INVESTIGATION INTO THE EFFECTS OF VARIABLE ROW SPACING IN BOLTED TIMBER CONNECTIONS SUBJECTED TO REVERSE CYCLIC LOADING

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of CALEB JESSE KNUDSON find it satisfactory and recommend that it be accepted.

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Chair

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Abstract

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The effects of variable row spacing in single-shear bolted timber connections subjected to reverse cyclic loading have been determined through this experimental research. A variety of performance characteristics including 5% offset yield strength, capacity and ductility have been examined for tested connections as row spacing varied; their results are addressed herein. Statistical analyses were conducted to determine whether inferences could be made regarding mean values for the ductility ratio, 5% offset yield strength and capacity of tested multiple-bolt connections, as row spacing was increased from 2D to 3D.

Bolted connections utilizing three different bolt diameters, four unique connection geometries, and variable row spacing within each connection geometry, were subjected to a displacement controlled loading protocol. The protocol used, which was developed by the CUREE-Caltech Wood frame Project is representative of natural hazard loading. Connections were fabricated in order to achieve specific yield modes based on predictions of the Yield Limit Model in order to determine the validity of this model as row spacing was varied.

The primary conclusion drawn from the results of this research addresses the current design recommendation for row spacing in bolted timber connections. The 2001 NDS (AF&PA, 2001) states within the provisions of the Geometry factor (C_{Δ}) that the minimum row spacing in bolted connections shall be 1.5D. This provision should first, be modified to require minimum row spacing for full design value of 3D. Additionally, a linear reduction should be applied in the same manner as current NDS reductions for end distance and bolt spacing, with minimum row spacing for reduced design value of 1.5D.

The predictions provided by the Yield Model were, in many cases, inaccurate. Several factors unaccounted for in the model including end fixity caused by the nut and washer, sliding friction between the members, and bolt tensioning, greatly influence connection yield behavior. The derivation of the model should be expanded to include these factors.

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Introduction

1.1 - Background

Bolted connections are very common in wood design. They are straight forward to design, and relatively simple to install on site. The responses of single-bolt timber connections to monotonic loading conditions are well understood, however, the behavior of bolted timber connections utilizing multiple-bolt configurations is not as well defined, particularly for connections subjected to cyclic loading conditions, such as those imposed by hurricane and earthquake forces.

Traditionally, bolted connection design has been based on monotonic load application and working stress levels. More specifically, designs were conducted so that the load induced would not exceed the proportional limit of a connection. Monotonic loading is representative of the type of load experienced during sustained dead or live loads. It has been assumed in design that a structure will respond in much the same manner when exposed to events such as high wind or earthquake as it will to sustained loading. Current design criterion for dowel-type connection design in the 2001 National Design Specification (NDS (AF&PA, 2001)) is based on the Yield Model, which was developed by European researchers in the mid-twentieth century. The minimum requirement for row spacing in bolted timber connections loaded parallel to grain is one and a half times the bolt diameter (1.5D) as recommended by early researchers.

Over the past two decades, much research has been conducted in order to achieve a better understanding of the behavior of bolted connections when exposed to natural hazard loading. Technology had governed earlier research; however, recently, methods

have been developed to allow simulated testing of dynamic forces imposed by earthquakes and high wind in a controlled laboratory environment. To gain better understanding of multiple-bolt connection behavior under natural hazard loading, the primary objective of this research is to determine the effects of row spacing on the performance of bolted timber connections when subjected to cyclic loading conditions. Additionally, it is of interest to determine if current NDS recommendations for row spacing are adequate.

1.2 - Objectives

The objectives of this research include:

- Quantifying the effect of variable row spacing on bolted connection strength characteristics including connection capacity, 5% offset yield strength, and ductility ratio.
- Identifying any apparent trends in connection performance as row spacing is varied and either proving or disproving them with statistical analyses.
- Determining the validity of the Yield Model's strength and yield mode predictions for variable row spacing in multiple-bolt connections exposed to cyclic loading.
- Quantifying additional connection performance parameters including stiffness, equivalent elastic plastic yield, equivalent viscous damping, hysteretic energy, displacement capacity, and strain energy for different multiple-bolt configurations.

1.3 - Significance

The current minimum row spacing recommended by the NDS (AF&PA, 2001) is one and a half times the diameter of the bolt (1.5D). This research will determine if the recommended row spacing is acceptable for multiple-bolt connections subjected to earthquake or high wind loading, or if alternate minimum row spacing should be considered for multiple-bolt connections.

1.4 - Thesis Overview

Chapter Two presents a literature review of past research conducted, which is considered relative to multiple-bolt connections subjected to reverse cyclic loading. The experimental procedures used in this research concerning full connection tests and all secondary testing are described in Chapter Three. Chapter Four presents and discusses results of this research based on raw data and statistical analyses; followed by Chapter Five which presents a summary of this research and conclusions drawn from its results. Finally, Appendix A presents load-deflection plots from cyclic testing along with raw data from a variety of strength and serviceability parameter analyses.

Literature Review

2.1 - Introduction

Forces imposed on timber structures from wind and earthquake events are the primary sources of lateral loading, and in timber construction, the majority of lateral loads are resisted by the connections. There is a large degree of uncertainty when addressing earthquakes pertaining to their magnitude and manner in which the resulting force is applied to a structure. Since it is not possible to control natural hazards, we must attain a better understanding of timber structure behavior when subjected to seismic loading, so that the design process considers a careful balance of strength, stiffness, and ductility (Popovski et al., 2002).

Relatively inexpensive and easy to install, bolts are a common fastener type used in timber connections. The behavior of bolted joints is highly variable based on the number of members connected, total bolt quantity, and connection geometry. The connection may be described as either a single-shear or a multiple-shear configuration, depending on the number of member interfaces. Bolted timber connections utilize either a single-bolt or multiple-bolt configuration. Single-bolt connections consist of a single bolt, whereas multiple-bolt connections feature multiple rows and/or multiple-bolts per row, with a row of bolts being defined as a line of bolts, parallel to the direction of the applied load. Connection geometry is based not only on the total number of bolts used, but on edge distance, end distance, bolt spacing, and row spacing of a connection.

2.2 - Background

The basis for recommendations used in current United States connection design philosophies can be traced back to research conducted by George Trayer (1932). Trayer performed several hundred connection tests utilizing different hardwood and softwood species with various bolt diameters and lengths. Additionally, load was applied both parallel and perpendicular to grain with varied connection geometries. From these tests, Trayer made recommendations for various connection parameters, and defined the proportional limit as the average stress under the bolt when the slip ceases to be proportional to the load being applied (Trayer, 1932). This concept is illustrated in Figure 2.1. Trayer's research is significant because it formed the basis for allowable bolt strengths used in U.S. timber design codes for many years to come (Moss, 1996).

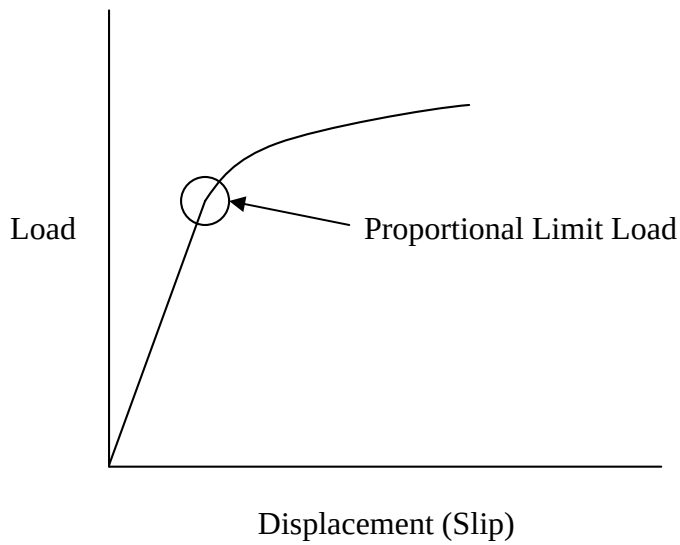

Figure 2.1: Proportional limit defined in a sample load-displacement plot.

The proportional limit load, as defined by Trayer, was the basis for allowable bolted timber connection design loads starting with the National Design Specification for

Stress Grade Lumber and its Fasteners (NLMA, 1944), continuing through the 1986 National Design Specification for Wood Construction (AF&PA, 1986). In the 1991 National Design Specification for Wood Construction (AF&PA, 1991), a mechanics based set of equations developed by European researchers was adopted to calculate bolted timber connection design values. The equations, referred to as the Yield Model, predict yield strength for dowel type connections based on dowel bearing strength of the wood, and fastener bending yield strength (Soltis and Wilkinson, 1991). The Yield Model is the current basis for determining bolted timber connection yield strength in the National Design Specification for Wood Construction (AF&PA, 2001) and will be discussed in detail in the following section.

The Yield Model is limited however, in that it only considers yielding of connections containing a single bolt, and does not consider brittle failure modes of single or multiple-bolt connections such as splitting or group tear-out. The 2001 National Design Specification does however include provisions to address the issue of failure in bolted timber connections. Non-mandatory Appendix E, *Local Stresses in Fastener Groups* (AF&PA, 2001) provides a series of equations based on mechanical strength properties of wood members and connection geometry to determine the ultimate capacity of multiple-bolt timber connections. The appendix equations provide a means of determining capacities for net-section tension rupture, row tear-out, and group tear-out, and will be discussed in detail later in this chapter.

2.3 - Yield Limit Model

The NDS Yield Model (YM) is derived from the European Yield Model (EYM) introduced by Johansen (1949), and predicts the lateral strength of a single dowel-type fastener connection (McLain, 1991). The YM also provides a description of possible bolt yield modes that can occur in timber connections. Yield strengths for the different modes are based on equilibrium equations resulting from free body diagrams of a bolt in a wood member. The yield mode resulting in the lowest yield load for a given connection will be the yield load for that connection (Patton-Mallory, 1991) and (Wilkinson, 1993). The four possible single-shear yield modes are shown in Figure 2.2

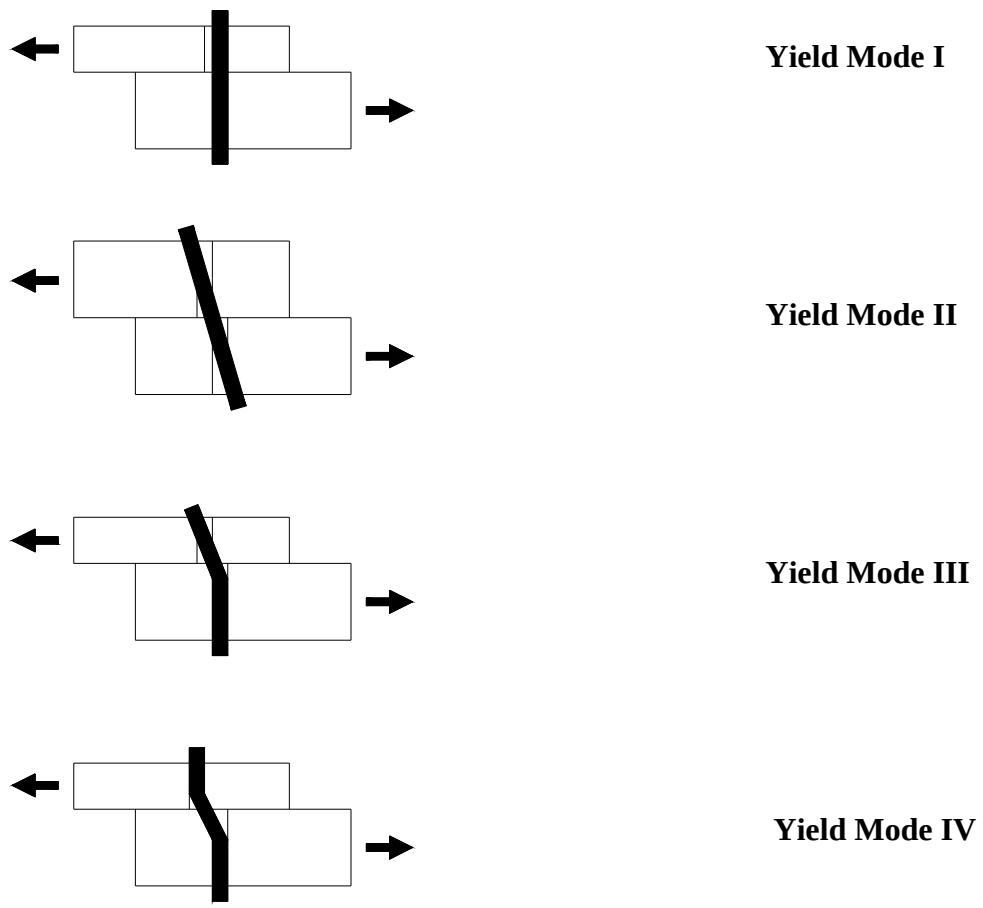

Figure 2.2: Single shear yield modes.

The four yield modes illustrated in Figure 2.2 encompass a total of six descriptions and design equations. Yield Mode I, and Yield Mode III have slight differences according to which member experiences yielding, and are subdivided into either side or main member yield. The 2001 NDS (AF&PA, 2001) Yield Limit modes are described as follows:

Yield Mode I – Wood crushing in either the main or the side member.

Yield Mode II – Localized wood crushing near the faces of the wood members based on rotation of a rigid fastener about the shear plane.

Yield Mode III - Fastener yield in bending at one plastic hinge point per shear plane and associated localized wood crushing.

Yield Mode IV – Fastener yield in bending at two plastic hinge points per shear plane and associated localized wood crushing.

Equations for the yield limit modes as used in the 2001 NDS (AF&PA, 2001) are presented below. The yield load of a connection is taken as the lowest value calculated from each equation. A subscript of "m" denotes yielding occurring in the main member, and a subscript of "s" denotes yielding in the side member.

Yield Modes:

$$Z_{\mathrm{Im}} = \frac{Dl_m F_{em}}{R_d} \tag{2.1}$$

$$Z_{Is} = \frac{Dl_s F_{es}}{R_d} \tag{2.2}$$

$$Z_{II} = \frac{k_1 Dl_s F_{es}}{R_d} \tag{2.3}$$

$$Z_{II\mathrm{Im}} = \frac{k_2 D l_m F_{em}}{(1+2R_e)R_d} \tag{2.4}$$

$$Z_{IIIs} = \frac{k_3 D l_s F_{em}}{(2+R_e)R_d} \tag{2.5}$$

$$Z_{IV} = \frac{D^2}{R_d}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}} \tag{2.6}$$

where:

$$k_1 = \frac{\sqrt{R_e + 2R_e^2(1+R_t+R_t^2) + R_t^2 R_e^3} - R_e(1+R_t)}{(1+R_e)} \tag{2.7}$$

$$k_2 = -1 + \sqrt{2(1+R_e) + \frac{2F_{yb}(1+2R_e)D^2}{3F_{em}l_m^2}} \tag{2.8}$$

$$k_3 = -1 + \sqrt{\frac{2(1+R_e)}{R_e} + \frac{2F_{yb}(2+R_e)D^2}{3F_{em}l_s^2}} \tag{2.9}$$

D = Fastener diameter, in..

F_{yb} = Dowel bending yield strength, psi.

F_{em} = Main member dowel bearing strength, psi.

F_{es} = Side member dowel bearing strength, psi.

l_m = Main member dowel bearing length, in..

l_s = Side member dowel bearing length, in..

$R_e = F_{em}/F_{es}$.

$R_t = l_m/l_s$.

R_d = Reduction term based on yield mode and dowel angle to grain.

Yield Model predictions have been compared to previous experimental research performed by Trayer (1932), Soltis and Wilkinson (1986), and McLain and Thangjtham (1983). Good agreement has been found between the data sets, with the Yield Model predicting slightly conservative values for yield strength in bolted timber joints loaded parallel to grain considering that friction in the joints is neglected. Inherent to the model was the assumption that yield strength would be reached when either the compressive strength of the wood beneath the bolt was exceeded, or one or more plastic hinges formed in the fastener. Several other underlying assumptions have been built into the YM as stated by McLain and Thangjtham (1983), and are listed below:

- The joint resists an externally applied lateral load through fastener bending resistance, and bearing resistance of the wood member.
- Bolts and any steel side plates used are homogeneous, isotropic, and elasto-plastic.
- Wood members are homogeneous, orthotropic and behave elasto-plastically when loaded parallel to grain.
- The effects of shear and tensile stresses in the development of plastic moments are neglected.
- The ends of the bolts are free to rotate, and bearing stress under the bolt is uniformly distributed with the bolt fitting tightly in the hole.
- Friction between the members is ignored.

Since the development of the YM, modifications have been proposed to allow the model to account for conditions that are more likely to occur in practice. McLain and Thangjtham (1983) proposed modifications that would account for end fixity imposed by

nuts and washers at the surfaces of timber members. Larsen (1973) introduced a modification to the model that would account for the sliding friction between the timber members of the connection. As listed above, the YM assumes a well-manufactured joint with a nearly perfect fit of the holes. United States design philosophies allow for a maximum bolt-hole over-drill of 1.6 mm (0.0625 in.) accounting for construction tolerances, which are unaccounted for in the YM. However, a study conducted by Wilkinson (1993) found that increased bolt-hole size had little effect on yield load or maximum load, but generally increased deformation for single-bolt connections.

Connection yield strength has been defined differently by various researchers. Prior to U.S. adoption in the 1991 NDS (AF&PA, 1991), the YM predicted that yield strength could potentially be any load on the load-deformation curve (Wilkinson, 1993). This definition of yield strength was not appropriate for the U.S. approach, which was to define a yield strength that enabled repeatability of results (Wilkinson, 1991). The yield load definition adopted into the 2001 NDS (AF&PA, 2001) is illustrated in Figure 2.3.

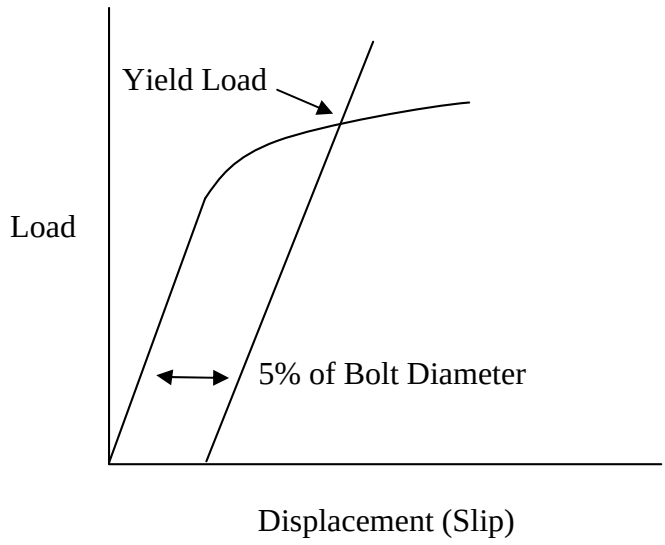

Figure 2.3: Definition of 5% offset yield load.

As illustrated in the previous figure, the yield load is the point at which the load-displacement curve intersects a straight line parallel to the initial linear portion of the curve. This line is offset by 5% of the fastener diameter from the origin of the load-displacement curve (Harding and Fowkes, 1984). Occasionally, when using larger diameter bolts, catastrophic failure will preclude this defined yield point from occurring, in which case, the 5% offset yield strength defines the ultimate load. The same definition is applied to determine dowel bearing yield strength and fastener bending yield strength as stated in ASTM D5764 ASTM (2004), and ASTM F1575 ASTM (2004) respectively. The yield point as defined above will fall between the proportional limit and the maximum load on the load-displacement curve for all components considered.

2.4 - Group Action Factor

According to Cramer (1968), Milton in 1885 was the first to note an unequal load distribution in a row of fasteners. He stated that the outermost and innermost rivets of double-butt strap joints transmit a greater proportion of the load than did the intermediate rivets. Doyle and Scholten (1963) expanded this research to include timber joints, and found that the bearing stress in multiple-bolt joints was less on a per-bolt basis than that of single-bolt joint.

In 1968, Cramer developed a linear-elastic analytical model to determine load distribution in a row of bolts. His model assumed a frictionless joint with non-uniform stress distribution through the cross-section of the members. Cramer verified this model by testing perfectly machined, butt-type timber joints with varying bolt spacing and number of bolts per row. Fairly good agreement was found between theoretical results

and experimental results (Cramer, 1968). Cramer did note that bolt-hole misalignment between the main member and splice plates, which was not accounted for in his model, produced an unpredictable load distribution in a row of bolts.

Lantos (1969) developed a similar linear-elastic analytical model to determine the load distribution within a row of bolts in timber connections. His model varied from Cramer's in that uniform stress distribution was assumed through the cross-section of a member. It was also assumed that a linear relationship existed between fastener deformation and load (Lantos, 1969). Lantos did not verify his model with experimental testing.

In their research, Lantos and Cramer made similar observations regarding rows of bolts. It was assumed that rows of bolts spaced far enough apart would act independently of each other (Cramer, 1968). Lantos (1969) noted that as the number of fasteners per row increases, the proportion of load to a single bolt decreases. Additionally, Lantos found that as the number of rows increased, there was a proportional increase in the strength of the joint.

Wilkinson (1980) expanded on the research conducted by Lantos and Cramer in an effort to develop a procedure that would account for single-bolt load-slip behavior and fabrication tolerances when determining load distribution in a row of bolts. He compared the model developed by Lantos to his own experimental data, finding that the model gave an accurate prediction of the proportional limit load for a row of fasteners. However, because the model did not consider non-linear behavior, capacity was overestimated. Wilkinson arrived at a similar conclusion to Cramer regarding fastener-hole misalignment between main and side members, stating that any bolt in a row may

transmit the largest percentage of load on the joint as capacity is approached, or virtually no load (Wilkinson, 1980).

Prior to the 1973 NDS (AF&PA, 1973), multiple-bolt connection design stated that the allowable load on a group of fasteners is the product of the single-bolt design value and the number of fasteners in the group (Lantos, 1969). Based on research conducted by Lantos (1969), row modification factors were introduced into the 1973 National Design Specification (AF&PA, 1973) to account for load reduction as the number of bolts per row was increased. Zahn (1991) reduced the Lantos model to a single equation, first present in the 1991 NDS (AF&PA, 1991), currently referred to as the group action factor, C_g, in the 2001 NDS (AF&PA, 2001). Current design recommendations by the NDS for multiple-fastener connections utilize the group action factor in conjunction with the nominal design value (Z) as shown in Equation 2.10.

$$Z' = n \times Z \times C_g \tag{2.10}$$

where:

$$C_g = \frac{\left[m(1-m^{2n})\right]}{n\left[(1+R_{EA}m^n)(1+m)-1+m^{2n}\right]}\frac{\left[1+R_{EA}\right]}{\left[1-m\right]} \tag{2.11}$$

C_g = 1.0 for dowel type fasteners with D < ¼ in.

n = Number of fasteners in row.

$$R_{EA} = \text{Lesser of } \frac{E_s A_s}{E_m A_m} \text{ or } \frac{E_m A_m}{E_s A_s} \tag{2.12}$$

E_m = Main member modulus of elasticity.

E_s = Side member modulus of elasticity.

A_m = Main member gross cross-sectional area.

A_s = Side member gross cross-sectional area.

$$m = u - \sqrt{(u^2 - 1)} \tag{2.13}$$

$$u = 1 + \gamma \frac{s}{2}\left[\frac{1}{E_m A_m} + \frac{1}{E_s A_s}\right] \tag{2.14}$$

s = Center to center spacing between fasteners in a row.

γ = Load/slip modulus; calculated as: [(180.000)($D^{1.5}$)] (lbs. /in.).

D = Fastener diameter, in.

2.5 - Brittle Failure Modes

Current U.S. design philosophies utilize the Yield Model, which is based on 5% offset yield strength. This model has been shown to accurately predict the yield load in single-bolt connections when the joint does not fail from axial load on the net section, and when the edge and end distances are sufficient to prevent failure due to shear or splitting (McLain and Thangjtham, 1983). However, when multiple-bolt connections are considered, the ultimate mode of failure observed could be much different based on the tendency of multiple-bolt timber connections to display brittle failure modes.

Considering the Yield Model's inability to accurately predict strength connections displaying brittle failure behavior, it is desirable to evolve toward a capacity based design procedure (Anderson, 2001). Capacity is currently defined as the load at which rupture occurs, or the load at a displacement of one inch, whichever occurs first as stated by ASTM D1761-88 *Test Method for Mechanical Fasteners in Wood* (ASTM, 2004). Connection capacity is affected not only by the wood members' physical and mechanical properties, but by the connection geometry as well. Recent research performed by Gutshall (1994), Anderson (2001), and Dodson (2003) have shown that brittle failure

modes, including splitting, tension rupture, and group-tear-out are all influenced by connection geometry.

The 2001 NDS (AF&PA, 2001) includes a non-mandatory provision providing capacity checks for connections displaying brittle failure modes including net-section tension rupture, row tear-out, and group tear-out. The non-mandatory provision in the most recent edition of the NDS (AF&PA, 2001) takes into account the effects of bolt spacing and row spacing on multiple-bolt connection capacity, and provides a more accurate representation of connection behavior. The brittle failure modes are used much in the same manner as the Yield Model in that the lowest calculated capacity will govern the connection displaying the associated mode of failure. Failure modes, as outlined in the 2001 NDS (AF&PA, 2001), are described and defined as follows:

Net section tension capacity: Occurs when a tension failure perpendicular to the direction of loading occurs at the critical cross-section of the bolted joint.

$$Z_{NT}' = F_t' A_{net} \tag{2.15}$$

where:

Z_{NT}' = Allowable tension capacity of net section area.

F_t' = Allowable tension design value parallel to grain.

A_{net} = Net cross-sectional area of critical section.

Row tear-out capacity for a single row of fasteners: Occurs when two shear lines form tangent to the row of bolts parallel to grain.

$$Z_{RTi}' = n_i F_v' t s_{critical} \tag{2.16}$$

where:

Z_{RTi}' = Allowable row tear-out capacity of row i.

F_v' = Allowable shear design value parallel to grain.

t = Thickness of member.

n_i = Number of fasteners in row i.

$s_{critical}$ = Minimum spacing in row i taken as the lesser of the end distance for the spacing between fasteners in row i.

Row tear-out capacity for multiple rows of fasteners: Occurs in the same manner as row tear-out for a single row, but multiple rows are considered.

$$Z_{RT}' = \sum_{i=1}^{n_{row}} Z_{RTi'} \tag{2.17}$$

where:

Z_{RT}' = Allowable row tear-out capacity of connection.

n_{row} = Number of rows.

Group tear-out capacity: Occurs due to tension rupture perpendicular to the direction of the applied load in the critical section between the two or more rows of bolts in combination with a shear failure line tangent to the outer rows of bolts parallel to the grain of the member. (This type of failure would be analogous to a block shear failure in steel design.)

$$Z_{GT}' = \frac{Z_{RT-1'}}{2} + \frac{Z_{RT-n'}}{2} + F_t' A_{group-net} \tag{2.18}$$

where:

Z_{GT}' = Allowable group tear-out capacity.

$Z_{RT\text{-}1}'$ = Allowable row tear-out capacity of row 1 of fasteners bounding the critical group area.

$Z_{RT\text{-}n}'$ = Allowable row tear-out capacity of row n of fasteners bounding the critical group area.

$A_{group\text{-}net}$ = Critical group net-section area between row 1 and row n.

Doyle (1964) first noted that multiple-bolt connections loaded in tension would fail by splitting, row tear-out, and group tear-out. While multiple-bolt connections often display brittle failure modes, it should be noted that single-bolt connections may also display brittle failure modes in addition to the ductile failure modes predicted by the YM (Jorissen, 1998). Jorissen (1998) developed a fracture mechanics based model to predict the ultimate load carrying capacity for double-shear joints producing brittle failure. Inherent to the model were the effects of tension parallel and perpendicular to grain, and shear parallel to grain. These factors were found to greatly influence capacity in connections displaying brittle failures.

Quenneville and Mohammad (2000) tested multiple-bolt connections with variable end distances, bolt spacing and number of bolts per row, row spacing and number of rows, member thickness, and member species. Brittle failure modes including row tear-out, group tear-out, and splitting were observed in connection tests loaded monotonically in tension. Quenneville and Mohammad (2000) derived from test

observations that the most significant material property influencing the capacity of multiple-bolt connections was the member's shear strength.

As the above research suggests, shear and tension strengths both perpendicular and parallel to grain have been shown to influence the behavior of bolted connections. It is important note that both single and multiple-bolt connections can display either ductile or brittle failure modes. The YM has been shown to compare favorably with experimental results from single-bolt connection tests displaying ductile behavior, but overestimates the capacities of connections displaying brittle failure. Furthermore, considering that the non-mandatory Appendix E of the NDS (AF&PA, 2001) has been shown to underestimate the capacity of a brittle connection as stated by Dodson (2003), despite being dependent on the row spacing and bolt spacing of a connection, a better understanding of connection behavior displaying brittle failure is vital.

2.6 - Effects of Row Spacing

The current recommendation for row spacing in U.S. design philosophies is based on research conducted by Trayer (1932). Based on the results of several hundred tests, Trayer stated that the center-to-center spacing between adjacent rows of bolts was controlled by the reduction in area at the critical section. It was recommended that the net tension area remaining at the critical section, when coniferous woods were used, should be at least 80% of the total area in bearing under all the bolts in the particular timber in question (Trayer, 1932). To better understand the definition that Trayer has given, see Figure 2.4.

Bearing area under bolts:

(4) 12.7 mm (½ in.) diameter bolts x 76.2 mm (3 in.) member thickness results in an area of 3870 mm^2 (6 $in.^2$).

Critical net section area:

[Gross width of 101.6 mm (4 in.) - (2) x 12.7 mm (½ in.) diameter bolts] x 76.2 mm (3 in.) thickness results in an area of 5806 mm^2 (9 $in.^2$).

The connection illustrated below is adequate because the critical net section area is equal to or greater than 80% of the total area in bearing under the bolts.

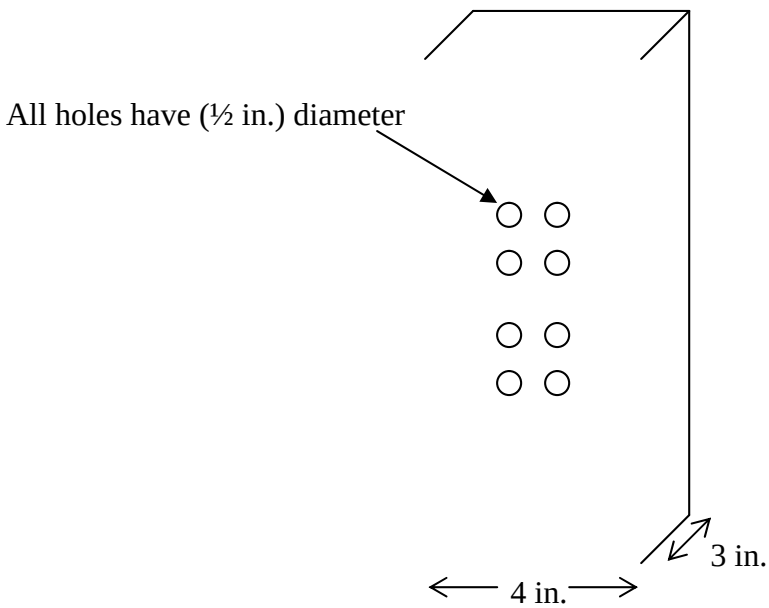

Figure 2.4: Illustration of minimum row spacing based on critical section.

Trayer's recommendation for row spacing was adopted into the first National Design Specification released (NLMA, 1944). Row spacing requirements were adapted in the 1971 National Design Specification (AF&PA, 1971) to provide an explicit center-

to-center row spacing for multiple rows connection loaded parallel to grain of not less than one and one half times the diameter of the bolt (1.5D).

Quenneville and Mohammad (2000) tested 460 steel-wood-steel double-shear tension connections using two different row spacings. It was noted that when a row spacing of 3D was used, the predominant mode of failure was group tear-out, and when a row spacing of 5D was used, the predominant mode of failure was row tear-out. Based on their results, the influence of row spacing on the failure mode and strength of the connection was argued to be very significant (Quenneville and Mohammad, 2000).

Dodson (2003) tested 27 steel-wood-steel double-shear tension connections loaded monotonically parallel to grain. All wood members used in Dodson's testing were Douglas fir glued laminated lumber (glulam). Row spacing was among the connection parameters varied within the different configurations. He found that the relative effects of row spacing appeared to be properly addressed in the NDS 2001 Appendix E provisions. Furthermore, failure modes as predicted by Appendix E provisions in the NDS (AF&PA, 2001) were predicted with a higher level of accuracy for multiple-bolt connections with larger row spacings when compared to those with smaller row spacings. NDS 2001 Appendix E equations did, however, over-predict the ultimate connection capacity. Ultimate test loads were, on average, only half of predicted capacities (Dodson, 2003).

2.7 - Cyclic Loading

The traditional method for testing timber joints with dowel type fasteners has typically been to apply a monotonic load to the joint in tension. This loading condition,

referred to as pseudo-static, simulates a static load over a small period of time, by applying a slow load at a constant rate (Anderson, 2001). Monotonic tests, however, do not provide adequate information about the behavior of bolted connections based on all loading conditions that they may be exposed to. Earthquake forces and high wind conditions such as hurricanes, may load a structure in an infinite number of planes in alternating directions, resulting in alternating tension and compression forces on a connection. To achieve a better understanding of the behavioral response of bolted timber connections when exposed to wind or earthquake forces, a testing method representative of those forces must be considered.

Several cyclic loading protocols have been reviewed and considered for standardization. All protocols described below feature loading patterns that cycle through zero and fully-reverse the force in the member from tension to compression. The Sequential Phased Displacement Protocol (SPD), used by Gutshall (1994), is a proposed ASTM draft standard according to Anderson (2001) which employs a loading pattern intended to define conservative estimates for performance and design (Dolan, 1994). The International Standards Organization (ISO) published a standard in 2003 entitled *Timber Structures – Joints made with Mechanical Fasteners – Quasi-Static Reversed Cyclic Test Method* according to Billings (2004). The loading protocol used by Anderson (2001), Billings (2004), and in the present research was a displacement based protocol developed by the Consortium of Universities for Research in Earthquake Engineering (CUREE) (Krawinkler et. al., 2001). The CUREE Protocol was developed to establish common testing protocols for all component tests of the CUREE/Caltech Woodframe Project. The CUREE loading protocol employs cumulative damage concepts to transform time history

responses into a representative deformation controlled loading history. It is based on a collection of twenty ordinary ground motions recorded in southern California whose probability of exceedance in 50 years is 10 percent (Krawinkler et. al., 2001). This allows the seismic performance of a structure to be evaluated based on ordinary ground motions which may precede the capacity level event in addition to ordinary ground motions of the capacity level event.

Several studies have been performed to determine the specific influences of dynamic loading relative to pseudo-static loading on the behavior of bolted timber connections. Dynamic loading has been shown to produce load-displacement plots displaying pinched, degrading hysteretic loops (Chun et al., 1996). The hysteretic loops may be used to characterize the performance of a bolted timber connection by the amount of energy that has been dissipated. This characteristic can be obtained from the load-displacement plot from a connection test, and is defined as the area enclosed by each hysteresis loop.

Popovski et al. (2002) tested a variety of timber connections under monotonic and quasi-static cyclic loading. Their study characterized the seismic behavior and failure modes of a variety of connections used in braced timber frames. They found that the behavior in bolted connections was dependent on the slenderness ratio of the bolt. Bolts with low slenderness ratios (length in bearing/bolt diameter) resulted in rigid connections with high local stresses in the wood and, ultimately, brittle failure mechanisms. Conversely, bolts with high slenderness ratios (smaller relative diameter bolts) resulted in more ductile connections. Additionally, energy dissipation in bolted connections with

small diameter bolts was much greater than for large diameter bolts, which suggested small diameter bolts were more desirable in seismic design (Popovski et al., 2002).

Quenneville and Mohammad (1998) developed a load driven ramped cyclic loading protocol with a frequency of one cycle per minute. The loading pattern was applied to Spruce-Lodgepole Pine glued laminated timber loaded parallel and perpendicular to grain. Similar failure modes were observed for specimens subjected to cyclic or monotonic loading, however, a larger degree of ductility and associated energy dissipation, defined as the area enclosed by the hysteretic loops, was observed in connections subjected to ramped cyclic loading. Higher residual strength values and lower maximum deflections were observed in connections subjected to the ramped cyclic loading protocol relative to those loaded monotonically. Additionally, the differences in loading regime were less significant when considering single-bolt connections as opposed to multiple-bolt connections (Quenneville and Mohammad, 1998).

Methods and Materials

3.1 - Introduction

In an effort to quantify the effects of row spacing on a variety of strength and serviceability parameters, single-shear multiple-bolt timber connections were subjected to reverse cyclic loading parallel to grain until catastrophic failure occurred in one or both of the members. Twenty connection configurations with different characteristics were considered. Variables within the different connection configurations included bolt diameter, member thickness, number of rows, bolts per row, and row spacing. A summary of the joint assemblies tested is given in Table 3.1.

Table 3.1: Summary of joint assemblies tested.

Configuration	Main Member*	Side Member*	Bolt Diameter	Number Of Rows	Bolts Per Row	Row Spacing	Expected Yield Mode
1	4x4	4x4	6.4 mm (¼ in.)	1	1	-	IV
2	4x4	4x4		1	3	-	
4	4x4	4x4		3	1	2D	
5	4x4	4x4		3	1	3D	
8	4x4	4x4		3	3	2D	
9	4x4	4x4		3	3	3D	
11	4x4	2x4	12.7 mm (½ in.)	1	1	-	III_S
12	4x4	2x4		1	3	-	
14	4x6	2x6		3	1	2D	
15	4x6	2x6		3	1	3D	
16	4x6	2x6		3	1	2.5D	
18	4x6	2x6		3	3	2D	
19	4x6	2x6		3	3	3D	
21	2x4	2x4	19.1 mm (¾ in.)	1	1	-	II
22	2x4	2x4		1	3	-	
24	2x8	2x8		3	1	2D	
25	2x10	2x10		3	1	3D	
28	2x8	2x8		3	3	2D	
29	2x10	2x10		3	3	3D	
30	2x8	2x8		3	3	2.5D	

*Nominal member dimensions in inches

Test geometries were selected in order to achieve Yield Modes II, III_S, and IV based on 2001 NDS (AF&PA, 2001) Yield Limit equations. Yield Mode I was excluded from this research as it is only likely to occur if the dowel is tightly fitted, which is not typical in bolted timber construction.

Connection capacities were calculated for comparison with test results based on the equations for local stresses in fastener groups given in Appendix E of the 2001 NDS (AF&PA, 2001). These equations are based on the capacity of the wood surrounding the connection, and include considerations for net section tension capacity, row tear-out capacity, and group tear-out capacity.

Secondary tests were conducted in order to obtain dowel embedment strength, bolt bending yield strength, moisture content, and specific gravity. All secondary tests were performed in accordance with ASTM standards as discussed in later sections.

3.2 - Specimen Identification

The identification reference system used was consistent for both the primary connection and secondary testing. Specimens were identified based on their configuration number from Table 3.1, rather than joint assembly specifics. An example of the reference system is shown in the Figure 3.1 below.

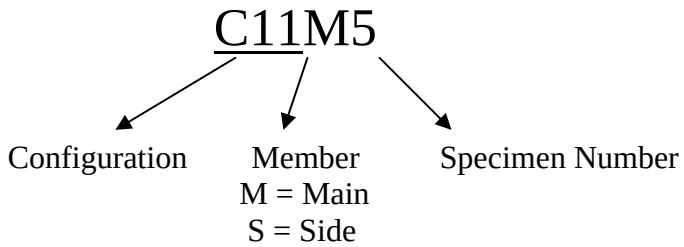

Figure 3.1: Description of reference system.

3.3 - Materials

Lumber used to fabricate all test specimens was kiln dried Douglas Fir-Larch purchased from local suppliers. All 51mm (2-inch) nominal thickness lumber and 102 mm (4-inch) by 152 mm (6-inch) nominal dimension lumber was graded Number 2 and Better, and 102 mm (4-inch) by 102 mm (4-inch) nominal dimension lumber was graded Number 1 and Better. Upon delivery and sizing of each specimen, the lumber was placed in a conditioning chamber for a minimum of 90 days, where the temperature was held at 24°C ± 1.1°C (75°F ± 2°F) and 64% ± 2% relative humidity to equilibrate to approximately 12 % moisture content.

Whenever possible, specimens were cut so that main and side members would be cut from the same board and end matched. In doing this, the strength properties and physical characteristics of each member would be similar so that the strength of one member would not necessarily govern over the other in an effort to minimize the effects of local variations within the board.

Bolt-holes were drilled 1.6 mm (0.0625 in.) larger than the bolt diameter using a drill press. The drill press provided an efficient and relatively accurate means for producing the holes, however, due to cupping of some boards, they were not able to rest flush against the surface of the drill press table causing holes to be drilled at a slight angle and bolt-hole misalignment to occur. Where specimens experienced bolt misalignment, the bolts were driven by force as would be done in actual construction.

All specimens were cut and bolt-hole locations chosen in order to minimize the effect of knots, checks, splits, etc. in critical sections of the connection. A critical section was defined as any location in which a defect in the wood might significantly reduce the

strength of the connection. While it was the intent to minimize the occurrence of defects adjacent to the bolt-hole locations and misalignment between the members, neither could be completely eliminated. The error resulting from each was not considered in the analysis or test results. It was assumed that these types of fabrication errors in multiple-bolted connections would approximate field conditions.

3.4 - Connection Design

All members tested were sized so that the 2001 NDS (AF&PA, 2001) recommendations for distances and spacing were met or exceeded. Bolt spacing and end distance were set at 7D based on preliminary results obtained from an associated project investigating the effect of bolt spacing within a row (Billings, 2004). Member widths were chosen so that the edge distance would be equal to or greater than the row spacing, while maintaining the 2001 NDS (AF&PA, 2001) minimum requirement of 1.5D. All bolts used in the connection tests were ASTM A307 bolts purchased though local suppliers.

Bolts with a diameter of 6.4 mm (¼ in.) were used in configurations predicted to yield in Mode IV; bolts with a diameter of 12.7 mm (½ in.) were used in configurations predicted to yield in Mode III_S, and bolts with a diameter of 19.1 mm (¾ in.) were used for configurations predicted to yield in Mode II. Bolt lengths were selected so that the threaded portion of the bolt was excluded from the shear plane in all tests. The minimum row spacing for this study was 2D. When considering 6.4 mm (¼ in.) and 12.7 mm (½ in.) bolts in configurations with three rows, the clearance between the rows of bolts was not adequate to accommodate the center row of washers on either side of the connection.

The washers had to be ground down on opposite sides in order to fit into the connection. Dimensions of a typical connection are shown in Figure 3.2, and a summary of all configuration dimensions is presented in Table 3.2.

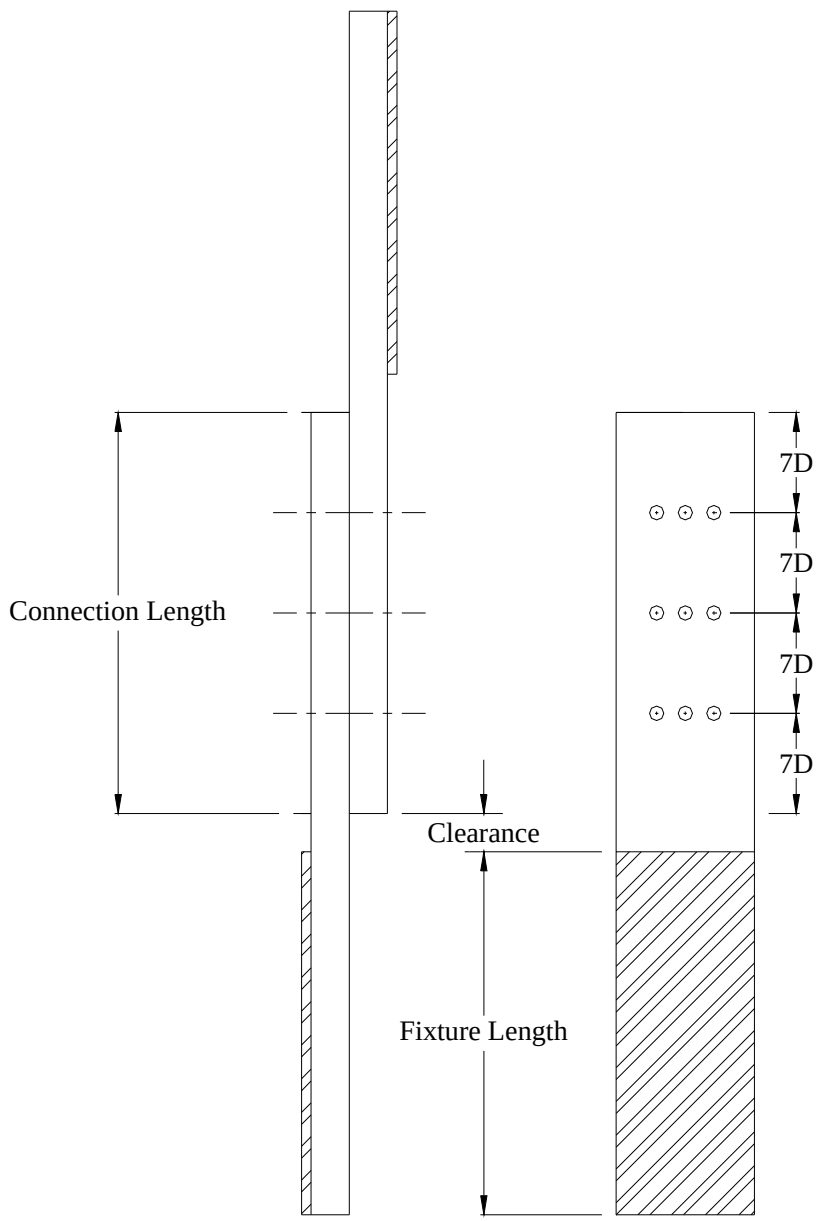

Figure 3.2: Specimen dimension definitions.

Table 3.2: Summary of specimen dimensions.

Config.	Bolt Diameter	Number Of Rows	Bolts Per Row	Fixture Length	Connection Length	Clearance Length	Member Length
1	6.4 mm (¼ in.)	1	1	483 mm (19 in.)	89 mm (3.5 in.)	273 mm (10.75 in.)	845 mm (33.25 in.)
2		1	3		178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
4		3	1		89 mm (3.5 in.)	273 mm (10.75 in.)	845 mm (33.25 in.)
5		3	1		89 mm (3.5 in.)	273 mm (10.75 in.)	845 mm (33.25 in.)
8		3	3		178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
9		3	3		178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
11	12.7 mm (½ in.)	1	1	483 mm (19 in.)	178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
12		1	3		356 mm (14 in.)	140 mm (5.5 in.)	978 mm (38.5 in.)
14		3	1		178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
15		3	1		178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
16		3	1		178 mm (7 in.)	229 mm (9 in.)	889 mm (35 in.)
18		3	3		356 mm (14 in.)	140 mm (5.5 in.)	978 mm (38.5 in.)
19		3	3		356 mm (14 in.)	140 mm (5.5 in.)	978 mm (38.5 in.)
21	19.1 mm (¾ in.)	1	1	483 mm (19 in.)	267 mm (10.5 in.)	184 mm (7.25 in.)	933 mm (36.75 in.)
22		1	3		533 mm (21 in.)	51 mm (2 in.)	1067 mm (42 in.)
24		3	1		267 mm (10.5 in.)	184 mm (7.25 in.)	933 mm (36.75 in.)
25		3	1		267 mm (10.5 in.)	184 mm (7.25 in.)	933 mm (36.75 in.)
28		3	3		533 mm (21 in.)	51 mm (2 in.)	1067 mm (42 in.)
29		3	3		533 mm (21 in.)	51 mm (2 in.)	1067 mm (42 in.)
30		3	3		533 mm (21 in.)	51 mm (2 in.)	1067 mm (42 in.)

3.5 - Test Equipment

All tests for this study were conducted at the Wood Materials and Engineering Laboratory (WMEL), at Washington State University (WSU). All necessary steel fixtures for the study were fabricated by the Technical Services Instrument Shop on the WSU campus using A36 Steel with a minimum yield stress of 248 MPa (36 ksi), and a minimum ultimate stress of 400 MPa (58 ksi).

Full connection tests were performed using a servo-hydraulic 450 kN (100,000 lbf) capacity Materials Testing System (MTS) actuator with a displacement range of 254 mm (10 in.). An MTS 407 digital controller was used in conjunction with a servo-hydraulic manifold to control to hydraulic fluid pressure in the actuator. A string

potentiometer with a displacement range of 0 mm-254 mm (0 in.-10 in.) served as the actuator feedback. Two different load cells were used in this study to record applied load levels. For configurations in which the ultimate load was predicted to exceed 111 kN (25,000 lb), an Interface load cell with a 222 kN (50,000 lb) capacity was used to monitor loads. For all other configurations, an Interface load cell with a 111 kN (25,000 lb) capacity was used to monitor applied loads. Two additional string potentiometers with displacement ranges of 0 mm-254 mm (0 in.-10 in.) were used to measure relative slip between the main member and side member. Potentiometer placement and connectivity are shown in Figure 3.3. Using this string-potentiometer configuration, the slip in the connection was measured as the displacement of potentiometer one (SP1) subtracted from the displacement of potentiometer two (SP2).

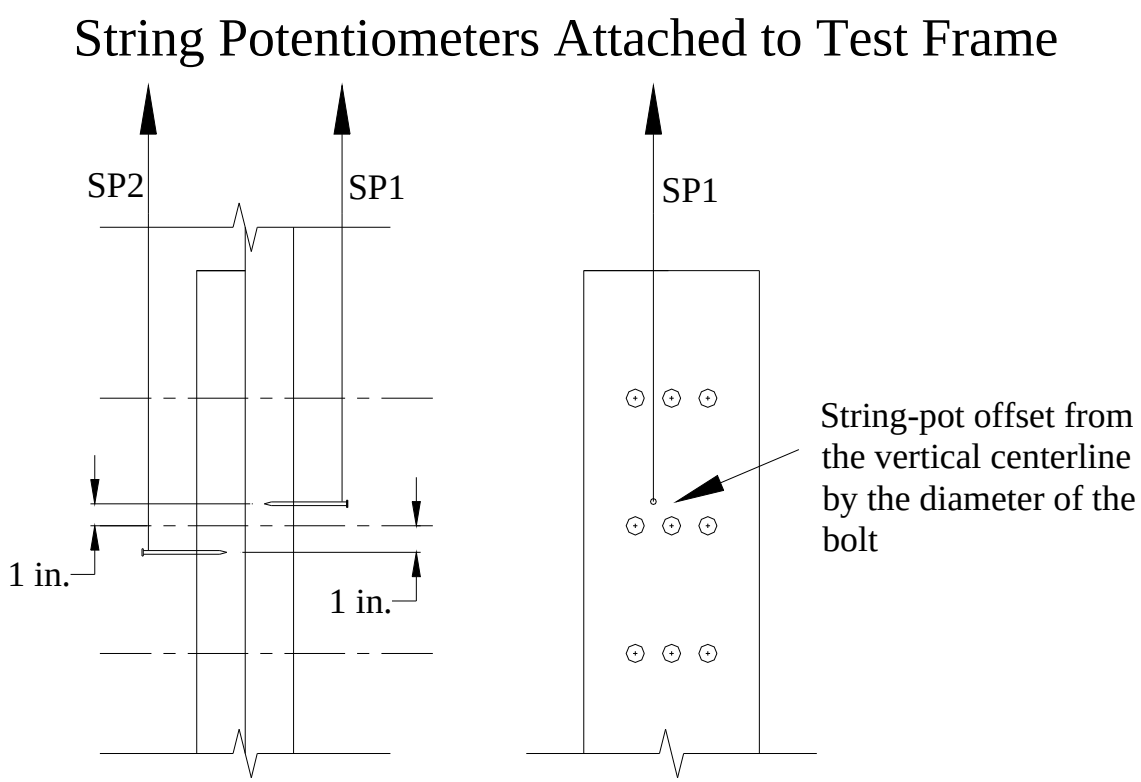

Figure 3.3: String potentiometer placement.

3.6 - Apparatus Design

The test apparatus used in this study was designed so that the only appreciable forces induced would be shear, parallel to the direction of the applied load. As a result, the effects moments in the connection and load cell caused by the eccentricity of the connection would be minimized. To reduce the moments experienced in the connection and load cell, a side bracing system was used in conjunction with bracing applied directly to the face of the actuator. Both systems inhibited actuator movement perpendicular to the face of the connection.

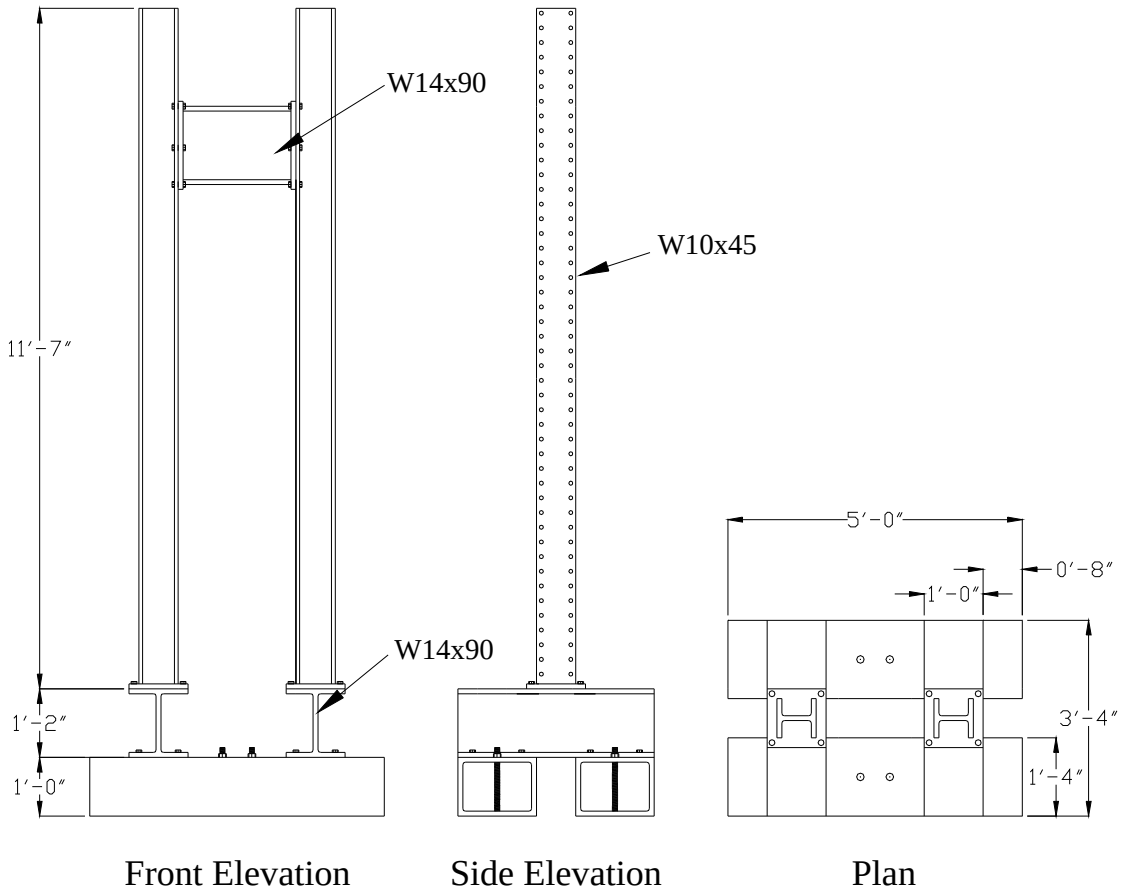

Figure 3.4: Existing steel test frame.

The test fixture was designed around the existing steel frame shown in Figure 3.4. The members at the base of the frame were rectangular HSS sections oriented parallel to each other and to the shear plane of the connection, and were directly attached to the strong-floor. Two W14x90 sections, with a length of 1.02 m (40 in.) each, were oriented perpendicular to the HSS sections and connected using eight 20.6 mm (13/16 in.) diameter ASTM A325 bolts each. A W10x45 column with a one-inch thick base plate welded through the web and flange was attached to each of the two horizontal W sections using four 20.6 mm (13/16 in.) diameter ASTM A325 bolts. Providing additional rigidity and a location to attach the actuator, a W14x90 section with base plates welded to each end of the beam through the web and flanges was connected to the column using six 19.1 mm (¾ in.) diameter ASTM A325 bolts per base plate.

An AutoCAD illustration of all elements used in the fixture design is shown in Figure 3.5. The bottom fixture of the designed apparatus was a 25.4 mm (1 in.) thick rectangular steel plate with four 27.0 mm (1-1/16 in.) diameter holes, which would receive 25.4 mm (1 in.) diameter all-thread rods for the fixture to frame connection. A 19.1 mm (¾ in.) steel plate was welded perpendicular to the horizontal plate, and was diagonally braced by two 12.7 mm (½ in.) steel plates. Four 17.5 mm (11/16 in.) diameter holes running vertically were drilled in both edges of the 19.1 mm (¾ in.) steel plate, to receive the bolts for the main member steel side plate. The top fixture, which was fabricated using 19.1 mm (¾ in.) steel plates, was directly attached to the load cell inline with the actuator. Its vertical plate was identical to the vertical plate of the bottom fixture considering both dimensional properties and bolt-hole location.

