	13
		1.47E+06	11
		1.19E+06	13
		1.28E+06	10
		1.21E+06	12
		2.03E+06	9
		9.78E+05	11
		1.29E+06	9
		1.68E+06	14
		1.82E+06	10
		1.71E+06	10
		1.32E+06	9
		9.26E+05	10
		1.10E+06	10

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
111	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X4 PLATE NO SHEATHING	2.39E+06	16
		1.45E+06	19
		2.08E+06	13
		1.29E+06	12
		1.90E+06	14
		1.77E+06	14
		1.58E+06	12
		1.20E+06	12
		1.42E+06	12
112	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X4 PLATE NO SHEATHING	1.76E+06	11
		1.32E+06	11
		1.39E+06	11
		1.43E+06	25
		1.94E+06	15
		1.80E+06	16
		1.24E+06	19
		1.47E+06	10
		1.13E+06	11
113	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X4 PLATE NO SHEATHING	1.86E+06	16
		2.11E+06	21
		1.30E+06	15
		2.11E+06	14
		2.25E+06	16
		1.56E+06	29
		1.53E+06	14
		1.92E+06	12
		1.13E+06	12
114	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X4 PLATE NO SHEATHING	1.75E+06	13
		1.45E+06	12
		2.25E+06	11
		1.38E+06	19
		1.46E+06	22
		2.07E+06	15
		1.56E+06	13
		1.03E+06	13
		1.61E+06	9

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
115	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X4 PLATE NO SHEATHING	1.71E+06	11
		1.50E+06	12
		1.84E+06	14
		2.29E+06	12
		1.47E+06	13
		1.17E+06	10
		1.64E+06	11
		1.83E+06	12
		1.90E+06	11
116	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE NO SHEATHING	1.99E+06	16
		1.49E+06	14
		1.79E+06	17
		1.58E+06	11
		1.65E+06	16
		1.84E+06	12
		1.57E+06	14
		1.73E+06	12
		9.44E+05	10
117	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE NO SHEATHING	2.25E+06	14
		1.39E+06	14
		1.55E+06	11
		1.14E+06	10
		1.63E+06	26
		1.66E+06	17
		9.35E+05	12
		9.22E+05	14
		1.24E+06	10
118	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE NO SHEATHING	1.34E+06	11
		1.67E+06	14
		1.46E+06	12
		1.73E+06	13
		2.04E+06	16
		1.85E+06	12
		1.21E+06	12
		1.19E+06	9
		1.34E+06	14

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
119	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE NO SHEATHING	1.38E+06	17
		1.53E+06	19
		1.22E+06	13
		1.35E+06	10
		1.64E+06	11
		1.38E+06	19
		1.31E+06	25
		1.97E+06	14
		1.78E+06	19
120	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE NO SHEATHING	1.23E+06	15
		2.15E+06	17
		1.38E+06	12
		1.16E+06	14
		1.92E+06	30
		1.76E+06	25
		1.32E+06	28
		1.49E+06	12
		1.09E+06	12
121	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 PLATE 7/16 SHEATHING	1.66E+06	13
		1.71E+06	11
		1.20E+06	13
		2.57E+06	16
		1.12E+06	11
		1.77E+06	12
		9.80E+05	11
		1.45E+06	11
		2.31E+06	14
122	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 PLATE 7/16 SHEATHING	1.69E+06	12
		1.12E+06	11
		2.11E+06	16
		1.51E+06	19
		1.43E+06	13
		1.94E+06	13
		2.25E+06	11
		1.45E+06	17
		1.40E+06	12

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
123	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 PLATE 7/16 SHEATHING	2.18E+06	26
		1.77E+06	17
		1.50E+06	12
		1.59E+06	11
		1.46E+06	13
		1.77E+06	13
		1.85E+06	20
		1.81E+06	15
		1.59E+06	13
124	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 PLATE 7/16 SHEATHING	1.53E+06	13
		1.60E+06	16
		1.68E+06	16
		1.48E+06	11
		1.33E+06	15
		2.03E+06	15
		1.60E+06	12
		1.56E+06	13
		1.75E+06	14
125	2X4 NO 2 DFL FRAMING 4 FT LENGTH 6X7 PLATE 7/16 SHEATHING	1.66E+06	14
		1.66E+06	12
		1.68E+06	18
		1.58E+06	12
		2.13E+06	12
		1.46E+06	11
		1.71E+06	13
		1.50E+06	12
		1.75E+06	14
126	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE 7/16 SHEATHING	1.30E+06	16
		1.69E+06	12
		1.46E+06	13
		1.28E+06	13
		1.84E+06	12
		1.63E+06	9
		1.79E+06	15
		9.51E+05	17
		1.08E+06	13