The side bracing system, also shown in Figure 3.5, consisted of 19.1 mm (¾ in.) steel plates fastened to the W section columns. The plates had a 0.36 m (14 in.) long slot with a 20.6 mm (13/16 in.) width. Each slot received a system of three 6.4 mm (¼ in.) ball bearings used in series with a total thickness, and outer diameter equal to 19.1 mm (¾ in.), or the thickness of the side plate. The ball bearings served to reduce friction forces in the side bracing system.

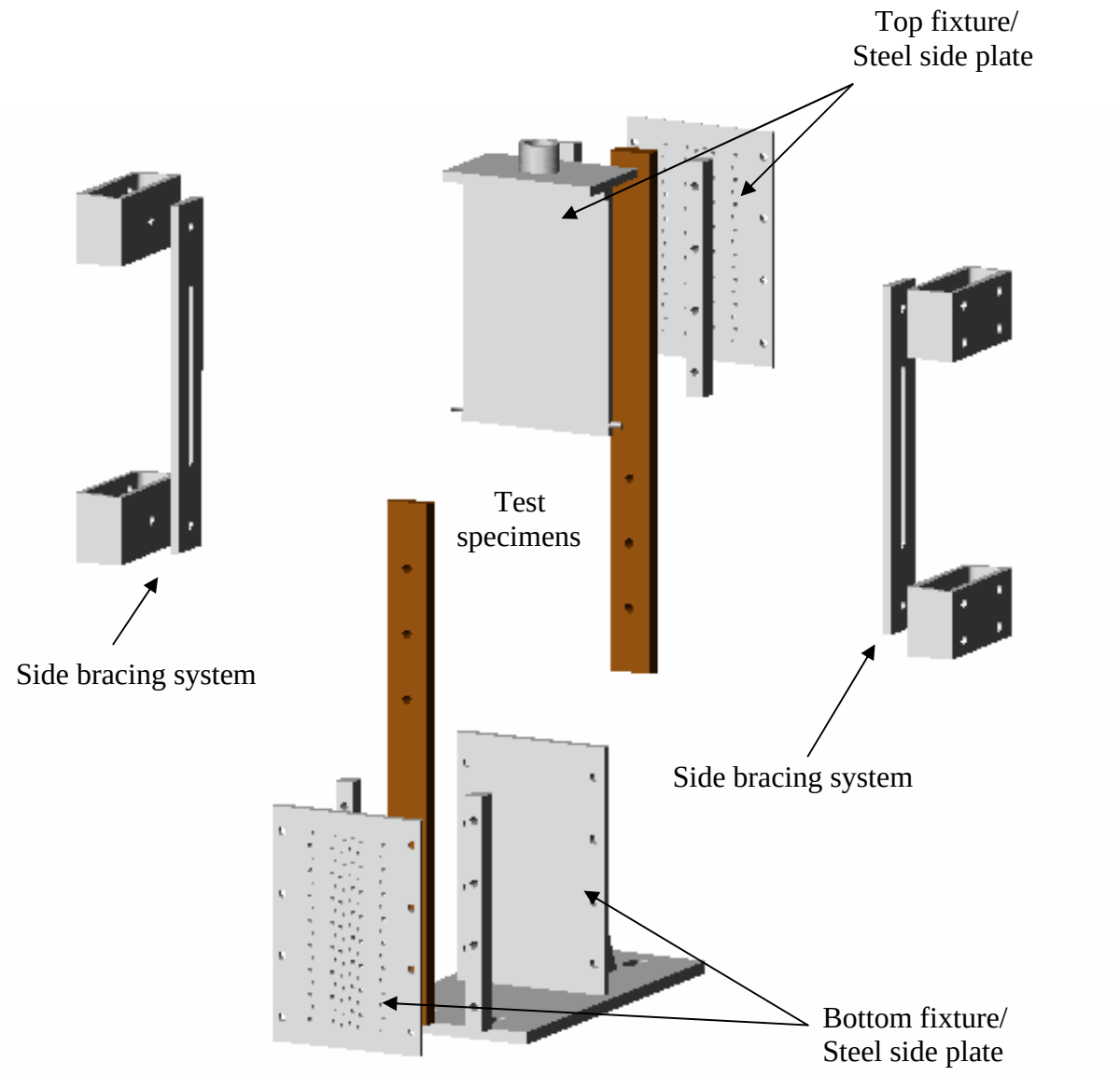

Figure 3.5: AutoCAD representation of all fixture elements.

All wood members were attached to 12.7 mm (½ in.) steel side plates with predrilled holes with an adequate number of 6.4 mm (¼ in.) diameter wood screws to prevent any appreciable slippage in the side plate-specimen connection as shown in Figure 3.6.

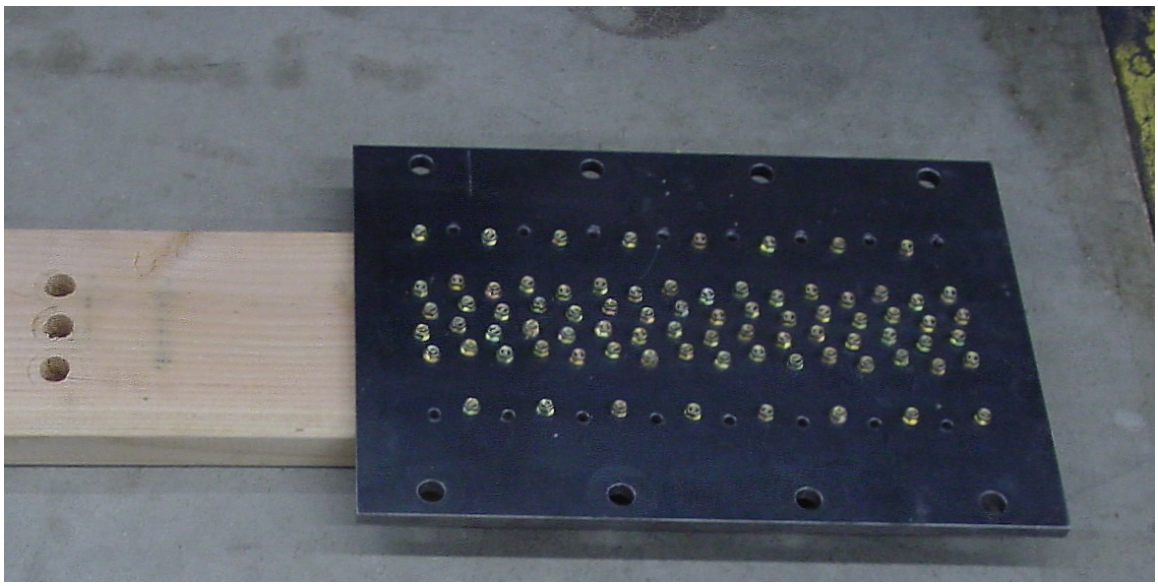

Figure 3.6: Wood specimen-to-steel side plate connection using Simpson "S" series screws.

Wood screws used were Simpson Strong-Tie Self-Tapping Strong Drive "S" series screws, SDS 6.4 mm (¼ in) x 38.1 mm (1 ½ in.). Steel side plates with attached wood members were bolted to the top and bottom fixtures using eight 15.9 mm (5/8 in.) diameter grade 8 bolts. Spacers with a depth 1.6 mm (1/16 in.) greater than the nominal depth of the member were placed between the steel plate and fixture to prevent wood member crushing.

3.7 - Test Procedures

In this section, testing procedures for single and multiple-bolt cyclic connection tests, bolt bending tests, dowel embedment tests, moisture content tests, and specific gravity tests are described. Errors and inconsistencies encountered during testing will also be discussed in this section.

3.7.1 - Cyclic Connection Tests

All full-connection tests were subjected to fully reverse cyclic loading. The CUREE deformation controlled quasi-static cyclic protocol, based on loading history for ordinary ground motions, was used for all cyclic tests (Krawinkler, et. al., 2000). This protocol was chosen primarily for its ability to simulate cumulative ordinary ground motions. To utilize the CUREE testing protocol, a reference deformation (Δ) must be determined. This variable is based on results from monotonic testing and is recommended to be 60% of the monotonic deformation capacity (Δ_m), with Δ_m defined as the deformation corresponding to 80% of the maximum load, after the maximum load has been reached (Krawinkler, et. al., 2000). Monotonic tests were excluded from this study; instead, necessary reference deformations based on the bolt diameter, and the number of bolts comprising a specific connection configuration, were extrapolated from monotonic tests performed by Anderson (2001). The protocol is defined by a series of triangular waveforms consisting of initiation, primary, and trailing cycles whose amplitudes are multiples of Δ.

The CUREE loading protocol is defined as follows:

- Six initiation cycles with amplitude of 0.05*Δ
- Primary cycle 1 with amplitude of 0.075*Δ
- Six trailing cycles with amplitude of 0.75*(0.075*Δ)
- Primary cycle 2 with amplitude of 0.1*Δ
- Six trailing cycles with amplitude of 0.75*(0.1*Δ)
- Primary cycle 3 with amplitude of 0.2*Δ
- Three trailing cycles with amplitude of 0.75*(0.2*Δ)
- Primary cycle 4 with amplitude of 0.3*Δ
- Three trailing cycles with amplitude of 0.75*(0.3*Δ)
- Primary cycle 5 with amplitude of 0.4*Δ
- Two Trailing cycles with amplitude of 0.75*(.7*Δ)
- Primary cycle 6 with amplitude of 0.7*Δ
- Two Trailing cycles with amplitude of 0.75*(.7*Δ)
- Primary cycle 7 with amplitude of 1.0*Δ
- Two Trailing cycles with amplitude of 0.75*(.7*Δ)
- Primary cycle i with amplitude equal to amplitude of (i-1) + 0.5*Δ
- Two trailing cycles with amplitude of 0.75*(Amplitude of primary cycle i)

Cyclic testing was generally terminated when the load had dropped below 80% of maximum load achieved, or when catastrophic failure occurred, whichever occurred first.

The CUREE protocol was assigned a constant displacement rate. To be consistent with testing performed by Anderson (2001), and Billings (2004), a displacement rate of 120 mm/min. (4.72 in./min.) was assigned to the protocol with a data acquisition rate of 20 Hz. Considering the limitations of equipment available at the WMEL, modifications were made within the Labview program which dictated the loading protocol and data acquisition. A triangular waveform was considered in the construction of the computer program, implying that to maintain a constant load rate, the frequency (Hz) of the protocol was variable. It was later discovered that the MTS 407 controller was limited to a minimum frequency of 0.1 Hz. In light of this, the protocol was adjusted so that when cycle amplitude required a frequency of less than 0.1 Hz; a constant frequency of 0.1 Hz was utilized rather than a constant displacement rate. The modified protocol is illustrated in Figure 3.7.

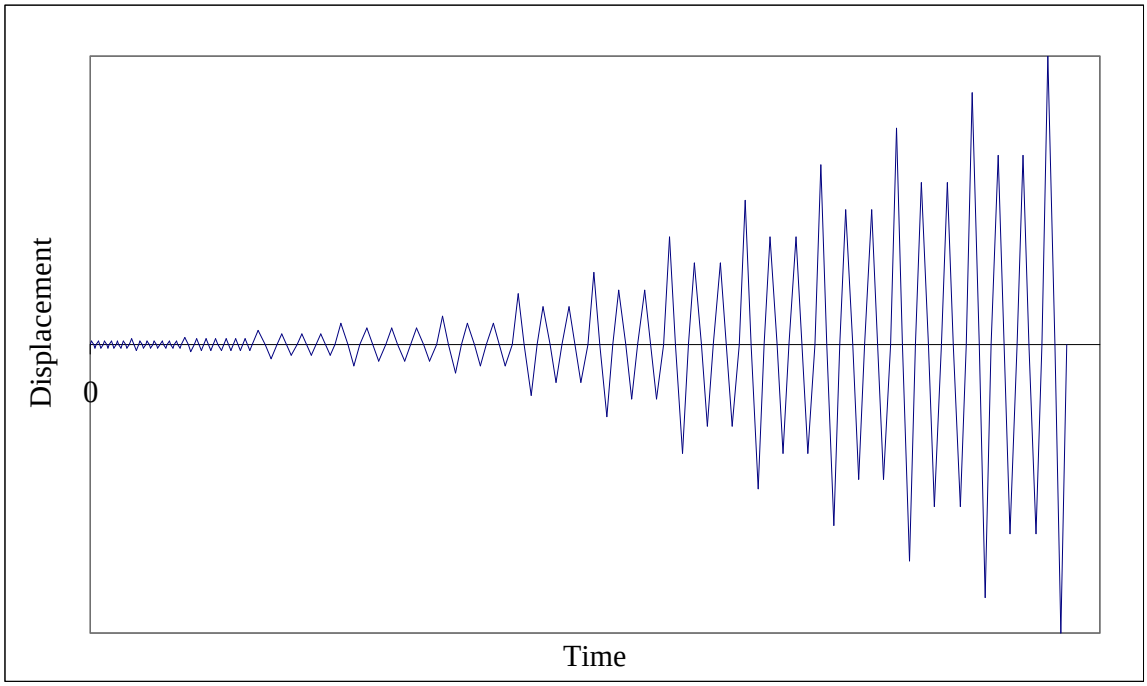

Figure 3.7: Modified CUREE protocol used for cyclic testing of bolted connections.

Additional problems also arose during testing. Error developed in communication between the computer and the MTS 407 controller resulting in inconsistencies between the intended displacement protocol and the actual displacement protocol. The error resulted in either the addition of half cycles to the protocol or the exclusion of half cycles from the protocol displacement sequence, effectively reversing the direction of cycle initiation. The error was sporadic throughout testing and when present, usually affected only trailing cycles. Certain aspects of the data analysis were problematic as a result of these errors, and will be discussed in the data analysis section of this chapter.

3.7.2 - Dowel Embedment Tests

Dowel embedment testing was performed in accordance with ASTM D5764-97a, Standard Test Method for Evaluating Dowel-Bearing Strength of Wood and Wood-Based Products (ASTM, 2004). A dowel embedment specimen was cut from each of the two members comprising a full-connection test. Dowel embedment testing was performed prior to full-connection tests, making it necessary to use the cut-off end portion taken from the end of the full-connection tests in which the bolts were to be placed as shown in Figure 3.8.

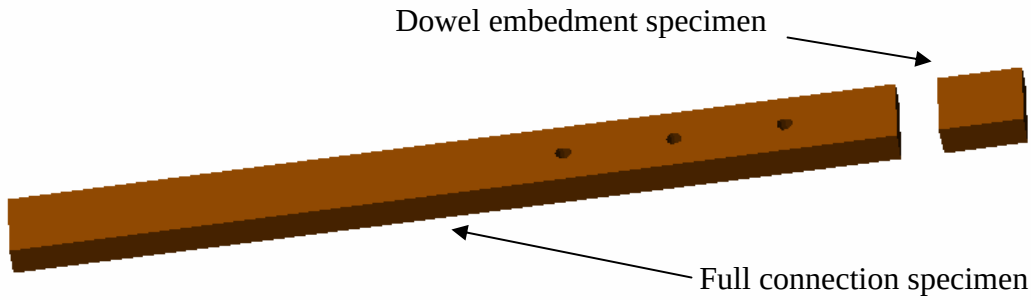

Figure 3.8: Dowel embedment cut-off segment from cyclic testing specimens.

Full-hole configurations were used for dowel embedment testing of 12.7 mm (½ in.) bolts, and 19.1 mm (¾ in.) diameter bolts. The total length of each specimen was 114.3 mm (4 ½ in.), with a loaded length of 76.2 mm (3 in.) The width and thickness of each specimen was 76.2 mm (3 in.) and 38.1 mm (1 ½ in.), respectively. Half-hole configurations were used for dowel embedment testing of 6.4 mm (¼ in.) diameter bolts. Specimen lengths and widths were both 76.2 mm (3 in.), and specimen thickness was 38.1 mm (1 ½ in.). Examples of full-hole and half-hole specimens are shown in Figure 3.9. A 134 kN (30,000 lb.) capacity Instron testing machine was used for testing, with a constant displacement rate of 2.0 mm/min. (0.08 in./min), so that maximum load was reached in 2 to 6 minutes.

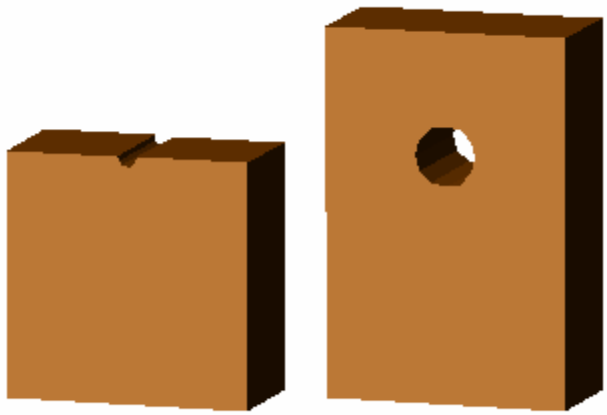

Figure 3.9: Half-hole (right) and full-hole (left) dowel embedment specimens.

The full-hole configuration was used when the slenderness ratio (λ) of the bolt, defined as l/D, (l equal to the dowel bearing length, and D equal to the bolt diameter), was sufficiently small to prevent excessive bolt bending. The full-hole configuration was used for the 12.7 mm (½ in.) and 19.1 mm (¾ in.) diameter bolts as the bolts were stiff enough

to prevent excessive bolt bending, consistent with the assumption built into the method that the bolt remains perfectly rigid. The configuration was advantageous because the extra material provided by the un-loaded length helped to resist splitting in the specimen prior to reaching ultimate capacity. The half-hole configuration was necessary for the 6.4 mm (¼ in.) diameter bolts to prevent bolt bending resulting from the high aspect ratio. This methodology allowed for a uniform stress distribution across the thickness of the sample.

3.7.3 - Bolt bending Yield Strength

Bolt bending yield strength tests for ASTM A307 bolts were performed in accordance with ASTM F1575-03, Standard Test Method for Determining Bending Yield Moment of Nails (ASTM, 2004). The procedure is outlined specifically for nails, but can be applied to bolts, provided that the threaded portion of the bolt is not included in the span length between the bearing points. Ten replications for each bolt diameter were tested. The results were used to provide the bolt bending yield strength, a necessary input for the Yield Model. Testing was performed using a screw driven 134 kN (30,000 lb.) capacity Instron testing machine with a displacement rate of 1.0 mm/min (0.04 in/min). A three point bending configuration with a span of 102 mm (4 in.) was used for testing 6.4 mm (¼ in.), and 12.7 mm (½ in.) diameter bolts. A cantilever configuration, with a cantilever length of 57.2 mm (2 ¼ in.), was used for testing 19.1 mm (¾ in.) diameter bolts. The supports for the three point bending configuration had diameters of 19.1 mm (3/4 in.), and the load head used for both configurations had a diameter of 12.7 mm (½ in.). The apparatuses used for the three-point configuration and the cantilever configuration, are shown in Figures 3.10 and 3.11 respectively.

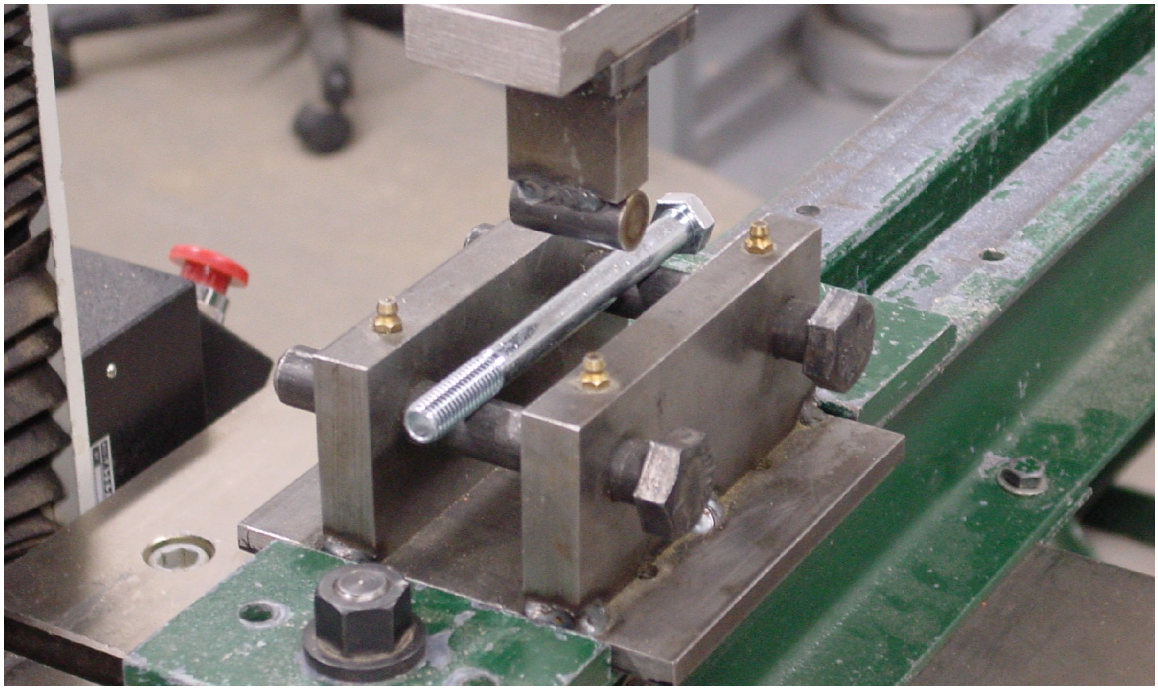

Figure 3.10: Three-point bolt bending test set-up.

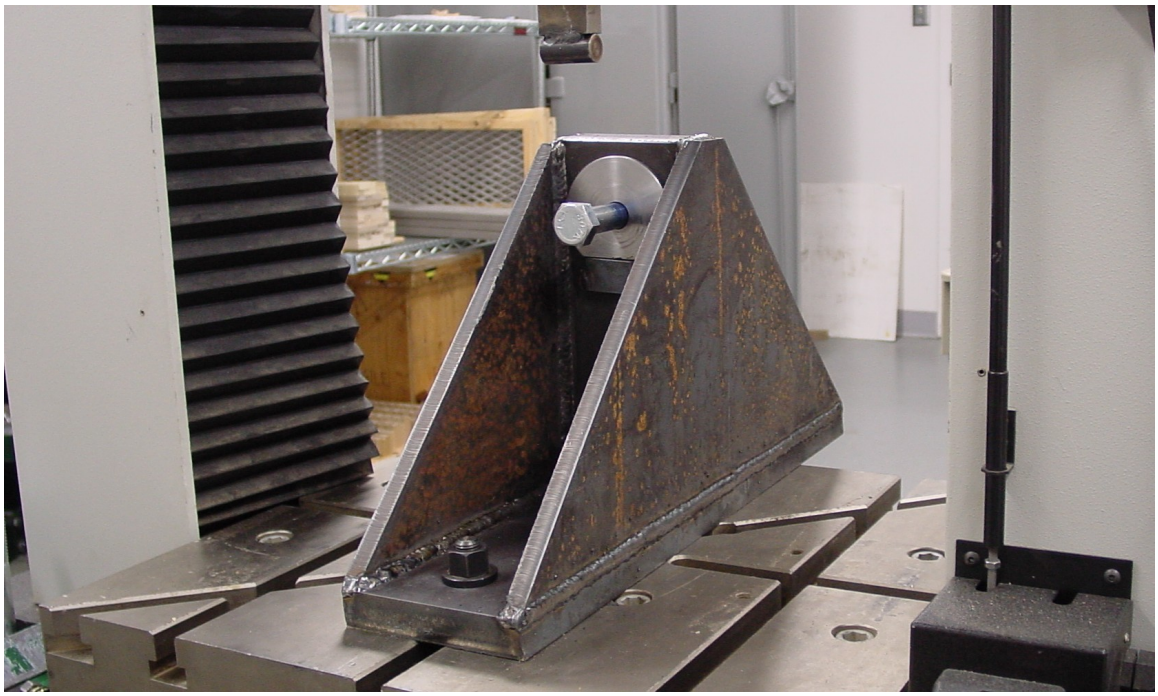

Figure 3.11: Cantilever bolt bending test set-up.

3.7.4 - Moisture Content Tests

Moisture content tests were performed in accordance with ASTM D4442-92 Standard Test Method for Direct Moisture Content Measurement of Wood and Wood-Based Materials (ASTM, 2004). Specimens were obtained from previously tested dowel embedment specimens, which had been returned to the conditioning chamber following testing to ensure equilibration. Method B for oven drying was the desirable method for determining the moisture content for each specimen. Specimens were placed in an oven at a temperature of approximately 102 ºC (215 ºF) until mass had stabilized as determined by intermediate measurements. Moisture content was calculated as follows:

$$MC\% = (A-B)/B * 100 \tag{3.1}$$

A = Original mass (g).

B = Oven-dry mass (g).

3.7.5 - Specific Gravity Tests

Specific gravity tests were performed in accordance with ASTM D2395-02 Standard Test Methods for Specific Gravity of Wood and Wood-Based Products (ASTM, 2004). Specimens tested were previously used to determine moisture content, providing specific gravity (SG) results for oven-dry volume. Method B for determining volume by water immersion was chosen for precision considering the irregular surface of the specimens. Specific gravity was calculated as follows:

$$SG = W/V \tag{3.2}$$

W = Weight of specimen at approximately 12% moisture content.

V = Oven-dry volume of specimen at approximately 12% moisture content.

3.8 - Test Data Analysis

Strength and serviceability parameters of full-connection cyclic testing were obtained based on the *Proposed Test Method for Dynamic Properties of Connections Assembled with Mechanical Fasteners* (Dolan, 1994). Primary parameters included connection capacity, equivalent elastic-plastic (E.E.P.) yield load, and ductility. To evaluate the above parameters, the maximum load and corresponding displacement for each successive hysteretic loop were used to create an envelope curve similar to that of a monotonic test. The parameters and points of interest used to determine the desired connection characteristics are illustrated in Figure 3.12 and defined below.

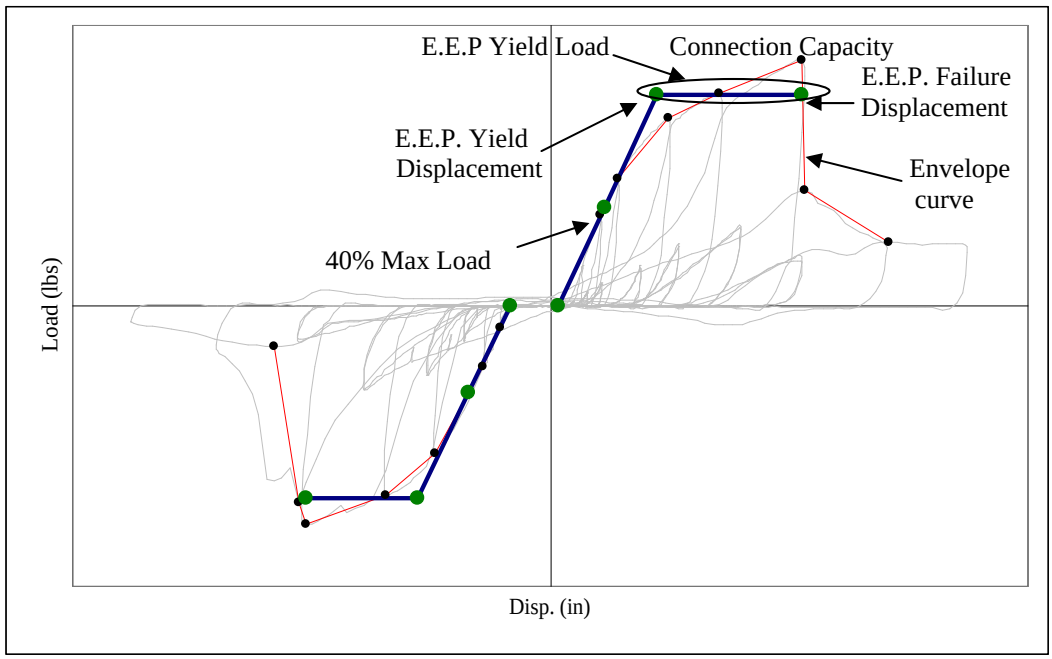

Figure 3.12: Bi-linear and envelope curves shown on a typical specimen.

A bi-linear curve was produced for each specimen to evaluate parameters of interest. An initial diagonal region originating at the point on the horizontal axis where slack in the

connection had been taken up passes through the point on the envelope curve corresponding to 40% of the maximum load. The horizontal region representing equivalent elastic-plastic (E.E.P.) yield load intersected the initial diagonal line, and extended until failure displacement. Failure displacement was the displacement corresponding to failure, which occurred at 80% of ultimate capacity. The E.E.P. yield load, by definition, falls between the maximum load and 80% of the maximum load, and was defined such that the area under the bi-linear curve was equal to the area under the envelope curve up to failure displacement. Ductility (μ) was then defined as $\Delta_{failure}/\Delta_{yield}$.

Strain energy, hysteretic energy, equivalent viscous damping, and cyclic stiffness are all determined on a cycle-by-cycle basis for each tested specimen. Definitions are provided below and illustrated in Figure 3.13. The strain energy for a given cycle was defined as the sum of the areas enclosed by the triangles CJK and REK. Hysteretic energy for a given cycle was defined as the sum of the areas enclosed by the load-deflection curve (the shaded portion on Figure 3.13). Cyclic stiffness for a given cycle was defined as the slope of the line EJ. The equivalent viscous damping ratio (ξ) for a given cycle is defined as hysteretic energy/2π*strain energy.

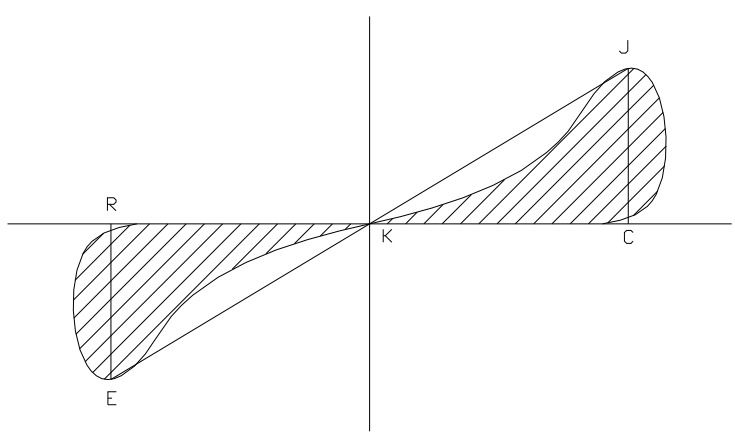

Figure 3.13: Hysteretic energy and strain energy.

When evaluating the energy-based parameters on a cycle-by-cycle basis, it was necessary to address the previously noted errors occurring within the protocol. When analyzing the data, it was not possible to strictly adhere to the prescribed protocol due to the potential addition or exclusion of half cycles. When a half cycle was erroneously added to the protocol, it was excluded in data analysis, and the following primary cycle experienced reversal in the direction of initiation. When a half cycle was erroneously excluded from the protocol, the previous half cycle was multiplied by two to account for the total energy of the cycle, and the following primary cycle experienced the same phenomenon as before. Refer to Figure 3.14 for an example time-displacement plot of the erroneous half cycles.

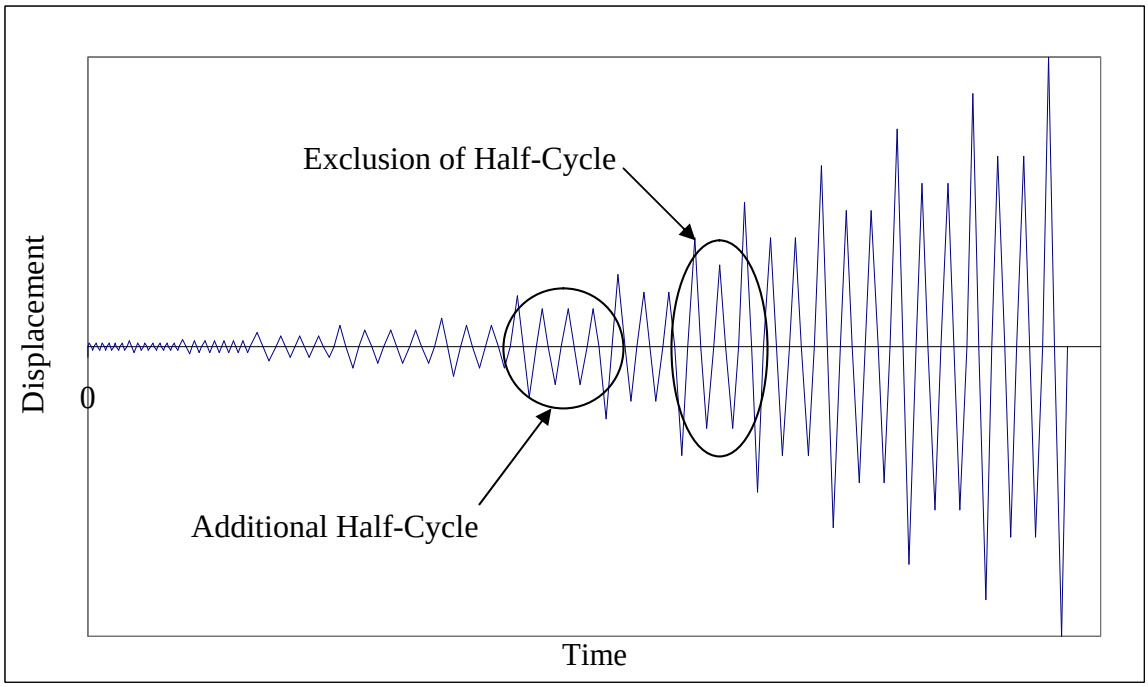

Figure 3.14: Time-displacement plot with erroneous half cycles.

Results and Discussion

4.1 - General

The present study is comprised of two hundred single and multiple-bolt connection tests subjected to reverse cyclic loading. Bolt diameter, member dimensions, joint geometry, and row spacing were varied to produce desired connection yield modes.

This chapter provides cyclic test results. Typical load-displacement plots for each series are presented in this chapter, and full results are available in Appendix A. Results of connection performance characteristics including connection capacity, 5% offset yield, equivalent elastic plastic yield, elastic stiffness, displacement at failure, and ductility ratio are listed for each configuration. Values for each series were divided by the number of bolts in the connection and then compared with the mean value for the single-bolt series. The ratio developed is analogous to the group action factor, with a value of 1.0 assigned to single-bolt connection means. This comparison was made for the 5% offset yield strength and connection capacity and will be referred to as the normalized value throughout this discussion. A similar approach was taken for connection ductility ratio; however the value was not divided by the number of bolts in the connection.

The 5% offset yield and capacity values from testing were compared with values predicted using the Yield Model (YM). The YM does not, however, account for brittle failure mechanisms such as splitting, net-section tension rupture, and group tear-out. The capacity and failure mode from tested specimens were compared to those determined using Appendix E of the 2001 NDS (AF&PA, 2001). Appendix E provides capacities and failure modes based on the local stresses in the wood member being considered.

Statistical analyses were performed to make inferences regarding the relative effects of row spacing on connection ductility ratio, connection capacity, and 5% offset yield strength, and to determine the ability of the YM to accurately predict the 5% offset yield strength and capacity of bolted connections subjected to the prescribed cyclic loading. It was assumed that the data was normally distributed, and the mean and population variances were equal. Two-sample t-tests, with a significance level of α = 0.05, were performed to test the null hypothesis that any two population means are equal. Values for the t-statistic were generated based on equation 4.1 and compared with t-critical values obtained from an elementary statistics tables (Johnson, 1976) based on α, and number of degrees of freedom. It was assumed that a normal data distribution as chosen for analysis would be sufficiently accurate based on sample size, and that alternative methods of data distribution would likely have yielded similar results.

$$t_{statistic} = \frac{\bar{x} - \mu}{s / \sqrt{n}} \tag{4.1}$$

where:

$\bar{x}$ = Sample mean.

μ = Population mean.

s = Sample standard deviation.

$\sqrt{n}$ = Square root of sample size.

Throughout this discussion, I will refer to failures modes either as ductile or brittle. These failure modes, or mechanisms as often referred to, are subjectively assigned based primarily on test observations and their subsequent load-displacement

plots. Tests experiencing ductile failure mechanisms typically exhibited relatively large displacements prior to failure. Furthermore, failure was characterized by a gradual loss of strength following maximum load. Conversely, a brittle failure was characterized by a sudden catastrophic failure such as splitting, group tear-out or tension failures in which the load resisted as displacement increased was significantly below the connection's maximum load.

4.2 - Mode II Yield

Connections expected to display Yield Mode II were fabricated using two-inch thick nominal lumber for both members, with 19.1 mm (¾ in.) diameter bolts. The width of the members was varied to accommodate the number of rows and row spacing. Additional information regarding specific configurations may be found in Table 3.1.

4.2.1 - Cyclic Test Results

Single row configurations consisting of single-bolt and three-bolt arrangements were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 11.4 mm (0.45 in.) for single-bolt tests, and 10.7 mm (0.42 in.) for three-bolt tests. All bolts remained straight and pivoted about the member interface, consistent with Mode II yield behavior. The primary mode of failure observed was splitting through the centerline of the bolt row, however, a combination of splitting on the compression stroke and plug shear on the tension stroke was also observed as illustrated in Figure 4.1. A typical load-deflection plot for the single-row configuration is shown in Figure 4.2.

Figure 4.1: Photograph of Mode II splitting/plug shear failure.

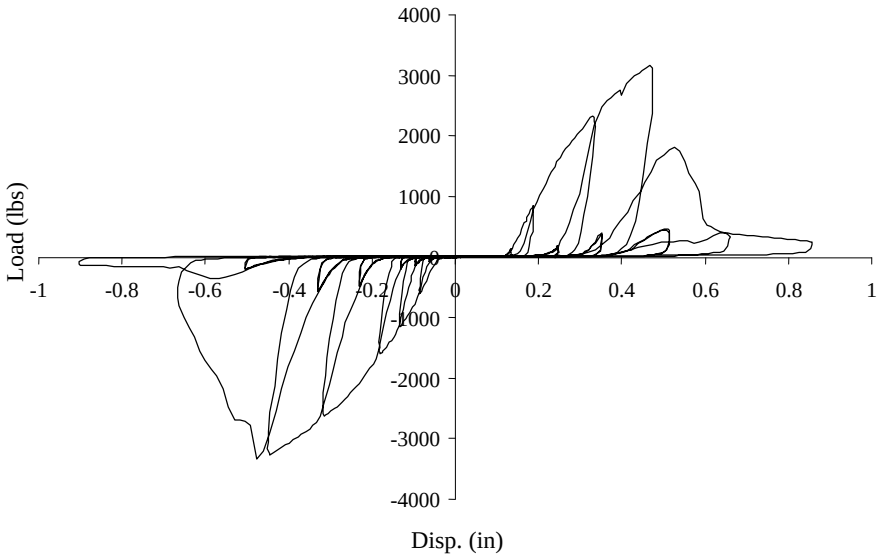

Figure 4.2: Typical load-deflection plot. Mode II yield; single bolt.

Three rows of one bolt-per-row arrangements consisting of 2D and 3D row spacings were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 10.2 mm (0.40 in.) for both sets. All bolts remained straight and pivoted about the member interface, consistent with Mode II yield behavior. There was an even distribution of group tear-out and splitting failures with the 2D spacing, while splitting through the centerline of the bolt rows was the dominant mode of failure with the 3D spacing. Splitting failures usually featured either splitting of all three rows of one member, or splitting of one row of a member and the opposite rows in the other member. Figure 4.3 illustrates splitting through the centerline of the outer two bolt rows of the main member, and center bolt row of the side member. A typical load-deflection plot for the above configurations is shown in Figure 4.4.

Figure 4.3: Photograph of different types of row splitting for a single specimen. Mode II yield; three rows of one bolt.

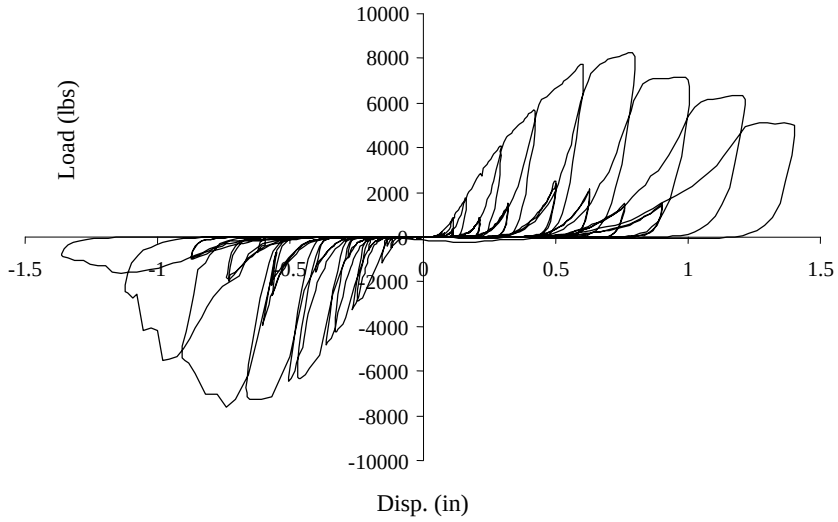

Figure 4.4: Typical load-deflection plot. Mode II yield; three rows of one bolt.

Three rows of three bolts-per-row arrangements consisting of 2D, 2.5D, and 3D row spacings were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 8.9 mm (0.35 in.) for all three sets. All bolts remained straight and pivoted about the member interface, consistent with Mode II yield behavior. There was an even distribution of group tear-out and splitting through the centerline of the bolt row failures with the 2D spacing, and a relatively even distribution of splitting through the centerline and group tear-out failures seen in the 2.5D and 3D spacing. Typically, the splitting failures occurred in the same manner as described for three rows of one bolt-per-row splitting failures. An example of group tear-out failure is shown in Figure 4.5. A typical load-deflection plot for the three rows of three configurations is shown in Figure 4.6.

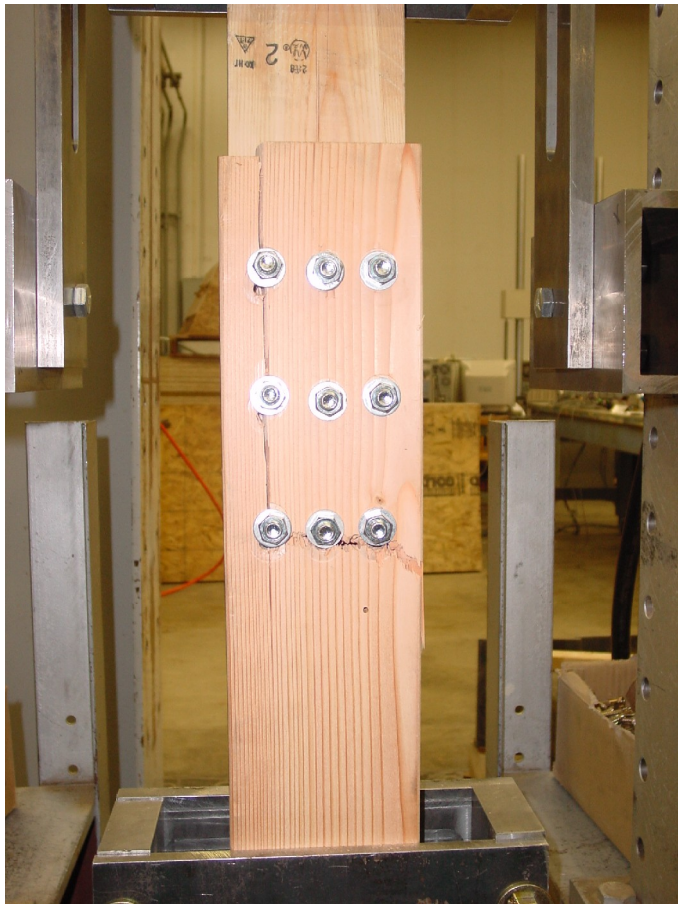

Figure 4.5: Photograph of group tear-out. Mode II yield; three rows of three bolts.

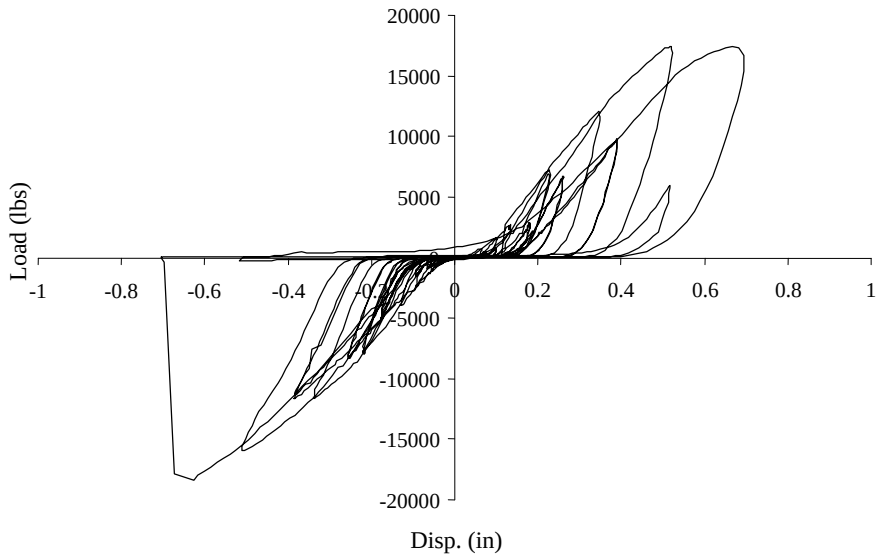

Figure 4.6: Typical load-deflection plot. Mode II yield; three rows of three bolts.

Connection performance results and material properties are displayed in Tables 4.1 and 4.2 respectively. Results were based on ten replications per configuration, unless otherwise noted. Configurations predicted to display Mode II yield generally displayed brittle failure modes occurring at displacement levels near or just above capacity. As row spacing increased from 2D to 3D, the mode of failure progressed towards splitting through the centerline of the bolt row rather than by group tear-out or net-section tension rupture. This trend was likely due to the decreased local stresses in the wood between rows of bolts.

Table 4.1a: Average connection performance results for Mode II yield predictions (SI).

	C21(1R1)		C22(1R3)		C24(3R1 2D)		C25(3R1 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (N)	14181	10.97	34888	11.18	39621	15.96	44446	8.52
@ Δ (mm)	16.0	23.33	10.4	24.17	20.3	18.26	20.1	18.59
Load/Bolt (N)	14181		11629		13207		14815	
Failure Load (N)	11345	10.97	27911	11.18	31697	15.96	35557	8.52
@ Δ (mm)	16.0	23.33	10.4	23.92	20.6	20.39	20.1	18.16
Load/Bolt (N)	11345		9304		10566		11852	
40% Max (N)	5672	10.97	13955	11.18	15849	15.96	17778	8.52
@ Δ (mm)	5.3	11.60	4.6	16.86	6.6	15.04	6.6	
E.E.P. Yield (N)*	12062	10.83	30776	9.79	35339	16.68	38875	9.06
@ Δ (mm)	9.1	16.14	7.9	23.40	12.2	12.30	12.2	13.53
Load/Bolt (N)	12062		10259		11780		12958	
5% Offset Yield (N)	10133	14.49	30740	9.31	29531	12.54	32699	13.11
@ Δ (mm)	8.9	12.31	9.1	16.50	11.7	9.01	11.4	11.97
Load/Bolt (N)	10133		10247		9844		10900	
Elastic Stiff. (N/mm)	1711	23.34	5372	20.00	3527	19.86	3731	14.75
E.E.P. Energy (N*m)**	126	31.78	176	37.46	501	39.26	512	24.14
Ductility Ratio	1.74	13.10	1.34	9.77	1.67	13.70	1.48	12.44

	C28(3R3 2D)		C30(3R3 2.5D)		C29(3R3 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (N)	85976	13.46	101684	9.74	102522	8.68
@ Δ (mm)	12.2	20.64	16.8	26.64	12.2	12.20
Load/Bolt (N)	9553		11298		11391	
Failure Load (N)	68781	13.46	81347	9.74	82017	8.68
@ Δ (mm)	12.2	20.80	16.8	26.64	12.2	12.20
Load/Bolt (N)	7642		9039		9113	
40% Max (N)	34391	13.46	40674	9.74	41009	8.68
@ Δ (mm)	4.8	11.40	6.1	13.21	4.3	6.67
E.E.P. Yield (N)*	76485	10.55	89311	14.57	88157	7.82
@ Δ (mm)	8.4	14.99	11.4	18.51	7.9	8.82
Load/Bolt (N)	8498		9923		9795	
5% Offset Yield (N)	68911	21.01	76901	25.47	82280	11.13
@ Δ (mm)	9.2	9.85	11.2	17.81	8.4	8.31
Load/Bolt (N)	7657		8545		9142	
Elastic Stiff. (N/mm)	11490	10.27	9238	21.25	14425	13.03
E.E.P. Energy (N*m)**	589	32.62	908	35.84	684	15.32
Ductility Ratio	1.48	11.30	1.48	16.18	1.58	7.88

*E.E.P. Yield: Equivalent Elastic-Plastic Yield
**E.E.P. Energy: Equivalent Elastic-Plastic Energy

Table 4.1b: Average connection performance results for Mode II yield predictions (Std.).

	C21(1R1)		C22(1R3)		C24(3R1 2D)		C25(3R1 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (lbs)	3188	10.97	7843	11.18	8907	15.96	9992	8.52
@ Δ (in)	0.63	23.33	0.41	24.17	0.80	18.26	0.79	18.59
Load/Bolt (lbs)	3188		2614		2969		3331	
Failure Load (lbs)	2550	10.97	6275	11.18	7126	15.96	7994	8.52
@ Δ (in)	0.63	23.33	0.41	23.92	0.81	20.39	0.79	18.16
Load/Bolt (lbs)	2550		2092		2375		2665	
40% Max (lbs)	1275	10.97	3137	11.18	3563	15.96	3997	8.52
@ Δ (in)	0.21	11.60	0.18	16.86	0.26	15.04	0.26	
E.E.P. Yield (lbs)*	2712	10.83	6919	9.79	7944	16.68	8739	9.06
@ Δ (in)	0.36	16.14	0.31	23.40	0.48	12.30	0.48	13.53
Load/Bolt (lbs)	2712		2306		2648		2913	
5% Offset Yield (lbs)	2278	14.49	6911	9.31	6639	12.54	7351	13.11
@ Δ (in)	0.35	12.31	0.36	16.50	0.46	9.01	0.45	11.97
Load/Bolt (lbs)	2278		2304		2213		2450	
Elastic Stiff. (lb/in)	9769	23.34	30676	20.00	20140	19.86	21307	14.75
E.E.P. Energy (lb*in)**	1118	31.78	1556	37.46	4435	39.26	4528	24.14
Ductility Ratio	1.74	13.10	1.34	9.77	1.67	13.70	1.64	12.44

	C28(3R3 2D)		C30(3R3 2.5D)		C29(3R3 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (lbs)	19328	13.46	22859	0.10	23048	8.68
@ Δ (in)	0.48	20.64	0.66	0.27	0.48	12.20
Load/Bolt (lbs)	2148		2540		2561	
Failure Load (lbs)	15463	13.46	18288	0.10	18438	8.68
@ Δ (in)	0.48	20.80	0.66	0.27	0.48	12.20
Load/Bolt (lbs)	1718		2032		2049	
40% Max (lbs)	7731	13.46	9144	0.10	9219	8.68
@ Δ (in)	0.19	11.40	0.24	0.13	0.17	6.67
E.E.P. Yield (lbs)*	17194	10.55	20078	0.15	19818	7.82
@ Δ (in)	0.33	14.99	0.45	0.19	0.31	8.82
Load/Bolt (lbs)	1910		2231		2202	
5% Offset Yield (lbs)	15492	21.01	17288	0.25	18497	11.13
@ Δ (in)	0.36	9.85	0.44	0.18	0.33	8.31
Load/Bolt (lbs)	1721		1921		2055	
Elastic Stiff. (lb/in)	65608	10.27	52750	0.21	82368	13.03
E.E.P. Energy (lb*in)**	5216	32.62	8032	0.36	6050	15.32
Ductility Ratio	1.48	11.30	1.48	0.16	1.58	7.88

*E.E.P. Yield: Equivalent Elastic-Plastic Yield
**E.E.P. Energy: Equivalent Elastic-Plastic Energy

Table 4.2a: Average connection material properties for Mode II yield predictions (SI).

	C21(1R1)		C22(1R3)		C24(3R1 2D)		C25(3R1 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.86	3.58	14.58	4.60	14.15	1.49	14.24	4.65
S.G.	0.48	10.43	0.49	7.15	0.44	5.69	0.47	6.69
D.E. 5% Offset Yield (N)	17919	15.21	18574	8.2	16103	7.98	17851	8.68
D.E. Capacity (N)	17979	15	18770	7.13	16259	8.39	17973	9.04
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.13	3.12	15.18	5.19	13.70	3.26	14.01	5.03
S.G.	0.47	11.99	0.50	7.02	0.43	8.13	0.47	5.65
D.E. 5% Offset Yield (N)	17580	13.8	18041	11.42	16324	7.05	17955	10.17
D.E. Capacity (N)	17601	13.89	18434	11.24	16597	8.13	18102	9.94

	C28(3R3 2D)		C30(3R3 2.5D)		C29(3R3 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.79	3.06	14.21	4.72	14.61	4.89
S.G.	0.45	12.92	0.52	9.14	0.48	11.54
D.E. 5% Offset Yield (N)	15997	10.94	20311	12.95	17565	9.24
D.E. Capacity (N)	16148	10.9	20839	12.29	17735	8.80
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.63	2.42	14.19	7.07	14.43	4.81
S.G.	0.46	11.06	0.52	7.58	0.48	8.41
D.E. 5% Offset Yield (N)	16861	6.83	21074	11.46	17924	14.22
D.E. Capacity (N)	17213	6.84	22291	11.18	18010	13.79

M.C.: Moisture Content
S.G.: Specific Gravity
D.E.: Dowel Embedment Data
xxD: Refers to Row Spacing

Table 4.2b: Average connection material properties for Mode II yield predictions (Std.).

	C21(1R1)		C22(1R3)		C24(3R1 2D)		C25(3R1 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.86	3.58	14.58	4.60	14.15	1.49	14.24	4.65
S.G.	0.48	10.43	0.49	7.15	0.44	5.69	0.47	6.69
D.E. 5% Offset Yield (lbs)	4028	15.21	4176	8.20	3620	7.98	4013	8.68
D.E. Capacity (lbs)	4042	15.00	4220	7.13	3655	8.39	4040	9.04
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.13	3.12	15.18	5.19	13.70	3.26	14.01	5.03
S.G.	0.47	11.99	0.50	7.02	0.43	8.13	0.47	5.65
D.E. 5% Offset Yield (lbs)	3952	13.80	4056	11.42	3670	7.05	4036	10.17
D.E. Capacity (lbs)	3957	13.89	4144	11.24	3731	8.13	4069	9.94

	C28(3R3 2D)		C30(3R3 2.5D)		C29(3R3 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.86	3.58	14.58	4.60	14.15	1.49
S.G.	0.48	10.43	0.49	7.15	0.44	5.69
D.E. 5% Offset Yield (lbs)	3596	10.94	4566	12.95	3949	9.24
D.E. Capacity (lbs)	3630	10.90	4685	12.29	3987	8.80
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.13	3.12	15.18	5.19	13.70	3.26
S.G.	0.47	11.99	0.50	7.02	0.43	8.13
D.E. 5% Offset Yield (lbs)	3791	6.83	4738	11.46	4030	14.22
D.E. Capacity (lbs)	3870	6.84	5011	11.18	4049	13.79

M.C.: Moisture Content
S.G.: Specific Gravity
D.E.: Dowel Embedment Data
xxD: Refers to Row Spacing

4.3 - Mode III_s Yield

Connections expected to display Yield Mode III_s were fabricated using 102 mm (4 in.) thick nominal lumber for the main member, and 51 mm (2 in.) thick nominal lumber for the side member, using 12.7 mm (½ in.) diameter bolts. The nominal member width for single-row configurations was 102 mm (4 in.), and 152 mm (6 in.) for the remaining configurations. Additional information regarding specific configurations can be found in Table 3.1.

4.3.1 - Cyclic Test Results

Single-row configurations consisting of one-bolt and three-bolt arrangements were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 13.5 mm (0.53 in.) for single-bolt tests, and 11.4 mm (0.45 in.) for three-bolt tests. All bolts in the single-bolt configuration tests formed a clearly defined plastic hinge, consistent with Mode III_s yield behavior. The single-row, three-bolt configurations often displayed a mixed mode yield mechanism, meaning that the bolts within a given test specimen may not all achieve the same yield mode. This is due to unequal load distribution to bolts in a connection as well as material property variations. The yield modes observed were Mode III_s, and a mixed yield mode ranging from Mode II to Mode III_s. When Mode III_s was observed, the plastic hinge formation was only slight, yet still evident. The primary mode of failure observed was splitting through the centerline of the bolt row. However, a combination of splitting and plug shear was also observed. Typical splitting failures for the single-bolt row and load-deflection plot for the single-bolt configuration are shown in Figures 4.7 and 4.8.

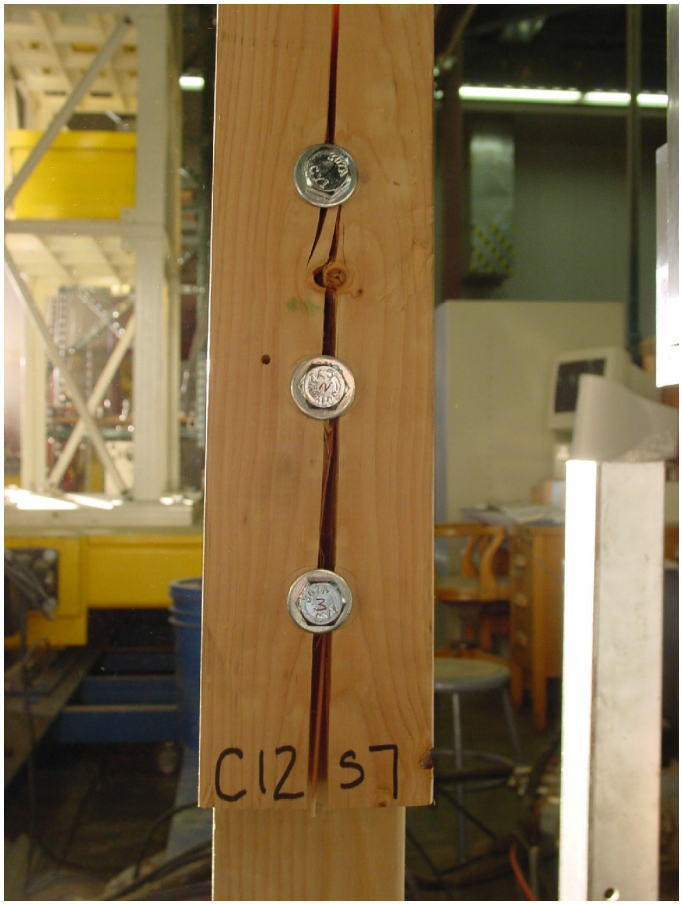

Figure 4.7: Photograph of typical splitting failure. Mode III_s yield; one row of three bolts.

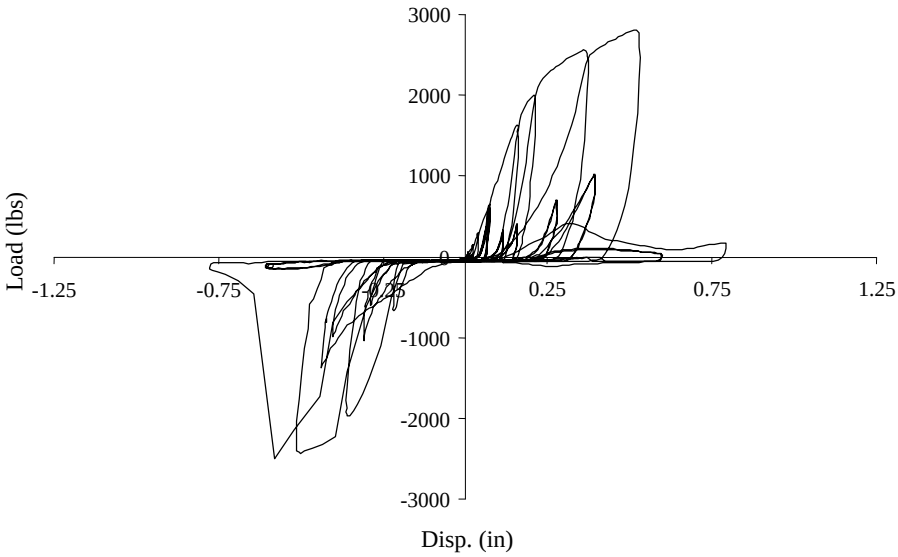

Figure 4.8: Typical load-deflection plot. Mode III_s yield; single bolt.

Three rows of one bolt-per-row arrangements consisting of 2D, 2.5D and 3D row spacings were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 11.4 mm (0.45 in.) for all three sets. The yield modes observed were Mode $III_{s,}$ Mode IV, and a mixed yield mode ranging from Mode III_s to Mode IV. When Mode III_s was observed, the formation of a plastic hinge was very distinct. However, when Mode IV yield was present, the reverse bending caused by the formation of two plastic hinges in the bolt was only very slight. As row spacing was increased, the primary mode of failure observed was splitting through the centerline of the bolt row, or splitting with plug shear on the opposite stroke. However, group tear-out failures were also observed. An example of splitting failure is shown in Figure 4.9. A typical load-deflection plot for a three rows of one bolt-per-row configuration is shown in Figure 4.10.

Reverse bending, as referenced above and in future discussions, refers to the geometry of the bolt after it has yielded. Two plastic hinges form by definition, inducing two bend angles in the bolt. If the bend angles are equal and opposite such that bolt ends are parallel, then reverse bending is present. If two plastic hinges form, but the bolt ends are not parallel, then reverse bending is not present.

Figure 4.9: Photograph of typical splitting. Mode III_s yield; three rows of one bolt.

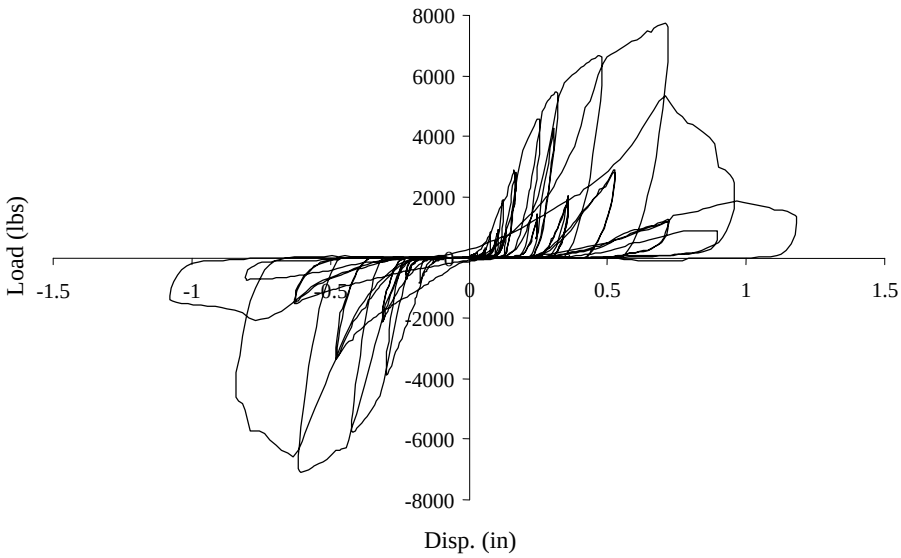

Figure 4.10: Typical load-deflection plot. Mode III_s yield; three rows of one bolt.

Three rows of three bolts-per-row arrangements consisting of 2D and 3D row spacings were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 7.6 mm (0.30 in.) for both sets. The yield modes observed were Mode III_s, and a mixed yield mode ranging from Mode II to Mode III_s. When Mode III_s was observed, the formation of a plastic hinge was typically very slight, yet still evident depending on the magnitude of load that a given row of bolts had resisted prior to failure. The primary mode of failure observed in connections with 2D row spacing was group tear-out, while splitting through the centerline of the bolt row was typical for connections with 3D row spacing. An example of group tear-out failure is shown in Figure 4.11. A typical load-deflection plot for the three rows of three bolts-per-row configuration is shown in Figure 4.12

Figure 4.11: Photograph of group tear-out. Mode III_s yield, three rows of three bolts.

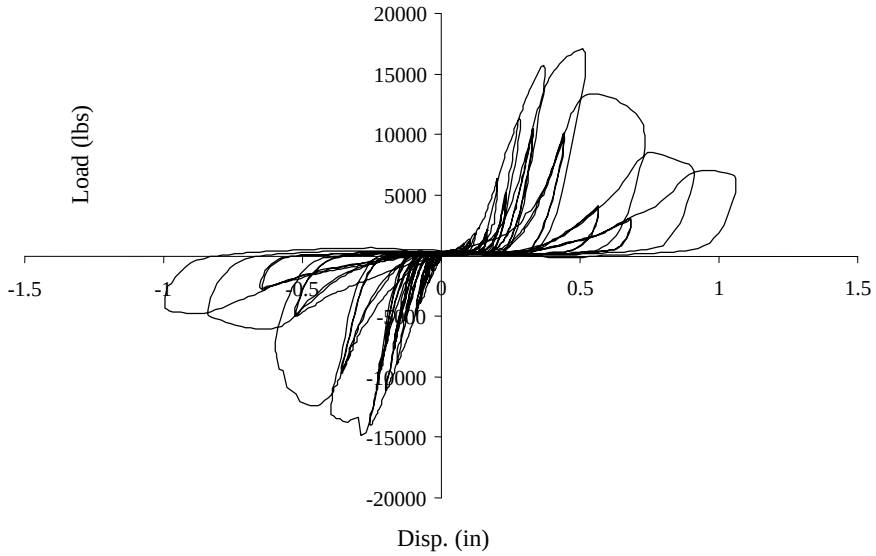

Figure 4.12: Typical load-deflection plot. Mode III_s yield, three rows of three bolts.

Connection performance results and material properties are displayed in Tables 4.3 and 4.4 respectively. Results are based on ten replications per configuration, unless otherwise noted. Generally, poor agreement was found between experimental results and the predictions of the Yield Model; however single-bolt connections were accurately predicted by the model. Connections with three rows of one bolt always attained or surpassed the yield mode predicted by the YM, while connections with three bolts-per-row did not always achieve the predicted yield mode. Splitting through the centerline of the row of bolts was the ultimate failure mode for the majority of these tests. However, configurations using one bolt-per-row displayed signs of bearing failure at larger displacements prior to splitting. Inaccuracies of the YM for these configurations will be discussed in detail near the end of this chapter

Table 4.3a: Average connection performance results for Mode III_s yield predictions (SI).

	C11(1R1)		C12(1R3)		C14(3R1 2D)		C16(3R1 2.5D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (N)	11416	9.93	25246	20.34	29614	14.69	35076	11.42
@ Δ (mm)	14.9	21.46	8.8	20.59	16.6	22.18	22.6	21.18
Load/Bolt (N)	11416		8415		9871		11692	
Failure Load (N)	9133	9.93	20197	20.34	23691	14.69	28061	11.42
@ Δ (mm)	15.0	21.66	8.8	20.59	19.9	28.50	22.7	21.61
Load/Bolt (N)	9133		6732		7897		9354	
40% Max (N)	4566	9.93	10099	20.34	11846	14.69	14195	11.12
@ Δ (mm)	0.2	9.86	0.2	12.92	0.2	9.23	0.2	16.41
E.E.P. Yield (N)*	9815	11.19	22745	19.32	26676	12.97	31298	12.30
@ Δ (mm)	7.9	12.10	7.2	15.71	9.5	11.68	12.2	18.24
Load/Bolt (N)	9815		7582		8892		10433	
5% Offset Yield (N)	8227	13.94	23177	18.54	22256	9.19	25144	15.28
@ Δ (mm)	7.91	18.37	7.86	14.37	8.9	8.37	10.7	19.44
Load/Bolt (N)	8227		7726		7418		8381	
Elastic Stiff. (N/mm)	1693	14.28	4258	11.48	3587	14.26	2869	18.01
E.E.P. Energy (N*m)**	102	34.80	104	40.51	379	38.30	506	33.21
Ductility Ratio	1.91	12.74	1.23	7.28	2.15	40.79	1.89	15.71

	C15(3R1 3D)		C18(3R3 2D)		C19(3R3 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (N)	35281	11.52	72297	9.55	79266	11.82
@ Δ (mm)	21.6	21.40	9.8	17.39	10.1	23.02
Load/Bolt (N)	11760		8033		8807	
Failure Load (N)	28225	11.52	57838	9.55	63413	11.82
@ Δ (mm)	21.6	21.40	9.8	17.39	10.6	23.40
Load/Bolt (N)	9408		6426		7046	
40% Max (N)	14112	11.52	28919	9.55	31707	11.82
@ Δ (mm)	6.3	12.29	4.0	11.44	3.9	13.81
E.E.P. Yield (N)*	31487	10.24	67025	6.38	71494	13.87
@ Δ (mm)	11.5	12.36	7.5	10.35	6.8	20.47
Load/Bolt (N)	10496		7447		7944	
5% Offset Yield (N)	24751	6.51	64025	5.97	67976	19.10
@ Δ (mm)	10.1	9.72	7.8	8.74	7.4	18.11
Load/Bolt (N)	8250		7114		7553	
Elastic Stiff. (N/mm)	3501	23.40	11879	29.73	12206	17.90
E.E.P. Energy (N*m)**	481	38.14	389	27.17	498	41.32
Ductility Ratio	1.86	11.31	1.34	7.83	1.53	17.80

*E.E.P. Yield: Equivalent Elastic-Plastic Yield
**E.E.P. Energy: Equivalent Elastic-Plastic Energy

Table 4.3b: Average connection performance results for Mode III_s yield predictions (Std.)

	C11(1R1)		C12(1R3)		C14(3R1 2D)		C16(3R1 2.5D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (lbs)	2566	9.93	5676	20.34	6657	14.69	7885	11.42
@ Δ (in)	0.59	21.46	0.35	20.59	0.65	22.18	0.89	21.18
Load/Bolt (lbs)	2566		1892		2219		2628	
Failure Load (lbs)	2053	9.93	4540	20.34	5326	14.69	6308	11.42
@ Δ (in)	0.59	21.66	0.35	20.59	0.78	28.50	0.89	21.61
Load/Bolt (lbs)	2053		1513		1775		2103	
40% Max (lbs)	1027	9.93	2270	20.34	2663	14.69	3191	11.12
@ Δ (in)	0.18	9.86	0.17	12.92	0.21	9.23	0.24	16.41
E.E.P. Yield (lbs)*	2206	11.19	5113	19.32	5997	12.97	7036	12.30
@ Δ (in)	0.31	12.10	0.28	15.71	0.38	11.68	0.48	18.24
Load/Bolt (lbs)	2206		1704		1999		2345	
5% Offset Yield (lbs)	1850	13.94	5210	18.54	5003	9.19	5653	15.28
@ Δ (in)	0.31	18.37	0.31	14.37	0.35	8.37	0.42	19.44
Load/Bolt (lbs)	1850		1737		1668		1884	
Elastic Stiff. (lb/in)	9668	14.28	24314	11.48	20483	14.26	16381	18.01
E.E.P. Energy (lb*in)**	903	34.80	924	40.51	3356	38.30	4482	33.21
Ductility Ratio	1.91	12.74	1.23	7.28	2.15	40.79	1.89	15.71

	C15(3R1 3D)		C18(3R3 2D)		C19(3R3 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (lbs)	7931	11.52	16253	9.55	17820	11.82
@ Δ (in)	0.85	21.40	0.38	17.39	0.40	23.02
Load/Bolt (lbs)	2644		1806		1980	
Failure Load (lbs)	6345	11.52	13002	9.55	14256	11.82
@ Δ (in)	0.85	21.40	0.38	17.39	0.42	23.40
Load/Bolt (lbs)	2115		1445		1584	
40% Max (lbs)	3173	11.52	6501	9.55	7128	11.82
@ Δ (in)	0.25	12.29	0.16	11.44	0.15	13.81
E.E.P. Yield (lbs)*	7079	10.24	15068	6.38	16072	13.87
@ Δ (in)	0.45	12.36	0.29	10.35	0.27	20.47
Load/Bolt (lbs)	2360		1674		1786	
5% Offset Yield (lbs)	5564	6.51	14393	5.97	15282	19.10
@ Δ (in)	0.40	9.72	0.31	8.74	0.29	18.11
Load/Bolt (lbs)	1855		1599		1698	
Elastic Stiff. (lb/in)	19992	23.40	67832	29.73	69697	17.90
E.E.P. Energy (lb*in)**	4254	38.14	3444	27.17	4406	41.32
Ductility Ratio	1.86	11.31	1.34	7.83	1.53	17.80

*E.E.P. Yield: Equivalent Elastic-Plastic Yield
**E.E.P. Energy: Equivalent Elastic-Plastic Energy

Table 4.4a: Average connection material properties for Mode III_s yield predictions (SI).

	C11(1R1)		C12(1R3)		C14(3R1 2D)		C16(3R1 2.5D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	16.29	4.29	16.19	3.85	15.61	2.70	15.52	4.11
S.G.	0.48	11.50	0.46	7.82	0.44	9.51	0.53	8.47
D.E. 5% Offset Yield (N)	166278	18.36	18192	4.77	15951	14.83	16488	18.1
D.E. Capacity (N)	17393	17.23	19063	5.75	16247	13.74	18245	15.67
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.57	3.21	14.18	5.53	16.05	3.08	15.38	7.44
S.G.	0.48	9.83	0.48	12.34	0.48	15.23	0.49	10.46
D.E. 5% Offset Yield (N)	19414	8.95	20480	12.15	18896	16.16	16530	9.14
D.E. Capacity (N)	19572	9.05	20740	12.09	19200	15.15	16631	8.92

	C15(3R1 3D)		C18(3R3 2D)		C19(3R3 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.77	3.67	15.14	4.39	16.06	1.71
S.G.	0.43	9.38	0.45	8.99	0.48	7.41
D.E. 5% Offset Yield (N)	15135	11.17	16756	13.09	18176	12.38
D.E. Capacity (N)	15984	10.33	17723	10.76	19227	8.79
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.69	4.05	16.05	7.81	16.32	5.26
S.G.	0.52	11.42	0.49	10.11	0.48	11.11
D.E. 5% Offset Yield (N)	18640	20.22	17395	12.01	16989	15.79
D.E. Capacity (N)	19374	18.16	18116	10.23	17763	14.38

M.C.: Moisture Content
S.G.: Specific Gravity
D.E.: Dowel Embedment Data
xxD: Refers to Row Spacing

Table 4.4b: Average connection material properties for Mode III_s yield predictions (Std.).

	C11(1R1)		C12(1R3)		C14(3R1 2D)		C16(3R1 2.5D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	16.29	4.29	16.19	3.85	15.61	2.70	15.52	4.11
S.G.	0.48	11.50	0.46	7.82	0.44	9.51	0.53	8.47
D.E. 5% Offset Yield (lbs)	3738	18.36	4090	4.77	3586	14.83	3707	18.10
D.E. Capacity (lbs)	3910	17.23	4286	5.75	3652	13.74	4102	15.67
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.57	3.21	14.18	5.53	16.05	3.08	15.38	7.44
S.G.	0.48	9.83	0.48	12.34	0.48	15.23	0.49	10.46
D.E. 5% Offset Yield (lbs)	4364	8.95	4604	12.15	4248	16.16	3716	9.14
D.E. Capacity (lbs)	4400	9.05	4662	12.09	4316	15.15	3739	8.92

	C15(3R1 3D)		C18(3R3 2D)		C19(3R3 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.77	3.67	15.14	4.39	16.06	1.71
S.G.	0.43	9.38	0.45	8.99	0.48	7.41
D.E. 5% Offset Yield (lbs)	3402	11.17	3767	13.09	4086	12.38
D.E. Capacity (lbs)	3593	10.33	3984	10.76	4322	8.79
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.69	4.05	16.05	7.81	16.32	5.26
S.G.	0.52	11.42	0.49	10.11	0.48	11.11
D.E. 5% Offset Yield (lbs)	4190	20.22	3910	12.01	3819	15.79
D.E. Capacity (lbs)	4356	18.16	4073	10.23	3993	14.38

M.C.: Moisture Content
S.G.: Specific Gravity
D.E.: Dowel Embedment Data
xxD: Refers to Row Spacing

4.4 - Mode IV Yield

Connections expected to display Yield Mode IV were fabricated using 102 mm (4 in.) thick by 102 mm (4 in.) thick nominal lumber for both members, with 6.4 mm (¼ in.) diameter bolts. Additional information regarding specific configurations can be found in Table 3.1.

4.4.1 - Cyclic Test Results

Single-row configurations consisting of one-bolt and three-bolt arrangements were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 20.3 mm (0.80 in.) for single-bolt tests, and 15.5 mm (0.61 in.) for three-bolt tests. All bolts in the single-bolt configuration formed two clearly defined plastic hinges and exhibited reverse bending consistent with Mode IV. Bolts in the single-row of three bolts configuration displayed either Yield Mode IV, or a mixed mode yield ranging from Mode III_s to Mode IV for each specimen. Bolts exhibiting Mode III_s yield typically formed two plastic hinges, however, reverse bending was not present. The primary failure mode observed in single-bolt tests was bolt fatigue, while splitting through the centerline of the bolt row was the failure mode observed in the single-row of three bolts configuration. Of the bolts that did not fracture, minor to significant necking, or reduction in cross-sectional area due to bolt fatigue, was observed at plastic hinge locations. A splitting failure showing necking of the bolt, and a load-deflection plot indicating ductile failure are shown in Figures 4.13 and 4.14 respectively.

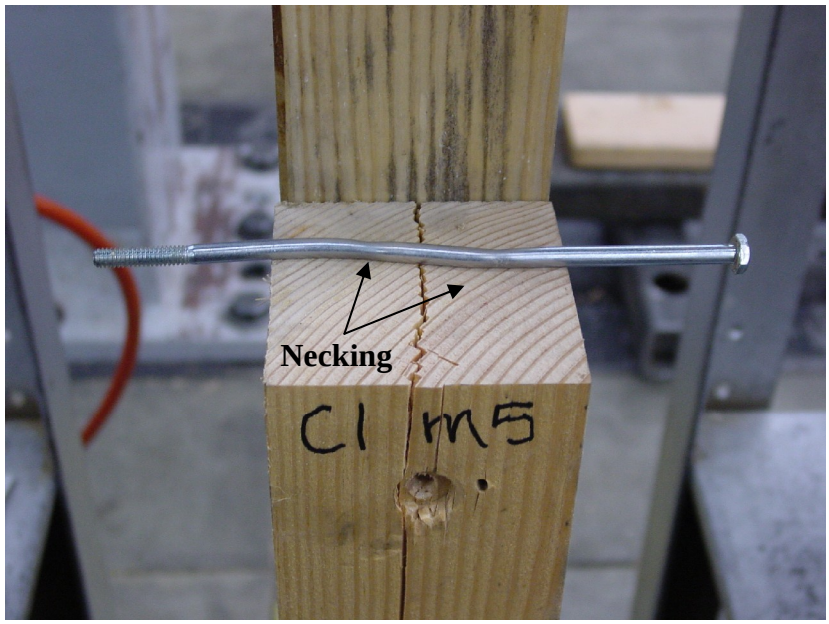

Figure 4.13: Photograph of necking. Mode IV yield; single bolt.

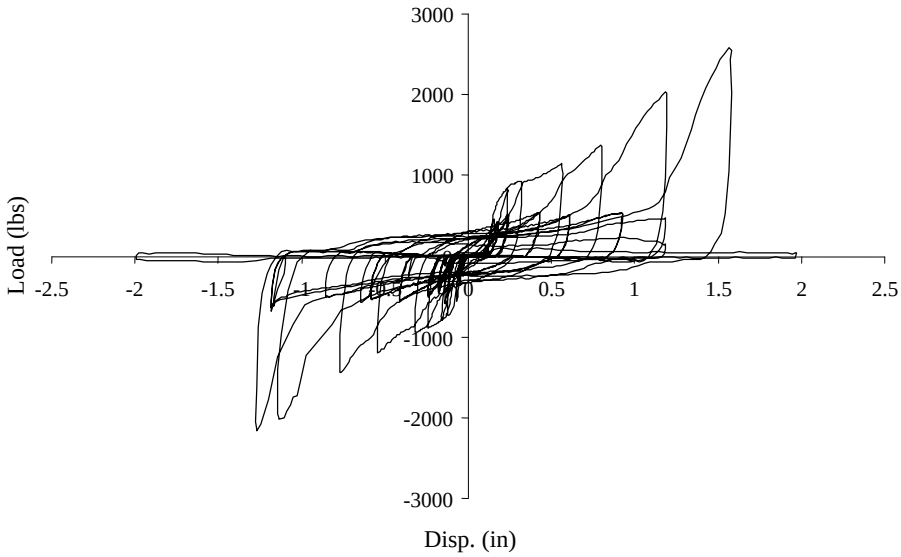

Figure 4.14: Typical load-deflection plot. Mode IV Yield; single bolt.

Three rows of one bolt-per-row arrangements consisting of 2D and 3D row spacing were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 15.5 mm (0.61 in.) for both sets. All bolts in this series exhibited Mode IV yield prior to failure. Even distributions of splitting and bolt fatigue failure mechanisms were observed in the 2D row spacing configuration. For the configuration with 3D spacing, bolt fatigue was the predominant failure mechanism. Bolt fatigue failure is shown in Figure 4.15, and a typical load-deflection plot for the three rows of one bolt configuration is shown in Figure 4.16.

Figure 4.15: Photograph of bolt failure. Mode IV yield; three rows of one bolt.

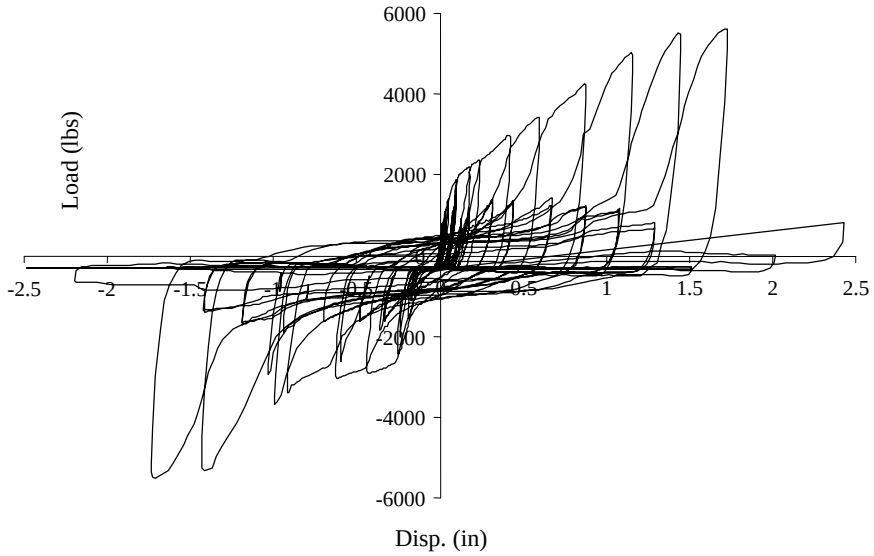

Figure 4.16: Typical load-deflection plot. Mode IV yield; three rows of one bolt.

Three rows of three bolts-per-row arrangements consisting of 2D and 3D row spacings were subjected to a displacement controlled cyclic protocol as described in Chapter 3. The reference deformation was equal to 15.5 mm (0.61 in.) for both sets. These configurations displayed either Yield Mode IV, or a mixed mode yield ranging from Mode III_s to Mode IV. Bolts exhibiting Mode III_s yield typically formed two plastic hinges, however, reverse bending was not present. For the configuration with 2D row spacing, wood splitting through the centerline of the bolt row(s) was the predominant failure mechanism. Wood splitting through the centerline of the bolt row(s) was also the predominant failure mechanism when row spacing was 3D, however, two bolt fatigue failures were observed, implicating a slightly larger degree of ductility than exhibited in the 2D row spacing configuration. A splitting failure through the centerline of the bolt row(s) is shown in Figure 4.17, and a typical load-deflection plot indicating ductile failure is shown in Figure 4.18.

Figure 4.17: Photograph of spitting. Mode IV yield; three rows of three bolts.

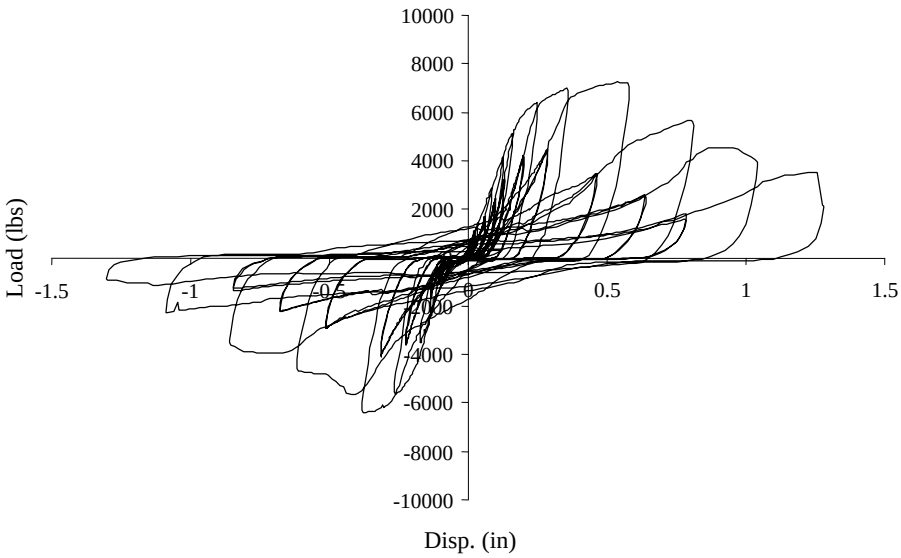

Figure 4.18: Typical load-deflection plot. Mode IV yield; three rows of three bolts.

Connection performance results and material properties are displayed in Tables 4.5 and 4.6 respectively. Results are based on ten replications per configuration unless otherwise noted, and indicate moderately good agreement between experimental data and Yield Model predictions. Single bolt-per-row configurations were accurately predicted based on the YM. Connections with three rows of one bolt-per-row always resulted in the yield mode predicted by the model, while connections with three bolts-per-row exhibited yield modes ranging from Mode III_s to Mode IV. Bolts in specimens exhibiting mixed mode yield that did not reach Yield Mode IV were all located within the same row and did not induce splitting of the wood through the centerline of the row of bolts. All bolts in the remaining rows, however, did achieve Mode IV yield. Fewer mixed mode yields were observed in the specimens with 3D row spacing, indicating an increased degree of ductility with larger row spacing. Connection specimens within this series exhibited ductile behavior prior to ultimate failure, which occurred at relatively large displacements. Splitting of the wood through the centerline of the bolts was the ultimate mode of failure for the majority of these tests.

Table 4.5a: Average connection performance results for Mode IV yield predictions (SI).

	C1(1R1)		C2(1R3)		C4(3R1 2D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (N)	9881	14.66	11830	13.22	21259	12.63
@ Δ (mm)	42.1	15.37	18.11	39.67	39.9	18.29
Load/Bolt (N)	9881		3943		7086	
Failure Load (N)	7905	14.66	9464	13.22	17007	12.63
@ Δ (mm)	42.5	15.45	18.1	39.67	41.0	16.06
Load/Bolt (N)	7905		3155		5669	
40% Max (N)	2999	15.48	4732	13.22	8042	14.19
@ Δ (mm)	4.0	8.88	2.9	12.85	4.4	23.78
E.E.P. Yield (N)*	7905	14.66	10561	8.81	17119	13.17
@ Δ (mm)	10.3	18.47	5.8	17.17	8.9	24.70
Load/Bolt (N)	7905		3520		5706	
5% Offset Yield (N)	3228	18.76	8019	13.20	8706	13.90
@ Δ (mm)	4.6	14.6	4.8	17.04	5.0	17.57
Load/Bolt (N)	3228		2673		2902	
Elastic Stiff. (N/mm)	832	21.83	2228	33.81	2216	26.10
E.E.P. Energy (N*m)**	293	18.67	163	51.19	623	20.26
Ductility Ratio	4.28	21.95	3.05	32.19	4.77	12.09

	C5(3R1 3D)		C8(3R3 2D)		C9(3R3 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (N)	20318	15.98	31391	11.73	30954	17.59
@ Δ (mm)	40.0	15.44	13.7	47.15	11.7	69.95
Load/Bolt (N)	6773		3488		3439	
Failure Load (N)	16254	15.98	25113	11.73	24763	17.59
@ Δ (mm)	41.6	13.53	14.8	61.76	15.5	69.69
Load/Bolt (N)	5418		2790		2751	
40% Max (N)	7643	13.35	12557	11.73	12382	17.59
@ Δ (mm)	4.2		3.1	16.08	3.0	12.65
E.E.P. Yield (N)*	16388	15.22	29424	10.73	28667	15.66
@ Δ (mm)	8.6	29.31	6.2	17.55	5.8	19.39
Load/Bolt (N)	5463		3269		3185	
5% Offset Yield (N)	8579	17.82	24328	7.73	25785	9.44
@ Δ (mm)	4.9	23.20	5.6	15.95	6.0	15.77
Load/Bolt (N)	2860		2703		2865	
Elastic Stiff. (N/mm)	2217	22.07	5070	12.46	5794	17.52
E.E.P. Energy (N*m)**	610	20.24	368	84.26	392	100.27
Ductility Ratio	5.20	21.25	2.43	44.45	2.56	53.30

*E.E.P. Yield: Equivalent Elastic-Plastic Yield
**E.E.P. Energy: Equivalent Elastic-Plastic Energy

Table 4.5b: Average connection performance results for Mode IV yield predictions (Std.).

	C1(1R1)		C2(1R3)		C4(3R1 2D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (lbs)	2221	14.66	2660	13.22	4779	12.63
@ Δ (in)	1.66	15.37	0.71	39.67	1.57	18.29
Load/Bolt (lbs)	2221		887		1593	
Failure Load (lbs)	1777	14.66	2128	13.22	3823	12.63
@ Δ (in)	1.67	15.45	0.71	39.67	1.61	16.06
Load/Bolt (lbs)	1777		709		1274	
40% Max (lbs)	674	15.48	1064	13.22	1808	14.19
@ Δ (in)	0.16	8.88	0.12	12.85	0.17	23.78
E.E.P. Yield (lbs)*	1777	14.66	2374	8.81	3849	13.17
@ Δ (in)	0.41	18.47	0.23	17.17	0.35	24.70
Load/Bolt (lbs)	1777		791		1283	
5% Offset Yield (lbs)	726	18.76	1803	13.20	1957	13.90
@ Δ (in)	0.18	14.59	0.19	17.04	0.20	17.57
Load/Bolt (lbs)	726		601		652	
Elastic Stiff. (lb/in)	4751	21.83	12721	33.81	12653	26.10
E.E.P. Energy (lb*in)**	2592	18.67	1439	51.19	5515	20.26
Ductility Ratio	4.28	21.95	3.05	32.19	4.77	12.09

	C5(3R1 3D)		C8(3R3 2D)		C9(3R3 3D)	
	Mean	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
Max Load (lbs)	4568	15.98	7057	11.73	6959	17.59
@ Δ (in)	1.57	15.44	0.54	47.15	0.46	69.95
Load/Bolt (lbs)	1523		784		773	
Failure Load (lbs)	3654	15.98	5646	11.73	5567	17.59
@ Δ (in)	1.64	13.53	0.58	61.76	0.61	69.69
Load/Bolt (lbs)	1218		627		619	
40% Max (lbs)	1718	13.35	2823	11.73	2784	17.59
@ Δ (in)	0.16		0.12	16.08	0.12	12.65
E.E.P. Yield (lbs)*	3684	15.22	6615	10.73	6445	15.66
@ Δ (in)	0.34	29.31	0.24	17.55	0.23	19.39
Load/Bolt (lbs)	1228		735		716	
5% Offset Yield (lbs)	1929	17.82	5469	7.73	5797	9.44
@ Δ (in)	0.19	23.20	0.22	15.95	0.23	15.77
Load/Bolt (lbs)	643		608		644	
Elastic Stiff. (lb/in)	12658	22.07	28952	12.46	33088	17.52
E.E.P. Energy (lb*in)**	5399	20.24	3260	84.26	3468	100.27
Ductility Ratio	5.20	21.25	2.43	44.45	2.56	53.30

*E.E.P. Yield: Equivalent Elastic-Plastic Yield
**E.E.P. Energy: Equivalent Elastic-Plastic Energy

Table 4.6a: Average connection material properties for Mode IV yield predictions (SI).

	C1(1R1)		C2(1R3)		C4(3R1 2D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	16.06	6.30	15.68	5.20	15.84	5.31
S.G.	0.54	13.40	0.49	10.25	0.52	6.82
D.E. 5% Offset Yield (N)	27421	19.31	23031	18.28	25898	16.01
D.E. Capacity (N)	31471	16.78	28993	15.29	31693	12.97
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.93	4.78	15.44	4.30	16.26	3.21
S.G.	0.53	15.63	0.48	11.03	0.51	9.41
D.E. 5% Offset Yield (N)	27124	19.50	23189	16.50	25738	15.88
D.E. Capacity (N)	29970	19.05	28201	14.45	30538	12.48

	C5(3R1 3D)		C8(3R3 2D)		C9(3R3 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.77	5.84	16.10	1.76	15.78	2.20
S.G.	0.49	12.92	0.47	9.92	0.49	7.35
D.E. 5% Offset Yield (N)	26503	19.18	21194	17.40	22007	18.98
D.E. Capacity (N)	30964	16.93	26565	11.41	27664	12.05
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.41	3.44	15.89	1.70	16.26	5.36
S.G.	0.49	10.35	0.49	8.13	0.48	15.01
D.E. 5% Offset Yield (N)	21418	19.24	21404	15.99	21598	16.54
D.E. Capacity (N)	28080	12.06	26885	14.58	27569	17.05

M.C.: Moisture Content
S.G.: Specific Gravity
D.E.: Dowel Embedment Data
xxD: Refers to Row Spacing

Table 4.6b: Average connection material properties for Mode IV yield predictions (Std.).

	C1(1R1)		C2(1R3)		C4(3R1 2D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	16.06	6.30	15.68	5.20	15.84	5.31
S.G.	0.54	13.40	0.49	10.25	0.52	6.82
D.E. 5% Offset Yield (lbs)	6165	19.31	5178	18.28	5822	16.01
D.E. Capacity (lbs)	7075	16.78	6518	15.29	7125	12.97
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.93	4.78	15.44	4.30	16.26	3.21
S.G.	0.53	15.63	0.48	11.03	0.51	9.41
D.E. 5% Offset Yield (lbs)	6098	19.50	5213	16.50	5786	15.88
D.E. Capacity (lbs)	6737	19.05	6340	14.45	6865	12.48

	C5(3R1 3D)		C8(3R3 2D)		C9(3R3 3D)	
Main Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	14.77	5.84	16.10	1.76	15.78	2.20
S.G.	0.49	12.92	0.47	9.92	0.49	7.35
D.E. 5% Offset Yield (lbs)	5958	19.18	4765	17.40	4947	18.98
D.E. Capacity (lbs)	6961	16.93	5972	11.41	6219	12.05
Side Member	**Mean**	**COV (%)**	**Mean**	**COV (%)**	**Mean**	**COV (%)**
M.C. (%)	15.41	3.44	15.89	1.70	16.26	5.36
S.G.	0.49	10.35	0.49	8.13	0.48	15.01
D.E. 5% Offset Yield (lbs)	4815	19.24	4812	15.99	4855	16.54
D.E. Capacity (lbs)	6313	12.06	6044	14.58	6198	17.05

M.C.: Moisture Content
S.G.: Specific Gravity
D.E.: Dowel Embedment Data
xxD: Refers to Row Spacing

4.5 - Effects of Row Spacing

In this section, the effects of variable row spacing on connection performance characteristics are analyzed and discussed. Connection performance characteristics including ductility ratio, connection capacity, and 5% offset yield strength have been normalized to means values obtained for single-bolt connection tests for each bolt diameter. To observe trends concerning 5% offset yield strength and connection capacity, values are shown a per-bolt basis for each connection tested. The results are presented in a series of plots to follow, with the Y-axis representing the parameter of interest, and the X-axis representing the total number of bolts. The mean values for single-row configurations, and those with 2D and 3D row spacings are connected using dashed lines to allow visualization of any trends present. One data set from each of the 12.7 mm (½ in.) and 19.1 mm (¾ in.) diameter bolt series indicating 2.5D row spacing, identified both by name and by a black range bar in the plot, is intended to verify a trend between 2D and 3D row spacing. Range bars encompassing the maximum and minimum values for a given configuration are included to provide an indication of the distribution of data around the mean.

A statistical analysis was performed for all tests undergoing the prescribed reverse cyclic loading protocol to make inferences regarding the relative effects of row spacing on connection ductility ratio, connection capacity, and 5% offset yield strength. It was assumed that the data was normally distributed, and the mean and population variances were equal. Two-sample t-tests, with a significance level of $\alpha = 0.05$, were performed to test the null hypothesis that any two population means are equal.

4.5.1 - Ductility Ratio

Ductility ratio is based on the elastic-plastic yield strength of a connection, and is defined as a connection's ability to resist load once it has yielded. Ductility ratio, and normalized ductility ratio data for tests performed using each of the three bolt diameters may be found in Tables 4.7, 4.9, and 4.11. Plots displaying normalized ductility ratio data for each bolt diameter are shown in Figures 4.19, 4.20, and 4.21. Statistical inferences to determine whether the null hypothesis could be rejected for each bolt diameter can be found in Tables 4.8, 4.10, and 4.12.

Table 4.7: Tested and normalized ductility ratio data; predicted Mode IV yield.

Tested	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	2.96	2.87	4.65	4.46	4.43	1.77
Test 2	4.87	3.62	4.76	3.22	1.94	4.89
Test 3	3.21	3.42	4.80	6.57	1.96	1.99
Test 4	4.48	1.25	4.85	4.73	1.32	1.63
Test 5	5.34	3.80	4.28	6.76	3.45	1.61
Test 6	5.35	2.70	3.97	6.03	1.42	2.60
Test 7	2.98	3.63	5.01	4.51	3.82	3.52
Test 8	4.19	3.10	5.81	4.58	1.64	1.54
Test 9	4.32	1.67	4.12	5.85	2.40	1.25
Test 10	5.11	4.48	5.49	5.27	1.97	4.78
Mean	4.28	3.05	4.77	5.20	2.43	2.56

Normalized	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	0.69	0.67	1.09	1.04	1.03	0.41
Test 2	1.14	0.84	1.11	0.75	0.45	1.14
Test 3	0.75	0.80	1.12	1.53	0.46	0.46
Test 4	1.05	0.29	1.13	1.11	0.31	0.38
Test 5	1.25	0.89	1.00	1.58	0.81	0.38
Test 6	1.25	0.63	0.93	1.41	0.33	0.61
Test 7	0.70	0.85	1.17	1.05	0.89	0.82
Test 8	0.98	0.72	1.36	1.07	0.38	0.36
Test 9	1.01	0.39	0.96	1.37	0.56	0.29
Test 10	1.19	1.05	1.28	1.23	0.46	1.12
Mean	1.00	0.71	1.12	1.21	0.57	0.60
Stdev	0.22	0.23	0.13	0.26	0.25	0.32

Predicted Mode IV yield normalized ductility ratio (based on single-bolt results).

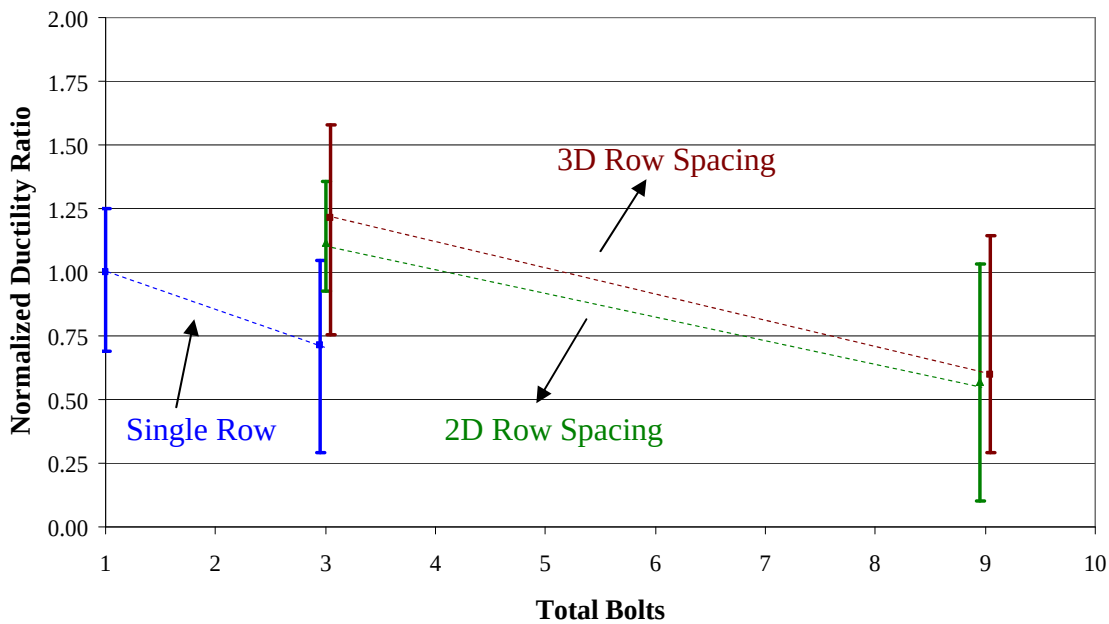

Figure 4.19: Normalized ductility ratio; 6.4 mm (¼ in.) diameter bolt series.

Table 4.8: Statistical inferences concerning means; predicted Mode IV yield.

t-statistic for small sample test concerning means differences

t-statistic	C1	C2	C4	C5	C8	C9
C1 (1R1 7D)	0					
C2 (1R3 7D)	2.85	0				
C4 (3R1 2D)	-1.42	-4.77	0			
C5 (3R1 3D)	-2.00	-4.59	-1.08	0		
C8 (3R3 2D)	4.07	1.34	6.03	5.65	0	
C9 (3R3 3D)	3.29	0.93	4.73	4.76	-0.22	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C1	C2	C4	C5	C8	C9
C1 (1R1 7D)	0					
C2 (1R3 7D)	Re. Ho	0				
C4 (3R1 2D)	C.R.Ho	Re. Ho	0			
C5 (3R1 3D)	C.R.Ho	Re. Ho	C.R.Ho	0		
C8 (3R3 2D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	0	
C9 (3R3 3D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.9: Tested and normalized ductility ratio data; predicted Mode III_s yield.

Tested	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	1.63	1.20	1.71	2.16	1.66	1.27	1.39
Test 2	2.09	1.31	2.70	1.73	1.83	1.23	1.92
Test 3	2.15	1.10	1.82	1.74	2.19	1.48	1.54
Test 4	1.77	1.27	2.51	1.78	1.86	1.30	1.21
Test 5	2.25	1.16	1.44	2.20	1.53	1.23	1.84
Test 6	1.48	1.11	Censored	2.46	1.92	1.44	1.48
Test 7	1.94	1.36	1.52	1.55	1.67	1.38	1.27
Test 8	1.91	Censored	2.19	1.66	2.10	1.22	1.27
Test 9	1.82	1.34	1.50	1.95	2.06	1.46	Censored
Test 10	2.10	1.26	1.80	1.64	1.81	1.43	1.43
Mean	1.91	1.23	1.91	1.89	1.86	1.34	1.48

Normalized	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	0.85	0.63	0.90	1.13	0.87	0.66	0.73
Test 2	1.09	0.68	1.41	0.91	0.96	0.65	1.00
Test 3	1.12	0.57	0.95	0.91	1.15	0.78	0.80
Test 4	0.92	0.66	1.31	0.93	0.97	0.68	0.63
Test 5	1.17	0.61	0.75	1.15	0.80	0.65	0.96
Test 6	0.77	0.58	Censored	1.28	1.00	0.75	0.78
Test 7	1.01	0.71	0.79	0.81	0.87	0.72	0.66
Test 8	1.00	Censored	1.15	0.87	1.10	0.64	0.66
Test 9	0.95	0.70	0.78	1.02	1.08	0.77	Censored
Test 10	1.10	0.66	0.94	0.86	0.95	0.75	0.75
Mean	1.00	0.64	1.00	0.99	0.97	0.70	0.78
Stdev	0.13	0.05	0.24	0.15	0.11	0.06	0.13

Predicted Mode III_s yield normalized ductility ratio (based on single-bolt results).

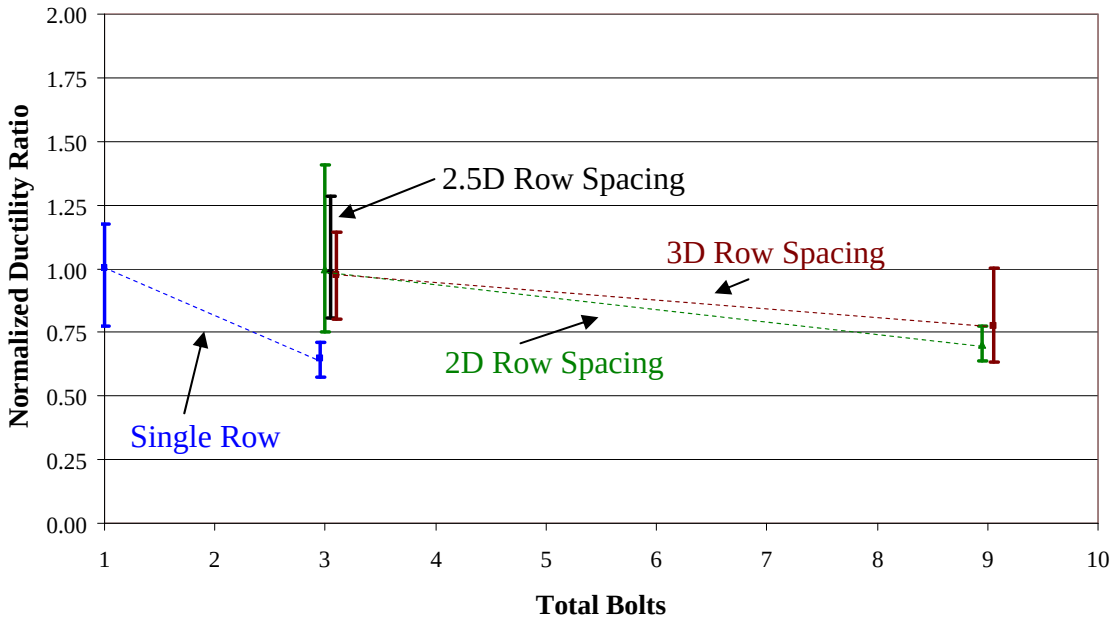

Figure 4.20: Normalized ductility ratio; 12.7 mm (½ in.) diameter bolt series.

Table 4.10: Statistical inferences concerning means; predicted Mode III_s yield.

t-statistic for small sample test concerning means differences

t-statistic	C11	C12	C14	C16	C15	C18	C19
C11 (1R1 3.5D)	0						
C12 (1R3 3.5D)	7.82	0					
C14 (3R1 2D)	0.02	-4.35	0				
C16 (3R1 2.5D)	0.21	-6.31	0.12	0			
C15 (3R1 3D)	0.48	-8.22	0.28	0.20	0		
C18 (3R3 2D)	6.77	-2.39	3.82	5.46	6.97	0	
C19 (3R3 3D)	3.78	-2.80	2.45	3.18	3.59	-1.61	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C11	C12	C14	C16	C15	C18	C19
C11 (1R1 3.5D)	0						
C12 (1R3 3.5D)	Re. Ho	0					
C14 (3R1 2D)	C.R.Ho	Re. Ho	0				
C16 (3R1 2.5D)	C.R.Ho	Re. Ho	C.R.Ho	0			
C15 (3R1 3D)	C.R.Ho	Re. Ho	C.R.Ho	C.R.Ho	0		
C18 (3R3 2D)	Re. Ho	Re. Ho	Re. Ho	Re. Ho	Re. Ho	0	
C19 (3R3 3D)	Re. Ho	Re. Ho	Re. Ho	Re. Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.11: Tested and normalized ductility ratio data; predicted Mode II yield.

Tested	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	1.84	1.22	1.84	1.54	1.31	1.38	1.57
Test 2	1.58	1.47	1.75	1.77	1.17	1.52	1.50
Test 3	1.62	1.26	1.64	1.61	1.58	1.85	1.71
Test 4	1.57	1.33	1.40	1.45	1.44	1.50	1.80
Test 5	1.50	1.54	1.77	1.98	1.34	1.77	1.42
Test 6	2.04	1.09	1.46	1.98	1.10	1.66	1.62
Test 7	1.74	1.27	1.73	1.62	1.14	1.05	1.55
Test 8	1.47	1.34	1.52	1.51	1.68	1.40	1.40
Test 9	2.11	1.35	1.88	1.52	1.57	1.39	1.66
Test 10	1.92	1.42	1.41	1.42	1.63	1.27	1.52
Mean	1.74	1.33	1.64	1.64	1.40	1.48	1.58

Normalized	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	1.06	0.70	1.06	0.89	0.75	0.79	0.90
Test 2	0.91	0.85	1.01	1.02	0.67	0.88	0.86
Test 3	0.93	0.72	0.94	0.92	0.91	1.06	0.98
Test 4	0.91	0.77	0.80	0.83	0.83	0.86	1.03
Test 5	0.86	0.89	1.02	1.14	0.77	1.02	0.82
Test 6	1.17	0.62	0.84	1.14	0.64	0.95	0.93
Test 7	1.00	0.73	0.99	0.93	0.66	0.60	0.89
Test 8	0.84	0.77	0.87	0.87	0.97	0.80	0.81
Test 9	1.21	0.78	1.08	0.87	0.90	0.80	0.95
Test 10	1.11	0.82	0.81	0.82	0.94	0.73	0.87
Mean	1.00	0.76	0.94	0.94	0.80	0.85	0.91
Stdev	0.13	0.08	0.10	0.12	0.12	0.14	0.07

Predicted Mode II normalized ductility ratio (based on single bolt results).

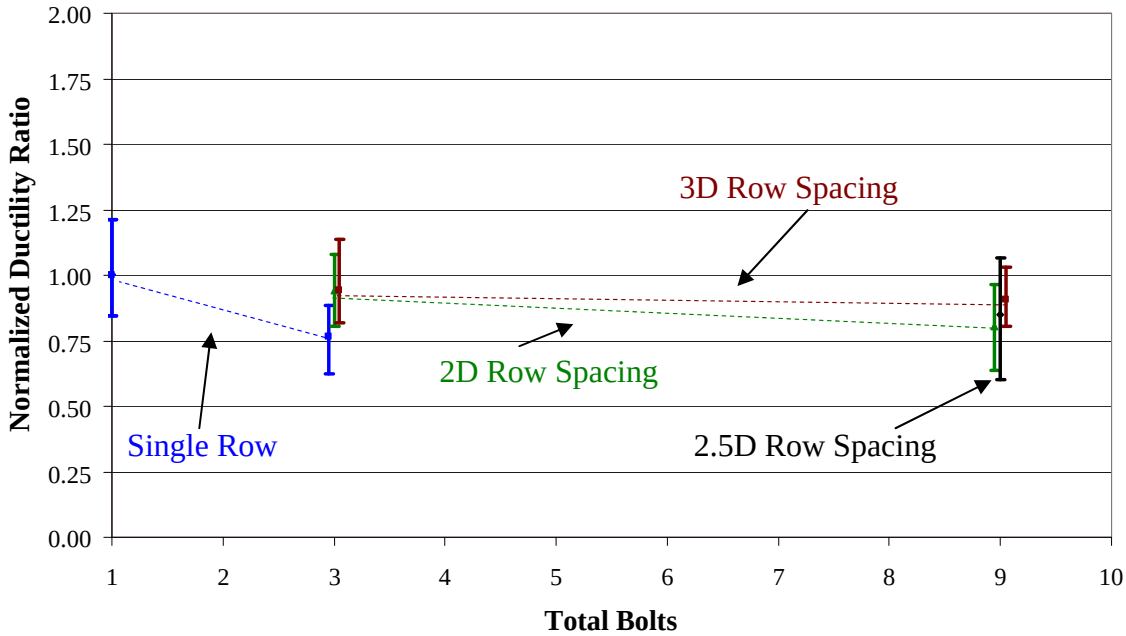

Figure 4.21: Normalized ductility ratio; 19.1 mm (¾ in.) diameter bolt series.

Table 4.12: Statistical inferences concerning means; predicted Mode II yield.

t-statistic for small sample test concerning means differences

t-statistic	C21	C22	C24	C25	C28	C30	C29
C21 (1R1 2.3D)	0						
C22 (1R3 2.3D)	4.94	0					
C24 (3R1 2D)	1.09	-4.39	0				
C25 (3R1 3D)	1.04	-4.05	0.00	0			
C28 (3R3 2D)	3.47	-0.86	2.73	2.59	0		
C30(3R3 2.5D)	2.50	-1.74	1.69	1.61	-0.80	0	
C29 (3R3 3D)	2.01	-4.31	0.92	0.85	-2.28	-1.13	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C21	C22	C24	C25	C28	C30	C29
C21 (1R1 2.3D)	0						
C22 (1R3 2.3D)	Re. Ho	0					
C24 (3R1 2D)	C.R.Ho	Re. Ho	0				
C25 (3R1 3D)	C.R.Ho	Re. Ho	C.R.Ho	0			
C28 (3R3 2D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	0		
C30(3R3 2.5D)	Re. Ho	C.R.Ho	C.R.Ho	C.R.Ho	C.R.Ho	0	
C29 (3R3 3D)	C.R.Ho	Re. Ho	C.R.Ho	C.R.Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Based on data concerning normalized ductility ratio, connection failure mechanism was shown to have an effect regardless of connection geometry. The ductile failures associated with 6.4 mm (¼ in.) diameter bolts produced a wider range of results than did the brittle failures associated with 19.1 mm (¾ in.) diameter bolts by visual inspection of ductility ratio plots.