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
127	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE 7/16 SHEATHING	1.49E+06	14
		1.53E+06	12
		2.08E+06	17
		1.58E+06	14
		1.50E+06	11
		1.65E+06	12
		1.37E+06	12
		1.16E+06	13
		1.56E+06	11
128	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE 7/16 SHEATHING	1.67E+06	12
		1.47E+06	13
		2.11E+06	14
		1.59E+06	23
		1.32E+06	12
		2.00E+06	15
		1.10E+06	10
		1.57E+06	12
		1.14E+06	12
129	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE 7/16 SHEATHING	1.97E+06	14
		1.56E+06	14
		1.84E+06	12
		1.63E+06	11
		2.25E+06	12
		1.07E+06	11
		1.31E+06	9
		1.22E+06	13
		1.19E+06	14
130	2X4 NO 2 DFL FRAMING 4 FT LENGTH 3X4 PLATE 7/16 SHEATHING	9.53E+05	10
		1.53E+06	14
		1.26E+06	12
		1.55E+06	10
		2.05E+06	12
		1.49E+06	13
		1.44E+06	12
		1.47E+06	12
		1.44E+06	12

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
131	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 PLATE 7/16 SHEATHING	1.45E+06	12
		1.36E+06	12
		1.27E+06	11
		1.46E+06	12
		1.41E+06	12
		1.56E+06	14
		9.55E+05	10
		1.38E+06	10
		1.74E+06	13
132	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 PLATE 7/16 SHEATHING	1.47E+06	20
		1.63E+06	10
		1.97E+06	12
		1.91E+06	14
		1.12E+06	12
		1.94E+06	12
		1.05E+06	10
		1.18E+06	16
		9.88E+05	11
133	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 PLATE 7/16 SHEATHING	1.23E+06	12
		1.61E+06	12
		1.24E+06	14
		9.76E+05	15
		2.03E+06	14
		1.76E+06	14
		1.81E+06	13
		1.41E+06	12
		8.38E+05	13
134	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 PLATE 7/16 SHEATHING	1.72E+06	13
		9.19E+05	12
		1.98E+06	13
		1.34E+06	14
		1.77E+06	14
		1.66E+06	12
		1.40E+06	11
		1.23E+06	10
		9.15E+05	13

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
135	2X4 NO 2 DFL FRAMING 4 FT LENGTH 4X5 PLATE 7/16 SHEATHING	9.26E+05	10
		1.74E+06	11
		2.00E+06	13
		1.83E+06	14
		1.35E+06	14
		2.31E+06	13
		1.80E+06	10
		1.42E+06	11
		1.38E+06	12
136	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.03E+06	11
		1.50E+06	10
		8.41E+05	13
		1.75E+06	14
		1.92E+06	14
		1.75E+06	15
		1.10E+06	10
		1.65E+06	11
		1.20E+06	11
137	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.65E+06	13
		1.38E+06	12
		1.71E+06	15
		1.15E+06	12
		1.80E+06	14
		1.52E+06	11
		1.62E+06	10
		1.10E+06	12
		1.27E+06	12
138	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.60E+06	10
		1.19E+06	16
		1.73E+06	10
		1.24E+06	12
		1.46E+06	12
		1.42E+06	13
		1.30E+06	12
		1.02E+06	19
		1.38E+06	14