Inferences concerning normalized ductility ratio data for a constant number of 6.4 mm (¼ in.) or 19.1 mm (¾ in.) diameter bolts in a row, indicated that there was no statistical difference between the means of single-row and three-row configurations, except for the series using three rows of three 19.1 mm (¾ in.) diameter bolts with bolt rows spaced at 3D. Normalized ductility ratio results indicated a statistical difference existed concerning mean values of single-row and three rows of three 12.7 mm (½ in.) diameter bolt configurations.

With the exception of the 19.1 mm (¾ in.) diameter bolt series, inferences concerning mean ductility ratios indicated that there was no statistical difference when row spacing was increased from 2D to 3D for either single-bolt-per-row configurations or three-bolts-per-row configurations. The mean ductility ratio for nine bolt configurations differed when row spacing was increased from 2D to 3D, likely due to the relative failure mechanisms exhibited. At a row spacing of 2D, group tear-out was the predominant failure mechanism, whereas splitting was more commonly observed at 3D row spacings. Increased material loaded in tension parallel to grain adjacent to rows of bolts likely influenced the shift in failure mode, and increased ductility.

In summary, it could not be statistically proven that there existed a significant benefit to connection mean ductility ratio when row spacing was increased from 2D to

3D at a significance level of $\alpha = 0.05$ for single-bolt-per-row, or three-bolt-per-row configurations.

4.5.2 - 5% Offset Yield

To observe trends of connection 5% offset yield strength, the normalized per-bolt data was plotted against the total number of bolts, representing the group action factor of a given configuration. The 5% offset yield strength, and normalized 5% offset yield strength data for tests performed using each of the three bolt diameters can be found in Tables 4.13, 4.15, and 4.17. Plots displaying normalized 5% offset yield strength data for each bolt diameter are shown in Figures 4.22, 4.23, and 4.24. Statistical inferences to determine whether the null hypothesis could be rejected for data from each bolt diameter may be found in Tables 4.14, 4.16, and 4.18.

Table 4.13a: Tested 5% offset yield data; predicted Mode IV yield (N).

Tested	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	3715	2875	3028	3298	2634	2716
Test 2	2023	1899	3377	3099	2691	3015
Test 3	3653	2619	3570	2452	2766	2884
Test 4	3687	3077	2966	3757	2844	3049
Test 5	2640	2331	2521	3151	3126	2428
Test 6	3483	2848	2497	2745	2812	2687
Test 7	3697	2602	2326	2196	2638	3335
Test 8	2716	2671	3168	2956	2437	2865
Test 9	2946	3071	2656	2106	2390	2576
Test 10	3723	2737	2912	2835	2693	3095
Mean	3228	2673	2902	2860	2703	2865

Table 4.13b: Tested 5% offset yield data; predicted Mode IV yield (lbs).

Tested	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	835	646	681	741	592	611
Test 2	455	427	759	697	605	678
Test 3	821	589	803	551	622	648
Test 4	829	692	667	845	639	685
Test 5	593	524	567	708	703	546
Test 6	783	640	561	617	632	604
Test 7	831	585	523	494	593	750
Test 8	610	600	712	664	548	644
Test 9	662	690	597	474	537	579
Test 10	837	615	655	637	605	696
Mean	726	601	652	643	608	644

Table 4.13c: Normalized 5% offset yield data; predicted Mode IV yield.

Normalized	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	1.15	0.89	0.94	1.02	0.82	0.84
Test 2	0.63	0.59	1.05	0.96	0.83	0.93
Test 3	1.13	0.81	1.11	0.76	0.86	0.89
Test 4	1.14	0.95	0.92	1.16	0.88	0.94
Test 5	0.82	0.72	0.78	0.98	0.97	0.75
Test 6	1.08	0.88	0.77	0.85	0.87	0.83
Test 7	1.15	0.81	0.72	0.68	0.82	1.03
Test 8	0.84	0.83	0.98	0.92	0.75	0.89
Test 9	0.91	0.95	0.82	0.65	0.74	0.80
Test 10	1.15	0.85	0.90	0.88	0.83	0.96
Mean	1.00	0.83	0.90	0.89	0.84	0.89
Stdev	0.19	0.11	0.13	0.16	0.06	0.08

Predicted Mode IV normalized 5% offset yield (based on single-bolt results).

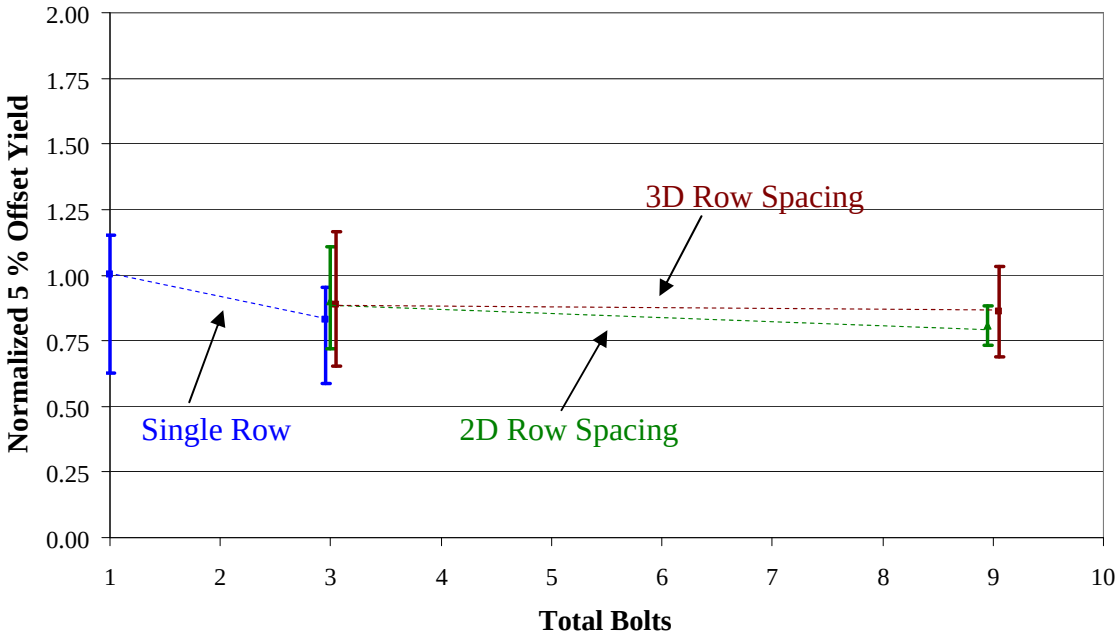

Figure 4.22: Normalized 5% offset yield strength; 6.4 mm (¼ in.) diameter bolt series.

Table 4.14: Statistical inferences concerning means; predicted Mode IV yield.

t-statistic for small sample test concerning means differences

t-statistic	C1	C2	C4	C5	C8	C9
C1 (1R1 7D)	0					
C2 (1R3 7D)	2.51	0				
C4 (3R1 2D)	1.42	-1.35	0			
C5 (3R1 3D)	1.47	-0.95	0.21	0		
C8 (3R3 2D)	2.59	-0.23	1.38	0.90	0	
C9 (3R3 3D)	1.73	-1.37	0.24	-0.03	-1.50	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C1	C2	C4	C5	C8	C9
C1 (1R1 7D)	0					
C2 (1R3 7D)	Re. Ho	0				
C4 (3R1 2D)	C.R.Ho	C.R.Ho	0			
C5 (3R1 3D)	C.R.Ho	C.R.Ho	C.R.Ho	0		
C8 (3R3 2D)	Re. Ho	C.R.Ho	C.R.Ho	C.R.Ho	0	
C9 (3R3 3D)	C.R.Ho	C.R.Ho	C.R.Ho	C.R.Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.15a: Tested 5% offset yield data; predicted Mode III_s yield (N).

Tested	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	8969	7913	8437	6847	8274	7302	4587
Test 2	7448	8160	7870	7892	8780	7568	7406
Test 3	6757	8479	8031	8482	9391	7265	7074
Test 4	8503	9347	7352	10728	8486	7537	8664
Test 5	6570	7563	6736	8422	8276	7019	8221
Test 6	9491	6703	6820	6913	8160	6883	6734
Test 7	8583	8159	7824	7795	7542	6576	9831
Test 8	10072	Censored	6217	10332	7811	6275	7734
Test 9	7489	8482	7202	7823	7858	7412	Censored
Test 10	8387	8313	7699	8582	7927	7301	7724
Mean	8227	8124	7419	8381	8250	7114	7553

Table 4.15b: Tested 5% offset yield data; predicted Mode III_s yield (lbs).

Tested	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	2016	1779	1897	1539	1860	1642	1031
Test 2	1674	1834	1769	1774	1974	1701	1665
Test 3	1519	1906	1806	1907	2111	1633	1590
Test 4	1912	2101	1653	2412	1908	1694	1948
Test 5	1477	1700	1514	1893	1860	1578	1848
Test 6	2134	1507	1533	1554	1834	1547	1514
Test 7	1929	1834	1759	1752	1695	1478	2210
Test 8	2264	Censored	1398	2323	1756	1411	1739
Test 9	1684	1907	1619	1759	1767	1666	Censored
Test 10	1886	1869	1731	1929	1782	1641	1737
Mean	1850	1826	1668	1884	1855	1599	1698

Table 4.15c: Normalized 5% offset yield data; predicted Mode III_s yield.

Normalized	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	1.09	0.96	1.03	0.83	1.01	0.89	0.56
Test 2	0.91	0.99	0.96	0.96	1.07	0.92	0.90
Test 3	0.82	1.03	0.98	1.03	1.14	0.88	0.86
Test 4	1.03	1.14	0.89	1.30	1.03	0.92	1.05
Test 5	0.80	0.92	0.82	1.02	1.01	0.85	1.00
Test 6	1.15	0.81	0.83	0.84	0.99	0.84	0.82
Test 7	1.04	0.99	0.95	0.95	0.92	0.80	1.20
Test 8	1.22	Censored	0.76	1.26	0.95	0.76	0.94
Test 9	0.91	1.03	0.88	0.95	0.96	0.90	Censored
Test 10	1.02	1.01	0.94	1.04	0.96	0.89	0.94
Mean	1.00	0.99	0.90	1.02	1.00	0.86	0.92
Stdev	0.14	0.09	0.08	0.16	0.07	0.05	0.18

Predicted Mode III_s normalized 5% offset yield (based on single-bolt results).

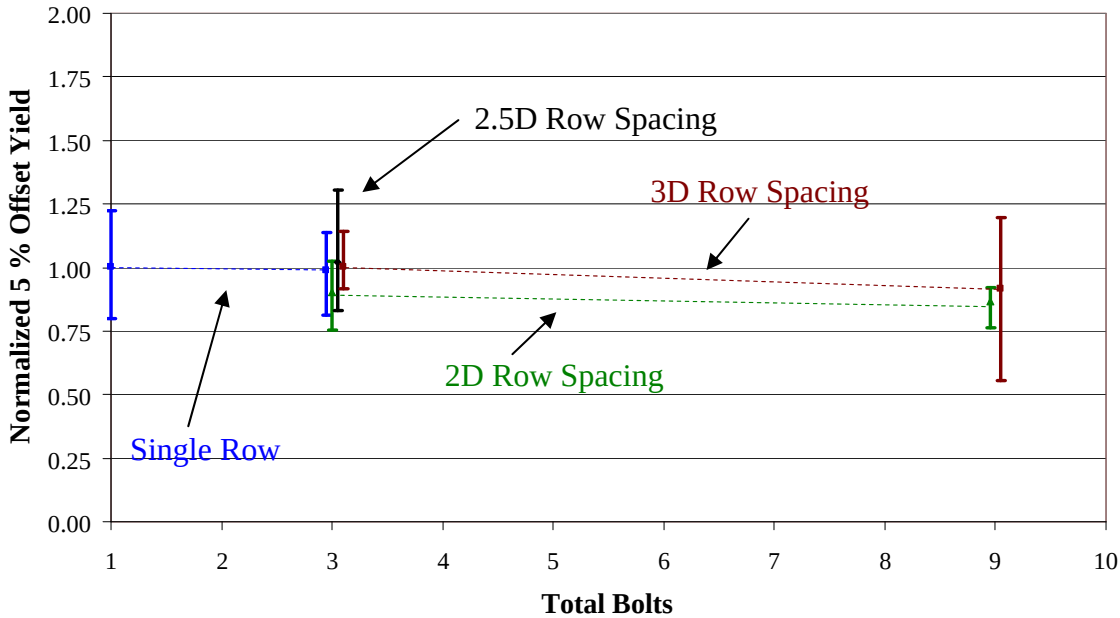

Figure 4.23: Normalized 5% offset yield strength; 12.7 mm (½ in.) diameter bolt series.

Table 4.16: Statistical inferences concerning means; predicted Mode III_s yield.

t-statistic for small sample test concerning means differences

t-statistic	C11	C12	C14	C16	C15	C18	C19
C11 (1R1 3.5D)	0						
C12 (1R3 3.5D)	0.23	0					
C14 (3R1 2D)	1.92	2.19	0				
C16 (3R1 2.5D)	-0.28	-0.53	-2.10	0			
C15 (3R1 3D)	-0.06	-0.44	-3.03	0.30	0		
C18 (3R3 2D)	2.88	3.77	1.20	2.97	5.25	0	
C19 (3R3 3D)	1.13	1.06	-0.26	1.33	1.43	-0.92	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C11	C12	C14	C16	C15	C18	C19
C11 (1R1 3.5D)	0						
C12 (1R3 3.5D)	C.R.Ho	0					
C14 (3R1 2D)	C.R.Ho	Re. Ho	0				
C16 (3R1 2.5D)	C.R.Ho	C.R.Ho	C.R.Ho	0			
C15 (3R1 3D)	C.R.Ho	C.R.Ho	Re. Ho	C.R.Ho	0		
C18 (3R3 2D)	Re. Ho	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	0	
C19 (3R3 3D)	C.R.Ho	C.R.Ho	C.R.Ho	C.R.Ho	C.R.Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.17a: Tested 5% offset yield data; predicted Mode II yield (N).

Tested	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	10937	9690	9643	11784	7076	10128	8331
Test 2	12065	9482	9485	12075	8417	6217	8555
Test 3	9046	11544	8915	11595	8567	6083	8620
Test 4	10520	10297	8829	10816	8680	10008	7711
Test 5	11184	9157	7709	8725	9250	5966	10403
Test 6	9564	9727	11275	8747	6364	6425	9071
Test 7	8672	12527	10517	11181	7976	10739	9301
Test 8	11378	9717	10605	11001	8306	8582	11075
Test 9	7260	10406	11834	9881	8002	9733	8614
Test 10	10700	10061	9625	13191	7291	11565	9743
Mean	10133	10261	9844	10900	7993	8545	9142

Table 4.17b: Tested 5% offset yield data; predicted Mode II yield (lbs.).

Tested	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	2459	2178	2168	2649	1591	2277	1873
Test 2	2712	2132	2132	2714	1892	1398	1923
Test 3	2034	2595	2004	2607	1926	1368	1938
Test 4	2365	2315	1985	2432	1951	2250	1734
Test 5	2514	2059	1733	1962	2079	1341	2339
Test 6	2150	2187	2535	1966	1431	1444	2039
Test 7	1950	2816	2364	2514	1793	2414	2091
Test 8	2558	2184	2384	2473	1867	1929	2490
Test 9	1632	2339	2660	2221	1799	2188	1937
Test 10	2405	2262	2164	2965	1639	2600	2190
Mean	2278	2307	2213	2450	1797	1921	2055

Table 4.17c: Normalized 5% offset yield data; predicted Mode II yield.

Normalized	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	1.08	0.96	0.95	1.16	0.70	1.00	0.82
Test 2	1.19	0.94	0.94	1.19	0.83	0.61	0.84
Test 3	0.89	1.14	0.88	1.14	0.85	0.60	0.85
Test 4	1.04	1.02	0.87	1.07	0.86	0.99	0.76
Test 5	1.10	0.90	0.76	0.86	0.91	0.59	1.03
Test 6	0.94	0.96	1.11	0.86	0.63	0.63	0.90
Test 7	0.86	1.24	1.04	1.10	0.79	1.06	0.92
Test 8	1.12	0.96	1.05	1.09	0.82	0.85	1.09
Test 9	0.72	1.03	1.17	0.98	0.79	0.96	0.85
Test 10	1.06	0.99	0.95	1.30	0.72	1.14	0.96
Mean	1.00	1.01	0.97	1.08	0.79	0.84	0.90
Stdev	0.14	0.10	0.12	0.14	0.08	0.21	0.10

Predicted Mode II normalized 5% offset yield (based on single-bolt results).

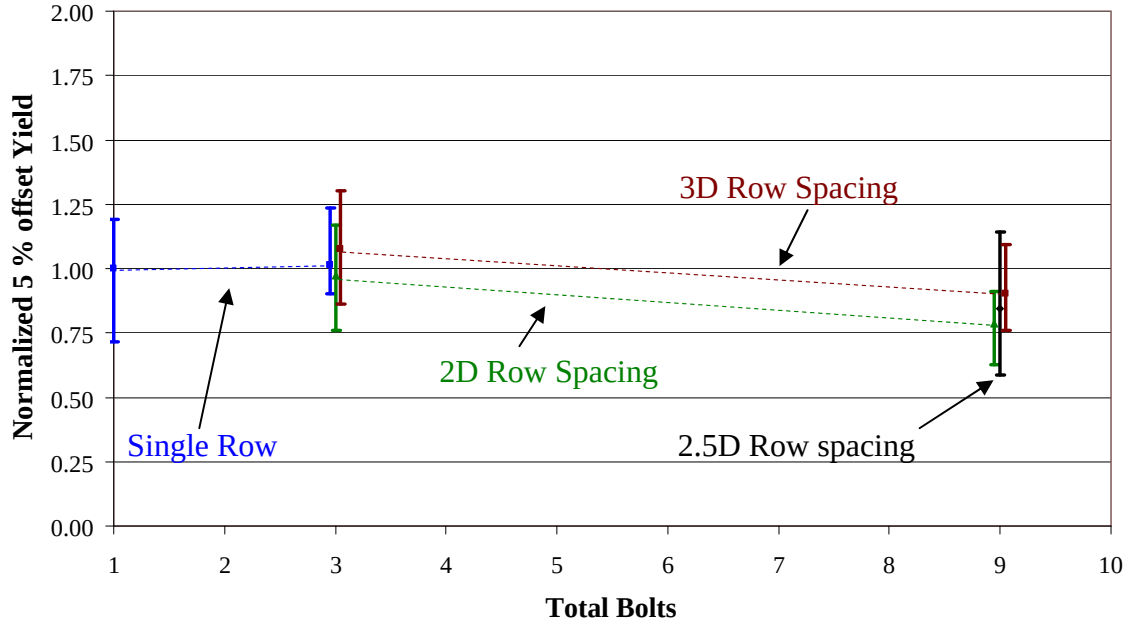

Figure 4.24: Normalized 5% offset yield strength; 19.1 mm (¾ in.) diameter bolt series.

Table 4.18: Statistical inferences concerning means; predicted Mode II yield.

t-statistic for small sample test concerning means differences

t-statistic	C21	C22	C24	C25	C28	C30	C29
C21 (1R1 2.3D)	0						
C22 (1R3 2.3D)	-0.23	0					
C24 (3R1 2D)	0.48	0.82	0				
C25 (3R1 3D)	-1.18	-1.15	-1.77	0			
C28 (3R3 2D)	3.98	5.34	3.89	5.51	0		
C30(3R3 2.5D)	1.91	2.25	1.64	2.86	-0.75	0	
C29 (3R3 3D)	1.75	2.44	1.39	3.17	-2.73	-0.79	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C21	C22	C24	C25	C28	C30	C29
C21 (1R1 2.3D)	0						
C22 (1R3 2.3D)	C.R.Ho	0					
C24 (3R1 2D)	C.R.Ho	C.R.Ho	0				
C25 (3R1 3D)	C.R.Ho	C.R.Ho	C.R.Ho	0			
C28 (3R3 2D)	Re. Ho	Re. Ho	Re. Ho	Re. Ho	0		
C30(3R3 2.5D)	C.R.Ho	Re. Ho	C.R.Ho	Re. Ho	C.R.Ho	0	
C29 (3R3 3D)	C.R.Ho	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Predicted Yield Mode IV multiple-bolt connections indicated no significant statistical difference concerning means based on normalized 5% offset yield strength data. Single-bolt connections within this series showed a significant statistical difference compared to single row of three-bolt, and three rows of three-bolt connections. Based on the above trend, any group action effect present in the connections tested was constant, thus independent of row spacing. This conclusion is consistent with current design philosophies in the United States which state that the group action factor is a function of a row of bolts and not row spacing.

With the exception of 2D row spacing, normalized 5% offset yield data for all 12.7 mm (½ in.) diameter bolt configurations tested indicate that there was no statistical difference between single-bolt and multiple-bolt configuration mean values. Based on the above trend, group action affects could be negated for connection geometries with three or fewer bolts per row, provided that spacing of bolts within a row is 7D, and when applicable, the row spacing is 2.5D or greater.

Inferences concerning normalized 5% offset yield data for all 19.1 mm (¾ in.) diameter bolt configurations tested, other than the three rows of three-bolts connection with 2D row spacing, indicated no significant statistical difference between single-bolt and multiple-bolt configuration values. Considering the three row of three-bolt configurations, a significant statistical difference did exist between 2D and 3D row spacing. The difference in 5% offset yield strength levels displayed by the above configurations was likely due to the observed failure mechanisms. The group tear-out failures displayed by the three rows of three bolt connections with 2D row spacing, inhibited a sufficient non-linear response to occur prior to catastrophic failure, preventing

the 5% offset yield value to be obtained. By definition, the 5% offset yield value defaulted to capacity for these connections.

In summary, row spacing had a less significant effect on the 5% offset yield strength in connections exhibiting ductile failure mechanisms. While it was clear from visual inspection of the normalized plots concerning 5% offset yield strength that larger row spacing increased this strength parameter, it could not be proven statistically that there was a difference between mean 2D and 3D row spacing values at a level of significance $\alpha = 0.05$ in the majority of configurations tested.

4.5.3 - Connection Capacity

To observe the trends of a connection's capacity, the normalized per-bolt data was plotted against the total number of bolts, representing the group action factor at capacity of a given configuration. Connection capacity, and normalized connection capacity data for tests performed using each of the three bolt diameters, can be found in Tables 4.19, 4.21, and 4.23. Plots displaying normalized connection capacity data for each bolt diameter are shown in Figures 4.25, 4.26, and 4.27. Statistical inferences to determine whether the null hypothesis could be rejected for data from each bolt diameter may be found in Tables 4.20, 4.22, and 4.24.

Table 4.19a: Tested connection capacity data; predicted Mode IV yield (N).

Tested	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	10526	4114	7231	8261	4363	3285
Test 2	9207	4539	7229	6685	3301	4090
Test 3	9535	3975	8337	5854	3372	3155
Test 4	10356	3474	7228	8401	3171	3049
Test 5	9254	3398	6196	5960	3859	3121
Test 6	9692	3690	8602	6052	3261	3014
Test 7	12992	4781	6355	7891	3844	3651
Test 8	8021	3363	6956	6806	3036	3555
Test 9	11021	3593	7035	6578	3226	2713
Test 10	8210	4507	5693	5239	3446	4761
Mean	9881	3943	7086	6773	3488	3439

Table 4.19b: Tested connection capacity data; predicted Mode IV yield (lbs.).

Tested	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	2366	925	1626	1857	981	738
Test 2	2070	1020	1625	1503	742	919
Test 3	2143	894	1874	1316	758	709
Test 4	2328	781	1625	1889	713	685
Test 5	2080	764	1393	1340	868	702
Test 6	2179	829	1934	1361	733	678
Test 7	2921	1075	1429	1774	864	821
Test 8	1803	756	1564	1530	683	799
Test 9	2478	808	1582	1479	725	610
Test 10	1846	1013	1280	1178	775	1070
Mean	2221	887	1593	1523	784	773

Table 4.19c: Normalized connection capacity data; predicted Mode IV yield.

Normalized	C1 (1R1)	C2 (1R3)	C4 (3R1)	C5 (3R1)	C8 (3R3)	C9 (3R3)
Test 1	1.07	0.42	0.73	0.84	0.44	0.33
Test 2	0.93	0.46	0.73	0.68	0.33	0.41
Test 3	0.96	0.40	0.84	0.59	0.34	0.32
Test 4	1.05	0.35	0.73	0.85	0.32	0.31
Test 5	0.94	0.34	0.63	0.60	0.39	0.32
Test 6	0.98	0.37	0.87	0.61	0.33	0.31
Test 7	1.31	0.48	0.64	0.80	0.39	0.37
Test 8	0.81	0.34	0.70	0.69	0.31	0.36
Test 9	1.12	0.36	0.71	0.67	0.33	0.27
Test 10	0.83	0.46	0.58	0.53	0.35	0.48
Mean	1.00	0.40	0.72	0.69	0.35	0.35
Stdev	0.15	0.05	0.09	0.11	0.04	0.06

Predicted Mode IV yield normalized connection capacity (based on single -bolt results).

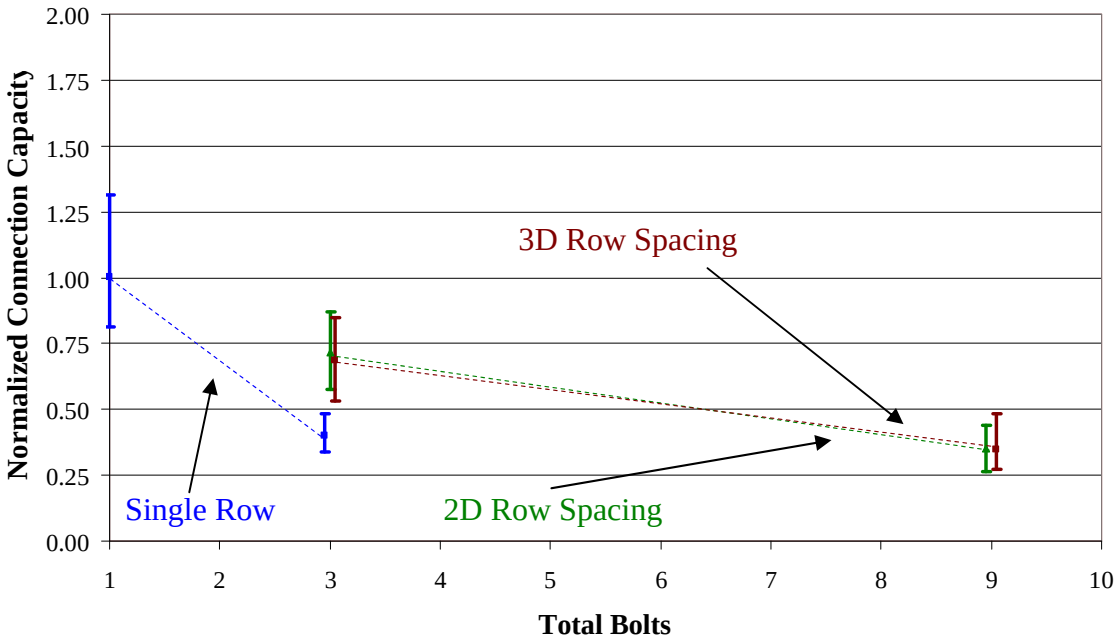

Figure 4.25: Normalized connection capacity; 6.4 mm (¼ in.) diameter bolt series.

Table 4.20: Statistical inferences concerning means; predicted Mode IV yield.

t-statistic for small sample test concerning means differences

t-statistic	C1	C2	C4	C5	C8	C9
C1 (1R1 7D)	0					
C2 (1R3 7D)	12.20	0				
C4 (3R1 2D)	5.19	-9.59	0			
C5 (3R1 3D)	5.44	-7.45	0.71	0		
C8 (3R3 2D)	13.43	2.17	11.56	8.98	0	
C9 (3R3 3D)	12.98	2.00	10.67	8.50	0.21	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C1	C2	C4	C5	C8	C9
C1 (1R1 7D)	0					
C2 (1R3 7D)	Re. Ho	0				
C4 (3R1 2D)	Re. Ho	Re. Ho	0			
C5 (3R1 3D)	Re. Ho	Re. Ho	C.R.Ho	0		
C8 (3R3 2D)	Re. Ho	Re. Ho	Re. Ho	Re. Ho	0	
C9 (3R3 3D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.21a: Tested connection capacity data; predicted Mode III_s yield (N).

Tested	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	11419	7913	10994	10927	10810	7969	7306
Test 2	11794	9402	9968	10433	12092	7886	9055
Test 3	10999	8479	11381	10909	14503	8822	8470
Test 4	11337	10428	11689	14605	10643	8890	9157
Test 5	10663	7563	8261	12713	11088	7540	9319
Test 6	9491	6890	7882	11310	12193	8011	7112
Test 7	13325	9883	9555	9941	9843	7893	10296
Test 8	11805	Censored	7795	12269	11263	6275	8867
Test 9	10427	9613	10402	12111	13223	8732	Censored
Test 10	12901	9272	10786	11702	11945	8313	9685
Mean	11416	8827	9871	11692	11760	8033	8807

Table 4.21b: Tested connection capacity data; predicted Mode III_s yield (lbs.).

Tested	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	2567	1779	2471	2456	2430	1791	1642
Test 2	2651	2114	2241	2345	2718	1773	2036
Test 3	2473	1906	2559	2452	3260	1983	1904
Test 4	2549	2344	2628	3283	2393	1998	2059
Test 5	2397	1700	1857	2858	2493	1695	2095
Test 6	2134	1549	1772	2543	2741	1801	1599
Test 7	2996	2222	2148	2235	2213	1774	2315
Test 8	2654	Censored	1752	2758	2532	1411	1993
Test 9	2344	2161	2338	2723	2973	1963	Censored
Test 10	2900	2085	2425	2631	2685	1869	2177
Mean	2566	1984	2219	2628	2644	1806	1980

Table 4.21c: Normalized connection capacity data; predicted Mode III_s yield.

Normalized	C11 (1R1)	C12 (1R3)	C14 (3R1)	C16 (3R1)	C15 (3R1)	C18 (3R3)	C19 (3R3)
Test 1	1.00	0.69	0.96	0.96	0.95	0.70	0.64
Test 2	1.03	0.82	0.87	0.91	1.06	0.69	0.79
Test 3	0.96	0.74	1.00	0.96	1.27	0.77	0.74
Test 4	0.99	0.91	1.02	1.28	0.93	0.78	0.80
Test 5	0.93	0.66	0.72	1.11	0.97	0.66	0.82
Test 6	0.83	0.60	0.69	0.99	1.07	0.70	0.62
Test 7	1.17	0.87	0.84	0.87	0.86	0.69	0.90
Test 8	1.03	Censored	0.68	1.07	0.99	0.55	0.78
Test 9	0.91	0.84	0.91	1.06	1.16	0.76	Censored
Test 10	1.13	0.81	0.94	1.03	1.05	0.73	0.85
Mean	1.00	0.77	0.86	1.02	1.03	0.70	0.77
Stdev	0.10	0.10	0.13	0.12	0.12	0.07	0.09

Predicted Mode III_s yield normalized connection capacity (based on single-bolt results).

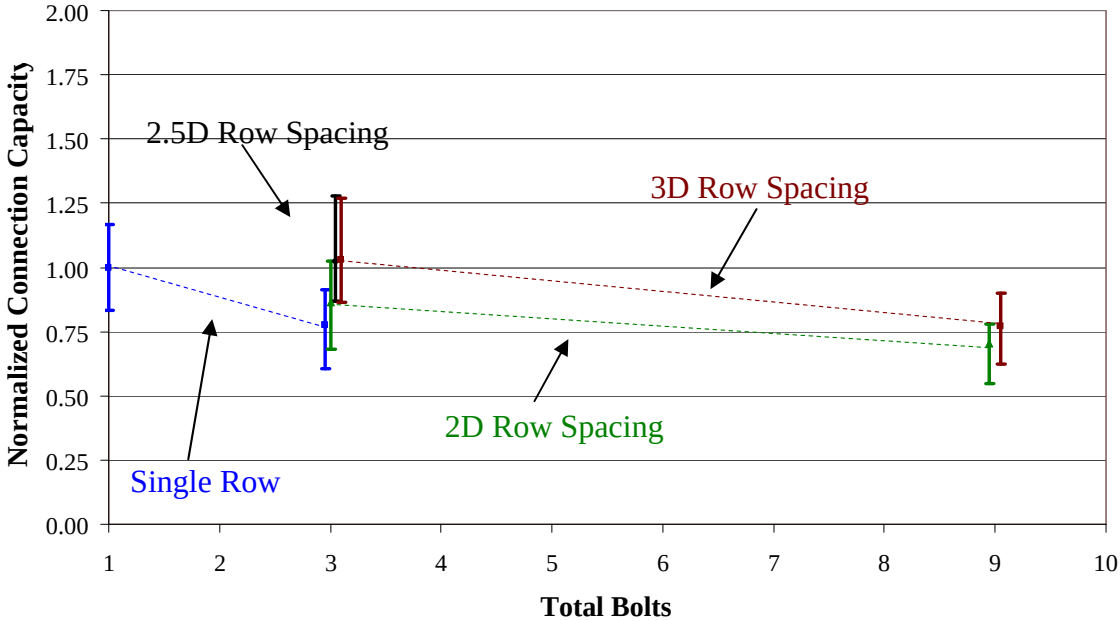

Figure 4.26: Normalized connection capacity; 12.7 mm (½ in.) diameter bolt series.

Table 4.22: Statistical inferences concerning means; predicted Mode III_s yield.

t-statistic for small sample test concerning means differences

t-statistic	C11	C12	C14	C16	C15	C18	C19
C11 (1R1 3.5D)	0						
C12 (1R3 3.5D)	4.88	0					
C14 (3R1 2D)	2.65	-1.71	0				
C16 (3R1 2.5D)	-0.50	-4.93	-2.92	0			
C15 (3R1 3D)	-0.62	-5.01	-3.01	-0.11	0		
C18 (3R3 2D)	7.81	1.76	3.54	7.52	7.57	0	
C19 (3R3 3D)	5.20	0.04	1.82	5.21	5.28	-1.86	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C11	C12	C14	C16	C15	C18	C19
C11 (1R1 3.5D)	0						
C12 (1R3 3.5D)	Re. Ho	0					
C14 (3R1 2D)	Re. Ho	C.R.Ho	0				
C16 (3R1 2.5D)	C.R.Ho	Re. Ho	Re. Ho	0			
C15 (3R1 3D)	C.R.Ho	Re. Ho	Re. Ho	C.R.Ho	0		
C18 (3R3 2D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	Re. Ho	0	
C19 (3R3 3D)	Re. Ho	C.R.Ho	C.R.Ho	Re. Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.23a: Tested connection capacity data; predicted Mode II yield (N).

Tested	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	15887	9822	13545	14667	8114	11297	10519
Test 2	15688	11633	14022	17135	8417	8847	11443
Test 3	12403	12499	11799	16230	9809	11386	10102
Test 4	13600	11882	11207	14549	10440	12082	9683
Test 5	14441	11492	10602	13073	10728	10157	11847
Test 6	15067	9065	13341	14531	6364	11713	12165
Test 7	12556	12995	13651	14113	7976	11357	11521
Test 8	14308	12498	13823	14509	10425	11943	12815
Test 9	11756	11412	18133	13423	11773	11365	12108
Test 10	16102	12995	11948	15925	8522	12836	11709
Mean	14181	11629	13207	14815	9257	11298	11391

Table 4.23b: Tested connection capacity data; predicted Mode II yield (lbs.).

Tested	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	3572	2208	3045	3297	1824	2540	2365
Test 2	3527	2615	3152	3852	1892	1989	2572
Test 3	2788	2810	2653	3649	2205	2560	2271
Test 4	3057	2671	2520	3271	2347	2716	2177
Test 5	3247	2584	2383	2939	2412	2283	2663
Test 6	3387	2038	2999	3267	1431	2633	2735
Test 7	2823	2921	3069	3173	1793	2553	2590
Test 8	3217	2810	3107	3262	2344	2685	2881
Test 9	2643	2566	4077	3018	2647	2555	2722
Test 10	3620	2921	2686	3580	1916	2886	2632
Mean	3188	2614	2969	3331	2081	2540	2561

Table 4.23c: Normalized connection capacity data; predicted Mode II yield.

Normalized	C21 (1R1)	C22 (1R3)	C24 (3R1)	C25 (3R1)	C28 (3R3)	C30 (3R3)	C29 (3R3)
Test 1	1.12	0.69	0.96	1.03	0.57	0.80	0.74
Test 2	1.11	0.82	0.99	1.21	0.59	0.62	0.81
Test 3	0.87	0.88	0.83	1.14	0.69	0.80	0.71
Test 4	0.96	0.84	0.79	1.03	0.74	0.85	0.68
Test 5	1.02	0.81	0.75	0.92	0.76	0.72	0.84
Test 6	1.06	0.64	0.94	1.02	0.45	0.83	0.86
Test 7	0.89	0.92	0.96	1.00	0.56	0.80	0.81
Test 8	1.01	0.88	0.97	1.02	0.74	0.84	0.90
Test 9	0.83	0.80	1.28	0.95	0.83	0.80	0.85
Test 10	1.14	0.92	0.84	1.12	0.60	0.91	0.83
Mean	1.00	0.82	0.93	1.04	0.65	0.80	0.80
Stdev	0.11	0.09	0.15	0.09	0.12	0.08	0.07

Predicted Mode II yield normalized connection capacity (based on single -bolt results).

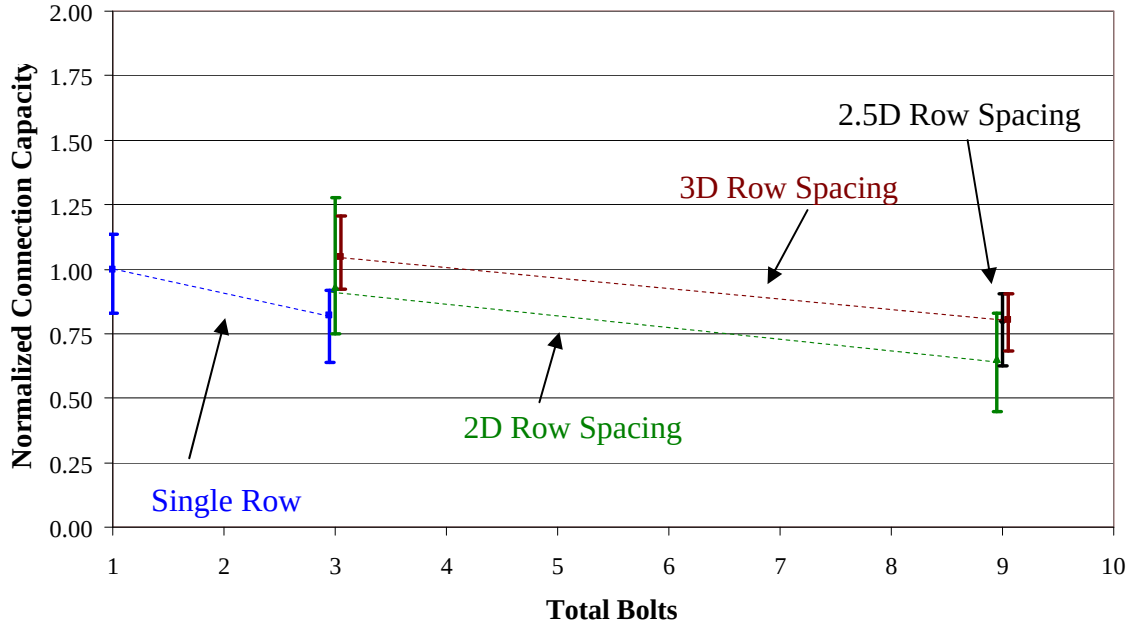

Figure 4.27: Normalized connection capacity; 19.1 mm (¾ in.) diameter bolt series.

Table 4.24: Statistical inferences concerning means; predicted Mode II yield.

t-statistic for small sample test concerning means differences

t-statistic	C21	C22	C24	C25	C28	C30	C29
C21 (1R1 2.33D)	0						
C22 (1R3 2.33D)	3.98	0					
C24 (3R1 2D)	1.18	-2.01	0				
C25 (3R1 3D)	-1.00	-5.56	-2.07	0			
C28 (3R3 2D)	6.90	3.59	4.68	8.50	0		
C30(3R3 2.5D)	4.79	0.61	2.54	6.64	-3.27	0	
C29 (3R3 3D)	4.79	0.46	2.47	6.75	-3.53	-0.20	0

$t_{\alpha/2}$ = 2.11 Level α = 0.05 and 18 dof's

Statistical inference between two means

Inference	C21	C22	C24	C25	C28	C30	C29
C21 (1R1 2.3D)	0						
C22 (1R3 2.3D)	Re. Ho	0					
C24 (3R1 2D)	C.R.Ho	C.R.Ho	0				
C25 (3R1 3D)	C.R.Ho	Re. Ho	C.R.Ho	0			
C28 (3R3 2D)	Re. Ho	Re. Ho	Re. Ho	Re. Ho	0		
C30(3R3 2.5D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	Re. Ho	0	
C29 (3R3 3D)	Re. Ho	C.R.Ho	Re. Ho	Re. Ho	Re. Ho	C.R.Ho	0

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Predicted Yield Mode IV multiple-bolt connections indicated no significant statistical difference concerning means based on normalized connection capacity data between 2D and 3D row spacing. There were, however, significant relative drops in capacity from single-bolt connections to three rows of one-bolt connections, and from three rows of one-bolt connections to three rows of three-bolt connections.

Inferences concerning normalized connection capacity data for three rows of one 12.7 mm (½ in.) diameter bolt configurations tested, other than that of 2D row spacing, indicated that there was no significant statistical difference between single-bolt and multiple-bolt configuration mean values for predicted Yield Mode III_s connections. Both nine-bolt configurations indicated a significant statistical difference concerning means when compared to single-bolt connections, but indicated no difference between 2D and 3D row spacing. This trend indicated that the group action effect at capacity for a given number of bolts-per-row was independent of row spacing, with the exception of the tested three rows of one bolt configurations at a row spacing of 2D.

Inferences concerning normalized connection capacity data for three rows of one 19.1 mm (¾ in.) diameter bolt configurations tested indicated that there was no significant statistical difference between mean single-bolt and multiple-bolt configuration values for predicted Yield Mode II connections. All three rows of three bolt configurations indicated a significant statistical difference concerning means when compared to single-bolt connections. Results of three rows of three bolt configurations indicated that the statistical differences between mean values at row spacings of 2.5D and 3D were not significant. However, the observed difference between the mean 2.5D and 2D row spacing was significant.

In summary, row spacing had a less significant effect on capacity in connections exhibiting ductile failure mechanisms than those exhibiting brittle failure mechanisms. This occurred when loads were unable to be redistributed to other bolts in the connection prior to failure. Row spacing trends were consistent independent of bolts per row, and indicated from visual inspection of the normalized plots that row spacing of 3D produced an increase in connection capacity relative to row spacing of 2D when considering Modes II and III_s yield. The increased material loaded in tension parallel to grain adjacent to rows of bolts likely accounted for the increase in connection capacity. Statistical analysis verified that it could not be disproved that the observed difference concerning mean connection capacity between configurations of 2D and 3D row spacing was significantly different at a level of significance $\alpha = 0.05$ for the majority of connections tested.

4.6 - Yield Limit Model

To begin this study, predictions were made to determine the yield mode and 5% offset yield strength based on NDS (AF&PA, 2001) recommendations for dowel bearing and specific gravity values, and the Yield Model. Members were sized and bolt diameters chosen in an attempt to produce the desired yield mode for each configuration tested. Preliminary tests including dowel bearing yield strength, bolt bending yield strength, and specific gravity were performed to determine whether the tabulated values of the NDS (2001) were correct, and if any configurations designed based on Yield Model predictions needed to be modified. Table 4.25 compares average experimental values for dowel bearing results with those obtained using the NDS dowel embedment equation of 11,200*G, where G is average specific gravity for each predicted yield mode.

Table 4.25a: Dowel embedment experimental/predicted results (kPa).

Predicted Yield Mode	Main member				Side Member			
	S.G.	11200*G	Tested	% Difference	S.G.	11200*G	Tested	% Difference
IV	0.50	38570	37730	-2.18	0.50	38380	36290	-5.46
III	0.47	36100	25980	-28.04	0.49	37790	28420	-24.80
II	0.47	36620	27530	-24.82	0.48	36850	27850	-24.44

Table 4.25b: Dowel embedment experimental/predicted results (psi).

Predicted Yield Mode	Main member				Side Member			
	S.G.	11200*G	Tested	% Difference	S.G.	11200*G	Tested	% Difference
IV	0.50	5594	5472	-2.18	0.50	5567	5263	-5.46
III	0.47	5236	3768	-28.04	0.49	5481	4122	-24.80
II	0.47	5311	3993	-24.82	0.48	5345	4039	-24.44

The 2001 NDS (AF&PA, 2001) equation predicting D.E. strength based on specific gravity was sufficiently accurate for Mode IV connections. Specific gravity values for Mode II and Mode III_s connections were consistent with those for mode IV. Problems inherent to this test method may account for the differences between NDS (2001) predicted and tested dowel embedment values for Mode II and Mode III_s connections shown in Table 4.25. Non-uniform stress distribution across the bolt bearing length and splitting in the test specimens prior to reaching the 5% offset strength was problematic with the larger diameter bolts despite utilization of the full-hole test method likely causing the difference between predicted and tested D.E. Strength values.

Additionally, strength values of tested bolts were greater than values recommended by the NDS (2001). Bending yield strength of 310 MPa (45,000 psi) and an ultimate bending capacity of 414 MPa (60,000 psi) are recommended for design by the NDS (2001). Listed in Table 4.26 are bolt bending yield strengths and capacities for the

three bolt diameter tested. Ten replications for each bolt diameter were tested in accordance with procedures outlined in Chapter Three.

Table 4.26a: F_{yb} Results (SI).

	6.4 mm diameter bolt		12.7 mm diameter bolt		19.1mm diameter bolt	
	Mean	COV (%)	Mean	COV (%)	Mean	COV (%)
F_{yb} (kPa)	551000	1.28	559000	2.83	556900	1.65
Capacity (kPa)	680800	0.78	645200	4.03	632800	2.73

Table 4.26b: F_{yb} Results (Std.).

	¼ in. diameter bolt		½ in. diameter bolt		¾ in. diameter bolt	
	Mean	COV (%)	Mean	COV (%)	Mean	COV (%)
F_{yb} (psi)	79920	1.28	81070	2.83	80760	1.65
Capacity (psi)	98750	0.78	93580	4.03	91780	2.73

Experimental values obtained in preliminary testing did not alter predicted yield modes, and full connection testing proceeded. The values obtained from dowel embedment tests and fastener bending yield tests were input directly into the yield limit equations provided by the NDS to determine the 5% offset yield strength and capacity of the connections tested. As such, design variables R_d, C_g, and C_D were taken as 1.0.

With the validity of YM predictions verified based on preliminary testing, experimental single-bolt and multiple-bolt 5% offset yield strengths and capacities were compared to those predicted using the YM. Experimental results are indicated by blue range bars encompassing maximum and minimum values, and correspond to the range bar to the left side of the parameter of interest. Predicted results are indicated by crimson range bars encompassing maximum and minimum values, and correspond to the range bar to the right side of the parameter of interest. Tested and predicted 5% offset yield strength values and capacities are illustrated in Figures 4.28 through 4.47.

A statistical analysis was performed for single-bolt and multiple-bolt tests in order to make inferences as to whether the model accurately predicted connection capacity and 5% offset yield strength values. A discussion of Yield Model results for all configurations tested will follow the presentation of graphical and statistical results. It was assumed that the data was normally distributed, and that the population variances and means were equal. Two-sample t-tests with a level of significance of $\alpha = 0.05$ were used to test the null hypothesis that any two population means are equal. Inferences concerning means were made based upon a $t_{critical}$ value of 2.11.

4.6.1 - Mode IV-Yield Limit Model

Yield strength and capacity values on a per bolt basis for configurations predicted to display Mode IV yield may be seen in Tables 4.27, 4.29, 4.31, 4.33, 4.35, and 4.37. Plots displaying tested and predicted values for 5% offset yield strength and capacity are shown in Figures 4.28, 4.29, 4.30, 4.31, 4.32, and 4.33. T-statistic values and decisions concerning statistical inferences may be found in Tables 4.28, 4.30, 4.32, 4.34, 4.36, and 4.38.

Table 4.27a: Mode IV experimental/predicted YLM comparison: C1 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	10526	4555	2.31	3715	3864	0.96
2	9207	3565	2.58	2023	3021	0.67
3	9535	4485	2.13	3653	3848	0.95
4	10356	3894	2.66	3687	3331	1.11
5	9254	3876	2.39	2640	3241	0.81
6	9692	4260	2.27	3483	3738	0.93
7	12992	4683	2.77	3697	3963	0.93
8	8021	4017	2.00	2716	3344	0.81
9	11021	4464	2.47	2946	3786	0.78
10	8210	3919	2.09	3723	3209	1.16
Mean	9881	4172	2.37	3228	3535	0.91

Table 4.27b: Mode IV experimental/predicted YLM comparison: C1 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2366	1024	2.31	835	869	0.96
2	2070	801	2.58	455	679	0.67
3	2143	1008	2.13	821	865	0.95
4	2328	875	2.66	829	749	1.11
5	2080	871	2.39	593	729	0.81
6	2179	958	2.27	783	840	0.93
7	2921	1053	2.77	831	891	0.93
8	1803	903	2.00	610	752	0.81
9	2478	1004	2.47	662	851	0.78
10	1846	881	2.09	837	721	1.16
Mean	2221	938	2.37	726	795	0.91

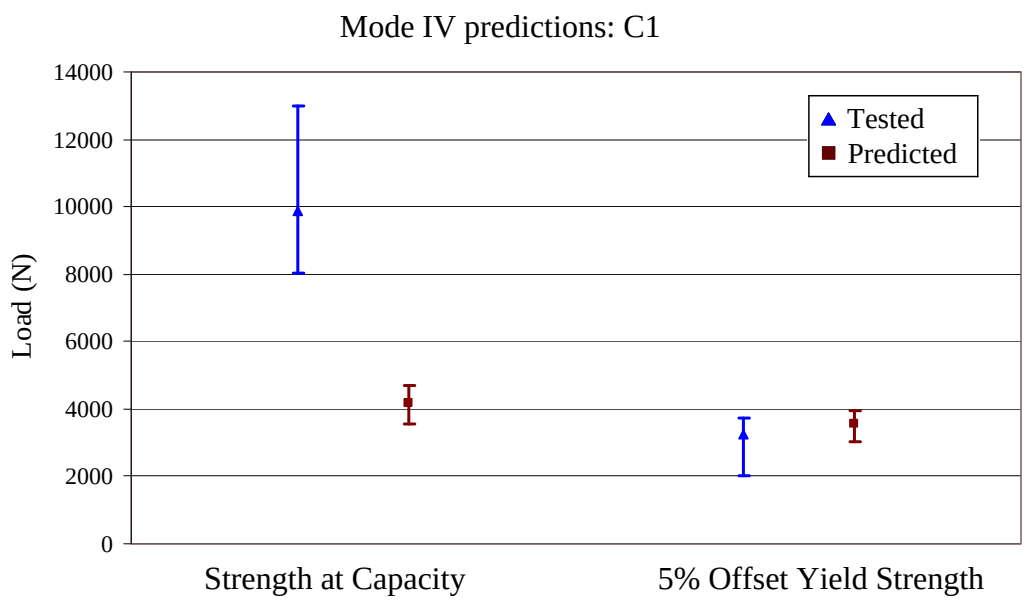

Figure 4.28a: Mode IV experimental/predicted YLM comparison plot: C1 (SI).

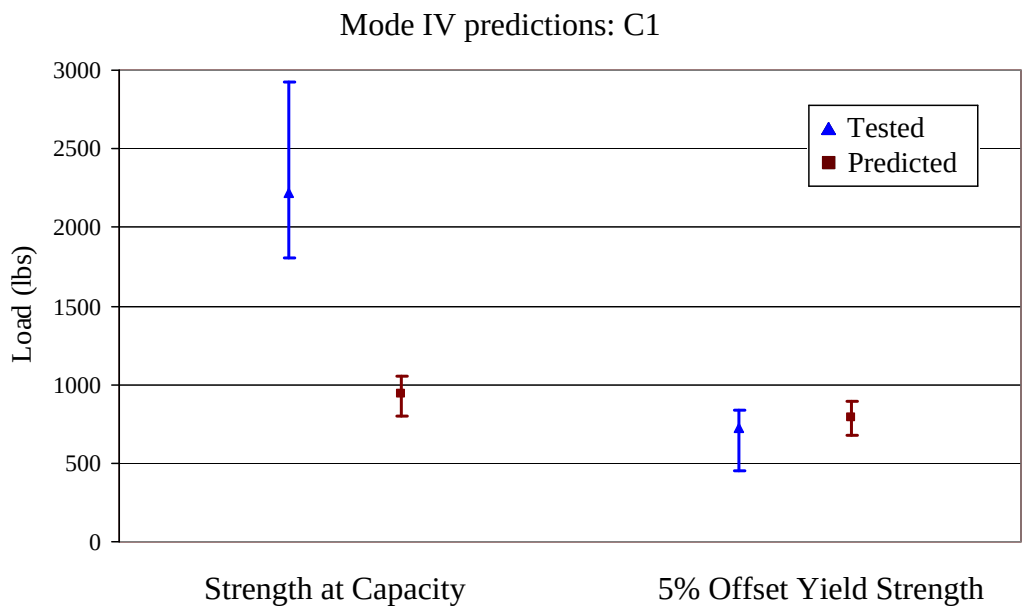

Figure 4.28b: Mode IV experimental/predicted YLM comparison plot: C1 (Std.).

Table 4.28: Inferences concerning means, predicted Mode IV yield: C1.

Inference	Capacity	5% Offset Yield
t-statistic	12.08	-1.40
Decision	Re. Ho	C.R.Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.29a: Mode IV experimental/predicted YLM comparison: C2 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	4114	4089	1.01	2875	3277	0.88
2	4539	4235	1.07	1899	3386	0.56
3	3975	3971	1.00	2619	3099	0.85
4	3474	4280	0.81	3077	3491	0.88
5	3398	3738	0.91	2331	2829	0.82
6	3690	3806	0.97	2848	3181	0.90
7	4781	3783	1.26	2602	3244	0.80
8	3363	4624	0.73	2671	3798	0.70
9	3593	4044	0.89	3071	3233	0.95
10	4507	3754	1.20	2737	3023	0.91
Mean	3943	4033	0.98	2673	3256	0.82

Table 4.29b: Mode IV experimental/predicted YLM comparison: C2 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	925	919	1.01	646	737	0.88
2	1020	952	1.07	427	761	0.56
3	894	893	1.00	589	697	0.85
4	781	962	0.81	692	785	0.88
5	764	840	0.91	524	636	0.82
6	829	856	0.97	640	715	0.90
7	1075	850	1.26	585	729	0.80
8	756	1040	0.73	600	854	0.70
9	808	909	0.89	690	727	0.95
10	1013	844	1.20	615	680	0.91
Mean	887	907	0.98	601	732	0.82

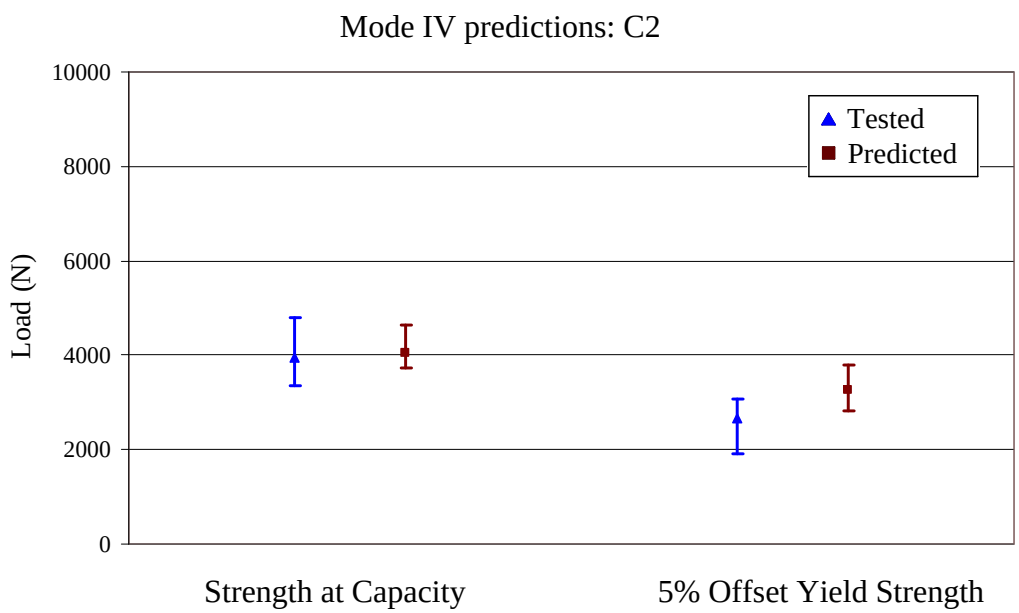

Figure 4.29a: Mode IV experimental/predicted YLM comparison plot: C2 (SI).

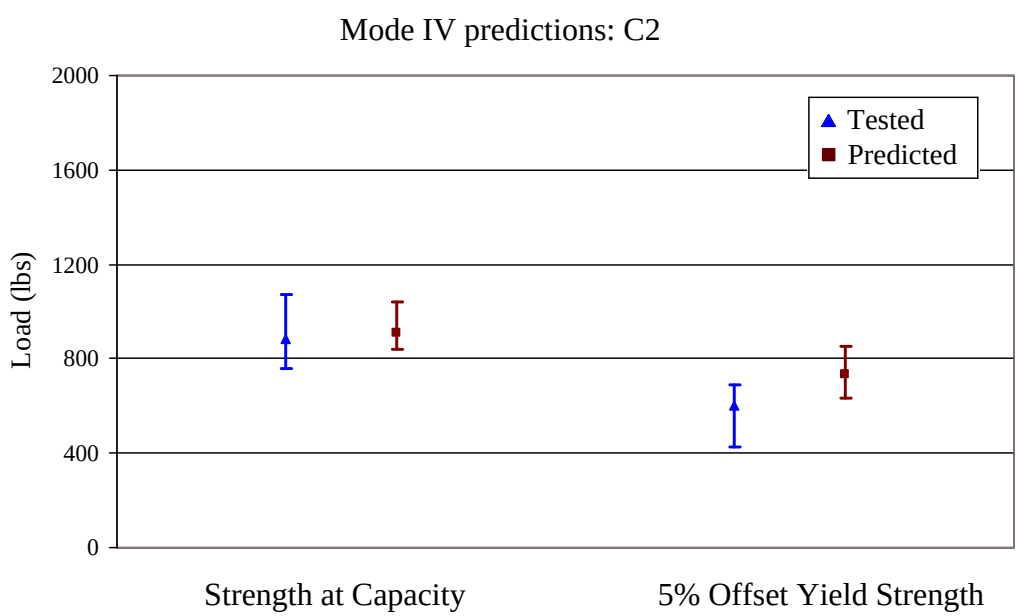

Figure 4.29b: Mode IV experimental/predicted YLM comparison plot: C2 (Std.).

Table 4.30: Inferences concerning means, predicted mode IV yield: C2.

Inference	Capacity	5% Offset Yield
t-statistic	-0.47	-4.17
Decision	C.R. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.31a: Mode IV experimental/predicted YLM comparison: C4 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	7231	4393	1.65	3028	3651	0.83
2	7229	4465	1.62	3377	3667	0.92
3	8337	4562	1.83	3570	3830	0.93
4	7228	3890	1.86	2966	3256	0.91
5	6196	3781	1.64	2521	2922	0.86
6	8602	4101	2.10	2497	3442	0.73
7	6355	4145	1.53	2326	3292	0.71
8	6956	4413	1.58	3168	3507	0.90
9	7035	4015	1.75	2656	3279	0.81
10	5693	4321	1.32	2912	3597	0.81
Mean	7086	4209	1.68	2902	3444	0.84

Table 4.31b: Mode IV experimental/predicted YLM comparison: C4 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	1626	988	1.65	681	821	0.83
2	1625	1004	1.62	759	824	0.92
3	1874	1025	1.83	803	861	0.93
4	1625	874	1.86	667	732	0.91
5	1393	850	1.64	567	657	0.86
6	1934	922	2.10	561	774	0.73
7	1429	932	1.53	523	740	0.71
8	1564	992	1.58	712	788	0.90
9	1582	903	1.75	597	737	0.81
10	1280	971	1.32	655	809	0.81
Mean	1593	946	1.68	652	774	0.84

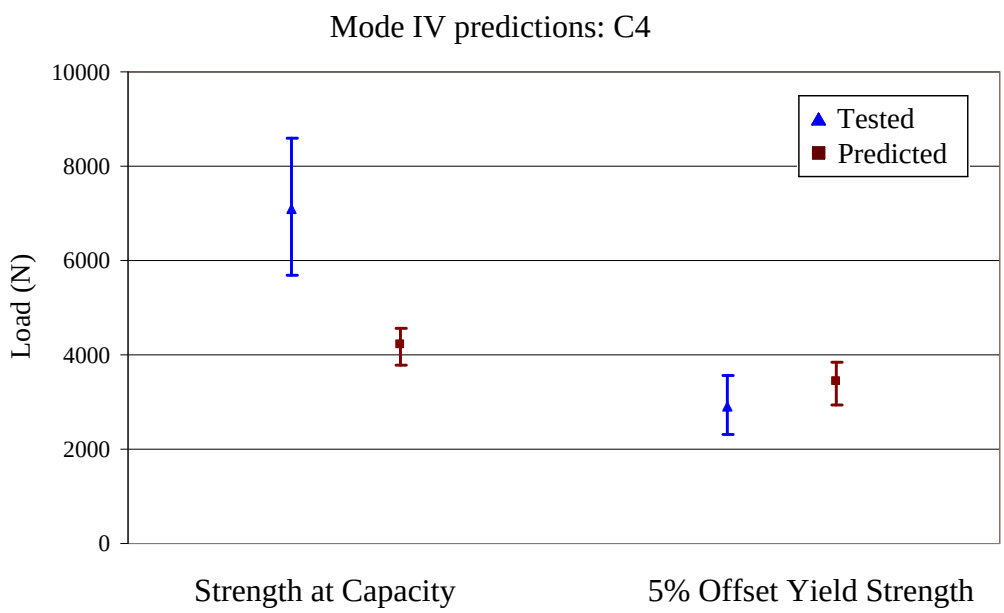

Figure 4.30a: Mode IV experimental/predicted YLM comparison plot: C4 (SI).

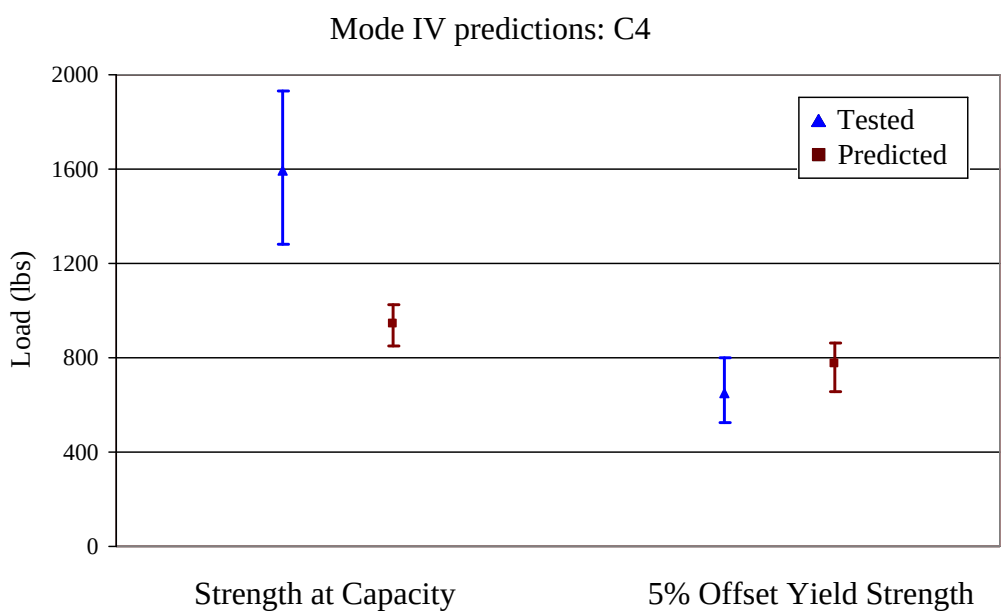

Figure 4.30b: Mode IV experimental/predicted YLM comparison plot: C4 (Std.).

Table 4.32: Inferences concerning means, predicted mode IV yield: C4.

Inference	Capacity	5% Offset Yield
t-statistic	9.76	-3.56
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.33a: Mode IV experimental/predicted YLM comparison: C5 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	8261	4313	1.92	3298	3540	0.93
2	6685	4267	1.57	3099	3477	0.89
3	5854	4156	1.41	2452	3140	0.78
4	8401	4657	1.80	3757	3874	0.97
5	5960	3681	1.62	3151	2940	1.07
6	6052	3875	1.56	2745	3404	0.81
7	7891	3906	2.02	2196	3146	0.70
8	6806	4204	1.62	2956	3373	0.88
9	6578	3864	1.70	2106	2878	0.73
10	5239	4000	1.31	2835	3163	0.90
Mean	6773	4092	1.65	2860	3294	0.87

Table 4.33b: Mode IV experimental/predicted YLM comparison: C5 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	1857	970	1.92	741	796	0.93
2	1503	959	1.57	697	782	0.89
3	1316	934	1.41	551	706	0.78
4	1889	1047	1.80	845	871	0.97
5	1340	827	1.62	708	661	1.07
6	1361	871	1.56	617	765	0.81
7	1774	878	2.02	494	707	0.70
8	1530	945	1.62	664	758	0.88
9	1479	869	1.70	474	647	0.73
10	1178	899	1.31	637	711	0.90
Mean	1523	920	1.65	643	740	0.87

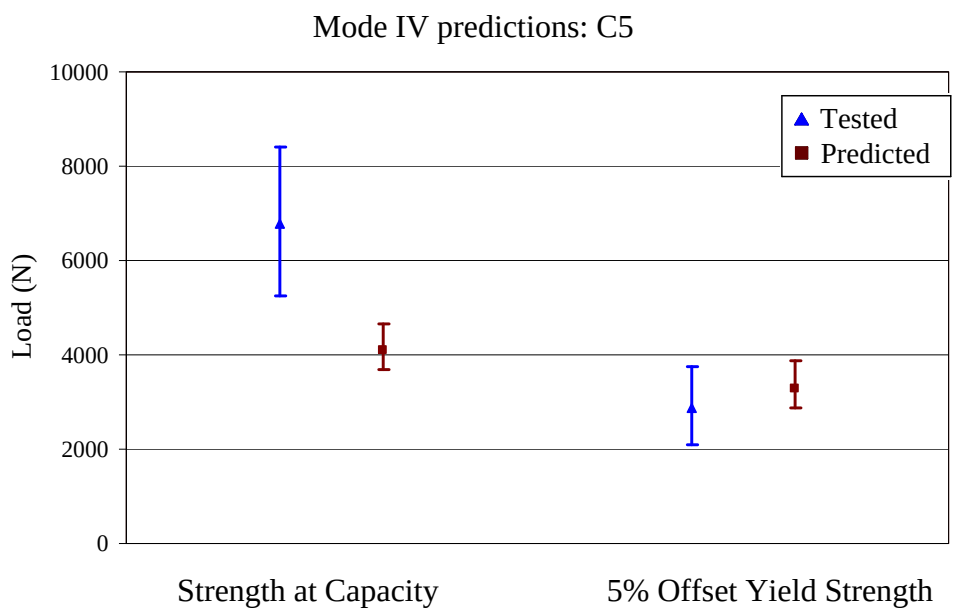

Figure 4.31a: Mode IV experimental/predicted YLM comparison plot: C5 (SI).

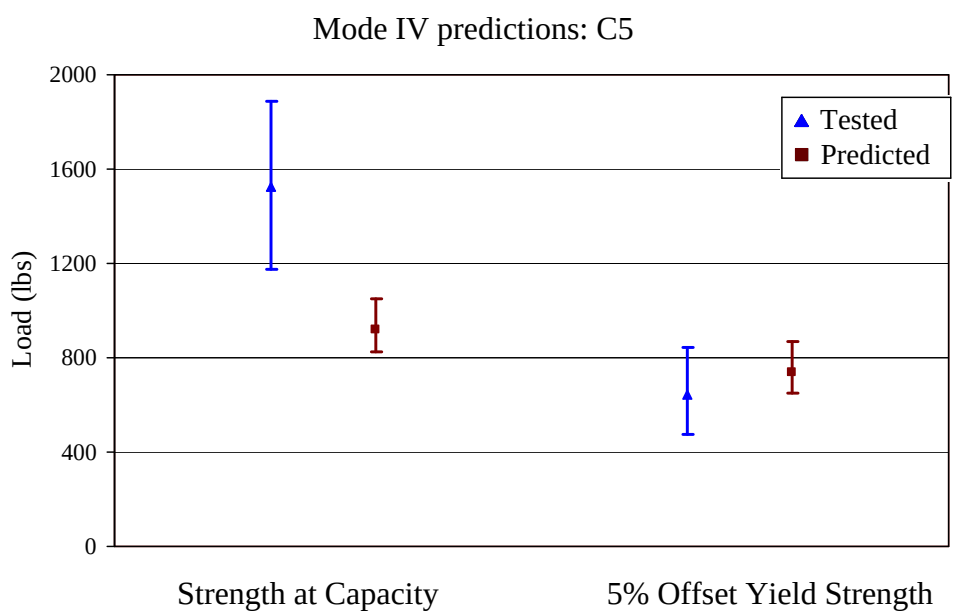

Figure 4.31b: Mode IV experimental/predicted YLM comparison plot: C5 (Std.).

Table 4.34: Inferences concerning means, predicted mode IV yield: C5.

Inference	Capacity	5% Offset Yield
t-statistic	7.58	-2.32
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.35a: Mode IV experimental/predicted YLM comparison: C8 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	4363	3667	1.19	2634	3026	0.87
2	3301	4175	0.79	2691	3253	0.83
3	3372	4241	0.80	2766	3444	0.80
4	3171	3934	0.81	2844	3296	0.86
5	3859	3899	0.99	3126	3084	1.01
6	3261	3781	0.86	2812	2972	0.95
7	3844	3833	1.00	2638	3247	0.81
8	3036	3884	0.78	2437	3127	0.78
9	3226	3525	0.92	2390	2761	0.87
10	3446	3988	0.86	2693	2947	0.91
Mean	3488	3893	0.90	2703	3116	0.87

Table 4.35b: Mode IV experimental/predicted YLM comparison: C8 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	981	824	1.19	592	680	0.87
2	742	939	0.79	605	731	0.83
3	758	954	0.80	622	774	0.80
4	713	884	0.81	639	741	0.86
5	868	876	0.99	703	693	1.01
6	733	850	0.86	632	668	0.95
7	864	862	1.00	593	730	0.81
8	683	873	0.78	548	703	0.78
9	725	792	0.92	537	621	0.87
10	775	896	0.86	605	663	0.91
Mean	784	875	0.90	608	700	0.87

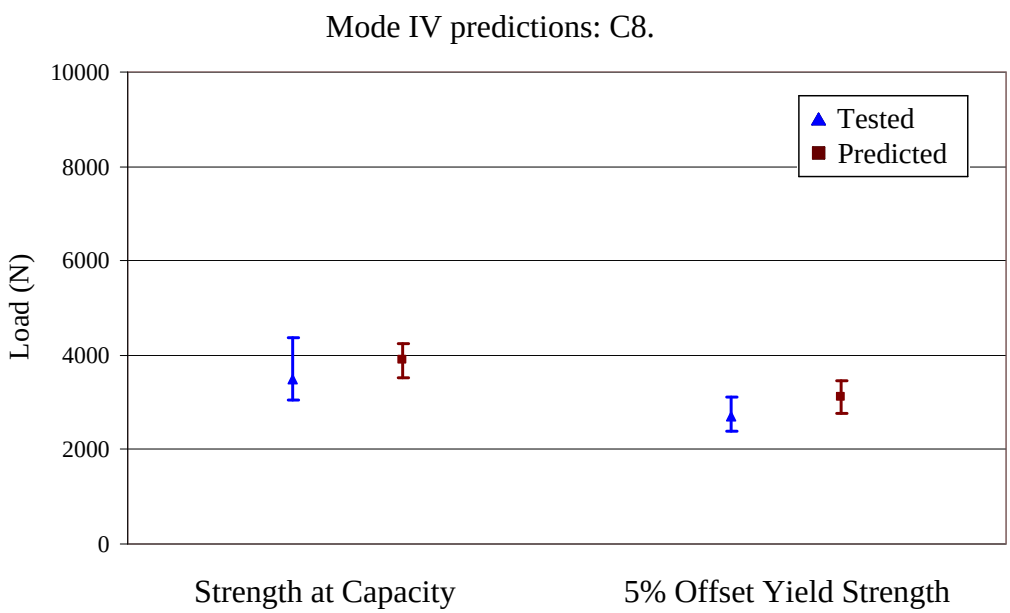

Figure 4.32a: Mode IV experimental/predicted YLM comparison plot: C8 (SI).

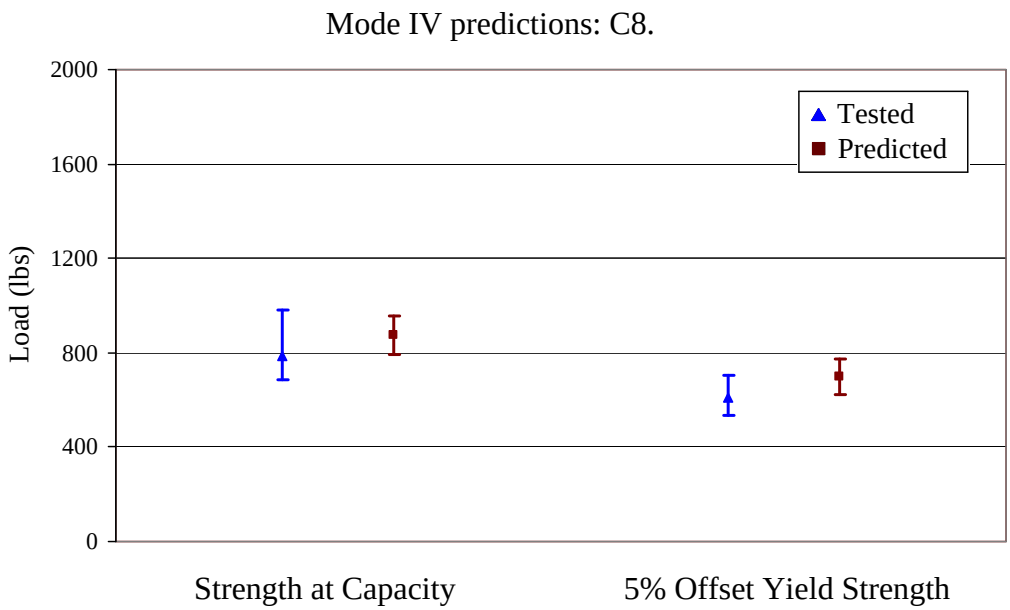

Figure 4.32b: Mode IV experimental/predicted YLM comparison plot: C8 (Std.).

Table 4.36: Inferences concerning means, predicted mode IV yield: C8.

Inference	Capacity	5% Offset Yield
t-statistic	-2.77	-4.51
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.37a: Mode IV experimental/predicted YLM comparison: C9 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	3285	3687	0.89	2716	2842	0.96
2	4090	4065	1.01	3015	3105	0.97
3	3155	4259	0.74	2884	3362	0.86
4	3049	4194	0.73	3049	3437	0.89
5	3121	3726	0.84	2428	2905	0.84
6	3014	3732	0.81	2687	3039	0.88
7	3651	4303	0.85	3335	3536	0.94
8	3555	4020	0.88	2865	3115	0.92
9	2714	3525	0.77	2576	2858	0.90
10	4761	4049	1.18	3095	3320	0.93
Mean	3439	3956	0.87	2865	3152	0.91

Table 4.37b: Mode IV experimental/predicted YLM comparison: C9 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	738	829	0.89	611	639	0.96
2	919	914	1.01	678	698	0.97
3	709	957	0.74	648	756	0.86
4	685	943	0.73	685	773	0.89
5	702	838	0.84	546	653	0.84
6	678	839	0.81	604	683	0.88
7	821	967	0.85	750	795	0.94
8	799	904	0.88	644	700	0.92
9	610	793	0.77	579	643	0.90
10	1070	910	1.18	696	746	0.93
Mean	773	889	0.87	644	709	0.91

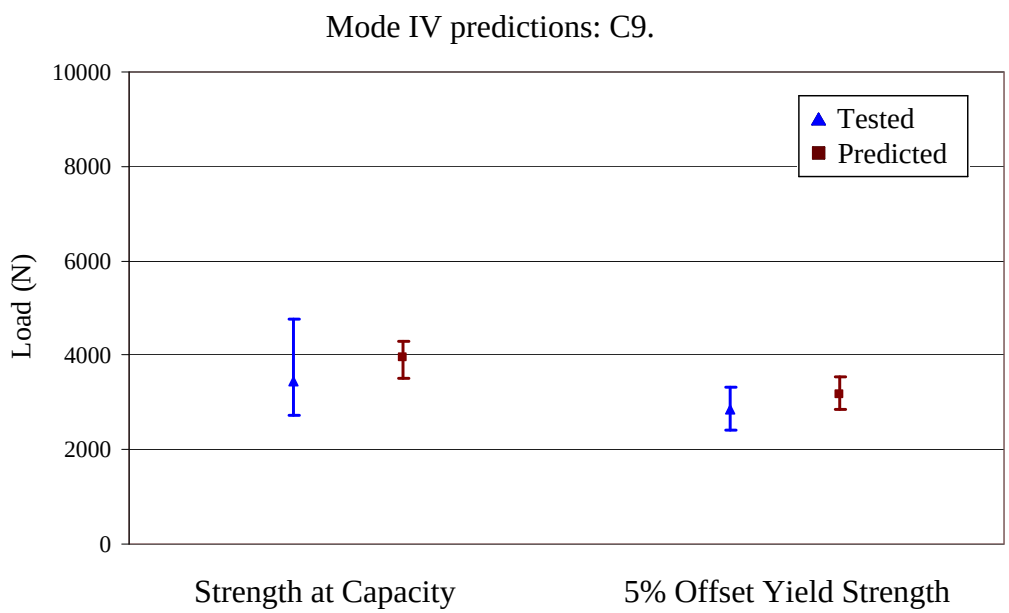

Figure 4.33a: Mode IV experimental/predicted YLM comparison plot: C9 (SI).

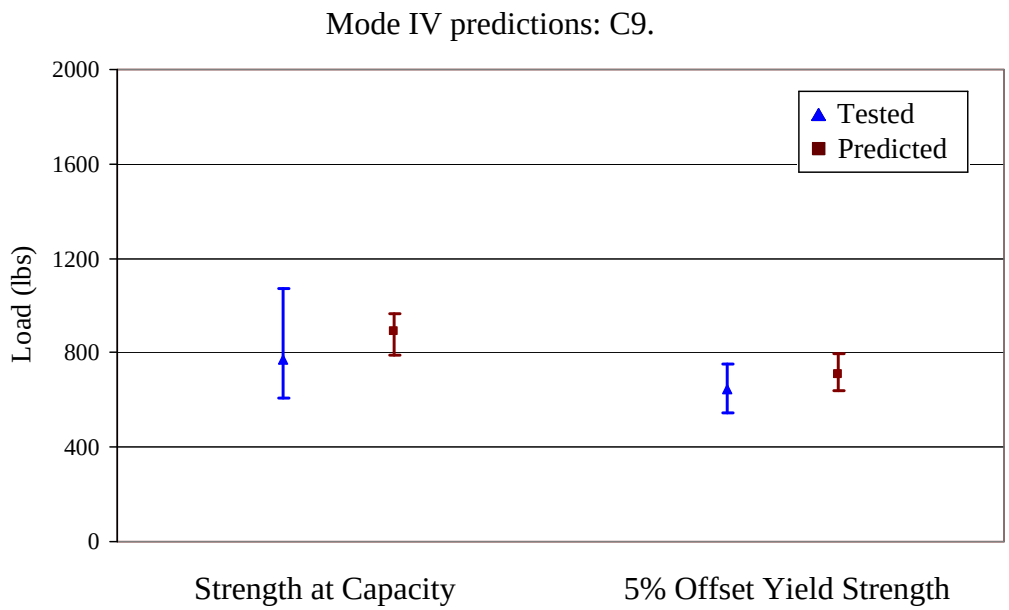

Figure 4.33b: Mode IV experimental/predicted YLM comparison plot: C9 (Std.).

Table 4.38: Inferences concerning means, predicted mode IV yield: C9.

Inference	Capacity	5% Offset Yield
t-statistic	-2.47	-2.46
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

4.6.2 - Mode III_s-Yield Limit Model

Yield strength and capacity values on a per bolt basis for configurations predicted to display Mode III_s yield may be seen in Tables 4.39, 4.41, 4.43, 4.45, 4.47, and 4.49, 4.50. Plots displaying tested and predicted values for 5% offset yield and capacity are shown in Figures 4.34, 4.35, 4.36, 4.37, 4.38, 4.39 and 4.40. T-statistic values and decisions concerning statistical inferences may be found in Tables 4.40, 4.42, 4.44, 4.46, 4.48, 4.50, and 4.52.

Table 4.39a: Mode III_s experimental/predicted YLM comparison: C11 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	11419	9473	1.21	8969	8978	1.00
2	11793	9118	1.29	7448	8441	0.88
3	10999	9176	1.20	6757	8553	0.79
4	11337	9180	1.24	8503	8587	0.99
5	10663	7848	1.36	6570	7476	0.88
6	9491	9257	1.03	9491	8686	1.09
7	13325	9823	1.36	8583	9040	0.95
8	11805	9531	1.24	10072	8662	1.16
9	10427	9688	1.08	7489	9077	0.83
10	12901	9323	1.38	8387	8792	0.95
Mean	11416	9242	1.24	8227	8629	0.95

Table 4.39b: Mode III_s experimental/predicted YLM comparison: C11 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2567	2130	1.21	2016	2018	1.00
2	2651	2050	1.29	1674	1898	0.88
3	2473	2063	1.20	1519	1923	0.79
4	2549	2064	1.24	1912	1930	0.99
5	2397	1764	1.36	1477	1681	0.88
6	2134	2081	1.03	2134	1953	1.09
7	2996	2208	1.36	1929	2032	0.95
8	2654	2143	1.24	2264	1947	1.16
9	2344	2178	1.08	1684	2041	0.83
10	2900	2096	1.38	1886	1977	0.95
Mean	2566	2078	1.24	1850	1940	0.95

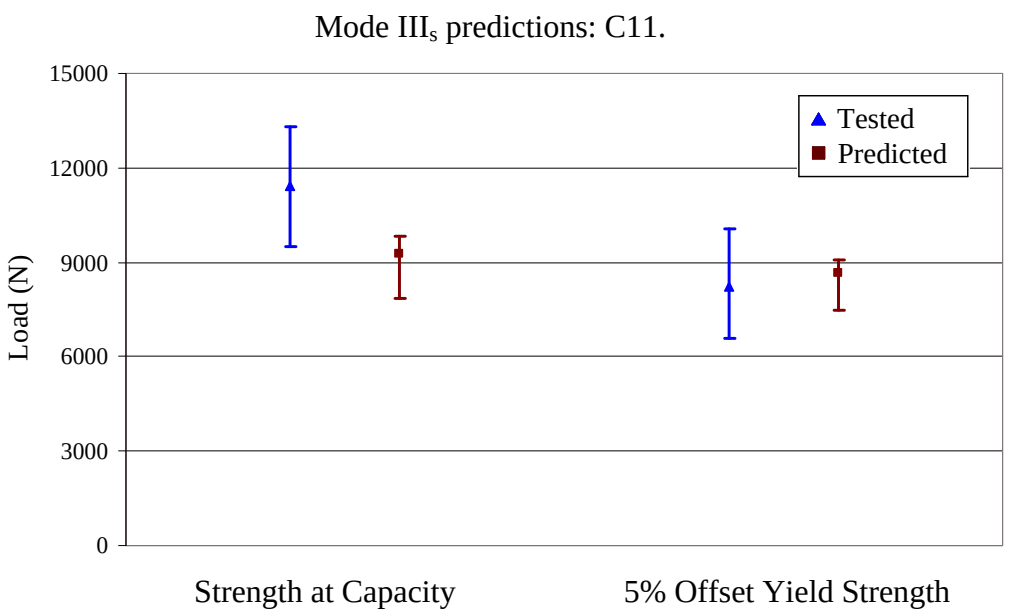

Figure 4.34a: Mode III$_s$ experimental/predicted YLM comparison plot: C11 (SI).

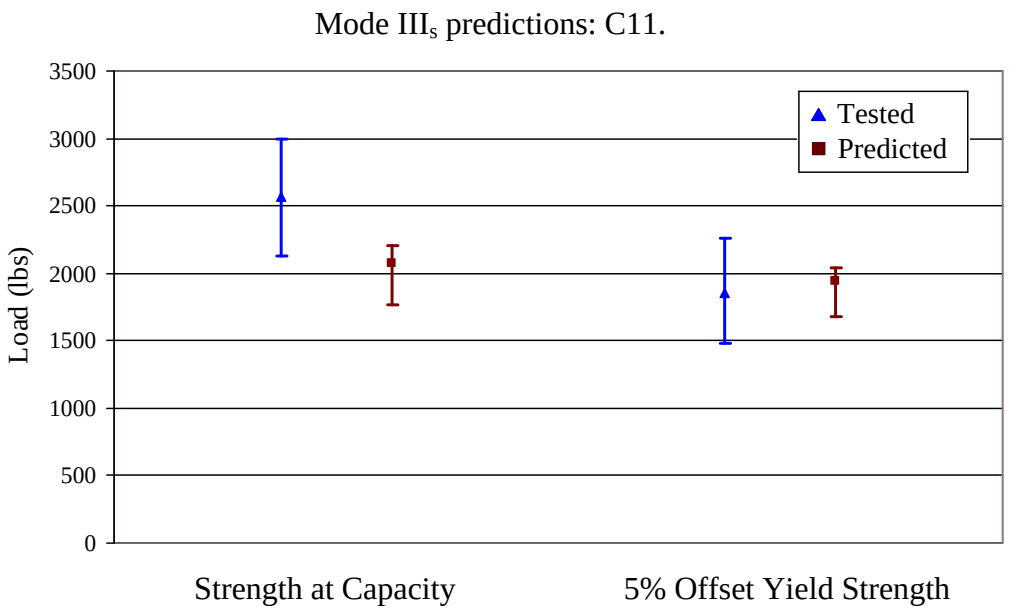

Figure 4.34b: Mode III$_s$ experimental/predicted YLM comparison plot: C11 (Std.).

Table 4.40: Inferences concerning means, predicted Mode III$_s$ yield: C11.

Inference	Capacity	5% Offset Yield
t-statistic	5.47	-1.03
Decision	Re. Ho	C.R.Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.41a: Mode III_s experimental/predicted YLM comparison: C12 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	7913	9624	0.82	7913	9012	0.88
2	9402	9307	1.01	8160	8715	0.94
3	8479	10799	0.79	8479	10146	0.84
4	10428	10419	1.00	9347	9579	0.98
5	7563	9594	0.79	7563	8892	0.85
6	6890	9490	0.73	6703	8868	0.76
7	9883	9686	1.02	8159	8976	0.91
8	Censored	Censored	-	Censored	Censored	-
9	9613	9047	1.06	8482	8408	1.01
10	9272	9404	0.99	8313	8755	0.95
Mean	8827	9708	0.91	8124	9039	0.90

Table 4.41b: Mode III_s experimental/predicted YLM comparison: C12 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	1779	2164	0.82	1779	2026	0.88
2	2114	2092	1.01	1834	1959	0.94
3	1906	2428	0.79	1906	2281	0.84
4	2344	2342	1.00	2101	2153	0.98
5	1700	2157	0.79	1700	1999	0.85
6	1549	2133	0.73	1507	1994	0.76
7	2222	2178	1.02	1834	2018	0.91
8	Censored	Censored	-	Censored	Censored	-
9	2161	2034	1.06	1907	1890	1.01
10	2085	2114	0.99	1869	1968	0.95
Mean	1984	2182	0.91	1826	2032	0.90

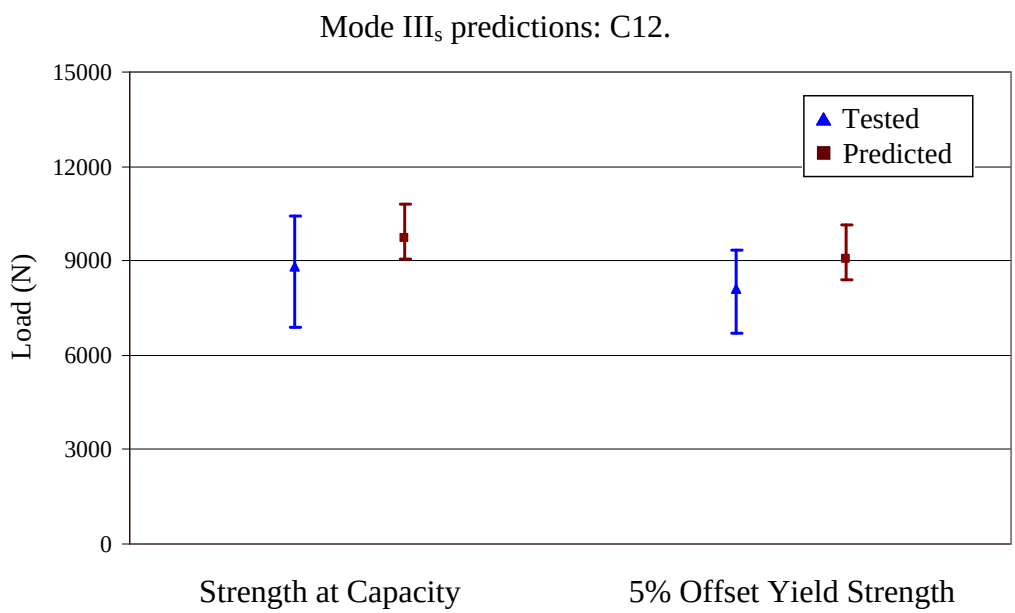

Figure 4.35a: Mode III$_s$ experimental/predicted YLM comparison plot: C12 (SI).

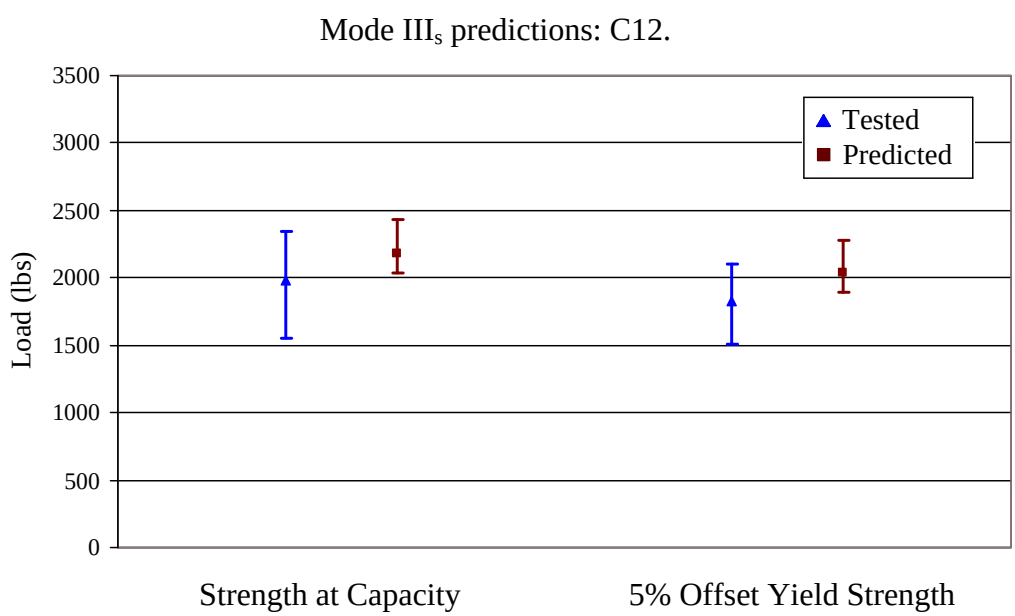

Figure 4.35b: Mode III$_s$ experimental/predicted YLM comparison plot: C12 (Std.).

Table 4.42: Inferences concerning means, predicted Mode III$_s$ yield: C12.

Inference	Capacity	5% Offset Yield
t-statistic	-2.03	-3.09
Decision	C.R.Ho	Re.Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.43a: Mode III_s experimental/predicted YLM comparison: C14 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	10994	9169	1.20	8437	8614	0.98
2	9968	8734	1.14	7870	8120	0.97
3	11381	9601	1.19	8031	9093	0.88
4	11689	9206	1.27	7352	8705	0.84
5	8261	8767	0.94	6736	8115	0.83
6	7882	8812	0.89	6820	8219	0.83
7	9555	8883	1.08	7824	8185	0.96
8	7795	8108	0.96	6217	7620	0.82
9	10402	8901	1.17	7201	8573	0.84
10	10786	9891	1.09	7699	9303	0.83
Mean	9871	9007	1.10	7419	8455	0.88

Table 4.43b: Mode III_s experimental/predicted YLM comparison: C14 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2471	2061	1.20	1897	1937	0.98
2	2241	1963	1.14	1769	1825	0.97
3	2559	2158	1.19	1806	2044	0.88
4	2628	2070	1.27	1653	1957	0.84
5	1857	1971	0.94	1514	1824	0.83
6	1772	1981	0.89	1533	1848	0.83
7	2148	1997	1.08	1759	1840	0.96
8	1752	1823	0.96	1398	1713	0.82
9	2338	2001	1.17	1619	1927	0.84
10	2425	2224	1.09	1731	2091	0.83
Mean	2219	2025	1.10	1668	1901	0.88

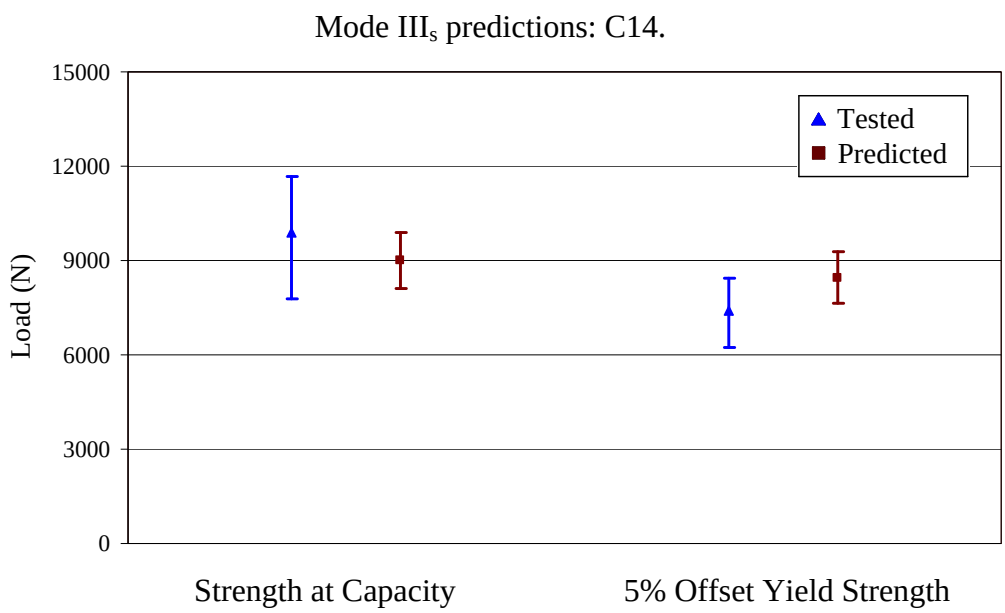

Figure 4.36a: Mode III$_s$ experimental/predicted YLM comparison plot: C14 (SI).

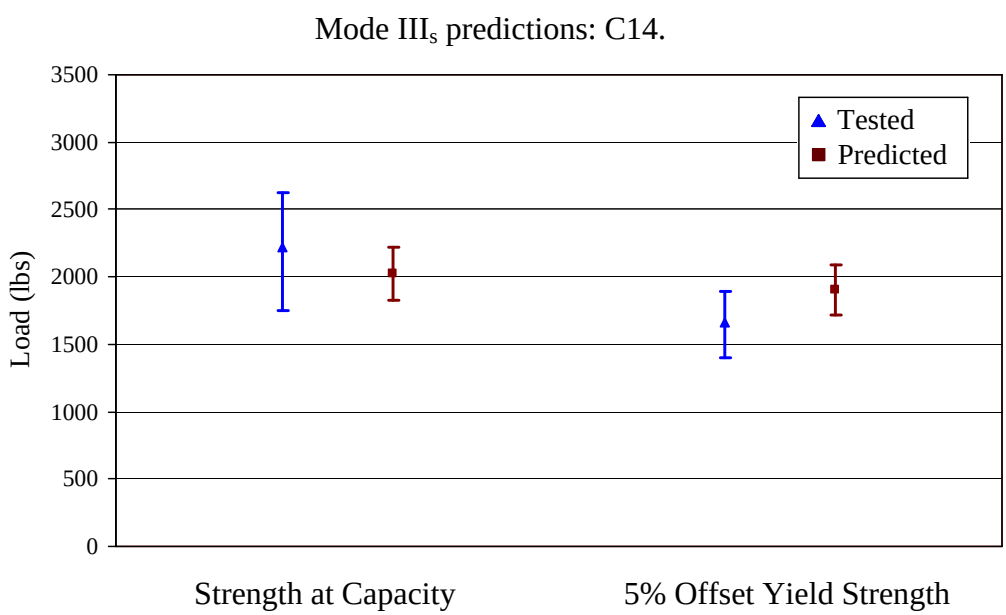

Figure 4.36b: Mode III$_s$ experimental/predicted YLM comparison plot: C14 (Std.).

Table 4.44: Inferences concerning means, predicted Mode III$_s$ yield: C14.

Inference	Capacity	5% Offset Yield
t-statistic	1.78	-3.86
Decision	C.R. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.45a: Mode III_s experimental/predicted YLM comparison: C15 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	10810	9122	1.19	8274	8271	1.00
2	12092	8612	1.40	8780	7868	1.12
3	14503	9097	1.59	9391	8557	1.10
4	10643	8534	1.25	8486	8110	1.05
5	11088	9240	1.20	8276	8557	0.97
6	12193	9422	1.29	8160	8900	0.92
7	9843	7781	1.27	7542	7042	1.07
8	11263	8592	1.31	7811	7576	1.03
9	13223	9644	1.37	7858	8780	0.89
10	11945	10155	1.18	7927	9396	0.84
Mean	11760	9020	1.30	8250	8306	0.99

Table 4.45b: Mode III_s experimental/predicted YLM comparison: C15 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2430	2051	1.19	1860	1859	1.00
2	2718	1936	1.40	1974	1769	1.12
3	3260	2045	1.59	2111	1924	1.10
4	2393	1919	1.25	1908	1823	1.05
5	2493	2077	1.20	1860	1924	0.97
6	2741	2118	1.29	1834	2001	0.92
7	2213	1749	1.27	1695	1583	1.07
8	2532	1932	1.31	1756	1703	1.03
9	2973	2168	1.37	1767	1974	0.89
10	2685	2283	1.18	1782	2112	0.84
Mean	2644	2028	1.30	1855	1867	0.99

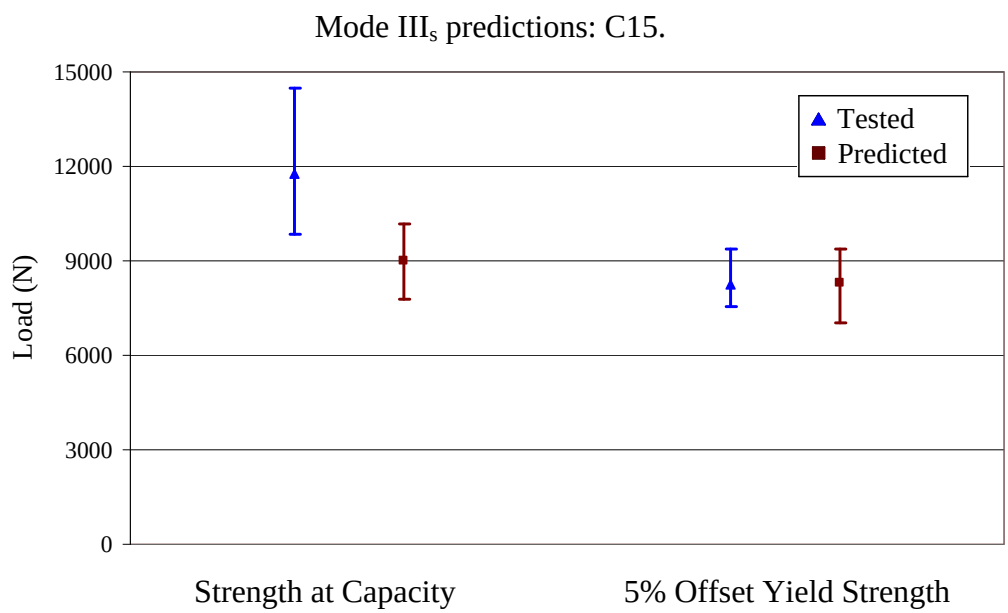

Figure 4.37a: Mode III$_s$ experimental/predicted YLM comparison plot: C15 (SI).

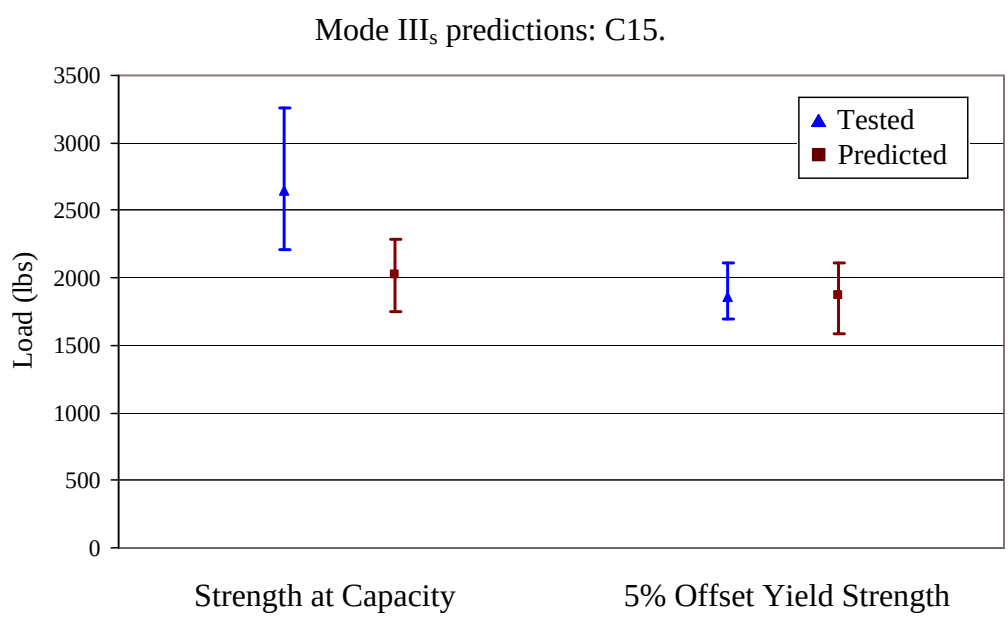

Figure 4.37b: Mode III$_s$ experimental/predicted YLM comparison plot: C15 (Std.).

Table 4.46: Inferences concerning means, predicted Mode III$_s$ yield: C15.

Inference	Capacity	5% Offset Yield
t-statistic	5.74	-0.20
Decision	Re. Ho	C.R.Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.47a: Mode III_s experimental/predicted YLM comparison: C16 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	10927	8801	1.24	6847	7767	0.88
2	10433	9091	1.15	7892	8380	0.94
3	10909	8411	1.30	8482	7653	1.11
4	14605	9069	1.61	10728	8411	1.28
5	12713	8715	1.46	8422	8017	1.05
6	11310	8575	1.32	6913	8000	0.86
7	9941	9093	1.09	7795	8417	0.93
8	12269	8987	1.37	10332	8385	1.23
9	12111	8716	1.39	7823	7812	1.00
10	11702	8926	1.31	8582	8258	1.04
Mean	11692	8838	1.32	8381	8110	1.03

Table 4.47b: Mode III_s experimental/predicted YLM comparison: C16 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2456	1979	1.24	1539	1746	0.88
2	2345	2044	1.15	1774	1884	0.94
3	2452	1891	1.30	1907	1720	1.11
4	3283	2039	1.61	2412	1891	1.28
5	2858	1959	1.46	1893	1802	1.05
6	2543	1928	1.32	1554	1798	0.86
7	2235	2044	1.09	1752	1892	0.93
8	2758	2020	1.37	2323	1885	1.23
9	2723	1959	1.39	1759	1756	1.00
10	2631	2007	1.31	1929	1857	1.04
Mean	2628	1987	1.32	1884	1823	1.03

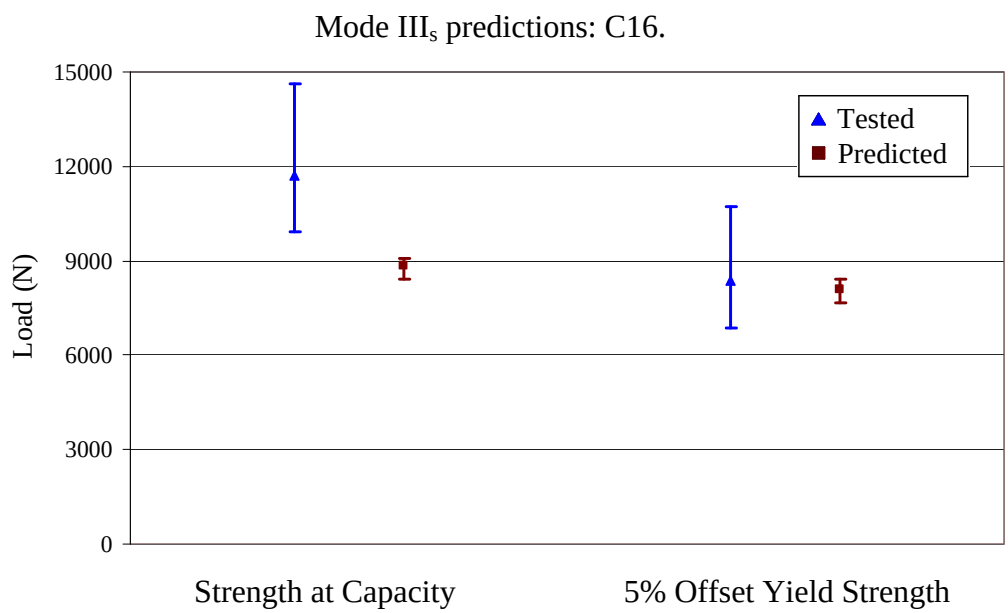

Figure 4.38a: Mode III$_s$ experimental/predicted YLM comparison plot: C16 (SI).

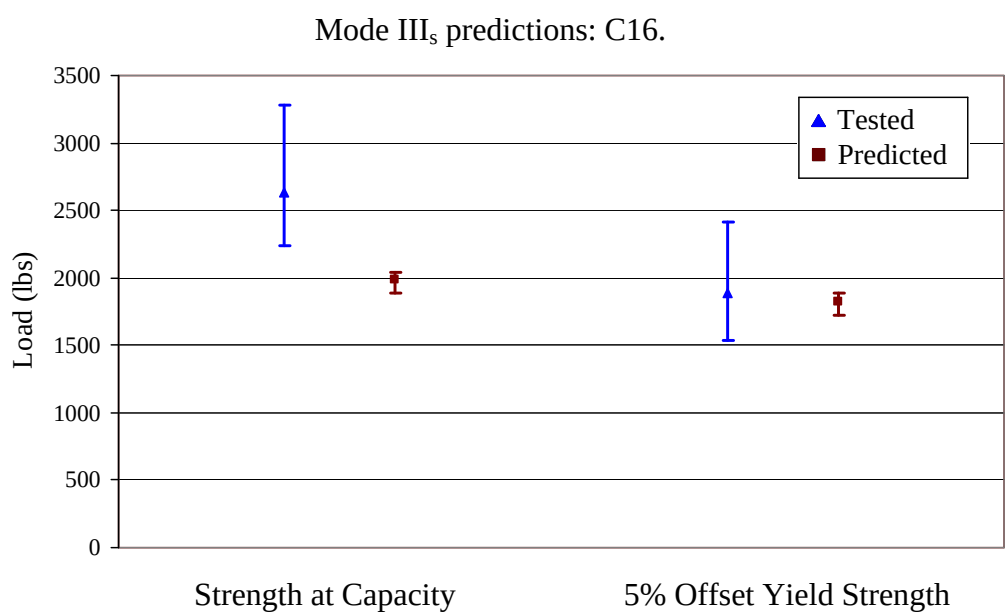

Figure 4.38b: Mode III$_s$ experimental/predicted YLM comparison plot: C16 (Std.).

Table 4.48: Inferences concerning means, predicted Mode III$_s$ yield: C16.

Inference	Capacity	5% Offset Yield
t-statistic	6.66	0.65
Decision	Re. Ho	C.R.Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.49a: Mode III_s experimental/predicted YLM comparison: C18 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	7969	9419	0.85	7302	8683	0.84
2	7886	9372	0.84	7568	8428	0.90
3	8822	9351	0.94	7265	8726	0.83
4	8890	8595	1.03	7537	7920	0.95
5	7540	8642	0.87	7019	7657	0.92
6	8011	8584	0.93	6883	7925	0.87
7	7893	9136	0.86	6576	8336	0.79
8	6275	8954	0.70	6275	8056	0.78
9	8732	9277	0.94	7412	8632	0.86
10	8313	9385	0.89	7301	8761	0.83
Mean	8033	9071	0.89	7114	8312	0.86

Table 4.49b: Mode III_s experimental/predicted YLM comparison: C18 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	1791	2117	0.85	1642	1952	0.84
2	1773	2107	0.84	1701	1895	0.90
3	1983	2102	0.94	1633	1962	0.83
4	1998	1932	1.03	1694	1781	0.95
5	1695	1943	0.87	1578	1721	0.92
6	1801	1930	0.93	1547	1782	0.87
7	1774	2054	0.86	1478	1874	0.79
8	1411	2013	0.70	1411	1811	0.78
9	1963	2085	0.94	1666	1941	0.86
10	1869	2110	0.89	1641	1970	0.83
Mean	1806	2039	0.89	1599	1869	0.86

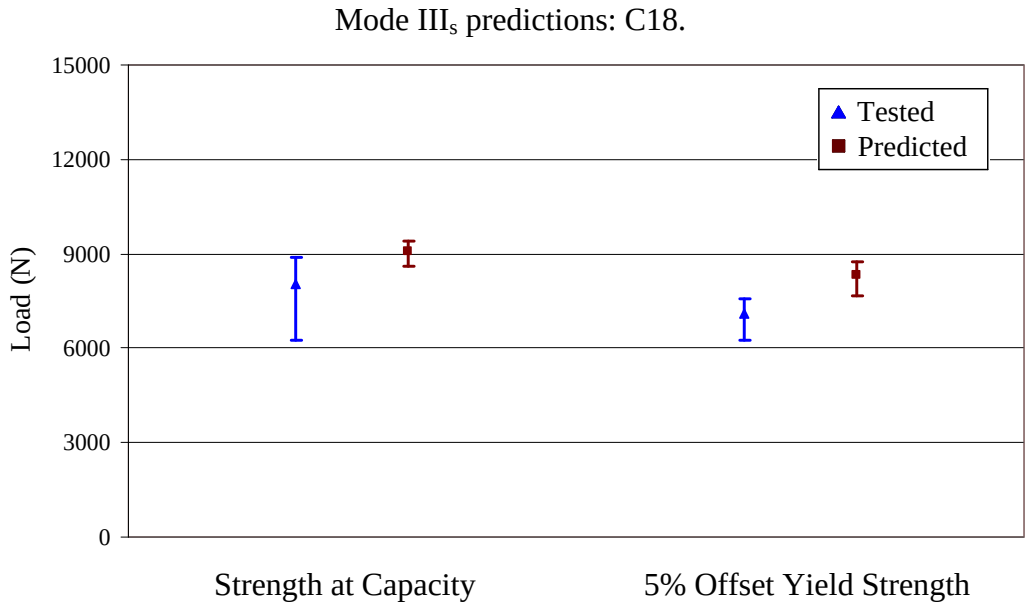

Figure 4.39a: Mode III$_s$ experimental/predicted YLM comparison plot: C18 (SI).

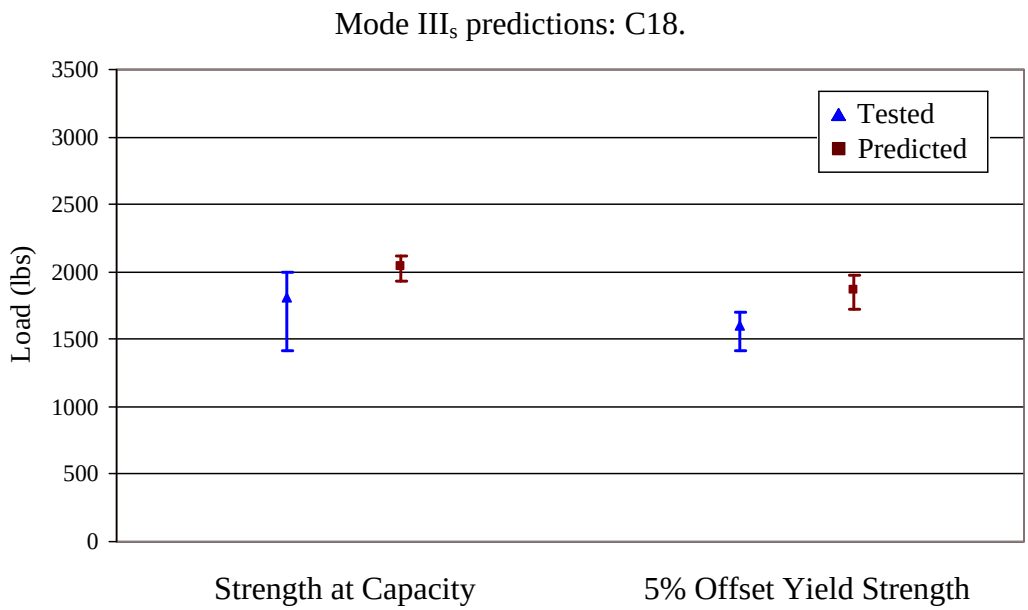

Figure 4.39b: Mode III$_s$ experimental/predicted YLM comparison plot: C18 (Std.).