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
139	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.76E+06	11
		1.31E+06	13
		1.49E+06	12
		1.56E+06	16
		2.25E+06	15
		1.55E+06	19
		9.42E+05	12
		1.12E+06	10
		1.30E+06	10
140	2X4 NO 2 DFL FRAMING 4 FT LENGTH 5X6 PLATE 7/16 SHEATHING	1.54E+06	11
		1.36E+06	10
		1.31E+06	10
		1.64E+06	9
		1.87E+06	11
		1.20E+06	12
		1.71E+06	14
		1.61E+06	9
		1.53E+06	12
141	2X4 NO 2 DFL FRAMING 8 FT LENGTH NAILED FRAMING NO SHEATHING	2.03E+06	10
		1.25E+06	10
		1.06E+06	13
		9.74E+05	12
		1.74E+06	10
		1.29E+06	9
		2.05E+06	8
		2.00E+06	12
		1.74E+06	13
		1.77E+06	10
		1.90E+06	10
		1.60E+06	10
142	2X4 NO 2 DFL FRAMING 8 FT LENGTH NAILED FRAMING NO SHEATHING	1.83E+06	13
		2.42E+06	14
		1.20E+06	13
		1.63E+06	13
		2.39E+06	15
		2.12E+06	12
		2.36E+06	10
		2.30E+06	13
		2.43E+06	12
		1.47E+06	9
		1.55E+06	9
		1.38E+06	12

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
143	2X4 NO 2 DFL FRAMING 8 FT LENGTH NAILED FRAMING NO SHEATHING	1.18E+06	10
		1.22E+06	12
		1.65E+06	12
		9.70E+05	11
		1.83E+06	12
		1.72E+06	13
		2.03E+06	9
		2.13E+06	9
		1.38E+06	10
		1.74E+06	9
		1.51E+06	10
		1.32E+06	13
144	2X4 NO 2 DFL FRAMING 8 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.74E+06	17
		2.09E+06	16
		1.25E+06	10
		1.52E+06	12
		1.45E+06	17
		1.32E+06	9
		1.72E+06	10
		1.58E+06	13
		1.63E+06	12
		1.50E+06	10
		1.38E+06	12
		2.28E+06	11
145	2X4 NO 2 DFL FRAMING 8 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.81E+06	17
		1.68E+06	10
		1.74E+06	10
		2.13E+06	12
		1.26E+06	12
		2.02E+06	9
		2.06E+06	10
		1.72E+06	10
		1.30E+06	10
		8.79E+05	11
		1.91E+06	12
		1.59E+06	11

WALL	WALL DISCRIPTION	EI (LB-IN²)	MC (%)
146	2X4 NO 2 DFL FRAMING 8 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.00E+06	9
		1.54E+06	10
		1.77E+06	9
		1.65E+06	12
		1.77E+06	13
		1.12E+06	13
		2.63E+06	12
		1.53E+06	12
		2.86E+06	13
		1.41E+06	11
		1.72E+06	11
		1.73E+06	12
151	2X4 NO 2 DFL FRAMING 12 FT LENGTH NAILED FRAMING NO SHEATHING	2.39E+06	12
		1.69E+06	11
		9.38E+05	13
		1.49E+06	10
		1.37E+06	12
		1.75E+06	9
		1.15E+06	11
		1.88E+06	9
		1.88E+06	11
		1.44E+06	12
		1.63E+06	11
		1.48E+06	10
		9.47E+05	12
		1.60E+06	12
		1.72E+06	11
152	2X4 NO 2 DFL FRAMING 12 FT LENGTH NAILED FRAMING NO SHEATHING	1.15E+06	10
		1.47E+06	10
		1.47E+06	12
		1.74E+06	9
		2.25E+06	10
		1.67E+06	9
		1.28E+06	10
		1.30E+06	10
		1.39E+06	9
		1.94E+06	10
		1.46E+06	10
		1.46E+06	11
		1.35E+06	12
		1.33E+06	14
		1.15E+06	9

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
153	2X4 NO 2 DFL FRAMING 12 FT LENGTH NAILED FRAMING NO SHEATHING	1.83E+06	11
		1.40E+06	11
		1.81E+06	12
		1.94E+06	9
		1.85E+06	12
		1.85E+06	9
		1.35E+06	10
		1.75E+06	13
		1.78E+06	13
		1.76E+06	11
		1.56E+06	10
		1.69E+06	10
		1.23E+06	9
		1.09E+06	12
		1.09E+06	12
154	2X4 NO 2 DFL FRAMING 12 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.78E+06	13
		7.80E+05	11
		1.57E+06	13
		1.25E+06	11
		1.30E+06	12
		1.51E+06	11
		1.01E+06	9
		1.22E+06	22
		1.64E+06	10
		1.69E+06	13
		1.23E+06	11
		1.37E+06	11
		1.32E+06	13
		1.00E+06	10
		1.26E+06	14