Table 4.50: Inferences concerning means, predicted Mode III$_s$ yield: C18.

Inference	Capacity	5% Offset Yield
t-statistic	-3.59	-6.51
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.51a: Mode III_s experimental/predicted YLM comparison: C19 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	7306	8742	0.84	4587	7965	0.58
2	9055	8780	1.03	7406	7980	0.93
3	8470	9156	0.93	7074	8194	0.86
4	9157	8621	1.06	8664	7803	1.11
5	9319	9787	0.95	8221	8942	0.92
6	7112	9630	0.74	6734	9079	0.74
7	10296	9048	1.14	9831	8278	1.19
8	8867	8656	1.02	7734	7842	0.99
9	Censored	Censored	-	Censored	Censored	-
10	9685	10161	0.95	7724	9435	0.82
Mean	8807	9176	0.96	7553	8391	0.90

Table 4.51b: Mode III_s experimental/predicted YLM comparison: C19 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	1642	1965	0.84	1031	1791	0.58
2	2036	1974	1.03	1665	1794	0.93
3	1904	2058	0.93	1590	1842	0.86
4	2059	1938	1.06	1948	1754	1.11
5	2095	2200	0.95	1848	2010	0.92
6	1599	2165	0.74	1514	2041	0.74
7	2315	2034	1.14	2210	1861	1.19
8	1993	1946	1.02	1739	1763	0.99
9	Censored	Censored	-	Censored	Censored	-
10	2177	2284	0.95	1737	2121	0.82
Mean	1980	2063	0.96	1698	1886	0.90

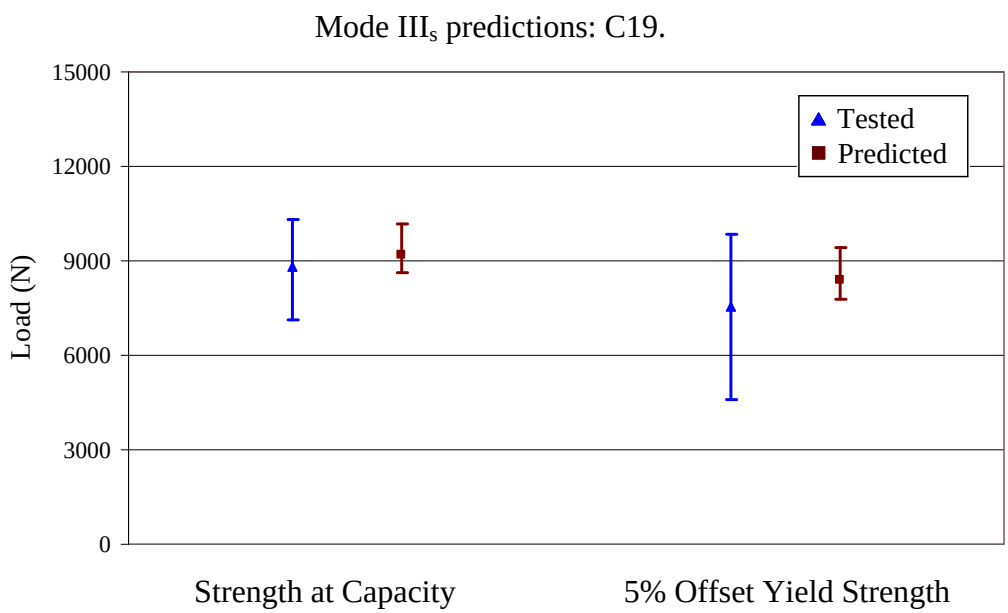

Figure 4.40a: Mode III$_s$ experimental/predicted YLM comparison plot: C19 (SI).

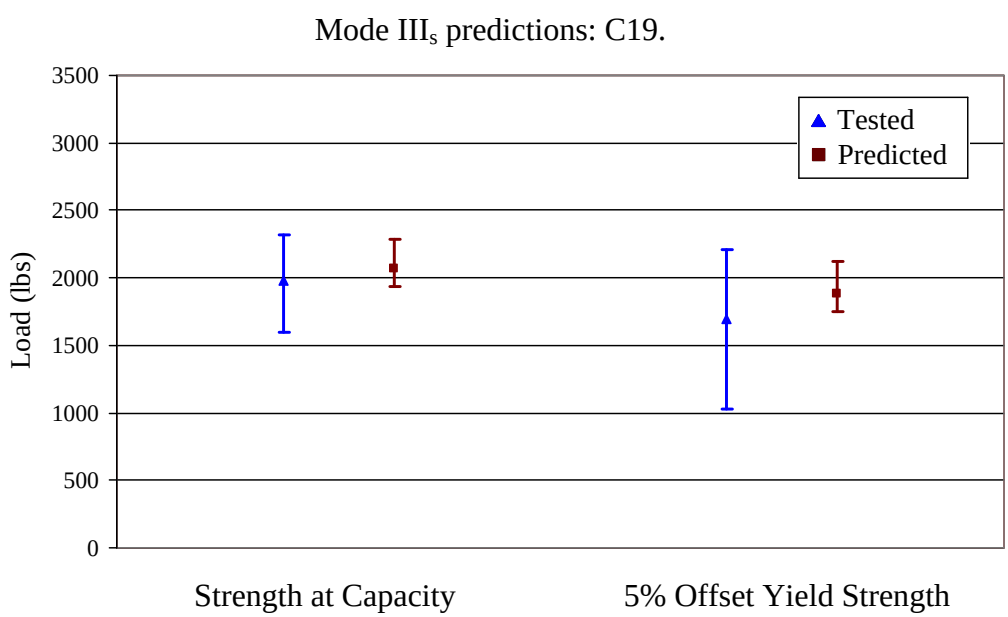

Figure 4.40b: Mode III$_s$ experimental/predicted YLM comparison plot: C19 (Std.).

Table 4.52: Inferences concerning means, predicted Mode III$_s$ yield: C19.

Inference	Capacity	5% Offset Yield
t-statistic	-0.94	-1.61
Decision	C.R.Ho	C.R.Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

4.6.3 - Mode II-Yield Limit Model

Yield strength and capacity values on a per bolt basis for configurations predicted to display Mode II yield may be seen in Tables 4.53, 4.55, 4.57, 4.59, 4.61, 4.63 and 4.65. Plots displaying tested and predicted values for 5% offset yield and capacity are shown in Figures 4.41, 4.42, 4.43, 4.44, 4.45, 4.46 and 4.47. T-statistic values and decisions concerning statistical inferences may be found in Tables 4.54, 4.56, 4.58, 4.60, 4.62, 4.64 and 4.66.

Table 4.53a: Mode II experimental/predicted YLM comparison: C21 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	15887	9333	1.70	10937	9308	1.17
2	15688	9056	1.73	12065	9024	1.34
3	12403	7005	1.77	9046	6989	1.29
4	13600	8653	1.57	10520	8653	1.22
5	14441	9525	1.52	11184	9525	1.17
6	15067	7667	1.97	9564	7566	1.26
7	12556	7221	1.74	8672	7221	1.20
8	14308	8783	1.63	11378	8783	1.30
9	11756	6347	1.85	7260	6347	1.14
10	16102	9287	1.73	10700	9270	1.15
Mean	14181	8288	1.71	10133	8269	1.23

Table 4.53b: Mode II experimental/predicted YLM comparison: C21 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	3572	2098	1.70	2459	2093	1.17
2	3527	2036	1.73	2712	2029	1.34
3	2788	1575	1.77	2034	1571	1.29
4	3057	1945	1.57	2365	1945	1.22
5	3247	2141	1.52	2514	2141	1.17
6	3387	1724	1.97	2150	1701	1.26
7	2823	1623	1.74	1950	1623	1.20
8	3217	1974	1.63	2558	1974	1.30
9	2643	1427	1.85	1632	1427	1.14
10	3620	2088	1.73	2405	2084	1.15
Mean	3188	1863	1.71	2278	1859	1.23

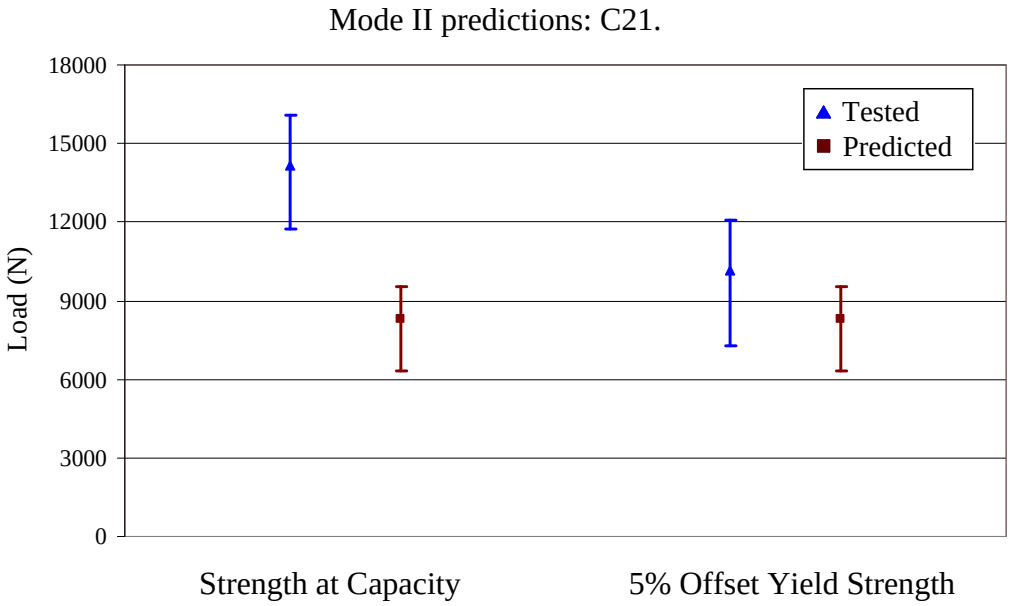

Figure 4.41a: Mode II experimental/predicted YLM comparison plot: C21 (SI).

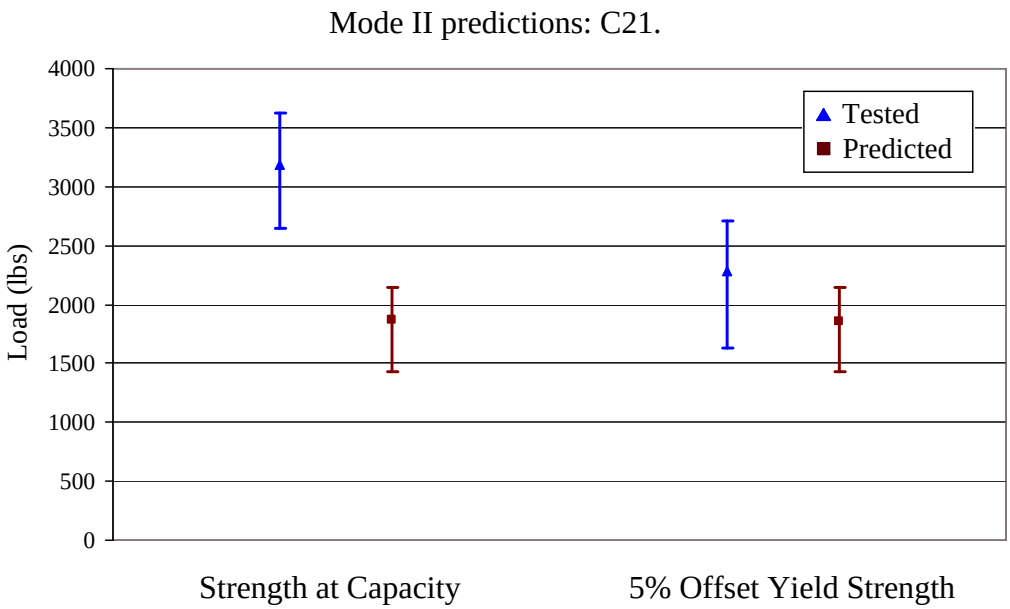

Figure 4.41b: Mode II experimental/predicted YLM comparison plot: C21 (Std.).

Table 4.54: Inferences concerning means, predicted Mode II yield: C21.

Inference	Capacity	5% Offset Yield
t-statistic	9.69	3.18
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.55a: Mode II experimental/predicted YLM comparison: C22 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	9822	9993	0.98	9690	9839	0.98
2	11633	7736	1.50	9482	7658	1.24
3	12499	8922	1.40	11544	8922	1.29
4	11882	8084	1.47	10297	7842	1.31
5	11492	8793	1.31	9157	8793	1.04
6	9065	8256	1.10	9727	8122	1.20
7	12995	9728	1.34	12527	9728	1.29
8	12498	7820	1.60	9717	7767	1.25
9	11412	8279	1.38	10406	8093	1.29
10	12995	9062	1.43	10061	8528	1.18
Mean	11629	8667	1.34	10261	8529	1.20

Table 4.55b: Mode II experimental/predicted YLM comparison: C22 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2208	2247	0.98	2178	2212	0.98
2	2615	1739	1.50	2132	1722	1.24
3	2810	2006	1.40	2595	2006	1.29
4	2671	1817	1.47	2315	1763	1.31
5	2584	1977	1.31	2059	1977	1.04
6	2038	1856	1.10	2187	1826	1.20
7	2921	2187	1.34	2816	2187	1.29
8	2810	1758	1.60	2184	1746	1.25
9	2566	1861	1.38	2339	1819	1.29
10	2921	2037	1.43	2262	1917	1.18
Mean	2614	1948	1.34	2307	1917	1.20

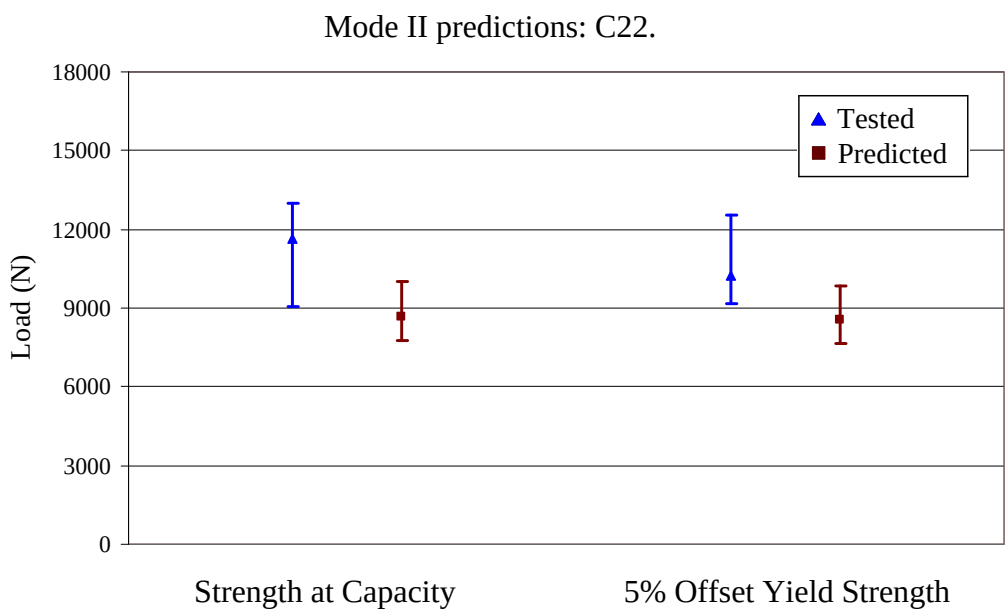

Figure 4.42a: Mode II experimental/predicted YLM comparison plot: C22 (SI).

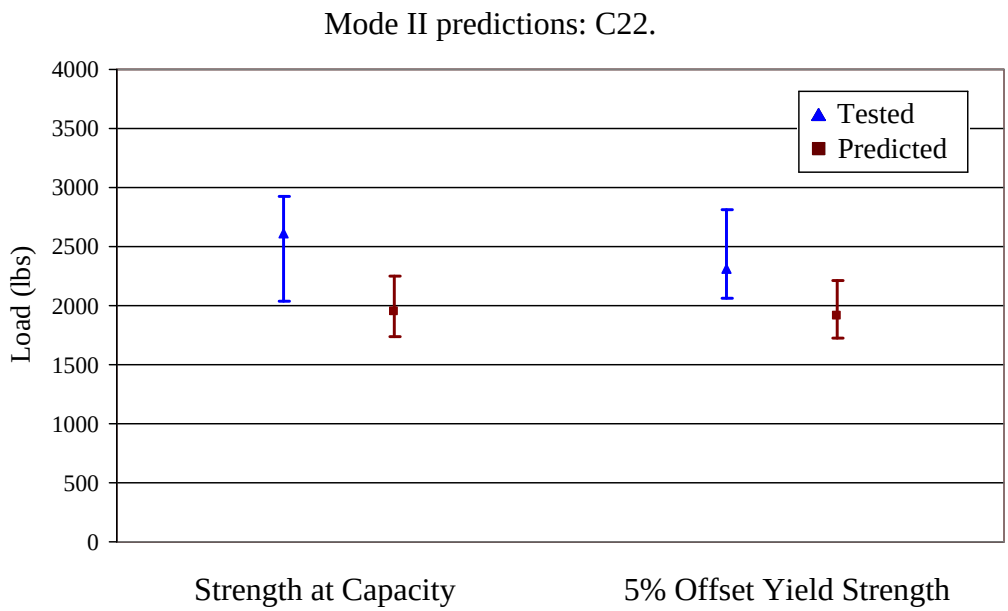

Figure 4.42b: Mode II experimental/predicted YLM comparison plot: C22 (Std.).

Table 4.56: Inferences concerning means, predicted Mode II yield: C22.

Inference	Capacity	5% Offset Yield
t-statistic	6.19	4.22
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.57a: Mode II experimental/predicted YLM comparison: C24 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	13545	7828	1.73	9643	7799	1.24
2	14022	7646	1.83	9485	7561	1.25
3	11799	8367	1.41	8915	8103	1.10
4	11207	8190	1.37	8829	8043	1.10
5	10602	6946	1.53	7709	6929	1.11
6	13341	7119	1.87	11275	6924	1.63
7	13651	7909	1.73	10517	7851	1.34
8	13823	7922	1.74	10605	7856	1.35
9	18133	7294	2.49	11834	7165	1.65
10	11948	7301	1.64	9626	7301	1.32
Mean	13207	7652	1.73	9844	7553	1.30

Table 4.57b: Mode II experimental/predicted YLM comparison: C24 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	3045	1760	1.73	2168	1753	1.24
2	3152	1719	1.83	2132	1700	1.25
3	2653	1881	1.41	2004	1822	1.10
4	2520	1841	1.37	1985	1808	1.10
5	2383	1561	1.53	1733	1558	1.11
6	2999	1600	1.87	2535	1557	1.63
7	3069	1778	1.73	2364	1765	1.34
8	3107	1781	1.74	2384	1766	1.35
9	4077	1640	2.49	2660	1611	1.65
10	2686	1641	1.64	2164	1641	1.32
Mean	2969	1720	1.73	2213	1698	1.30

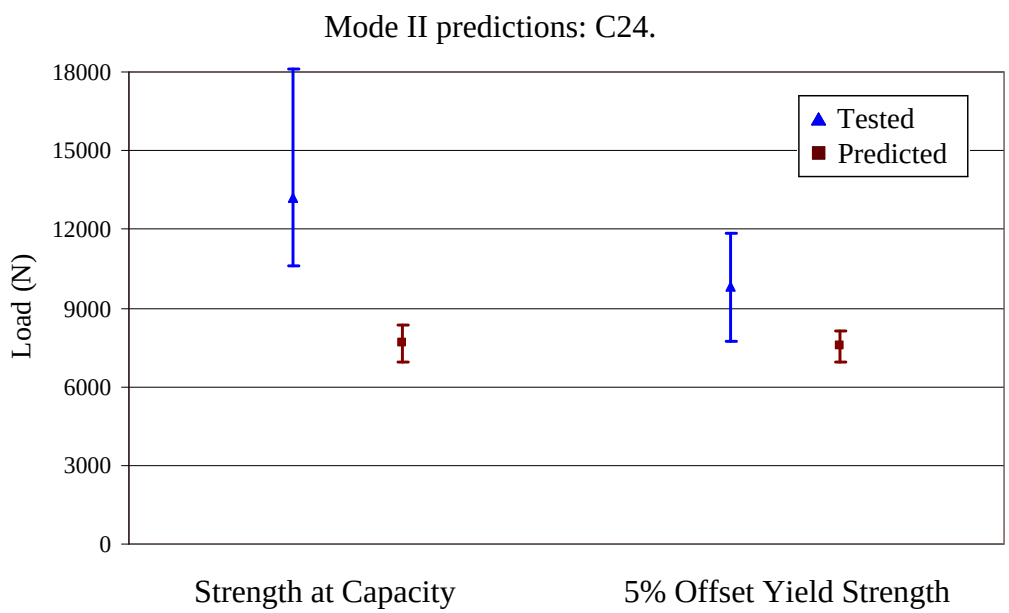

Figure 4.43a: Mode II experimental/predicted YLM comparison plot: C24 (SI).

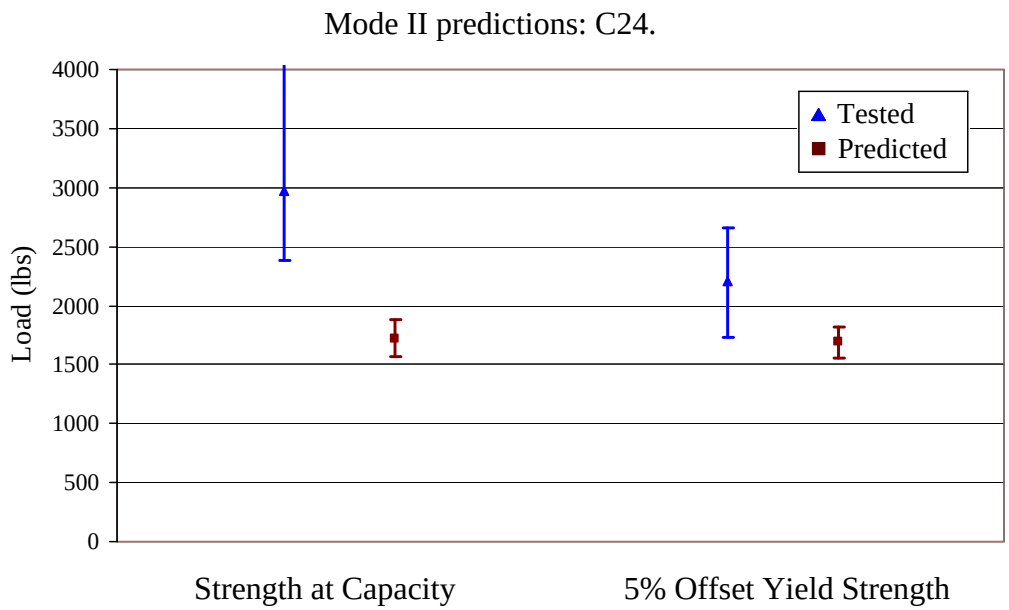

Figure 4.43b: Mode II experimental/predicted YLM comparison plot: C24 (Std.).

Table 4.58: Inferences concerning means, predicted Mode II yield: C24.

Inference	Capacity	5% Offset Yield
t-statistic	8.13	5.52
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.59a: Mode II experimental/predicted YLM comparison: C25 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	14667	9166	1.60	11784	9101	1.29
2	17135	9101	1.88	12075	8984	1.34
3	16230	8270	1.96	11595	8212	1.41
4	14549	7584	1.92	10816	7511	1.44
5	13073	7170	1.82	8725	7122	1.23
6	14531	7718	1.88	8747	7698	1.14
7	14113	8322	1.70	11181	8260	1.35
8	14509	9380	1.55	11001	9196	1.20
9	13423	8298	1.62	9881	8298	1.19
10	15925	9033	1.76	13191	9033	1.46
Mean	14815	8404	1.76	10900	8341	1.31

Table 4.59b: Mode II experimental/predicted YLM comparison: C25 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	3297	2061	1.60	2649	2046	1.29
2	3852	2046	1.88	2714	2020	1.34
3	3649	1859	1.96	2607	1846	1.41
4	3271	1705	1.92	2432	1689	1.44
5	2939	1612	1.82	1962	1601	1.23
6	3267	1735	1.88	1966	1731	1.14
7	3173	1871	1.70	2514	1857	1.35
8	3262	2109	1.55	2473	2067	1.20
9	3018	1865	1.62	2221	1865	1.19
10	3580	2031	1.76	2965	2031	1.46
Mean	3331	1889	1.76	2450	1875	1.31

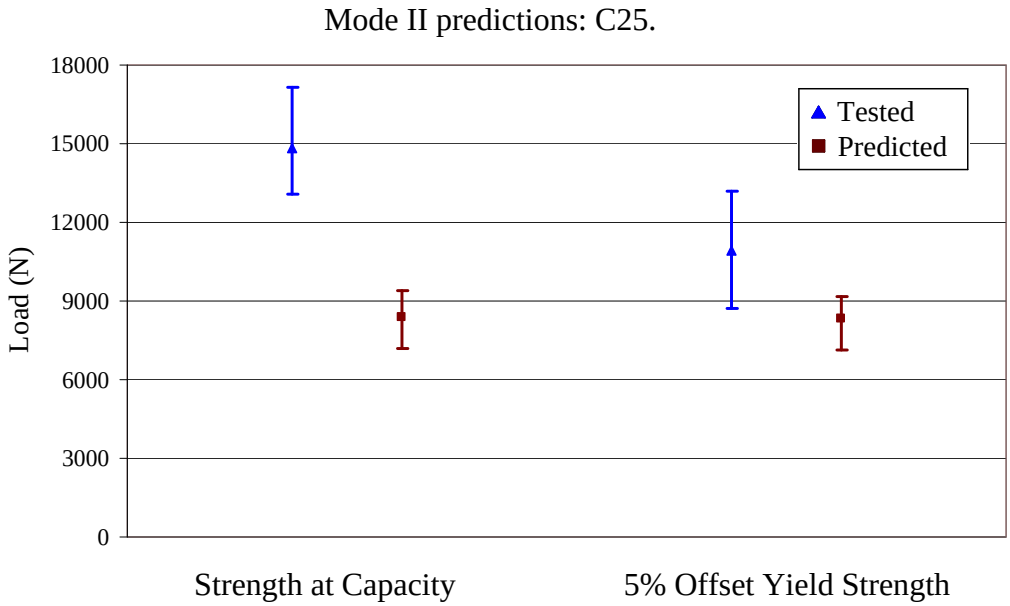

Figure 4.44a: Mode II experimental/predicted YLM comparison plot: C25 (SI).

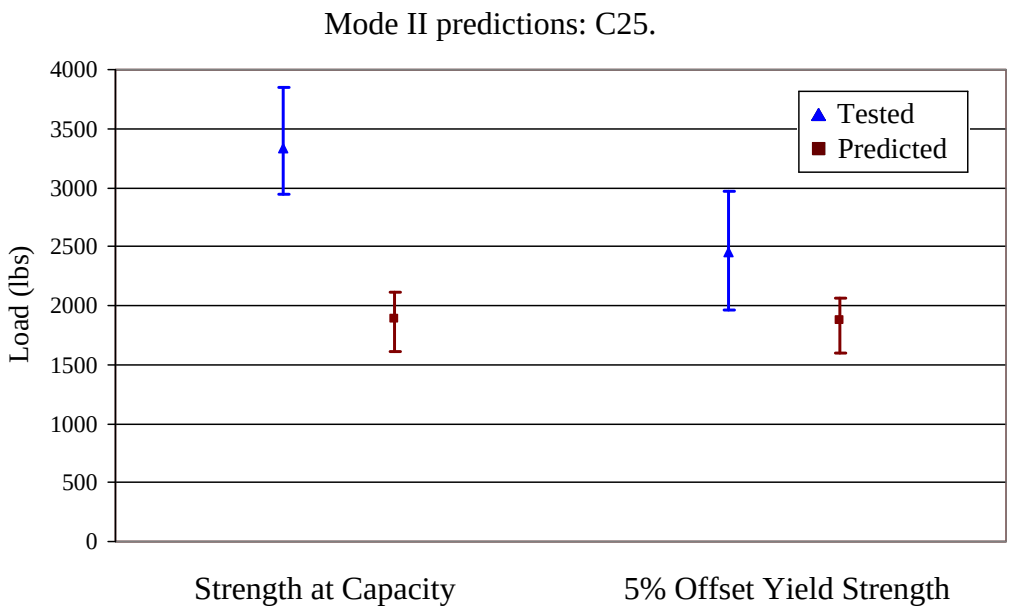

Figure 4.44b: Mode II experimental/predicted YLM comparison plot: C25 (Std.).

Table 4.60: Inferences concerning means, predicted Mode II yield: C25.

Inference	Capacity	5% Offset Yield
t-statistic	13.78	5.04
Decision	Re. Ho	Re. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.61a: Mode II experimental/predicted YLM comparison: C28 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	8114	6607	1.23	7076	6607	1.07
2	8417	7115	1.18	8417	7064	1.19
3	9809	7814	1.26	8567	7669	1.12
4	10440	7692	1.36	8680	7569	1.15
5	10728	8031	1.34	9250	7709	1.20
6	6364	7982	0.80	6364	7859	0.81
7	7976	8796	0.91	7976	8728	0.91
8	10425	8213	1.27	8306	8131	1.02
9	11773	7981	1.48	8002	7981	1.00
10	8522	7462	1.14	7291	7212	1.01
Mean	9257	7769	1.19	7993	7653	1.04

Table 4.61b: Mode II experimental/predicted YLM comparison: C28 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	1824	1485	1.23	1591	1485	1.07
2	1892	1600	1.18	1892	1588	1.19
3	2205	1757	1.26	1926	1724	1.12
4	2347	1729	1.36	1951	1702	1.15
5	2412	1806	1.34	2079	1733	1.20
6	1431	1795	0.80	1431	1767	0.81
7	1793	1977	0.91	1793	1962	0.91
8	2344	1846	1.27	1867	1828	1.02
9	2647	1794	1.48	1799	1794	1.00
10	1916	1677	1.14	1639	1621	1.01
Mean	2081	1747	1.19	1797	1720	1.04

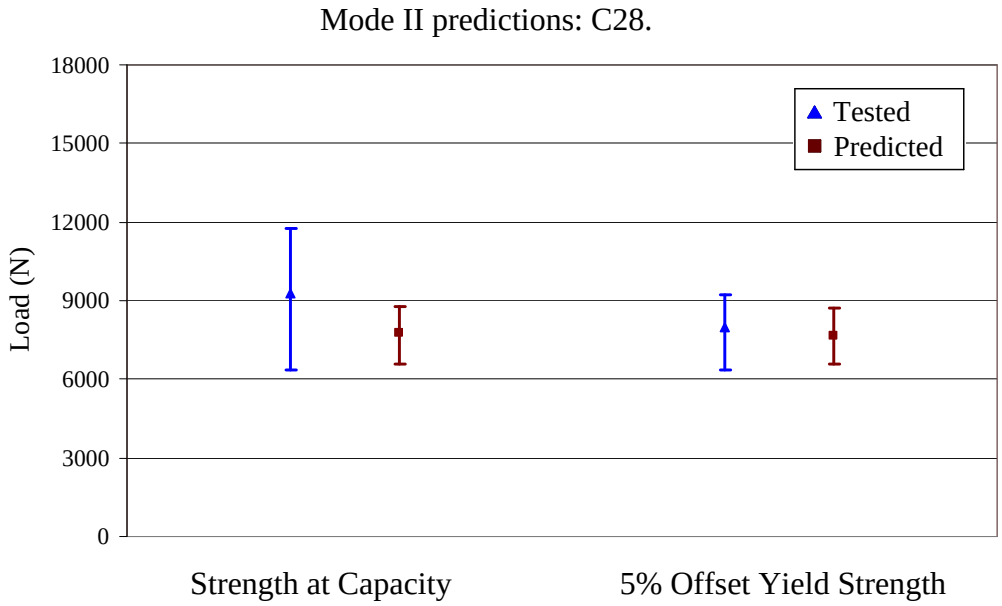

Figure 4.45a: Mode II experimental/predicted YLM comparison plot: C28 (SI).

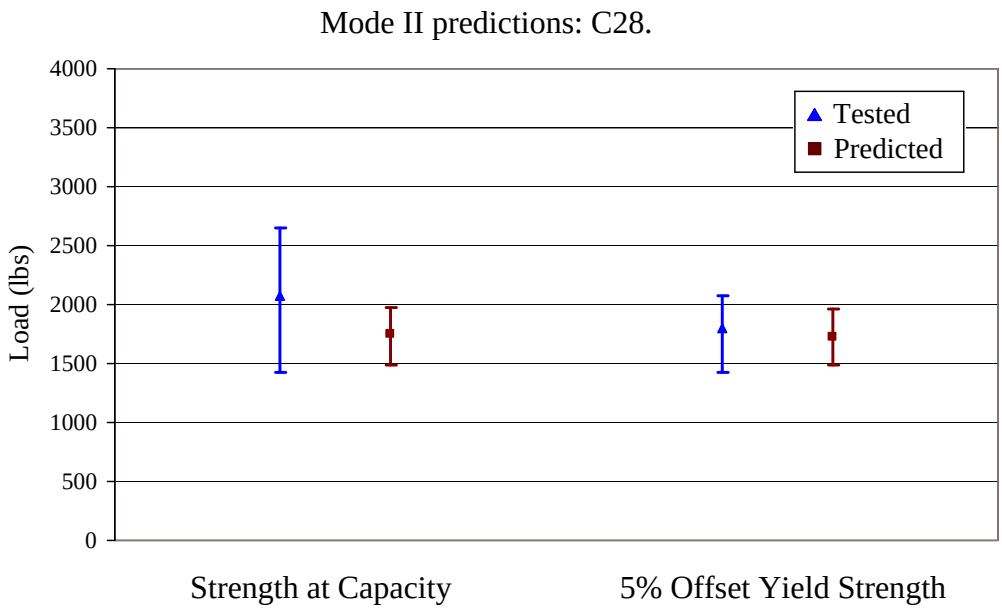

Figure 4.45b: Mode II experimental/predicted YLM comparison plot: C28 (Std.).

Table 4.62: Inferences concerning means, predicted Mode II yield: C28.

Inference	Capacity	5% Offset Yield
t-statistic	2.69	1.03
Decision	Re. Ho	C.R. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.63a: Mode II experimental/predicted YLM comparison: C29 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	10519	7853	1.34	8331	7711	1.08
2	11443	7721	1.48	8555	7662	1.12
3	10102	7471	1.35	8620	7408	1.16
4	9683	7712	1.26	7711	7702	1.00
5	11847	10488	1.13	10403	10488	0.99
6	12165	8501	1.43	9071	8482	1.07
7	11521	8953	1.29	9301	8953	1.04
8	12815	8693	1.47	11075	8683	1.28
9	12108	7473	1.62	8614	7355	1.17
10	11709	8408	1.39	9743	8232	1.18
Mean	11391	8327	1.37	9142	8268	1.11

Table 4.63b: Mode II experimental/predicted YLM comparison: C29 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2365	1765	1.34	1873	1734	1.08
2	2572	1736	1.48	1923	1723	1.12
3	2271	1680	1.35	1938	1665	1.16
4	2177	1734	1.26	1734	1732	1.00
5	2663	2358	1.13	2339	2358	0.99
6	2735	1911	1.43	2039	1907	1.07
7	2590	2013	1.29	2091	2013	1.04
8	2881	1954	1.47	2490	1952	1.28
9	2722	1680	1.62	1937	1653	1.17
10	2632	1890	1.39	2190	1851	1.18
Mean	2561	1872	1.37	2055	1859	1.11

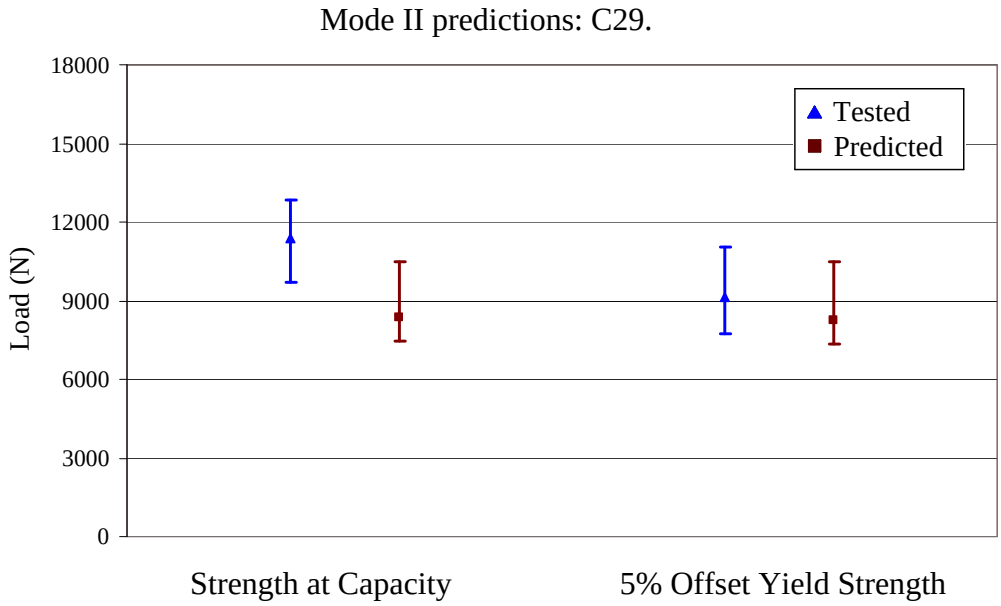

Figure 4.46a: Mode II experimental/predicted YLM comparison plot: C29 (SI).

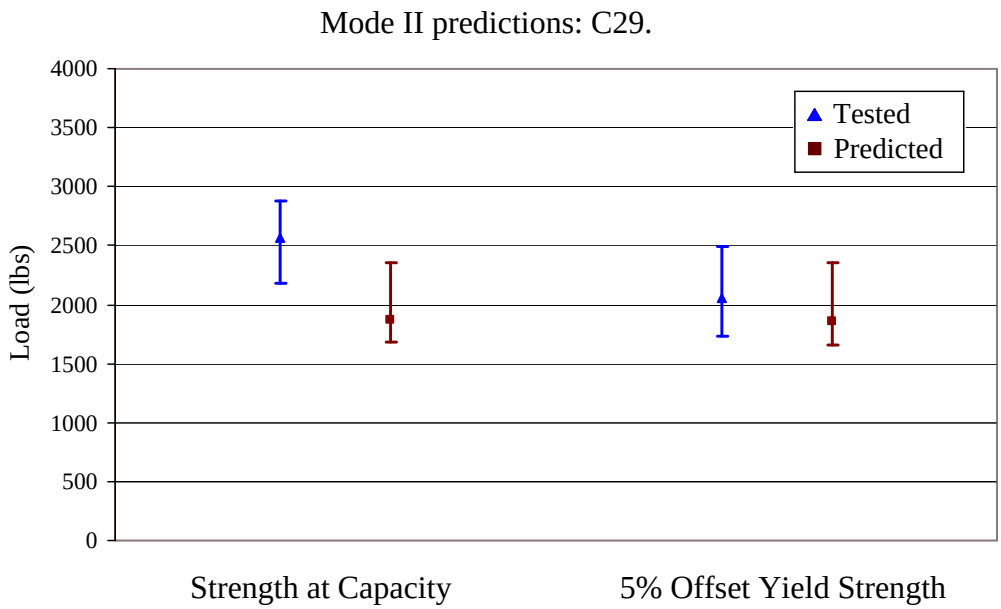

Figure 4.46b: Mode II experimental/predicted YLM comparison plot: C29 (Std.).

Table 4.64: Inferences concerning means, predicted Mode II yield: C29.

Inference	Capacity	5% Offset Yield
t-statistic	7.16	1.98
Decision	Re. Ho	C.R. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

Table 4.65a: Mode II experimental/predicted YLM comparison: C30 (SI).

Specimen	Capacity			5% Offset Yield		
	Tested (N)	Predicted (N)	Test/NDS	Tested (N)	Predicted (N)	Test/NDS
1	11297	9622	1.17	10128	9283	1.09
2	8847	9769	0.91	6217	9363	0.66
3	11386	9213	1.24	6083	8698	0.70
4	12082	8604	1.40	10008	8136	1.23
5	10157	9536	1.07	5966	9252	0.64
6	11713	9033	1.30	6425	8584	0.75
7	11357	11468	0.99	10739	11020	0.97
8	11943	11516	1.04	8582	11332	0.76
9	11365	10283	1.11	9733	10055	0.97
10	12836	11395	1.13	11565	10668	1.08
Mean	11298	10044	1.12	8545	9639	0.89

Table 4.65b: Mode II experimental/predicted YLM comparison: C30 (Std.).

Specimen	Capacity			5% Offset Yield		
	Tested (lbs.)	Predicted (lbs.)	Test/NDS	Tested (lbs.)	Predicted (lbs.)	Test/NDS
1	2540	2163	1.17	2277	2087	1.09
2	1989	2196	0.91	1398	2105	0.66
3	2560	2071	1.24	1368	1955	0.70
4	2716	1934	1.40	2250	1829	1.23
5	2283	2144	1.07	1341	2080	0.64
6	2633	2031	1.30	1444	1930	0.75
7	2553	2578	0.99	2414	2477	0.97
8	2685	2589	1.04	1929	2547	0.76
9	2555	2312	1.11	2188	2261	0.97
10	2886	2562	1.13	2600	2398	1.08
Mean	2540	2258	1.12	1921	2167	0.89

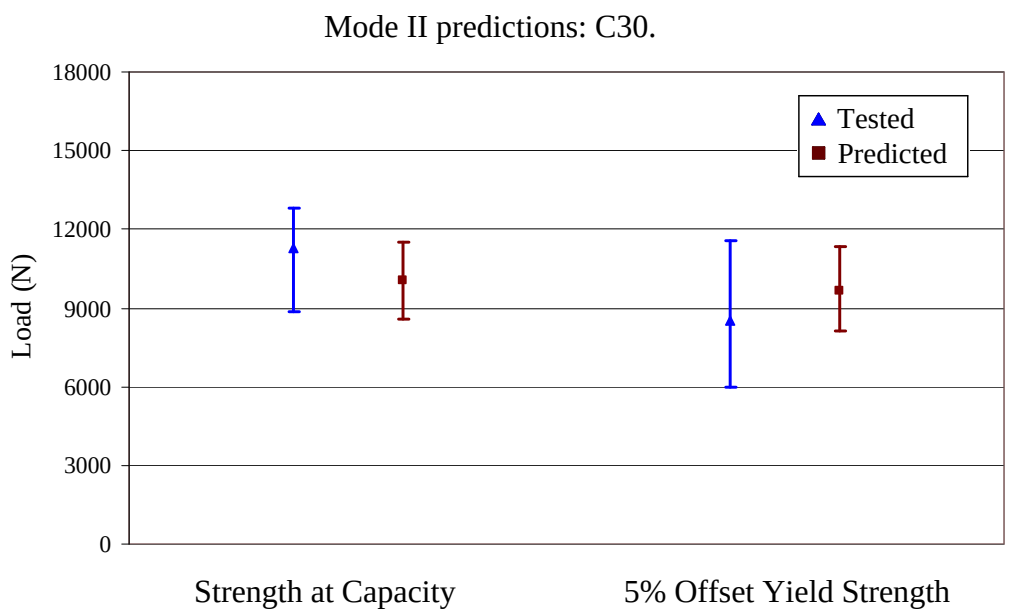

Figure 4.47a: Mode II experimental/predicted YLM comparison plot: C30 (SI).

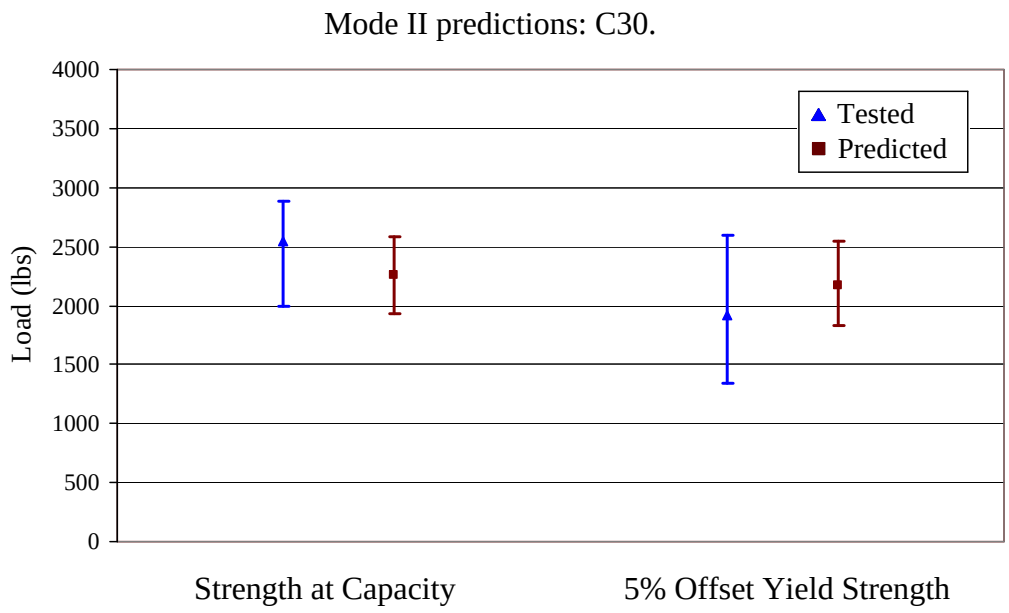

Figure 4.47b: Mode II experimental/predicted YLM comparison plot: C30 (Std.).

Table 4.66: Inferences concerning means, predicted Mode II yield: C30.

Inference	Capacity	5% Offset Yield
t-statistic	2.58	-1.42
Decision	Re. Ho	C.R. Ho

Re. Ho: Reject null hypothesis that means are equal.
C.R.Ho: Cannot reject null hypothesis that means are equal.

The Yield Model was found to accurately predict 5% offset yield strength values for single-bolt connections designed to display Mode III_s and Mode IV yield. Analyses comparing mean predicted and experimental values indicated that it could not be disproved that there existed a statistical difference between these configurations. However, when considering the single-bolt connection predicted to display Mode II yield, the YM was not accurate. Inherent to the Yield Model is the assumption that connections will exhibit ductile behavior, consistent with smaller diameter fasteners. The predicted Mode II yield connections using 19.1 mm (¾ in.) diameter bolts exhibited brittle failures; often producing splitting failures prior to reaching the 5% offset yield strength. The accuracy of the model when predicting single-bolt connection test results coincided with the assumption inherent to the model that the joint would not fail due to shear, splitting, or axial load on the section.

Multiple-bolt connections are typically designed using the Yield Model in conjunction with the Group Action Factor (C_g). As previously mentioned, the Group Action Factor was taken as 1.0 and direct comparisons were made between YM predicted results and experimental results on a per-bolt basis.

Bolt behavioral predictions for multiple-bolt connections expected to display behavior consistent with Mode II yield were correct, all bolts rigidly rotated about the shear plane. However, inferences concerning mean 5% offset yield strength values indicated a statistical difference between predicted and experimental results for all configurations except three-rows of three-bolt configurations. In these cases, the YM underestimated the yield strength. In the cases where the model was accurate, the per-bolt yield strength was much lower than the remaining configurations.

Behavioral predictions for multiple-bolt connections expected to display behavior consistent with Mode III_s yield were incorrect. A mixed mode yield ranging from Mode III_s to Mode IV was observed in specimens consisting of three rows. Conversely, one or more bolts in specimens consisting of three bolts-per-row did not attain Mode III_s yield. Inferences concerning mean 5% offset yield strength values indicated a statistical difference between predicted and experimental results for the single-row configurations and all multiple row configurations of 2D row spacing.

Predictions for multiple-bolt connections expected to display behavior consistent with Mode IV yield were correct for configurations consisting of a single bolt-per-row based on bolt behavior. One or more bolts in specimens containing three bolts-per-row did not attain Mode IV yield. Inferences concerning mean 5% offset yield strength values indicated a statistical difference between predicted and experimental results for all tested multiple-bolt configurations predicted to display behavior consistent with Mode IV yield.

Visual inspection indicated that connection capacity was underestimated by the YM for all configurations except those consisting of three bolts in a row predicted to display behavior consistent with Mode III_s and Mode IV Yield. Of the exceptions indicated above, statistical analyses indicated that there was not a significant difference between tested and predicted connection capacity for configurations using a single row of three bolts.

As suggested by Anderson (2001), material sampling and material property testing may have affected the accuracy of 5% offset yield strength and capacity predictions provided by the YM when compared to tested values. Material samples were

taken from the cut-off ends as described in section 3.7.2. The objective when fabricating dowel embedment samples was to utilize the clearest portion of the cut-off section, which did not always correspond to the section in-line with a row of bolts. It is possible that local variations in material properties and growth-ring patterns may have led to inconsistencies when comparing 5% offset yield strength predictions to tested values.

Factors inherent to the dowel bearing test method may also have led to inconsistencies between tested and YM predicted 5% offset yield values for some configurations tested. Despite using the full-hole method, premature splitting occurred when testing the 12.7 mm (½ in.) and 19.1 mm (¾ in.) diameter bolts. The 5% offset yield value was often not reached, resulting in an underestimation of both yield strength and capacity when using these values as input parameters for the YM.

Inconsistencies between tested and predicted results may also exist because of factors not accounted for by the YM. The model assumes a dowel type connection with ends possessing the ability to rotate freely. In reality, the nut, washer, and head of the bolt introduced end fixity in the connection restraining the bolts from rotation, potentially influencing the Yield Mode experienced by the connection. Furthermore, at larger displacements, bolts are subjected to tensile forces due to end fixity that cause friction to develop at the member interface. The load resisted by bearing on the bolts is equal to the total load imposed on the connection less the magnitude of the frictional force between the members, resulting in an underestimation by the model at capacity, and potentially at yield depending on the initial stiffness of the connection. The YM also assumes uniform stress beneath the bolt and a well manufactured joint, providing a nearly perfect fit of bolts in the holes. There is, however, a non-uniform stress distribution beneath each bolt

in the connection through the cross section of the member as it is loaded. The YM utilizes the dowel bearing strength test to describe the resistance of the wood to crushing beneath bolts, however, the test method does not necessarily facilitate direct comparison. The dowel bearing test sample is subjected to a monotonic load, uniformly distributed through the cross section of the sample, while the bolted connection test is subjected to a fully reverse cyclic load with a non-uniform stress distribution. Additionally, load is distributed unevenly among bolts in a row due to bolt hole misalignment and fabrication tolerances. The YM also states that the end distance in bolted connections shall be sufficient to prevent splitting failure mechanisms. The NDS end distance recommendation of seven times the bolt diameter was followed; however, splitting was the predominant failure mechanism for all connections, violating the model's material assumption that both wood and bolt will display infinite displacement capacity. The non-uniform stress distribution previously discussed, produced increased localized stresses at member surfaces leading to premature splitting failures and non-conservative predictions by the YM at capacity.

The splitting failures observed, while violating the YM material assumption, and influencing connection capacity, likely did not affect 5% offset yield strength predictions for connections predicted to display Mode III_s and Mode IV yield, however, those displaying behavior consistent with Mode II yield often produced splitting failures prior to reaching the 5% offset yield strength.

4.7 – 2001 NDS Appendix E Comparisons

Table 4.67 shows the tested and the predicted failure results using the 2001 NDS (AF&PA, 2001) Appendix E equations for local stresses in fastener groups. The Appendix E predicted values reflect a load duration factor (C_D) equal to 1.6 as provided by the 2001 NDS for a loading duration of 10 minutes, which would correspond to seismic loading. For each configuration, the values provided by the YM equations are listed and compared with the values yielded from performing the Appendix E equations. The conservative of the two equation sets is listed in the far right column of Table 4.67.

Table 4.67a: Appendix E results (SI).

Configuration	YM Predicted (N)	Tested		Appendix E Prediction		Tested/ Appendix E	Governing Model
		Capacity (N)	Failure Mode	Capacity (N)	Failure Mode		
1	3535	9881	BS	7847	RTO	1.26	YM
2	9768	11830	S	23540	RTO	0.50	YM
4	10333	21259	BS	13220	GTO	1.61	YM
5	9881	20318	BS	20376	GTO	1.00	YM
8	28043	31391	S	28917	GTO	1.09	YM
9	28366	30954	S	36070	GTO	0.86	YM
11	8629	11416	S	6726	RTO	1.70	Appendix E
12	27117	26481	S	20177	RTO	1.31	Appendix E
14	25364	29614	S	19259	GTO	1.54	Appendix E
15	24917	35281	S	20177	RTO	1.75	Appendix E
16	24330	35076	S	20177	RTO	1.74	Appendix E
18	74812	72297	GTO	32703	GTO	2.21	Appendix E
19	75518	79266	S	47030	GTO	1.69	Appendix E
21	8269	14181	S	10085	RTO	1.41	YM
22	25588	34888	S	16498	T	2.11	Appendix E
24	22659	39621	GTO	18526	GTO	2.14	Appendix E
25	25024	44446	S	27736	GTO	1.60	YM
28	68874	83311	S/GTO	29543	T	2.82	Appendix E
29	74408	102522	S/GTO	41835	T	2.45	Appendix E
30	86753	101684	S	29543	T	3.44	Appendix E

S = Splitting Failure
T = Net Section Tension Failure
BS = Bolt Shear Failure
GTO = Group Tear-Out Failure
RTO = Row Tear-Out Failure

Table 4.67b: Appendix E results (Std.).

Configuration	YM Predicted (lbs.)	Tested		Appendix E Prediction		Tested/ Appendix E	Governing Model
		Capacity (lbs.)	Failure Mode	Capacity (lbs.)	Failure Mode		
1	795	2221	BS	1764	RTO	1.26	YM
2	2196	2660	S	5292	RTO	0.50	YM
4	2323	4779	BS	2972	GTO	1.61	YM
5	2221	4568	BS	4581	GTO	1.00	YM
8	6304	7057	S	6501	GTO	1.09	YM
9	6377	6959	S	8109	GTO	0.86	YM
11	1940	2566	S	1512	RTO	1.70	Appendix E
12	6096	5953	S	4536	RTO	1.31	Appendix E
14	5702	6657	S	4330	GTO	1.54	Appendix E
15	5602	7931	S	4536	RTO	1.75	Appendix E
16	5470	7885	S	4536	RTO	1.74	Appendix E
18	16818	16253	GTO	7352	GTO	2.21	Appendix E
19	16977	17820	S	10573	GTO	1.69	Appendix E
21	1859	3188	S	2267	RTO	1.41	YM
22	5752	7843	S	3709	T	2.11	Appendix E
24	5094	8907	GTO	4165	GTO	2.14	Appendix E
25	5626	9992	S	6235	GTO	1.60	YM
28	15483	18729	S/GTO	6642	T	2.82	Appendix E
29	16728	23048	S/GTO	9405	T	2.45	Appendix E
30	19503	22859	S	6642	T	3.44	Appendix E

S = Splitting Failure
T = Net Section Tension Failure
BS = Bolt Shear Failure
GTO = Group Tear-Out Failure
RTO = Row Tear-Out Failure

The results provided in the table above confirm that the YM is a more conservative tool for predicting capacity in connections displaying ductile behavior consistent with Mode IV yield. The Appendix E equations were found to be conservative relative to tested values in all configurations except for two, nine, and five, with the tested/predicted ratio for configuration five equal to 1.0. A higher degree of conservatism was typically observed in configurations utilizing larger diameter bolts. The average ratio of tested/Appendix E for configurations predicted to display Mode IV, Mode III_s, and Mode II yield behavior was, respectively, 1.05, 1.70, and 2.28.

Limiting this discussion to bolted connections displaying brittle failure mechanisms, as earlier defined, failure mechanism trends observed in testing and listed in Table 4.67 seem to be properly addressed by the capacity equations provided in Appendix E of the 2001 NDS (NDS, 2001). As row spacing was increased from 2D to 3D, the predominant failure mechanism shifted from group tear-out to splitting through the centerline of a bolt row. This phenomenon was present for all connections with three rows of bolts predicted to display Mode II and Mode III_s yield behavior, with the exception of the 12.7 mm (½ in.) diameter bolts with three rows of a single bolt configuration. The increased material loaded in tension parallel to grain adjacent to rows of bolts likely influenced the shift in failure mode.

As row spacing was increased from 2D to 3D, connections predicted to display Mode III_s yield, showed an increase in capacity for three rows of one bolt, and three rows of three bolt connection geometries of 19% and nearly 10% respectively. Similarly, connections predicted to display Mode II yield, showed an increase in capacity for three rows of one bolt, and three rows of three bolt connection geometries of 12% and nearly 23% respectively. Appendix E, while overly conservative in capacity predictions for larger diameter bolts, did identify an increase in capacity as row spacing increased whereas, prediction by the YM made no such recognition.

Of the two hundred specimens tested, nearly seventy percent of those exhibited splitting failure mechanisms, which are not addressed as a possible failure mechanism in the equations provided by Appendix E of the 2001 NDS (NDS, 2001). Dodson (2003) suggests that splitting failures may be more suitably addressed by considering tension perpendicular to grain stresses in addition to shear parallel to grain stresses rather than

strictly shear parallel to grain stresses for connection capacity which would be more representative of the loading imposed by bolts in connections. Additionally, predictions provided by Appendix E may have been more accurate if tests had been performed to obtain the actual tension and shear capacities from material used in this study.

Summary, Conclusions, and Recommendations

5.1 - Summary

The primary objective of this research was to determine whether the performance of multiple-bolt connections subjected to cyclic loading would be enhanced by increased row spacing. The current minimum standard row spacing recommended by the NDS is 1.5D. This spacing is problematic because the clearance between adjacent bolt rows is not adequate to facilitate flat washers at each end of the bolt. Various connection geometries incorporating 2D and 3D row spacing were tested using the displacement controlled CUREE protocol.

Additionally, physical and material property tests were performed to determine moisture content, specific gravity, dowel embedment strength, and bolt bending yield strength. Raw data from the full connection tests was used to determine connection performance characteristics including ductility ratio, connection capacity, 5% offset yield strength, elastic stiffness, and E.E.P. yield load. Statistical analyses were performed to determine if inferences could be made regarding mean ductility ratios, 5% offset yield strengths, and connection capacities as row spacing was varied.

5.2 - Conclusions

5.2.1 - Row Spacing Effects

The ductility ratio, 5% offset yield strength, and capacity of each connection was normalized to single-bolt values for each bolt diameter, and then plotted. Results based

on statistical inferences concerning means for each predicted yield mode and numbers of bolts per row (BPR) are described below.

5.2.1.1 - 5% Offset Yield Strength and Connection Capacity Inferences

- 3D row spacing was optimal for connections with a single bolt-per-row predicted to display behavior consistent with Mode III_s yield.
- 3D row spacing was optimal for connections with three bolts-per-row predicted to display behavior consistent with Mode II yield.

5.2.1.2 - Connection Ductility Inferences

- 3D row spacing was optimal for connections with three bolts-per-row predicted to display behavior consistent with Mode II yield.

See Table 5.1 for easy visualization of the statistical inferences listed above. When 3D row spacing provided optimal results relative to 2D row spacing for a given connection performance characteristic, the cell is labeled as 3D. For those cells left blank, it could not be determined that 3D row spacing had a significant benefit on the connection performance characteristic of interest based on statistical analyses.

Table 5.1: Optimal connection performance.

Yield Mode	Ductility		5% Offset Yield		Capacity	
	1 BPR	3 BPR	1 BPR	3 BPR	1 BPR	3 BPR
Mode IV	-	-	-	-	-	-
Mode III_s	-	-	3D	-	3D	-
Mode II	-	3D	-	3D	-	3D

5.2.1.3 - Observed Trends as Row Spacing Increases

- When no statistical inferences could be made at a significance level of $\alpha = 0.05$ for connection performance characteristics above as row spacing was increased from 2D to 3D, visual inspection of normalized plots indicated that for predicted Mode II and Mode III_s yield tests, increased row spacing did improve performance in multiple-bolt connections.
- Row spacing had a negligible effect on connections predicted to display behavior consistent with Mode IV yield, or those displaying ductile failure mechanisms.
- Connection performance characteristics are affected most significantly by an increase in bolt-per-row quantities, resulting from non-uniform load distribution.

5.2.2 - Yield Limit Model Predictions

- The Yield Model was accurate in predicting 5% offset yield strength for single-bolt, single-shear connections displaying behavior consistent with Modes III_s and IV yield when exposed to reverse cyclic loading parallel to grain.
- Testing indicated that the YM may be valid when predicting yield strength for multiple-bolt connections displaying behavior consistent with Mode III_S yield when row spacing is 2.5D or larger.
- A similar trend as above was observed in connections predicted to display Mode IV yield behavior; however, no firm conclusions based on statistical inferences could be made.
- Table 5.2 summarizes the accuracy of the YM predictions when compared to tested values for 5% offset yield strength based on statistical inferences.

Table 5.2: Summary of YM predictions and observed yield modes.

Mode IV	5% Offset Yield	Observed Yield Modes
1R1	C.R. Ho	IV
1R3	Re. Ho	III_s-IV and IV
3R1 2D	Re. Ho	IV
3R1 3D	Re. Ho	IV
3R3 2D	Re. Ho	III_s-IV and IV
3R3 3D	Re. Ho	III_s-IV and IV

Mode III_s	5% Offset Yield	Observed Yield Modes
1R1	C.R. Ho	III_s
1R3	Re. Ho	II-III_s and III_s
3R1 2D	Re. Ho	III_s and III_s-IV
3R1 2.5D	C.R. Ho	III_s and III_s-IV
3R1 3D	C.R. Ho	III_s and III_s-IV and IV
3R3 2D	Re. Ho	II-III_s and III_s
3R3 3D	C.R. Ho	II-III_s and III_s

Mode II	5% Offset Yield	Observed Yield Modes
1R1	Re. Ho	II
1R3	Re. Ho	II
3R1 2D	Re. Ho	II
3R1 3D	Re. Ho	II
3R3 2D	C.R. Ho	II
3R3 2.5D	C.R. Ho	II
3R3 3D	C.R. Ho	II

Re. Ho: Reject null hypothesis that YM predicted and tested means are equal.
C.R.Ho: Cannot reject null hypothesis that YM predicted and tested means are equal.

5.2.2 - Yield Limit Model Discussion

Table 5.2 also provides expected yield mechanisms and observed yield mechanisms. Aside from the joints predicted to display behavior consistent with Mode II yield, the YM was not able to predict yield behavior with any significant degree of accuracy. Limiting this discussion to Mode III_s and Mode IV yield predictions, the ability of the YM to accurately predict yield behavior seems largely a function of joint geometry. Connections with geometries consisting of a single bolt-per-row produced

yield behavior consistent with YM predictions and mixed mode yields migrating past the predicted yield mode. Conversely, connections with geometries consisting of three bolts in a row produced yield behavior consistent with YM predictions and mixed mode yields in which the predicted yield mode was not attained by all bolts in the connection. Unequal load distribution due to fabrication tolerances and shear lag was apparent in joints containing three bolts in a row, producing splitting failure mechanisms typically preventing one or more bolts in a joint from reaching the predicted yield mode. It is also possible that end fixity caused by nut, washer, and bolt head inhibited bolt rotation, thus introducing variable load distribution across the thickness of the member. Additionally, as a result of end fixity, the frictional forces induced at larger displacements between main and side member of the connection increased the magnitude of connection capacity, leading to overly conservative predictions by the YM at capacity.

Multiple-bolted joints containing a single-bolt per row typically exhibited increased ductility relative to connections with three bolts in a row based on load-deflection behavior and failure mechanisms. One or more bolts in joints predicted to display behavior consistent with Mode III_s yield migrated past the predicted yield mode to display Mode IV yield characteristics, creating a mixed mode yield condition for those connections. In configurations predicted to display behavior consistent with Mode IV yield, tension forces evidenced by significant necking were present; however, the reverse bending associated with Mode IV yield was not always present.

5.2.3 - Appendix E Predictions

- Capacity is overestimated for multiple-bolt connections displaying brittle failure mechanisms. Mean Tested/Appendix E Predicted ratios for Mode II and Mode III_s yield connections are 1.70 and 2.28 respectively.
- As row spacing increased from 2D to 3D, failure mechanism shifted form group tear-out to splitting. Appendix E equations recognize additional capacity and changing failure mode as row spacing is increased.
- Splitting is not identified as a potential failure mechanism. Roughly 70% of connections tested displayed splitting failure mechanisms.

5.3 - Design Recommendations

The following recommendations should be adhered to by those designing multiple-bolt connections and incorporated into wood connection design standards including future editions of the National Design Specification for Wood Construction

- Row spacing recommendations shall be based on a distance of three times the bolt diameter for full design value. Reduced design values shall be solved for by dividing the actual row spacing by 3D row spacing, provided that the actual row spacing is at least 1.5D. The value obtained will be the Geometry Factor (C_Δ).
- To better understand bolted connection behavior, particularly in connections using larger diameter bolts, the Appendix E equations of the 2001 NDS should be used to indicate relative failure modes as connection geometry, member dimensions, and fastener diameter are varied.

- A conservative designer should use the lesser value obtained when comparing Appendix E equations for local stresses in fastener groups and the Yield Model.

5.4 - Limitations of Research

Limitations of the present research include:

- Only single-shear connections were considered.
- A single wood species was considered (Douglas Fir-Larch).
- A limited range of moisture contents were considered (12% – 16%).
- Loading was only performed parallel to grain.
- A limited range of connection geometries were considered.

5.5 - Recommendations for Future Research

Future research performed should expand on the limitations of the present research. Further testing could be conducted, perhaps considering additional row spacings, and a larger sample size. These two factors would ultimately determine whether performance characteristics are enhanced, and whether the YM accurately predicts 5% offset yield strength as row spacing is increased. Furthermore, additional factors that should be considered are double-shear, and perpendicular-to-grain configurations.

Considering the inconsistencies observed between the predicted and actual yield modes attained, further research should focus on factors affecting yield theory. In the present research, splitting of the wood through the centerline of a row of bolts oftentimes inhibited full migration of all bolts in a connection to their predicted yield mode for

configurations predicted to display Mode III_s and Mode IV yield. Consideration for the failure mechanisms observed in multiple-bolt connections, particularly in those using larger diameter bolts showing catastrophic failure mechanisms such as splitting and group tear-out, should be included in the derivation of the Yield Model. Additionally, as noted by Anderson (2002), the model should be expanded to include consideration for end fixity provided by nut, washer, and bolt head, and friction between the members caused by bolt tensioning. Additionally, the non-uniform stress distribution through the member's cross-section shall be considered. As the Yield Model is expanded to include considerations for the above, a more accurate depiction of yield and capacity level behavior that exists in multiple-bolt connections will be attained.

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Appendix A Cyclic Connection Tests

A.1

Strength and serviceably parameters described in chapter three are tabulated for all connections tested, and are presented in this chapter. Physical and material properties including dowel embedment strength and specific gravity for each member per configuration are also tabulated in this chapter. Load-displacement plots with connection envelope curves and E.E.P. characteristics as described in chapter three are presented for each connection tested. A mean envelope curve for each configuration is presented prior to individual load-displacement plots. The curve is constructed by selecting the maximum load from each primary cycle of a connection test, and determining the mean value of that cycle for all ten test replications of each configuration. This procedure is carried out for the negative and positive portion of each curve for primary cycles until failure.

A1.1 - Predicted Yield Mode IV Configurations

Table A.1a: Connection performance properties (SI), Configuration 1.

Connection Performance Properties: Configuration 1

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	10.53	9.21	9.53	10.36	9.25	9.69	12.99	8.02	11.02	8.21	9.88	1.45	0.15
@ Displacement (mm)	36.00	53.84	34.51	49.59	49.44	39.40	39.01	40.69	38.42	40.50	42.14	6.48	0.15
Failure Load (kN)	8.42	7.37	7.63	8.28	7.40	7.75	10.39	6.42	8.82	6.57	7.91	1.16	0.15
@ Displacement (mm)	36.00	54.78	34.75	49.62	49.61	40.02	39.05	40.69	39.69	40.50	42.47	6.56	0.15
40% Max (kN)	3.16	2.76	2.86	3.11	2.30	2.91	3.90	2.41	3.31	3.28	3.00	0.46	0.15
@ Displacement (mm)	4.13	4.56	3.74	3.91	3.69	3.48	4.39	4.09	3.81	4.45	4.02	0.36	0.09
Yield (kN)	8.42	7.37	7.63	8.28	7.40	7.75	10.39	6.42	8.82	6.57	7.91	1.16	0.15
@ Displacement (mm)	12.19	11.38	10.76	11.13	9.32	7.49	13.87	9.72	9.37	8.19	10.34	1.91	0.18
5% Offset Yield (kN)	3.71	2.02	3.65	3.69	2.64	3.48	3.70	2.72	2.95	3.72	3.23	0.61	0.19
@ Displacement (mm)	5.41	3.59	5.33	5.04	4.39	4.28	4.29	4.83	3.64	5.26	4.60	0.67	0.15
Elastic Stiff. (N/mm)	695.02	686.35	695.14	716.91	970.26	1209.31	726.84	717.39	1024.25	879.19	832.07	181.60	0.22
E.E.P. Energy (N*m)	256.91	359.34	228.63	367.51	328.26	276.83	340.74	227.38	306.45	236.09	292.81	54.68	0.19
Ductility Ratio	2.96	4.87	3.21	4.48	5.34	5.35	2.98	4.19	4.32	5.11	4.28	0.94	0.22
Yield Mode	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV			
Failure Mode	Blt Shr	Blt Shr	Blt Shr	Blt Shr	Splitting	Blt Shr	Blt Shr	Splitting	Blt Shr	Splitting			
Governing Member	N.A.	N.A.	N.A.	N.A.	Main	N.A.	N.A.	Side	N.A.	Main			

Table A.1b: Connection performance properties (Std.), Configuration 1.

Connection Performance Properties: Configuration 1

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	2366.39	2069.82	2143.48	2328.17	2080.38	2178.77	2920.82	1803.25	2477.59	1845.63	2221.43	325.58	0.15
@ Displacement (in)	1.42	2.12	1.36	1.95	1.95	1.55	1.54	1.60	1.51	1.59	1.66	0.25	0.15
Failure Load (lbs)	1893.12	1655.85	1714.78	1862.54	1664.31	1743.02	2336.65	1442.60	1982.07	1476.50	1777.14	260.47	0.15
@ Displacement (in)	1.42	2.16	1.37	1.95	1.95	1.58	1.54	1.60	1.56	1.59	1.67	0.26	0.15
40% Max (lbs)	709.92	620.94	643.04	698.45	517.74	653.63	876.24	540.98	743.28	738.25	674.25	104.36	0.15
@ Displacement (in)	0.16	0.18	0.15	0.15	0.15	0.14	0.17	0.16	0.15	0.18	0.16	0.01	0.09
Yield (lbs)	1893.12	1655.85	1714.78	1862.54	1664.31	1743.02	2336.65	1442.60	1982.07	1476.50	1777.14	260.47	0.15
@ Displacement (in)	0.48	0.45	0.42	0.44	0.37	0.29	0.55	0.38	0.37	0.32	0.41	0.08	0.18
5% Offset Yield (lbs)	835.16	454.71	821.27	828.88	593.42	783.00	831.20	610.48	662.20	836.96	725.73	136.13	0.19
@ Displacement (in)	0.21	0.14	0.21	0.20	0.17	0.17	0.17	0.19	0.14	0.21	0.18	0.03	0.15
Elastic Stiff. (lb/in)	3968.64	3919.17	3969.36	4093.66	5540.34	6905.35	4150.36	4096.40	5848.64	5020.29	4751.22	1036.98	0.22
E.E.P. Energy (lb*in)	2273.89	3180.41	2023.52	3252.70	2905.36	2450.13	3015.80	2012.49	2712.33	2089.57	2591.62	483.94	0.19
Ductility Ratio	2.96	4.87	3.21	4.48	5.34	5.35	2.98	4.19	4.32	5.11	4.28	0.94	0.22
Yield Mode	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV			
Failure Mode	Blt Shr	Blt Shr	Blt Shr	Blt Shr	Splitting	Blt Shr	Blt Shr	Splitting	Blt Shr	Splitting			
Governing Member	N.A.	N.A.	N.A.	N.A.	Main	N.A.	N.A.	Side	N.A.	Main			

Table A.2a: Member properties (SI), Configuration 1.

Member Properties: Configuration 1

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.78	15.79	16.30	16.91	15.62	17.39	16.64	13.64	16.20	16.36	16.06	1.01	0.06
S.G.	0.63	0.48	0.55	0.48	0.49	0.60	0.62	0.45	0.60	0.46	0.54	0.07	0.13
D.E. 5% Offset Yield (kPa)	52657	33801	52212	34733	34359	47732	51269	38605	45873	33790	42503	8208.70	0.19
D.E. Capacity (kPa)	59848	38292	57498	39187	43147	49384	57570	46897	54638	41339	48780	8186.28	0.17
Side Member													
M.C. (%)	15.87	17.02	15.71	16.34	15.03	16.92	16.66	15.55	15.04	15.19	15.93	0.76	0.05
S.G.	0.68	0.44	0.58	0.52	0.51	0.54	0.62	0.44	0.56	0.43	0.53	0.08	0.16
D.E. 5% Offset Yield (kPa)	47609	27879	47196	39950	36009	45893	53992	36362	50348	35181	42042	8198.06	0.19
D.E. Capacity (kPa)	53024	31294	51820	43180	38525	49004	61419	40977	53383	41907	46453	8847.50	0.19

Table A.2b: Member properties (Std.), Configuration 1.

Member Properties: Configuration 1

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.78	15.79	16.30	16.91	15.62	17.39	16.64	13.64	16.20	16.36	16.06	1.01	0.06
S.G.	0.63	0.48	0.55	0.48	0.49	0.60	0.62	0.45	0.60	0.46	0.54	0.07	0.13
D.E. 5% Offset Yield (psi)	7637.18	4902.33	7572.63	5037.49	4983.35	6922.96	7435.91	5599.15	6653.26	4900.86	6164.51	1190.56	0.19
D.E. Capacity (psi)	8680.20	5553.81	8339.36	5683.52	6257.86	7162.52	8349.81	6801.81	7924.52	5995.63	7074.90	1187.31	0.17
Side Member													
M.C. (%)	15.87	17.02	15.71	16.34	15.03	16.92	16.66	15.55	15.04	15.19	15.93	0.76	0.05
S.G.	0.68	0.44	0.58	0.52	0.51	0.54	0.62	0.44	0.56	0.43	0.53	0.08	0.16
D.E. 5% Offset Yield (psi)	6905.04	4043.54	6845.12	5794.23	5222.61	6656.19	7830.84	5273.88	7302.38	5102.50	6097.63	1189.02	0.19
D.E. Capacity (psi)	7690.39	4538.78	7515.80	6262.72	5587.61	7107.38	8908.06	5943.12	7742.45	6078.07	6737.44	1283.21	0.19

Table A.3a: Hysteretic connection properties (SI), Configuration 1.

Hysteretic Connection Properties: Configuration 1

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	0.65	0.59	0.92	0.95	0.56	0.59	-0.82	0.93	1.14	-1.23	0.17	0.14
Primary2	0.98	0.84	0.85	1.46	0.75	0.51	-1.24	1.14	0.91	-1.80	0.09	0.05
Primary3	2.89	1.09	0.38	3.87	0.12	0.03	-2.86	1.14	0.40	-4.04	0.09	0.02
Primary4	3.66	1.24	0.34	5.94	0.09	0.02	-3.69	0.62	0.17	-6.00	0.14	0.02
Primary5	3.90	1.32	0.34	7.95	0.17	0.02	-4.04	0.71	0.18	-7.86	0.31	0.04
Primary6	4.86	1.75	0.36	14.29	0.17	0.01	-5.09	1.17	0.23	-13.47	0.65	0.05
Primary7	6.05	2.12	0.35	20.44	0.22	0.01	-6.03	1.52	0.25	-19.21	0.53	0.03
Primary8	8.32	2.96	0.36	30.44	0.38	0.01	-7.96	1.86	0.23	-28.79	0.47	0.02
Primary9	9.84	3.45	0.35	40.23	0.35	0.01	-8.43	2.73	0.32	-35.72	3.10	0.09
Primary10	7.51	3.80	0.51	48.75	2.02	0.04	-8.05	3.56	0.44	-44.19	4.52	0.10
Primary11	5.14	5.04	0.98	55.77	4.22	0.08	-8.67	0.49	0.06	-56.03	1.54	0.03

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	1.14	1.31	1.15	0.91	0.60	0.66	0.17	0.12	0.70	643.08	459.02	0.71
Primary2	1.99	1.90	0.96	1.97	0.76	0.39	0.14	0.09	0.65	684.35	366.71	0.54
Primary3	9.54	4.19	0.44	11.34	2.38	0.21	0.13	0.04	0.33	726.10	152.23	0.21
Primary4	19.73	5.80	0.29	21.92	2.93	0.13	0.14	0.03	0.21	616.31	85.80	0.14
Primary5	30.19	6.90	0.23	31.38	4.58	0.15	0.15	0.02	0.14	502.25	71.57	0.14
Primary6	85.96	15.63	0.18	69.12	13.02	0.19	0.20	0.01	0.05	358.96	67.57	0.19
Primary7	130.68	23.17	0.18	119.82	22.71	0.19	0.17	0.01	0.08	304.89	57.69	0.19
Primary8	230.11	38.33	0.17	241.10	46.30	0.19	0.15	0.02	0.11	274.95	53.73	0.20
Primary9	271.56	57.24	0.21	350.40	77.46	0.22	0.12	0.01	0.10	240.37	49.11	0.20
Primary10	291.18	88.12	0.30	366.15	144.35	0.39	0.13	0.03	0.20	165.69	58.01	0.35
Primary11	286.31	32.48	0.11	389.42	109.11	0.28	0.12	0.02	0.17	122.96	23.01	0.19

Table A.3b: Hysteretic connection properties (Std.), Configuration 1.

Hysteretic Connection Properties: Configuration 1

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	145.08	132.84	0.92	0.04	0.02	0.59	-183.94	208.77	1.14	-0.05	0.01	0.14
Primary2	221.28	188.22	0.85	0.06	0.03	0.51	-279.87	255.27	0.91	-0.07	0.00	0.05
Primary3	649.16	245.21	0.38	0.15	0.00	0.03	-642.11	256.38	0.40	-0.16	0.00	0.02
Primary4	823.76	278.54	0.34	0.23	0.00	0.02	-828.88	138.45	0.17	-0.24	0.01	0.02
Primary5	876.37	297.66	0.34	0.31	0.01	0.02	-908.05	159.12	0.18	-0.31	0.01	0.04
Primary6	1093.64	394.50	0.36	0.56	0.01	0.01	-1145.33	264.10	0.23	-0.53	0.03	0.05
Primary7	1360.64	477.02	0.35	0.80	0.01	0.01	-1356.60	342.66	0.25	-0.76	0.02	0.03
Primary8	1869.76	665.62	0.36	1.20	0.01	0.01	-1790.18	417.63	0.23	-1.13	0.02	0.02
Primary9	2212.53	775.79	0.35	1.58	0.01	0.01	-1895.10	614.79	0.32	-1.41	0.12	0.09
Primary10	1687.62	854.89	0.51	1.92	0.08	0.04	-1809.99	801.44	0.44	-1.74	0.18	0.10
Primary11	1155.23	1132.23	0.98	2.20	0.17	0.08	-1949.94	110.06	0.06	-2.21	0.06	0.03

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	10.10	11.63	1.15	8.07	5.32	0.66	0.17	0.12	0.70	3672.08	2621.09	0.71
Primary2	17.62	16.85	0.96	17.39	6.70	0.39	0.15	0.11	0.72	3907.73	2093.99	0.54
Primary3	84.41	37.08	0.44	100.36	21.04	0.21	0.15	0.05	0.35	4146.12	869.25	0.21
Primary4	174.58	51.30	0.29	194.05	25.92	0.13	0.15	0.03	0.22	3519.21	489.93	0.14
Primary5	267.19	61.09	0.23	277.72	40.53	0.15	0.17	0.03	0.20	2867.93	408.66	0.14
Primary6	760.81	138.31	0.18	611.74	115.28	0.19	0.22	0.04	0.20	2049.74	385.81	0.19
Primary7	1156.65	205.07	0.18	1060.53	201.04	0.19	0.20	0.05	0.27	1740.94	329.42	0.19
Primary8	2036.62	339.29	0.17	2133.90	409.80	0.19	0.18	0.06	0.32	1569.98	306.82	0.20
Primary9	2403.51	506.59	0.21	3101.29	685.57	0.22	0.12	0.01	0.10	1372.55	280.44	0.20
Primary10	2577.13	779.95	0.30	3240.71	1277.57	0.39	0.13	0.03	0.20	946.12	331.27	0.35
Primary11	2534.07	287.50	0.11	3446.69	965.68	0.28	0.12	0.02	0.17	702.09	131.40	0.19

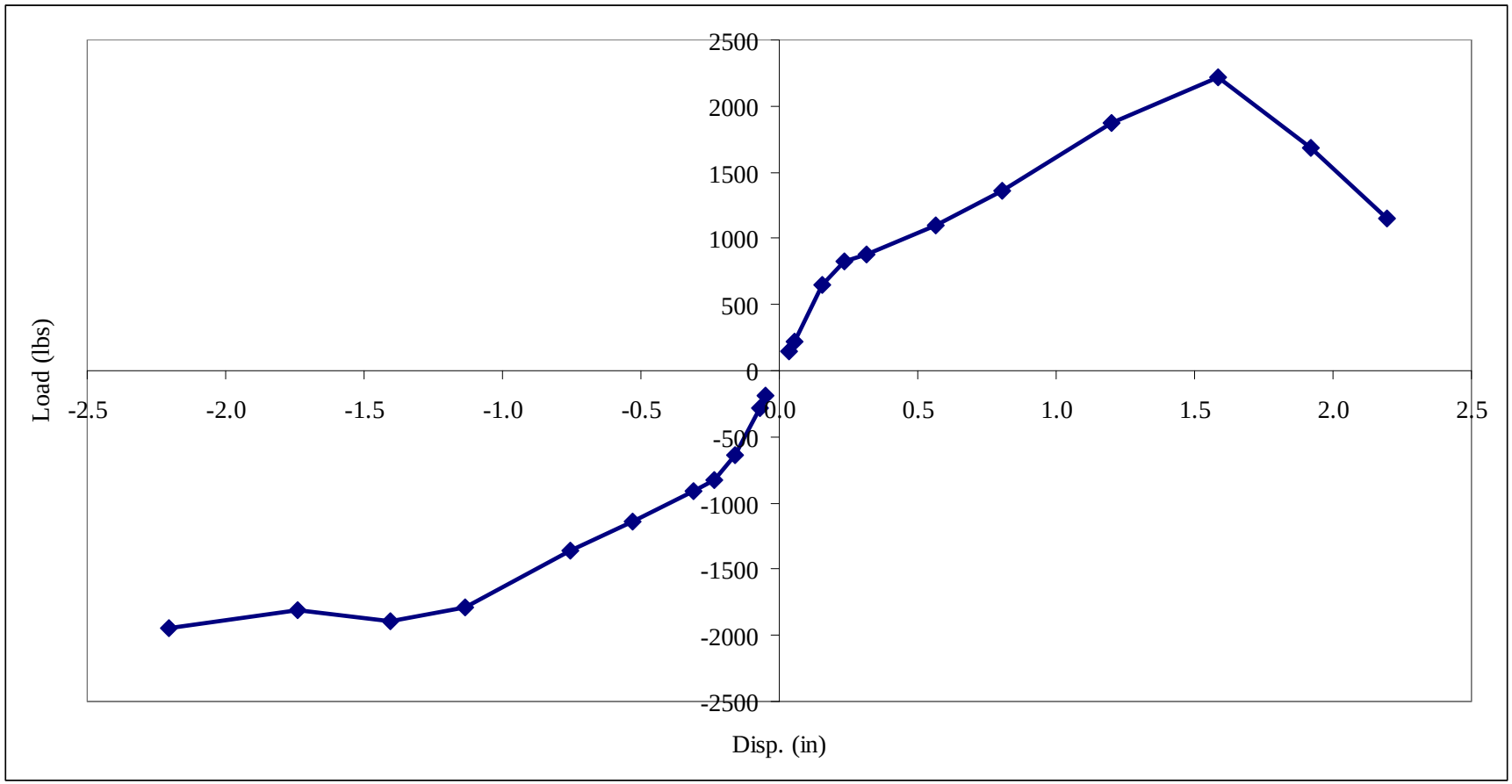

Figure A.1: Mean envelope curve: Configuration 1.

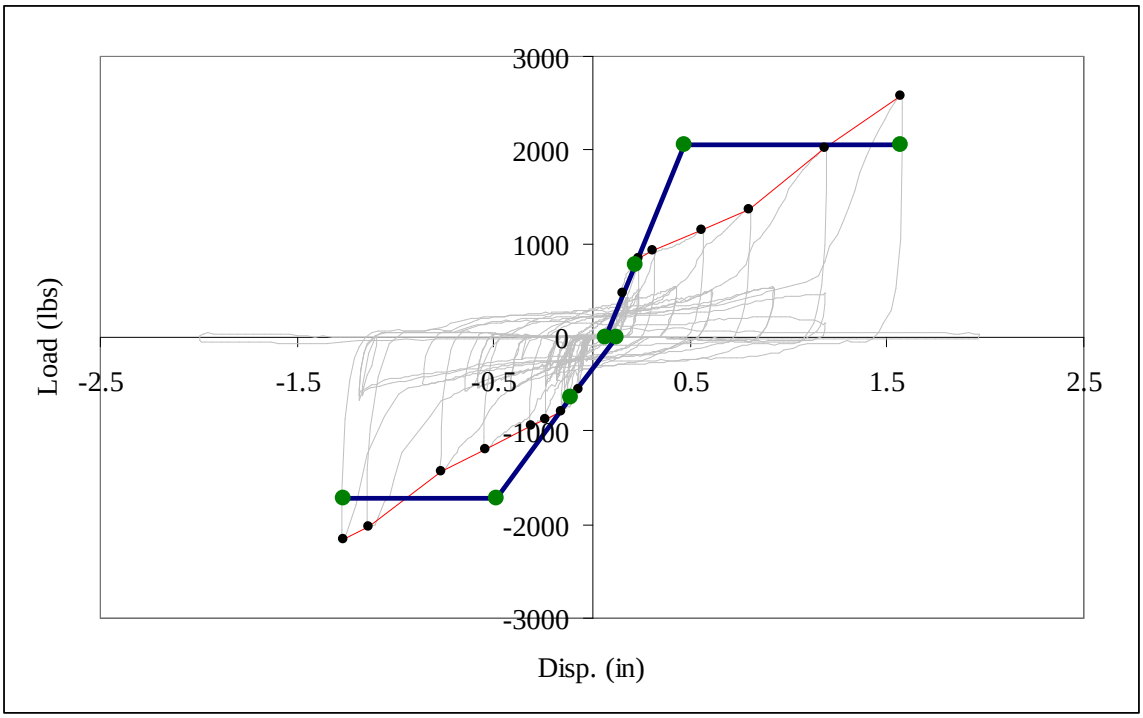

Figure A.2: Load-Deflection plot: C1-1.

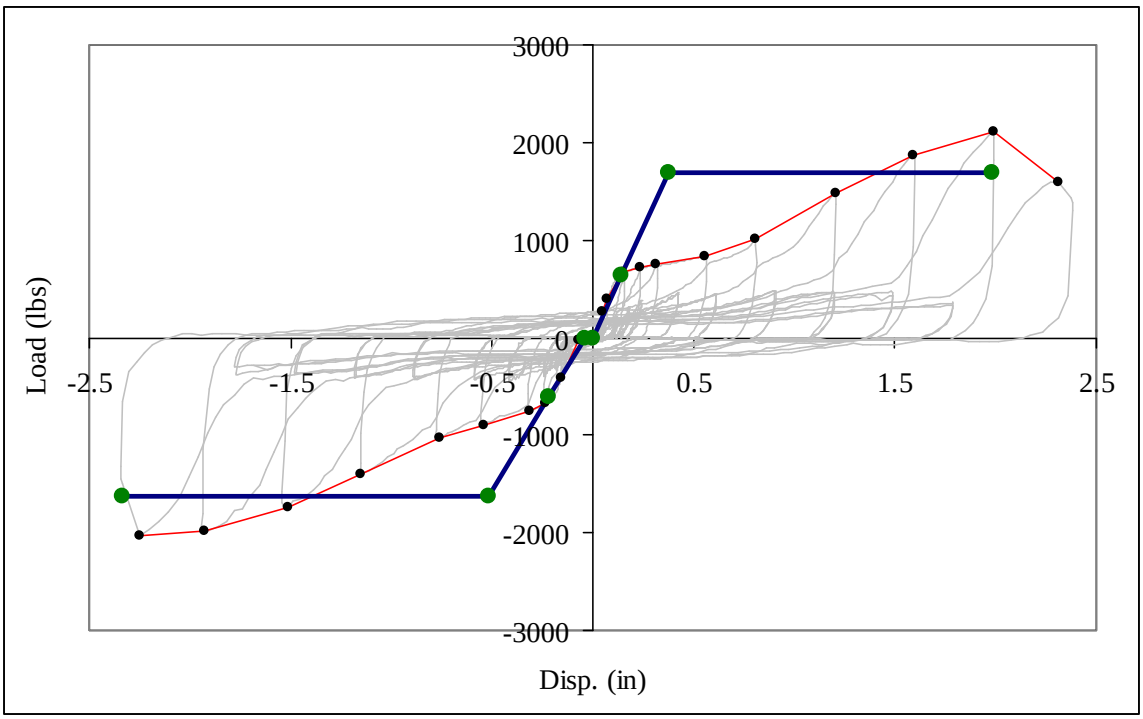

Figure A.3: Load-Deflection plot: C1-2.

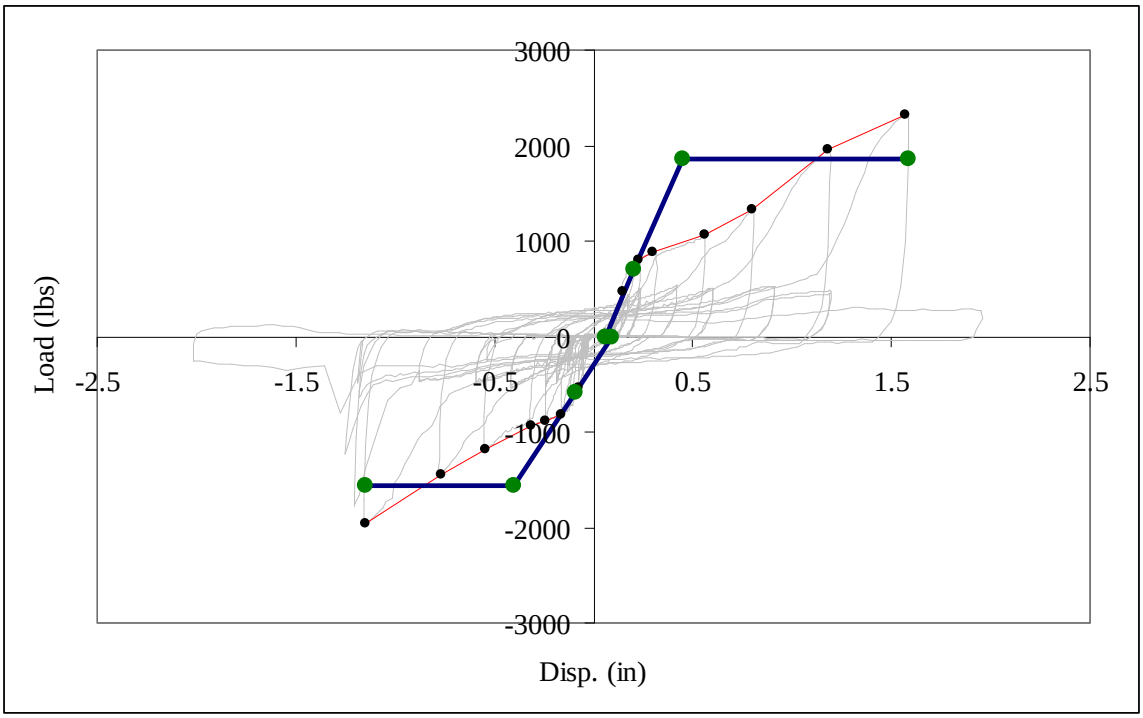

Figure A.4: Load-Deflection plot: C1-3.

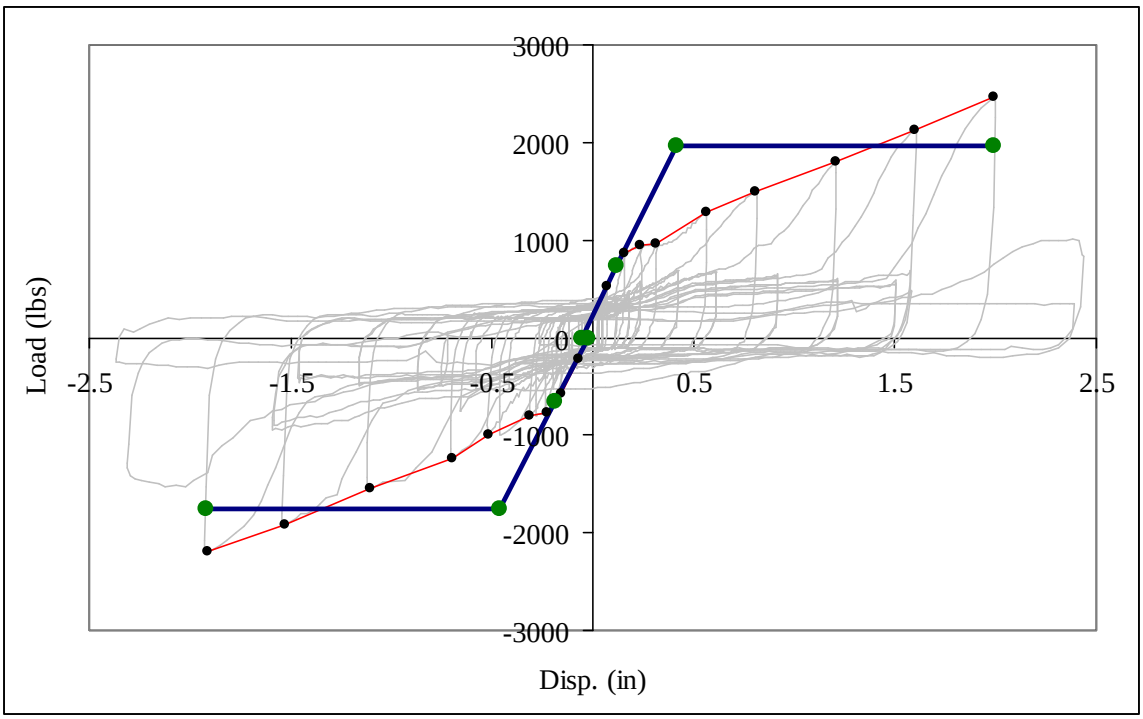

Figure A.5: Load-Deflection plot: C1-4.

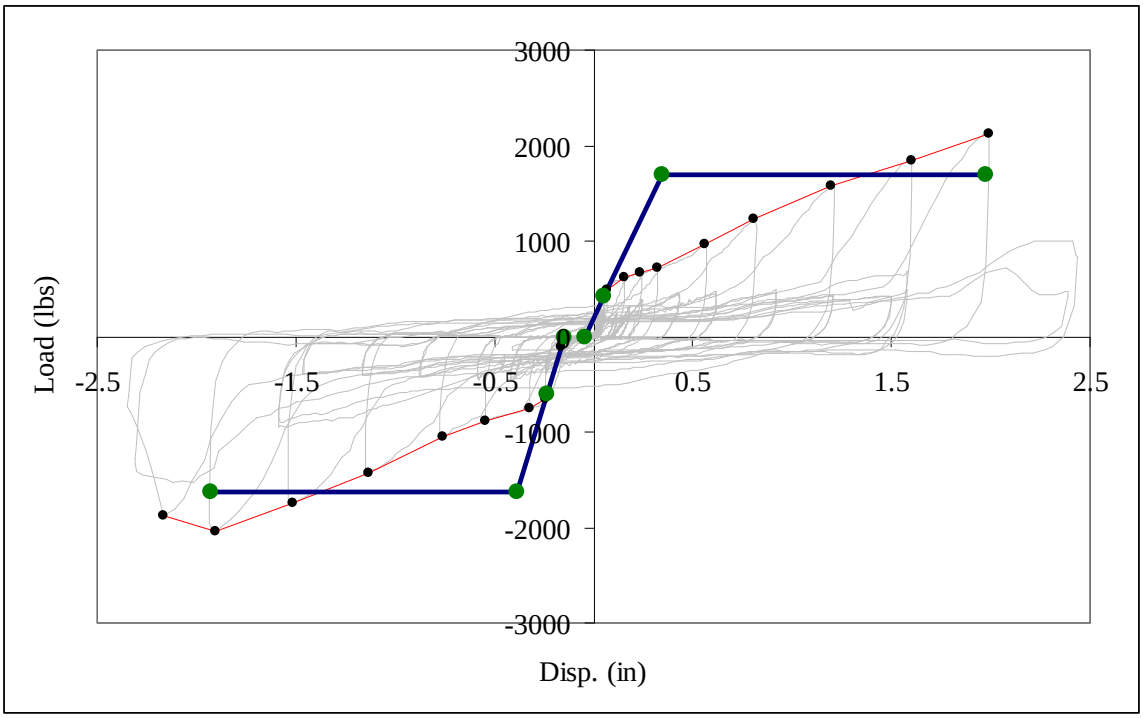

Figure A.6: Load-Deflection plot: C1-5.

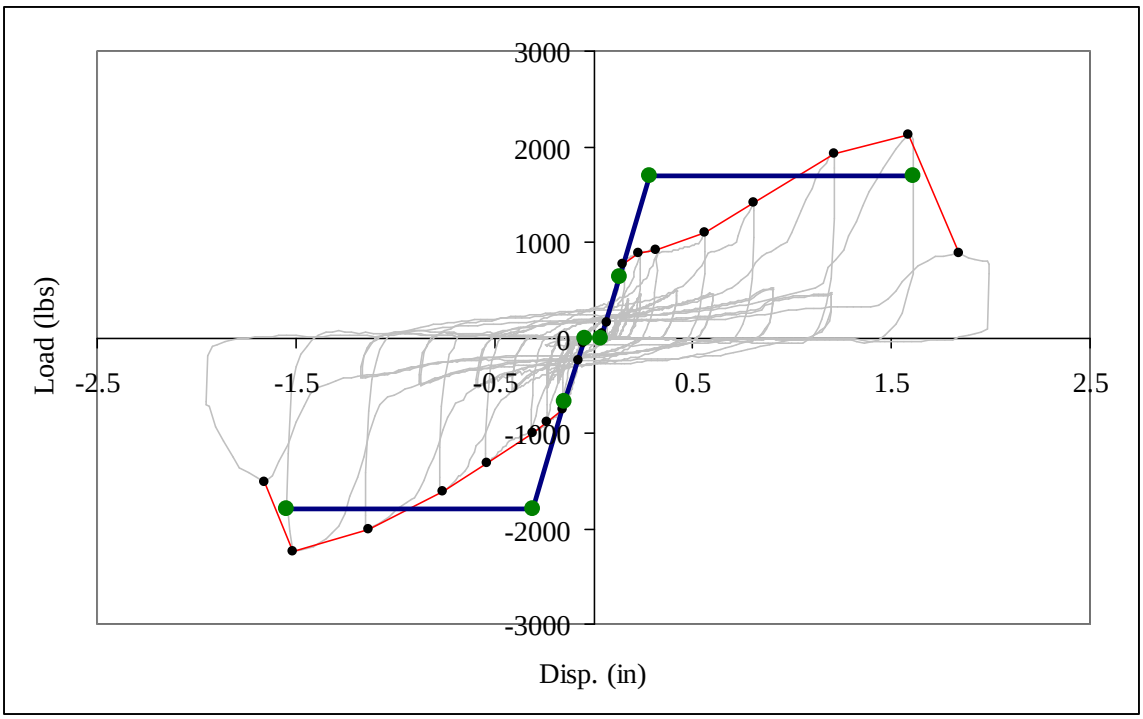

Figure A.7: Load-Deflection plot: C1-6.

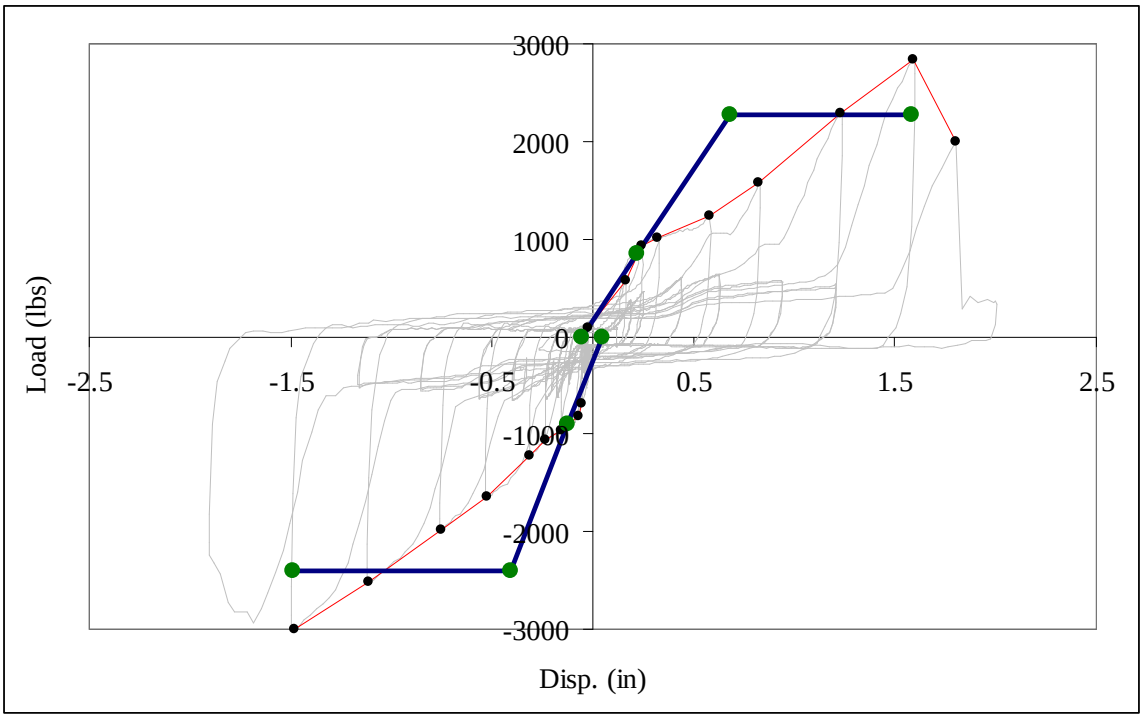

Figure A.8: Load-Deflection plot: C1-7.

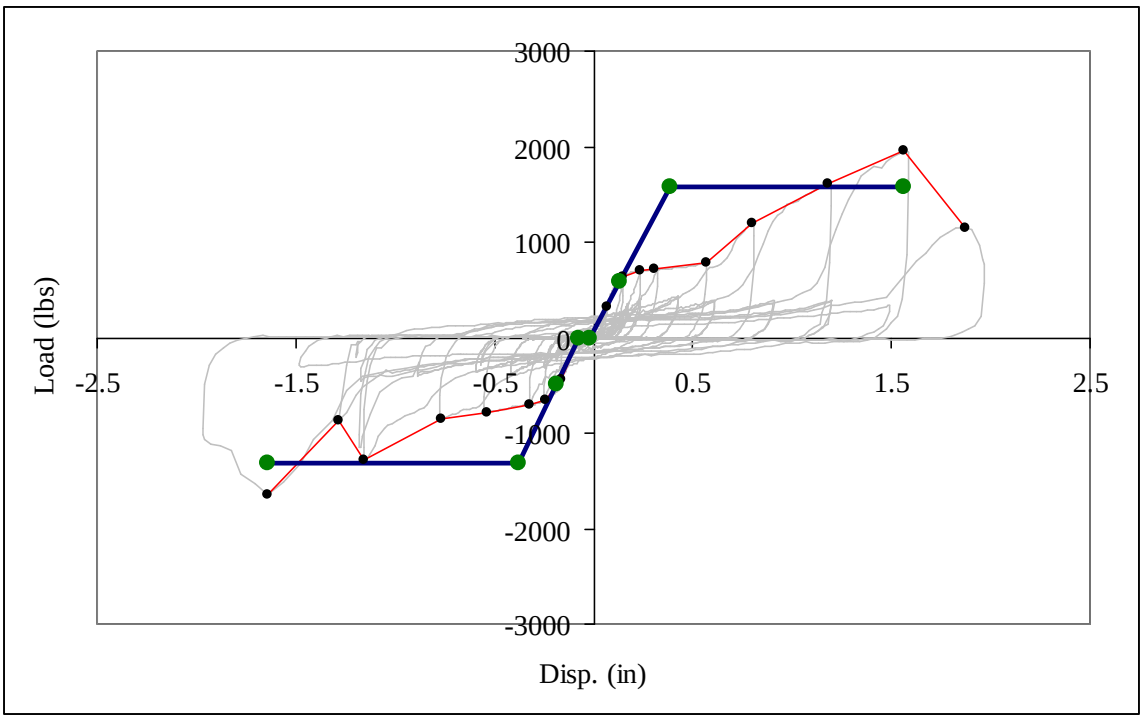

Figure A.9: Load-Deflection plot: C1-8.

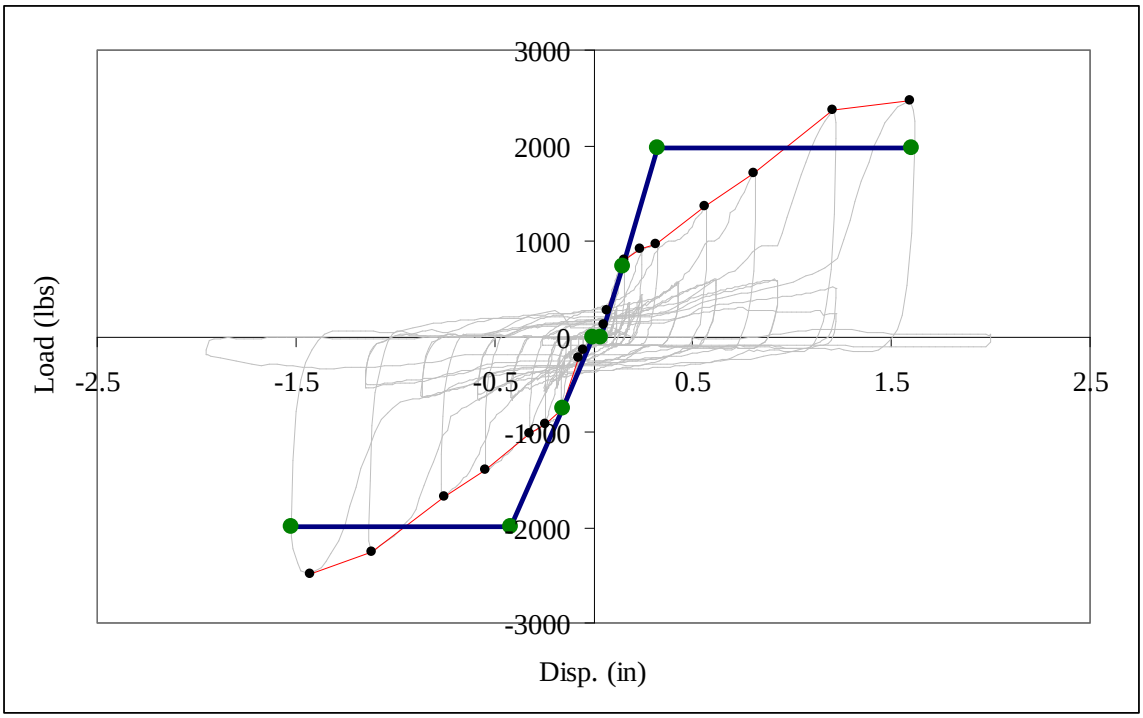

Figure A.10: Load-Deflection plot: C1-9.

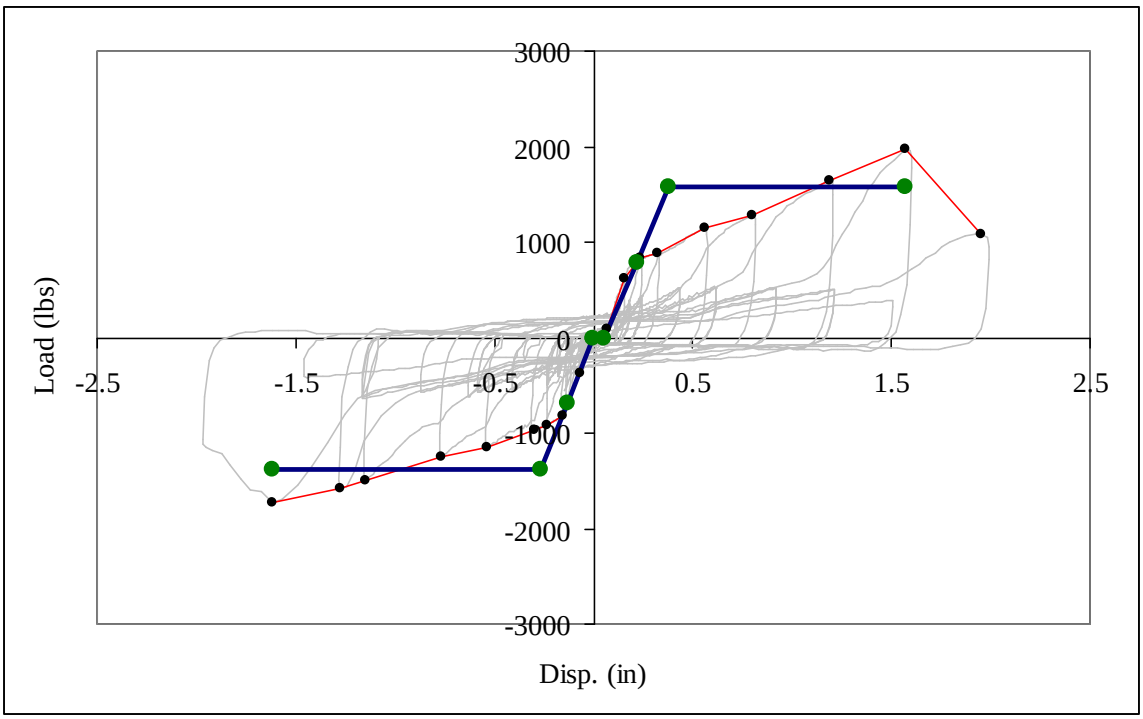

Figure A.11: Load-Deflection plot: C1-10.

Table A.4a: Connection performance properties (SI), Configuration 2.

Connection Performance Properties: Configuration 2

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	12.34	13.62	11.92	10.42	10.19	11.07	14.34	10.09	10.78	13.52	11.83	1.56	0.13
@Displacement (mm)	15.28	21.70	19.86	4.84	21.74	16.36	25.18	14.64	11.44	30.00	18.11	7.18	0.40
Failure Load (kN)	9.87	10.89	9.54	8.34	8.16	8.85	11.47	8.07	8.62	10.82	9.46	1.25	0.13
@Displacement (mm)	15.28	21.70	19.86	4.84	21.74	16.36	25.18	14.64	11.44	30.00	18.11	7.18	0.40
40% Max (kN)	4.94	5.45	4.77	4.17	4.08	4.43	5.74	4.04	4.31	5.41	4.73	0.63	0.13
@Displacement (mm)	2.78	2.92	3.32	2.56	2.93	2.80	3.64	2.48	2.62	3.30	2.94	0.38	0.13
Yield (kN)	11.00	11.54	10.40	9.50	9.46	10.10	11.99	9.66	10.31	11.64	10.56	0.93	0.09
@Displacement (mm)	5.36	6.38	5.77	3.87	5.88	5.93	6.93	4.53	6.67	6.80	5.81	1.00	0.17
5% Offset Yield (kN)	8.63	5.70	7.86	9.23	6.99	8.54	7.80	8.01	9.21	8.21	8.02	1.06	0.13
@Displacement (mm)	4.68	3.18	4.97	4.10	4.87	5.38	5.05	4.28	6.24	5.07	4.78	0.81	0.17
Elastic Stiff. (N/mm)	2375.22	1831.77	2318.18	4100.13	1835.22	1814.31	1901.44	2768.12	1493.95	1839.86	2227.82	753.14	0.34
E.E.P. Energy (N*m)	134.80	214.41	171.27	20.07	174.04	136.99	257.37	120.15	88.13	308.89	162.61	83.24	0.51
Ductility Ratio	2.87	3.62	3.42	1.25	3.80	2.70	3.63	3.10	1.67	4.48	3.05	0.98	0.32
Yield Mode	IV	IV	IIIs-IV	IIIs-IV	IV	IV	IV	IV	IIIs-IV	IV			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Main	Side	Main	Main	Main	Main	Main	Main	Side	Main			

Table A.4b: Connection performance properties (Std.), Configuration 2.