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
155	2X4 NO 2 DFL FRAMING 12 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.85E+06	16
		2.16E+06	13
		1.43E+06	11
		1.02E+06	16
		1.44E+06	12
		1.29E+06	13
		1.23E+06	12
		1.20E+06	13
		1.21E+06	15
		1.50E+06	14
		1.85E+06	14
		1.40E+06	11
		1.85E+06	27
		1.30E+06	24
		1.57E+06	16
56	2X4 NO 2 DFL FRAMING 12 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.04E+06	17
		2.19E+06	13
		1.22E+06	16
		1.59E+06	14
		1.79E+06	14
		1.47E+06	11
		1.31E+06	12
		1.55E+06	16
		1.91E+06	18
		1.50E+06	15
		2.05E+06	12
		1.31E+06	11
		1.81E+06	11
		1.38E+06	13
		1.61E+06	13

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
161	2X4 NO 2 DFL FRAMING 16 FT LENGTH NAILED FRAMING NO SHEATHING	1.91E+06	10
		1.50E+06	12
		1.85E+06	11
		1.44E+06	12
		1.99E+06	11
		1.56E+06	12
		1.28E+06	11
		1.85E+06	10
		2.44E+06	10
		1.93E+06	9
		1.88E+06	11
		1.32E+06	12
		1.73E+06	15
		1.85E+06	11
		1.39E+06	12
		1.46E+06	10
		1.28E+06	9
		1.51E+06	11
162	2X4 NO 2 DFL FRAMING 16 FT LENGTH NAILED FRAMING NO SHEATHING	1.75E+06	10
		1.26E+06	9
		1.48E+06	15
		1.47E+06	11
		2.29E+06	11
		1.97E+06	11
		2.70E+06	14
		1.58E+06	9
		1.57E+06	9
		1.22E+06	9
		1.98E+06	11
		1.86E+06	8
		1.00E+06	11
		1.36E+06	10
		1.79E+06	15
		8.22E+05	11
		9.66E+05	10
		9.10E+05	10

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
163	2X4 NO 2 DFL FRAMING 16 FT LENGTH NAILED FRAMING NO SHEATHING	1.83E+06	12
		2.08E+06	11
		1.17E+06	8
		1.36E+06	8
		1.07E+06	9
		1.25E+06	11
		1.90E+06	11
		1.79E+06	10
		1.64E+06	8
		1.64E+06	10
		1.14E+06	9
		1.48E+06	9
		1.32E+06	9
		1.56E+06	9
		1.21E+06	12
		1.26E+06	9
		1.46E+06	9
		2.15E+06	12
164	2X4 NO 2 DFL FRAMING 16 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.70E+06	10
		2.15E+06	10
		1.35E+06	12
		1.34E+06	14
		1.37E+06	12
		1.51E+08	14
		1.69E+06	11
		2.22E+06	10
		1.90E+06	11
		1.84E+06	12
		1.97E+06	9
		1.30E+06	10
		1.69E+06	13
		1.94E+06	11
		2.12E+06	10
		1.75E+06	11
		1.04E+06	12
		1.68E+06	12

WALL	WALL DISCRIPTION	EI (LB-IN^2)	MC (%)
165	2X4 NO 2 DFL FRAMING 16 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.50E+06	11
		1.23E+06	9
		1.18E+06	13
		2.36E+06	12
		2.15E+06	9
		2.00E+06	13
		1.44E+06	13
		1.79E+06	12
		1.72E+06	10
		2.33E+06	12
		1.39E+06	14
		2.31E+06	14
		1.94E+06	10
		1.52E+06	10
		1.45E+06	10
		1.98E+06	11
		1.30E+06	10
		1.64E+06	9
166	2X4 NO 2 DFL FRAMING 16 FT LENGTH NAILED FRAMING 7/16 SHEATHING	1.62E+06	12
		1.91E+06	11
		2.07E+06	11
		1.51E+06	11
		1.60E+06	9
		1.78E+06	11
		1.26E+06	10
		1.63E+06	12
		1.21E+06	11
		1.91E+06	10
		3.38E+06	9
		1.87E+06	10
		1.79E+06	12
		1.21E+06	14
		9.82E+05	12
		2.05E+06	13
		2.76E+06	9
		1.63E+06	11

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