Connection Performance Properties: Configuration 2

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	2774.47	3061.36	2680.53	2343.12	2291.82	2488.32	3224.53	2268.24	2423.44	3039.83	2659.56	351.58	0.13
@ Displacement (in)	0.60	0.85	0.78	0.19	0.86	0.64	0.99	0.58	0.45	1.18	0.71	0.28	0.40
Failure Load (lbs)	2219.57	2449.09	2144.42	1874.49	1833.45	1990.66	2579.62	1814.59	1938.75	2431.86	2127.65	281.26	0.13
@ Displacement (in)	0.60	0.85	0.78	0.19	0.86	0.64	0.99	0.58	0.45	1.18	0.71	0.28	0.40
40% Max (lbs)	1109.79	1224.55	1072.21	937.25	916.73	995.33	1289.81	907.30	969.38	1215.93	1063.83	140.63	0.13
@ Displacement (in)	0.11	0.11	0.13	0.10	0.12	0.11	0.14	0.10	0.10	0.13	0.12	0.01	0.13
Yield (lbs)	2473.53	2595.19	2338.62	2136.28	2126.96	2271.40	2694.80	2171.67	2317.12	2616.33	2374.19	209.22	0.09
@ Displacement (in)	0.21	0.25	0.23	0.15	0.23	0.23	0.27	0.18	0.26	0.27	0.23	0.04	0.17
5% Offset Yield (lbs)	1939.30	1280.87	1766.23	2075.29	1572.17	1920.75	1754.59	1801.27	2070.95	1845.57	1802.70	238.00	0.13
@ Displacement (in)	0.18	0.13	0.20	0.16	0.19	0.21	0.20	0.17	0.25	0.20	0.19	0.03	0.17
Elastic Stiff. (lb/in)	13562.85	10459.69	13237.15	23412.34	10479.37	10359.99	10857.49	15806.36	8530.68	10505.84	12721.18	4300.52	0.34
E.E.P. Energy (lb*in)	1193.08	1897.72	1515.84	177.64	1540.39	1212.49	2277.89	1063.38	780.02	2733.88	1439.23	736.75	0.51
Ductility Ratio	2.87	3.62	3.42	1.25	3.80	2.70	3.63	3.10	1.67	4.48	3.05	0.98	0.32
Yield Mode	IV	IV	IIIs-IV	IIIs-IV	IV	IV	IV	IV	IIIs-IV	IV			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Main	Side	Main	Main	Main	Main	Main	Main	Side	Main			

Table A.5a: Member properties (SI), Configuration 2.

Member Properties: Configuration 2

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.49	16.49	15.98	15.85	16.57	14.50	16.61	15.89	14.42	14.98	15.68	0.82	0.05
S.G.	0.50	0.56	0.48	0.52	0.47	0.43	0.45	0.59	0.45	0.47	0.49	0.05	0.10
D.E. 5% Offset Yield (kPa)	39902	37213	33875	40836	26118	35154	32779	49247	32300	29557	35698	6524.45	0.18
D.E. Capacity (kPa)	48207	50116	43785	51933	37002	41436	37624	57764	42903	38632	44940	6871.00	0.15
Side Member													
M.C. (%)	15.14	15.22	15.33	15.13	14.56	15.13	15.18	15.54	16.83	16.36	15.44	0.66	0.04
S.G.	0.49	0.53	0.46	0.49	0.40	0.45	0.44	0.59	0.48	0.45	0.48	0.05	0.11
D.E. 5% Offset Yield (kPa)	32711	39648	30593	40791	27528	32717	38097	47412	38206	31721	35942	5931.59	0.17
D.E. Capacity (kPa)	42750	47204	41730	47572	38790	37302	40022	58147	45832	37761	43711	6316.91	0.14

Table A.5b: Member properties (Std.), Configuration 2.

Member Properties: Configuration 2

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.49	16.49	15.98	15.85	16.57	14.50	16.61	15.89	14.42	14.98	15.68	0.82	0.05
S.G.	0.50	0.56	0.48	0.52	0.47	0.43	0.45	0.59	0.45	0.47	0.49	0.05	0.10
D.E. 5% Offset Yield (psi)	5787.21	5397.28	4913.13	5922.74	3788.06	5098.65	4754.11	7142.63	4684.69	4286.89	5177.54	946.29	0.18
D.E. Capacity (psi)	6991.84	7268.60	6350.42	7532.17	5366.69	6009.75	5456.86	8377.90	6222.50	5603.12	6517.99	996.55	0.15
Side Member													
M.C. (%)	15.14	15.22	15.33	15.13	14.56	15.13	15.18	15.54	16.83	16.36	15.44	0.66	0.04
S.G.	0.49	0.53	0.46	0.49	0.40	0.45	0.44	0.59	0.48	0.45	0.48	0.05	0.11
D.E. 5% Offset Yield (psi)	4744.25	5750.41	4437.15	5916.21	3992.55	4745.24	5525.46	6876.56	5541.32	4600.72	5212.99	860.30	0.17
D.E. Capacity (psi)	6200.39	6846.31	6052.43	6899.68	5626.01	5410.19	5804.72	8433.39	6647.39	5476.78	6339.73	916.19	0.14

Table A.6a: Hysteretic connection properties (SI), Configuration 2.

Hysteretic Connection Properties: Configuration 2

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.33	1.37	1.02	0.70	0.40	0.56	-1.10	0.61	0.55	-0.89	0.10	0.11
Primary2	1.78	1.73	0.97	1.22	0.12	0.10	-1.82	1.16	0.64	-1.31	0.14	0.11
Primary3	4.47	2.59	0.58	2.51	1.11	0.44	-4.66	2.35	0.50	-2.89	0.32	0.11
Primary4	6.92	3.33	0.48	4.17	0.71	0.17	-7.26	1.06	0.15	-4.38	0.82	0.19
Primary5	8.45	3.48	0.41	5.74	0.76	0.13	-7.85	2.61	0.33	-5.57	1.13	0.20
Primary6	9.73	4.03	0.41	9.96	1.83	0.18	-8.89	2.77	0.31	-8.89	2.38	0.27
Primary7	11.23	3.87	0.34	15.19	0.48	0.03	-9.90	2.05	0.21	-13.47	2.38	0.18
Primary8	11.10	5.44	0.49	20.67	3.58	0.17	-8.25	4.42	0.54	-17.74	3.57	0.20
Primary9	7.53	6.27	0.83	28.71	3.13	0.11	-5.50	4.55	0.83	-26.38	3.93	0.15

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.86	0.46	0.53	1.03	0.48	0.47	0.13	0.02	0.14	1457.56	700.47	0.48
Primary2	1.54	0.70	0.45	2.28	0.77	0.34	0.11	0.02	0.22	1424.14	496.85	0.35
Primary3	6.99	3.74	0.54	12.51	2.75	0.22	0.09	0.04	0.44	1710.28	487.67	0.29
Primary4	17.70	6.05	0.34	31.08	9.02	0.29	0.09	0.02	0.19	1647.69	150.88	0.09
Primary5	30.12	11.33	0.38	47.94	15.41	0.32	0.10	0.02	0.22	1418.62	207.34	0.15
Primary6	104.74	41.02	0.39	92.77	32.05	0.35	0.17	0.04	0.25	969.42	142.11	0.15
Primary7	177.23	27.82	0.16	153.72	25.48	0.17	0.18	0.02	0.10	737.63	62.11	0.08
Primary8	241.04	85.04	0.35	198.06	87.20	0.44	0.23	0.10	0.43	488.10	169.30	0.35
Primary9	210.44	118.97	0.57	179.22	130.57	0.73	0.21	0.05	0.23	242.68	173.35	0.71

Table A.6b: Hysteretic connection properties (Std.), Configuration 2.

Hysteretic Connection Properties: Configuration 2

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	299.54	306.94	1.02	0.03	0.02	0.56	-246.74	136.36	0.55	-0.03	0.00	0.11
Primary2	400.22	388.51	0.97	0.05	0.00	0.10	-409.07	260.61	0.64	-0.05	0.01	0.11
Primary3	1003.96	582.33	0.58	0.10	0.04	0.44	-1047.54	528.53	0.50	-0.11	0.01	0.11
Primary4	1555.37	749.03	0.48	0.16	0.03	0.17	-1632.58	238.60	0.15	-0.17	0.03	0.19
Primary5	1900.43	781.36	0.41	0.23	0.03	0.13	-1765.86	587.82	0.33	-0.22	0.04	0.20
Primary6	2188.34	906.49	0.41	0.39	0.07	0.18	-1997.68	623.56	0.31	-0.35	0.09	0.27
Primary7	2524.86	868.90	0.34	0.60	0.02	0.03	-2225.83	460.13	0.21	-0.53	0.09	0.18
Primary8	2495.70	1221.90	0.49	0.81	0.14	0.17	-1855.40	993.13	0.54	-0.70	0.14	0.20
Primary9	1693.87	1409.07	0.83	1.13	0.12	0.11	-1237.29	1022.13	0.83	-1.04	0.15	0.15

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	7.65	4.08	0.53	9.14	4.29	0.47	0.13	0.02	0.11	8322.86	3999.80	0.48
Primary2	13.63	6.15	0.45	20.16	6.78	0.34	0.11	0.02	0.21	8132.06	2837.07	0.35
Primary3	61.84	33.14	0.54	110.74	24.35	0.22	0.09	0.04	0.43	9765.97	2784.69	0.29
Primary4	156.65	53.58	0.34	275.09	79.80	0.29	0.09	0.02	0.19	9408.53	861.56	0.09
Primary5	266.60	100.24	0.38	424.28	136.40	0.32	0.10	0.03	0.28	8100.52	1183.93	0.15
Primary6	927.06	363.08	0.39	821.10	283.68	0.35	0.17	0.05	0.30	5535.52	811.45	0.15
Primary7	1568.58	246.19	0.16	1360.58	225.53	0.17	0.20	0.03	0.17	4212.00	354.67	0.08
Primary8	2133.36	752.64	0.35	1752.97	771.78	0.44	0.24	0.09	0.40	2787.13	966.72	0.35
Primary9	1862.54	1052.97	0.57	1586.26	1155.63	0.73	0.24	0.07	0.29	1385.71	989.88	0.71

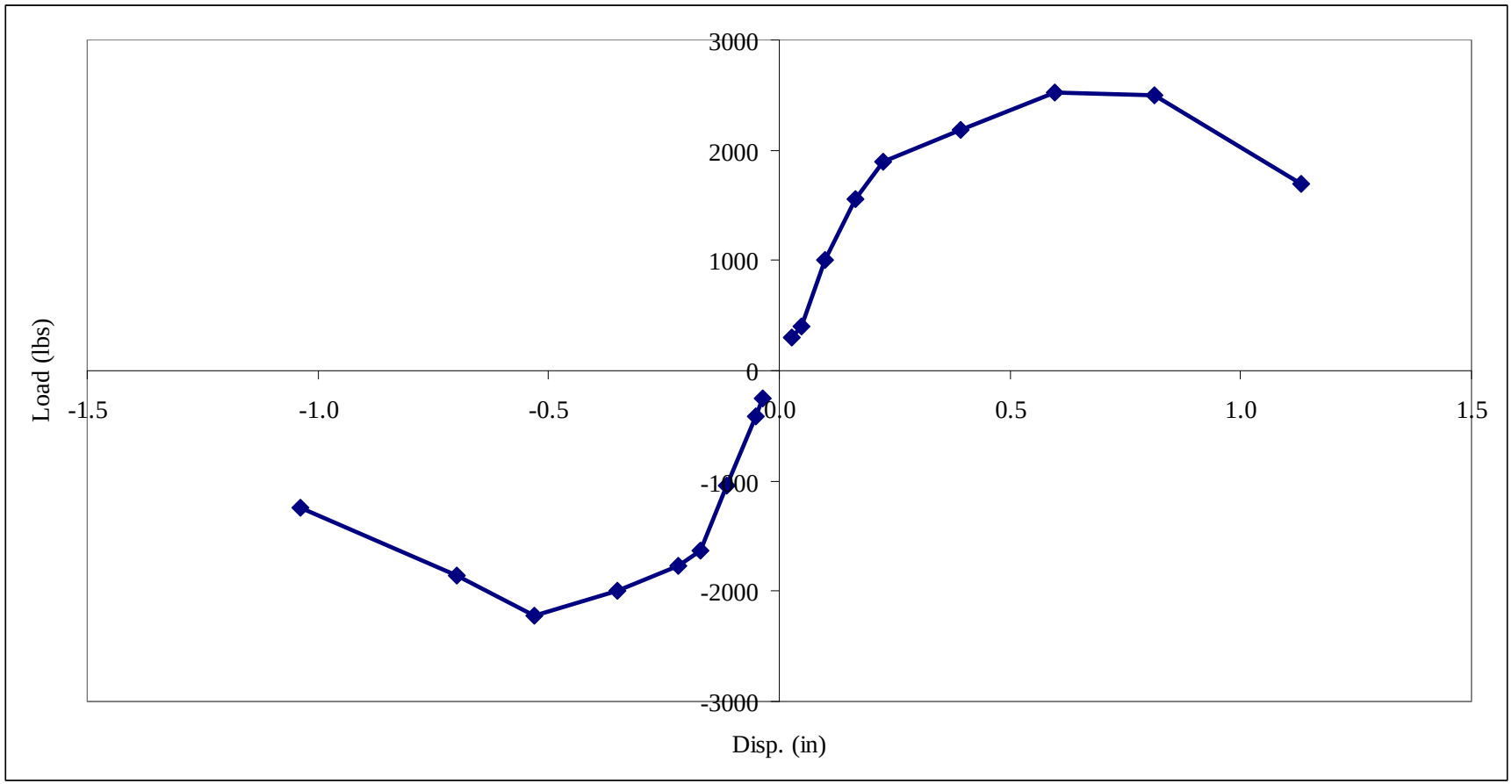

Figure A.12: Mean envelope curve: Configuration 2.

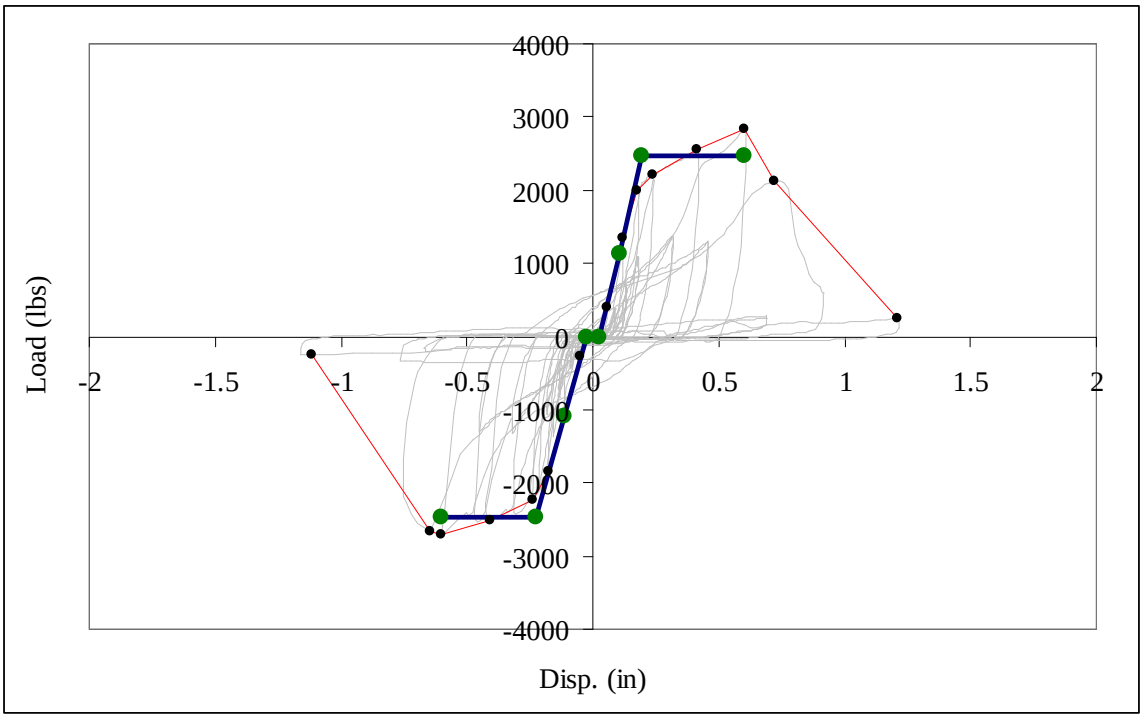

Figure A.13: Load-Deflection plot: C2-1.

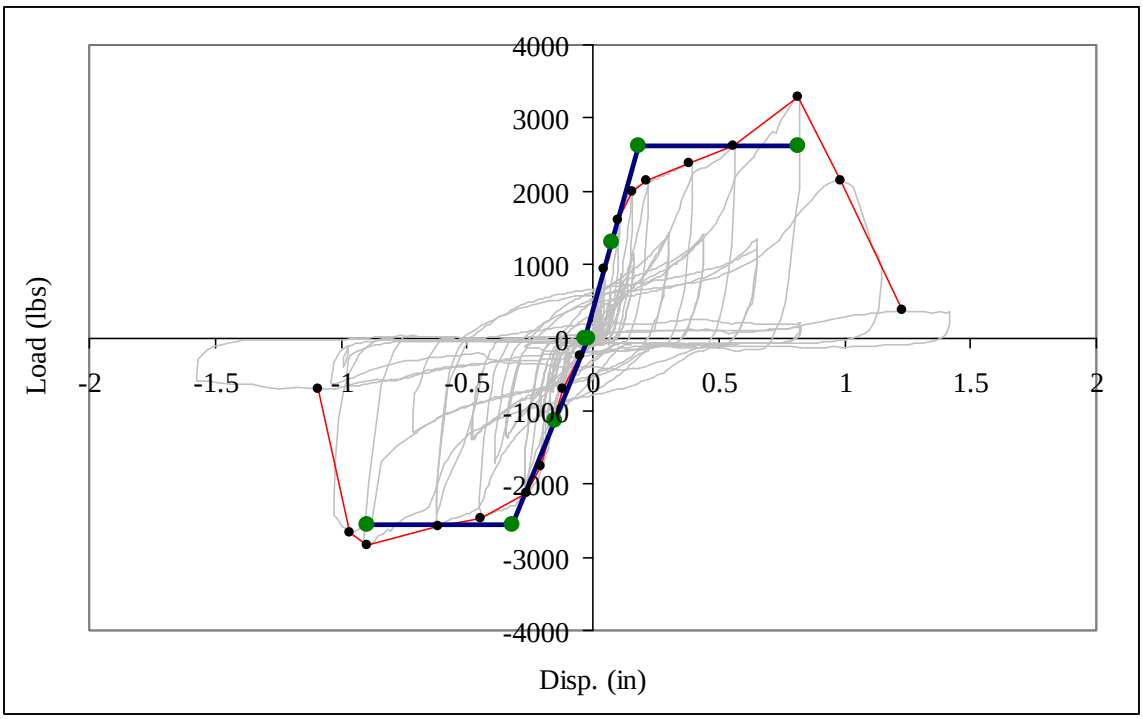

Figure A.14: Load-Deflection plot: C2-2.

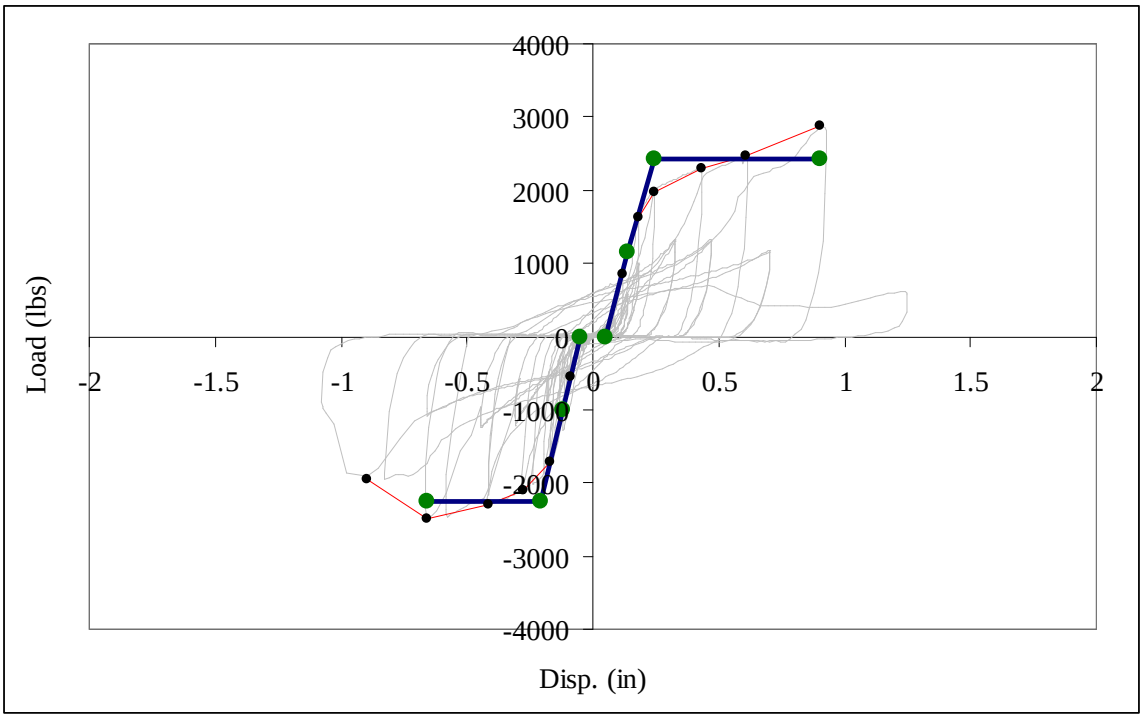

Figure A.15: Load-Deflection plot: C2-3.

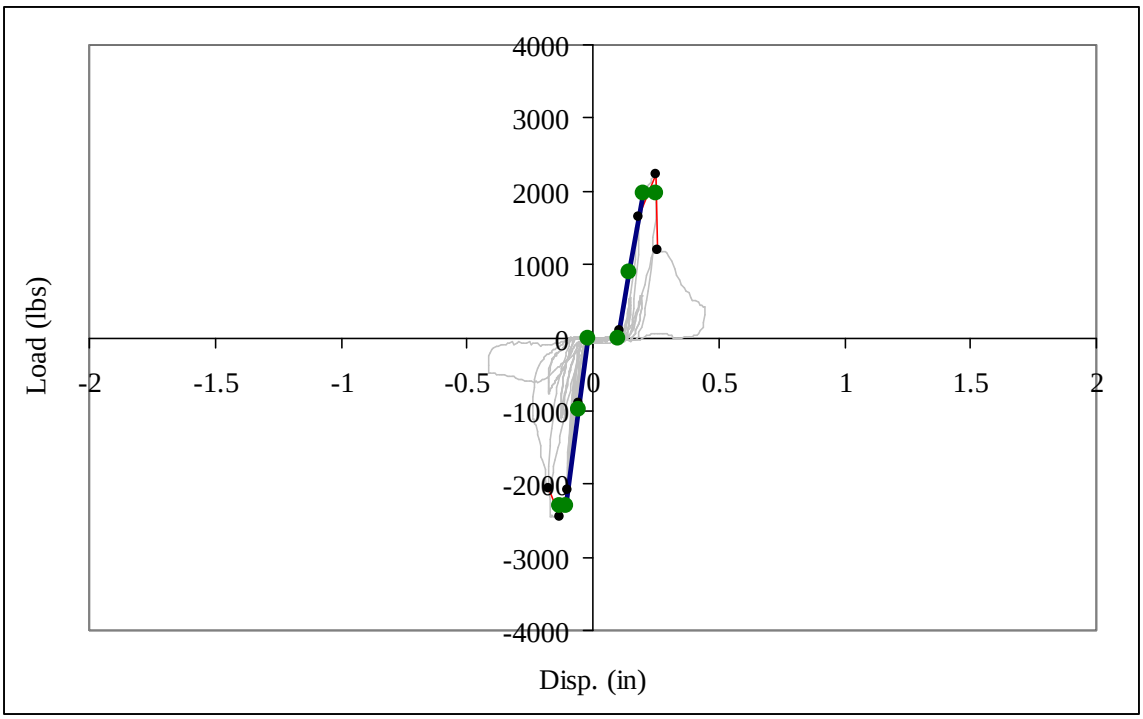

Figure A.16: Load-Deflection plot: C2-4.

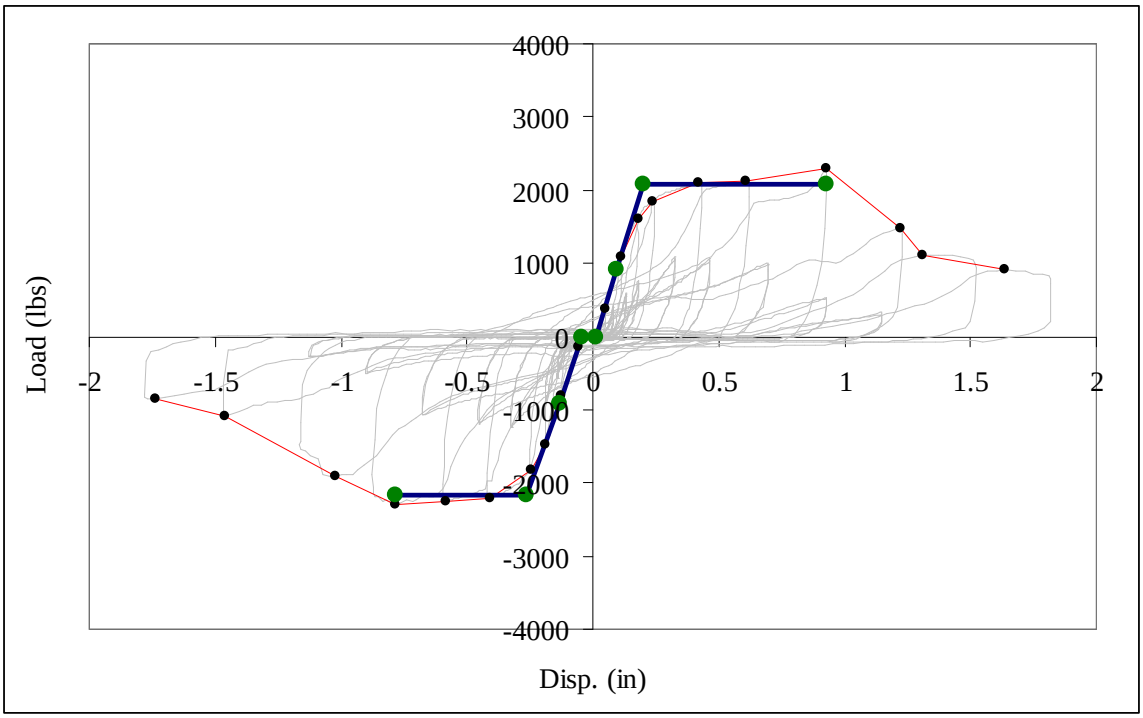

Figure A.17: Load-Deflection plot: C2-5.

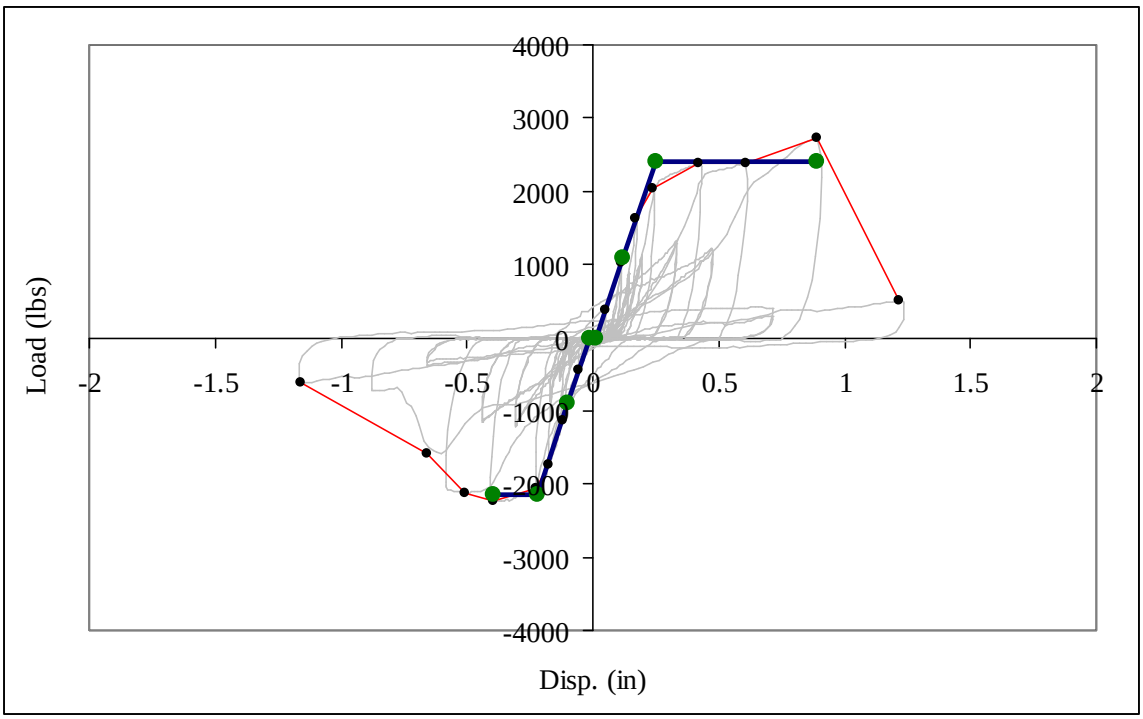

Figure A.18: Load-Deflection plot: C2-6.

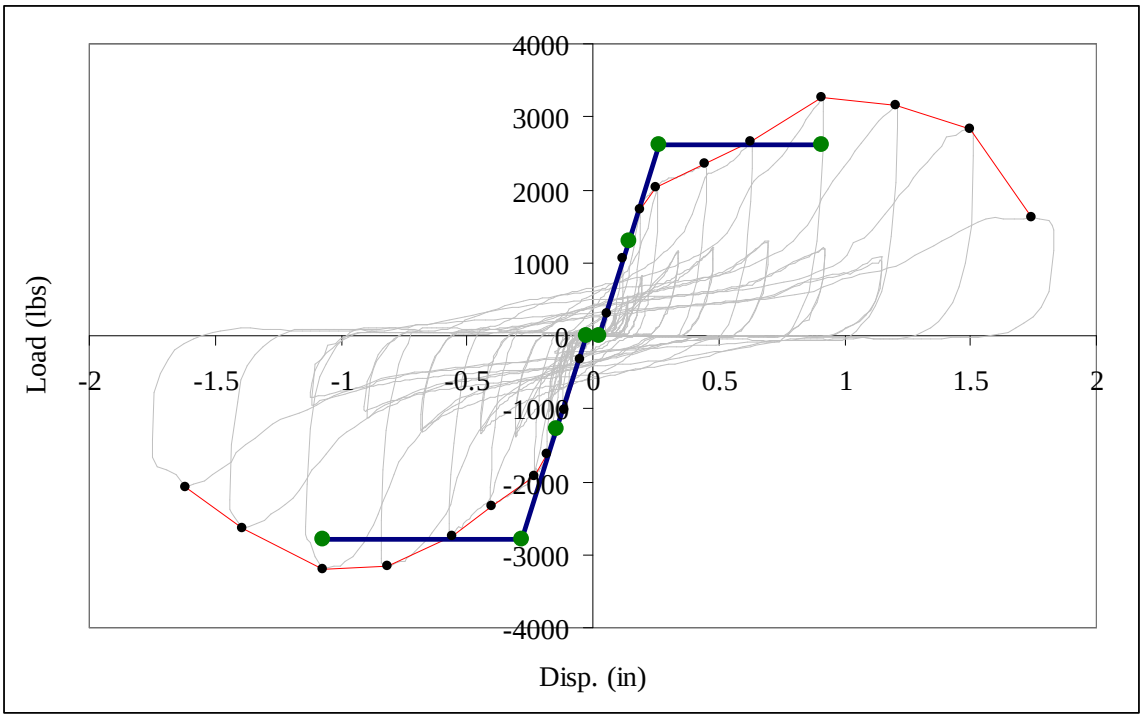

Figure A.19: Load-Deflection plot: C2-7.

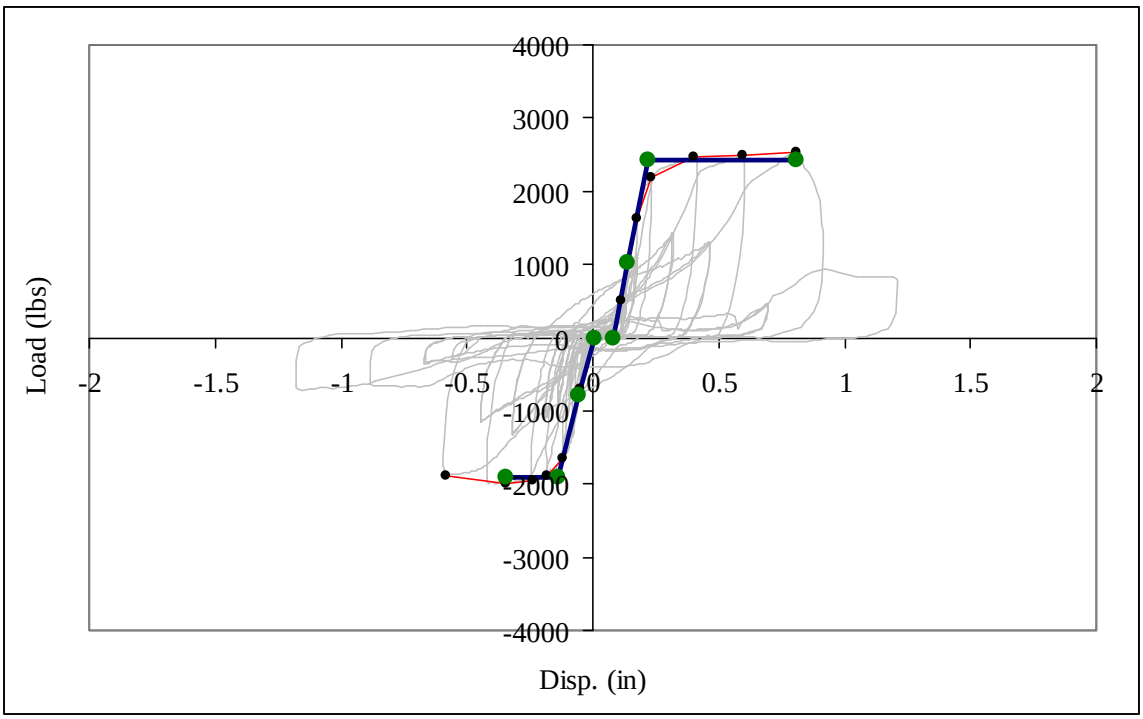

Figure A.20: Load-Deflection plot: C2-8.

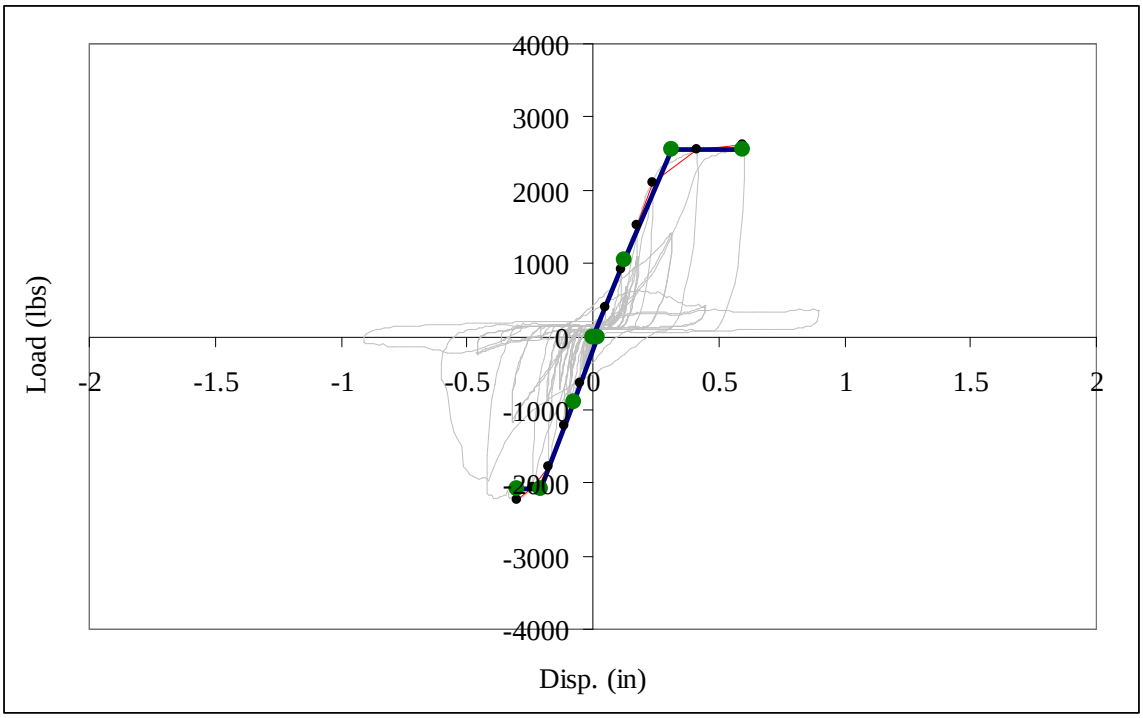

Figure A.21: Load-Deflection plot: C2-9.

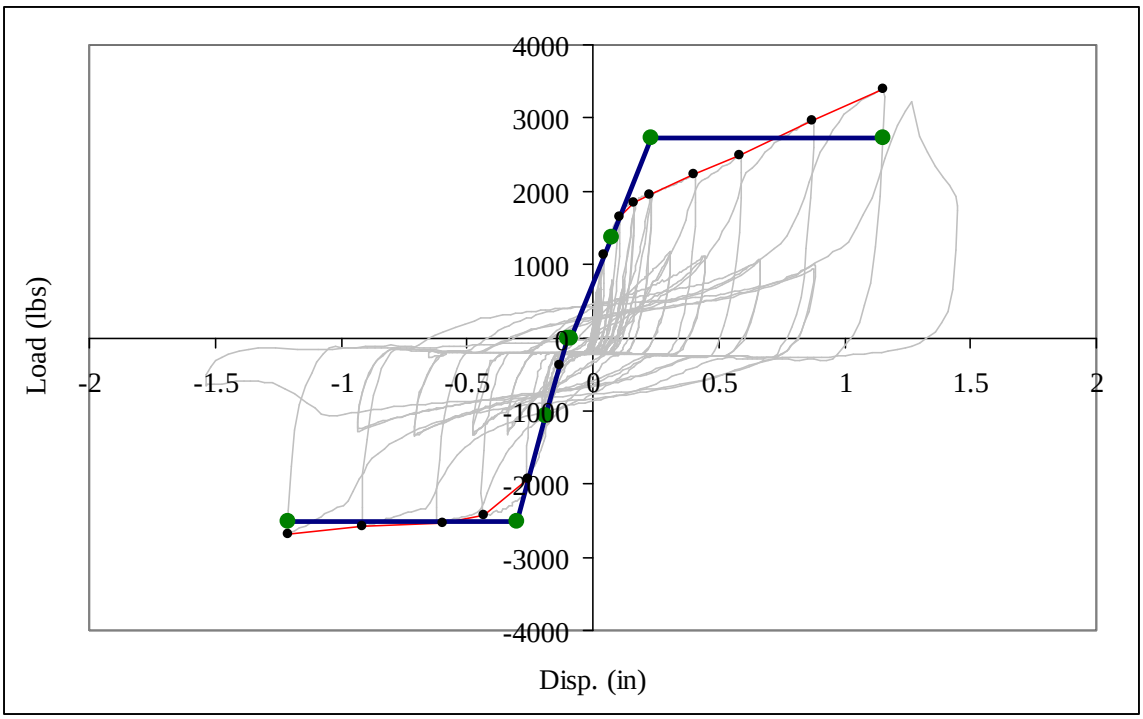

Figure A.22: Load-Deflection plot: C2-10.

Table A.7a: Connection performance properties (SI), Configuration 4.

Connection Performance Properties: Configuration 4

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	21.69	21.69	25.01	21.68	18.59	25.81	19.06	20.87	21.11	17.08	21.26	2.69	0.13
@Displacement (mm)	38.68	33.45	30.62	47.71	52.46	43.36	39.29	37.73	45.03	30.53	39.89	7.30	0.18
Failure Load (kN)	17.36	17.35	20.01	17.35	14.87	20.65	15.25	16.69	16.89	13.66	17.01	2.15	0.13
@Displacement (mm)	38.68	33.45	40.96	47.71	52.68	43.38	39.29	37.73	45.03	30.53	40.95	6.57	0.16
40% Max (kN)	8.68	8.68	7.50	8.67	7.44	10.32	7.63	8.35	6.33	6.83	8.04	1.14	0.14
@Displacement (mm)	4.51	3.95	3.50	5.05	6.61	5.66	4.09	3.63	4.15	3.22	4.44	1.06	0.24
Yield (kN)	17.36	17.39	20.86	17.35	14.87	20.65	15.25	16.69	16.89	13.90	17.12	2.25	0.13
@Displacement (mm)	8.32	7.18	8.58	9.85	12.38	10.94	7.92	6.53	11.21	5.64	8.86	2.19	0.25
5% Offset Yield (kN)	9.08	10.13	10.71	8.90	7.56	7.49	6.98	9.50	7.97	8.74	8.71	1.21	0.14
@Displacement (mm)	5.00	4.84	5.06	5.50	7.02	4.49	4.03	4.35	5.55	4.19	5.00	0.88	0.18
Elastic Stiff. (N/mm)	2271.84	2677.80	2624.69	1931.93	1297.22	1955.70	2000.40	2894.98	1502.22	3001.31	2215.81	578.28	0.26
E.E.P. Energy (N*m)	592.54	522.31	760.62	740.03	685.10	778.99	537.48	569.15	665.84	379.02	623.11	126.26	0.20
Ductility Ratio	4.65	4.76	4.80	4.85	4.28	3.97	5.01	5.81	4.12	5.49	4.77	0.58	0.12
Yield Mode	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV			
Failure Mode	Splitting	Splitting	Splitting	Blt Shr	Blt Shr	Blt Shr	Splitting	Blt Shr	Blt Shr	Splitting			
Governing Member	Both	Side	Side	N.A.	N.A.	N.A.	Both	N.A.	N.A.	Both			

Table A.7b: Connection performance properties (Std.), Configuration 4.

Connection Performance Properties: Configuration 4

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	4877.11	4875.61	5622.73	4874.97	4178.86	5801.63	4285.81	4691.30	4744.88	3839.22	4779.21	603.81	0.13
@ Displacement (in)	1.52	1.32	1.21	1.88	2.07	1.71	1.55	1.49	1.77	1.20	1.57	0.29	0.18
Failure Load (lbs)	3901.68	3900.49	4498.19	3899.98	3343.08	4641.30	3428.64	3753.04	3795.90	3071.37	3823.37	483.05	0.13
@ Displacement (in)	1.52	1.32	1.61	1.88	2.07	1.71	1.55	1.49	1.77	1.20	1.61	0.26	0.16
40% Max (lbs)	1950.84	1950.24	1686.82	1949.99	1671.54	2320.65	1714.32	1876.52	1423.46	1535.69	1808.01	256.56	0.14
@ Displacement (in)	0.18	0.16	0.14	0.20	0.26	0.22	0.16	0.14	0.16	0.13	0.17	0.04	0.24
Yield (lbs)	3901.68	3909.98	4688.60	3899.98	3343.08	4641.30	3428.64	3753.04	3795.90	3123.87	3848.61	506.87	0.13
@ Displacement (in)	0.33	0.28	0.34	0.39	0.49	0.43	0.31	0.26	0.44	0.22	0.35	0.09	0.25
5% Offset Yield (lbs)	2042.31	2277.59	2407.88	2000.09	1700.06	1683.89	1568.51	2136.75	1791.17	1964.08	1957.23	272.15	0.14
@ Displacement (in)	0.20	0.19	0.20	0.22	0.28	0.18	0.16	0.17	0.22	0.16	0.20	0.03	0.18
Elastic Stiff. (lb/in)	12972.55	15290.61	14987.36	11031.61	7407.34	11167.31	11422.57	16530.74	8577.92	17137.91	12652.59	3302.07	0.26
E.E.P. Energy (lb*in)	5244.38	4622.82	6732.03	6549.85	6063.62	6894.65	4757.13	5037.38	5893.16	3354.62	5514.97	1117.46	0.20
Ductility Ratio	4.65	4.76	4.80	4.85	4.28	3.97	5.01	5.81	4.12	5.49	4.77	0.58	0.12
Yield Mode	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV			
Failure Mode	Splitting	Splitting	Splitting	Blt Shr	Blt Shr	Blt Shr	Splitting	Blt Shr	Blt Shr	Splitting			
Governing Member	Both	Side	Side	N.A.	N.A.	N.A.	Both	N.A.	N.A.	Both			

Table A.8a: Member properties (SI), Configuration 4.

Member Properties: Configuration 4

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.58	16.19	16.12	14.23	15.72	16.73	16.20	16.68	16.33	15.56	15.84	0.84	0.05
S.G.	0.50	0.55	0.56	0.49	0.50	0.50	0.47	0.54	0.57	0.53	0.52	0.04	0.07
D.E. 5% Offset Yield (kPa)	43493	41321	52242	34625	29058	40800	36118	40691	37133	45938	40142	6428.30	0.16
D.E. Capacity (kPa)	51718	53139	60721	41750	40910	46046	47567	53998	42864	52531	49124	6373.71	0.13
Side Member													
M.C. (%)	15.41	16.56	16.29	16.61	16.85	16.80	16.52	15.86	15.46	16.21	16.26	0.52	0.03
S.G.	0.52	0.55	0.53	0.44	0.47	0.49	0.46	0.54	0.59	0.55	0.51	0.05	0.09
D.E. 5% Offset Yield (kPa)	45856	49472	46348	36428	28151	38586	36459	41698	34939	41009	39895	6336.90	0.16
D.E. Capacity (kPa)	52906	54953	52641	40284	36804	45116	45620	51631	44561	48818	47334	5907.23	0.12

Table A.8b: Member properties (Std.), Configuration 4.

Member Properties: Configuration 4

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.58	16.19	16.12	14.23	15.72	16.73	16.20	16.68	16.33	15.56	15.84	0.84	0.05
S.G.	0.50	0.55	0.56	0.49	0.50	0.50	0.47	0.54	0.57	0.53	0.52	0.04	0.07
D.E. 5% Offset Yield (psi)	6308.13	5993.04	7577.06	5021.88	4214.51	5917.55	5238.46	5901.72	5385.61	6662.75	5822.07	932.34	0.16
D.E. Capacity (psi)	7501.04	7707.11	8806.73	6055.33	5933.48	6678.41	6898.94	7831.63	6216.79	7618.87	7124.83	924.42	0.13
Side Member													
M.C. (%)	15.41	16.56	16.29	16.61	16.85	16.80	16.52	15.86	15.46	16.21	16.26	0.52	0.03
S.G.	0.52	0.55	0.53	0.44	0.47	0.49	0.46	0.54	0.59	0.55	0.51	0.05	0.09
D.E. 5% Offset Yield (psi)	6650.84	7175.26	6722.24	5283.40	4083.00	5596.42	5287.83	6047.72	5067.44	5947.76	5786.19	919.08	0.16
D.E. Capacity (psi)	7673.30	7970.20	7634.93	5842.68	5337.94	6543.53	6616.61	7488.43	6462.94	7080.47	6865.10	856.77	0.12

Table A.9a: Hysteretic connection properties (SI), Configuration 4.

Hysteretic Connection Properties: Configuration 4

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	1.35	1.17	0.86	0.78	0.11	0.14	-1.27	1.09	0.86	-0.86	0.14	0.17
Primary2	1.96	1.50	0.77	1.16	0.12	0.11	-1.88	1.49	0.79	-1.26	0.25	0.20
Primary3	5.07	2.61	0.51	2.78	0.13	0.04	-5.01	2.58	0.52	-2.83	0.67	0.24
Primary4	8.33	3.00	0.36	4.39	0.21	0.05	-7.80	2.52	0.32	-4.33	0.75	0.17
Primary5	9.91	3.40	0.34	5.96	0.26	0.04	-9.27	2.56	0.28	-5.75	0.85	0.15
Primary6	11.05	4.40	0.40	9.99	1.96	0.20	-10.79	2.79	0.26	-9.68	1.82	0.19
Primary7	12.21	4.87	0.40	14.76	2.34	0.16	-11.91	2.77	0.23	-13.90	2.19	0.16
Primary8	15.18	6.44	0.42	21.96	3.61	0.16	-13.73	3.82	0.28	-20.70	3.52	0.17
Primary9	17.61	7.81	0.44	29.21	4.09	0.14	-15.15	3.99	0.26	-27.36	4.08	0.15
Primary10	19.28	9.45	0.49	36.27	4.59	0.13	-16.03	4.23	0.26	-33.42	4.42	0.13
Primary11	16.32	9.61	0.59	41.80	5.17	0.12	-15.67	7.19	0.46	-38.82	4.42	0.11

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	0.95	0.51	0.53	1.08	0.56	0.52	0.14	0.05	0.33	1596.54	830.17	0.52
Primary2	1.74	0.80	0.46	2.31	0.86	0.37	0.12	0.03	0.27	1580.09	546.43	0.35
Primary3	9.81	3.10	0.32	14.40	4.14	0.29	0.11	0.02	0.17	1778.87	312.27	0.18
Primary4	21.78	7.08	0.33	35.83	8.82	0.25	0.09	0.02	0.16	1835.17	321.10	0.17
Primary5	38.11	11.13	0.29	56.97	12.29	0.22	0.10	0.01	0.13	1628.67	259.44	0.16
Primary6	136.56	21.68	0.16	119.79	14.91	0.12	0.18	0.01	0.07	1104.20	152.70	0.14
Primary7	215.90	27.71	0.13	187.98	27.06	0.14	0.18	0.01	0.06	839.95	136.26	0.16
Primary8	385.57	45.56	0.12	338.29	55.07	0.16	0.18	0.01	0.06	675.81	145.32	0.22
Primary9	485.32	55.41	0.11	517.33	82.27	0.16	0.15	0.01	0.07	591.20	99.51	0.17
Primary10	577.96	48.56	0.08	693.40	112.68	0.16	0.14	0.02	0.16	526.28	88.01	0.17
Primary11	650.58	158.37	0.24	749.31	254.15	0.34	0.14	0.03	0.18	417.30	130.18	0.31

Table A.9b: Hysteretic connection properties (Std.), Configuration 4.

Hysteretic Connection Properties: Configuration 4

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	304.59	262.11	0.86	0.03	0.00	0.14	-284.61	244.32	0.86	-0.03	0.01	0.17
Primary2	440.08	336.83	0.77	0.05	0.00	0.11	-422.59	334.99	0.79	-0.05	0.01	0.20
Primary3	1140.08	585.63	0.51	0.11	0.00	0.04	-1125.95	581.08	0.52	-0.11	0.03	0.24
Primary4	1873.35	675.01	0.36	0.17	0.01	0.05	-1754.36	566.53	0.32	-0.17	0.03	0.17
Primary5	2227.22	763.34	0.34	0.23	0.01	0.04	-2083.83	575.34	0.28	-0.23	0.03	0.15
Primary6	2484.26	988.28	0.40	0.39	0.08	0.20	-2425.79	626.65	0.26	-0.38	0.07	0.19
Primary7	2743.97	1095.19	0.40	0.58	0.09	0.16	-2677.91	623.06	0.23	-0.55	0.09	0.16
Primary8	3411.53	1448.11	0.42	0.86	0.14	0.16	-3086.64	858.29	0.28	-0.81	0.14	0.17
Primary9	3958.73	1754.81	0.44	1.15	0.16	0.14	-3405.64	896.86	0.26	-1.08	0.16	0.15
Primary10	4334.29	2124.29	0.49	1.43	0.18	0.13	-3604.35	951.24	0.26	-1.32	0.17	0.13
Primary11	3669.89	2160.57	0.59	1.65	0.20	0.12	-3522.64	1616.16	0.46	-1.53	0.17	0.11

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	8.38	4.47	0.53	9.58	4.94	0.52	0.14	0.05	0.33	9116.45	4740.38	0.52
Primary2	15.42	7.04	0.46	20.49	7.61	0.37	0.12	0.03	0.27	9022.52	3120.22	0.35
Primary3	86.84	27.42	0.32	127.46	36.63	0.29	0.11	0.02	0.17	10157.62	1783.08	0.18
Primary4	192.81	62.70	0.33	317.10	78.05	0.25	0.10	0.01	0.11	10479.12	1833.51	0.17
Primary5	337.31	98.48	0.29	504.26	108.79	0.22	0.11	0.01	0.11	9299.95	1481.45	0.16
Primary6	1208.67	191.86	0.16	1060.19	131.92	0.12	0.19	0.02	0.08	6305.15	871.94	0.14
Primary7	1910.91	245.24	0.13	1663.77	239.53	0.14	0.20	0.03	0.15	4796.25	778.09	0.16
Primary8	3412.55	403.27	0.12	2994.15	487.42	0.16	0.20	0.03	0.18	3858.97	829.79	0.22
Primary9	4295.41	490.38	0.11	4578.78	728.19	0.16	0.15	0.01	0.07	3375.82	568.24	0.17
Primary10	5115.34	429.76	0.08	6137.13	997.31	0.16	0.14	0.04	0.29	3005.16	502.53	0.17
Primary11	5758.14	1401.65	0.24	6631.92	2249.42	0.34	0.20	0.07	0.36	2382.82	743.32	0.31

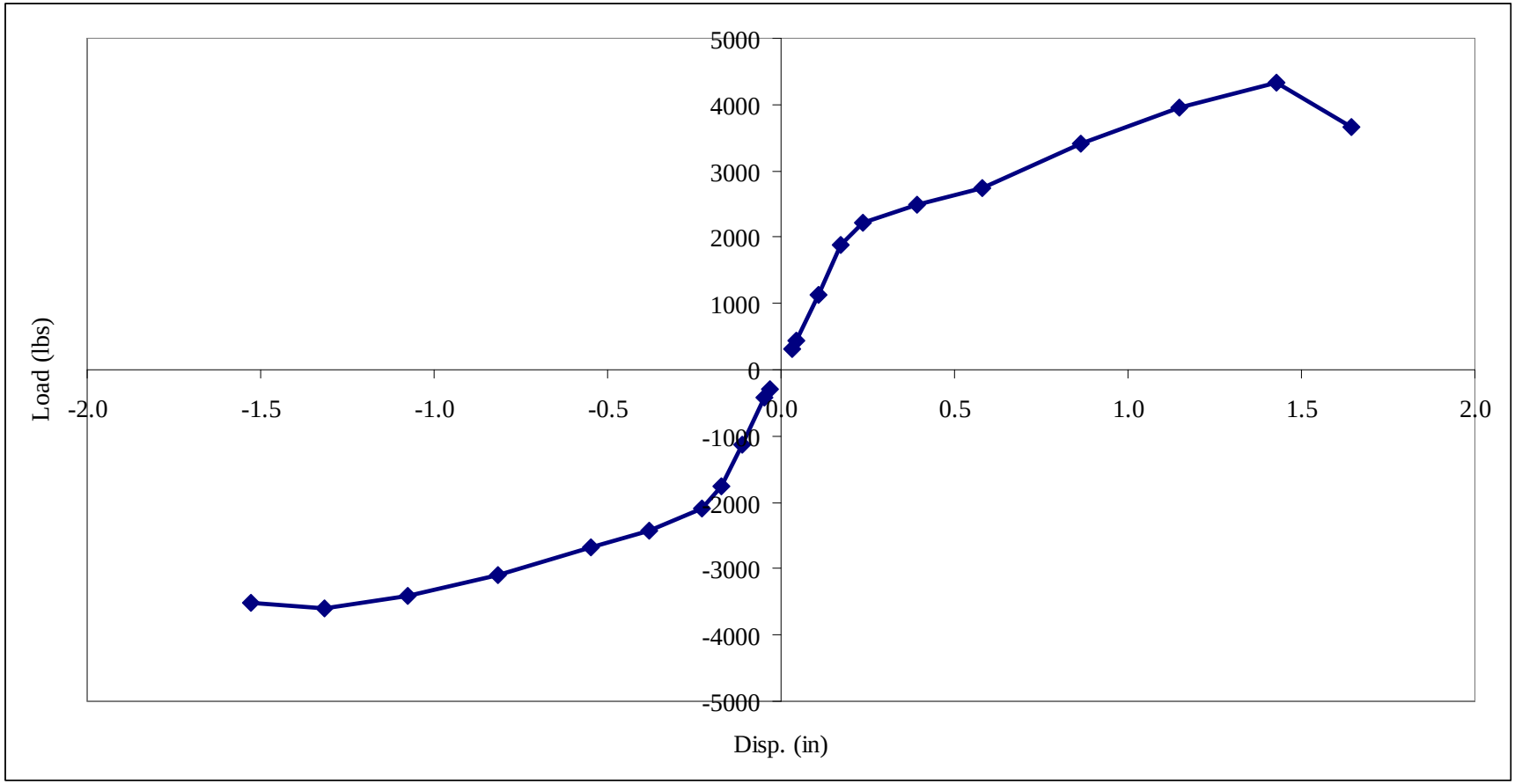

Figure A.23: Mean envelope curve: Configuration 4.

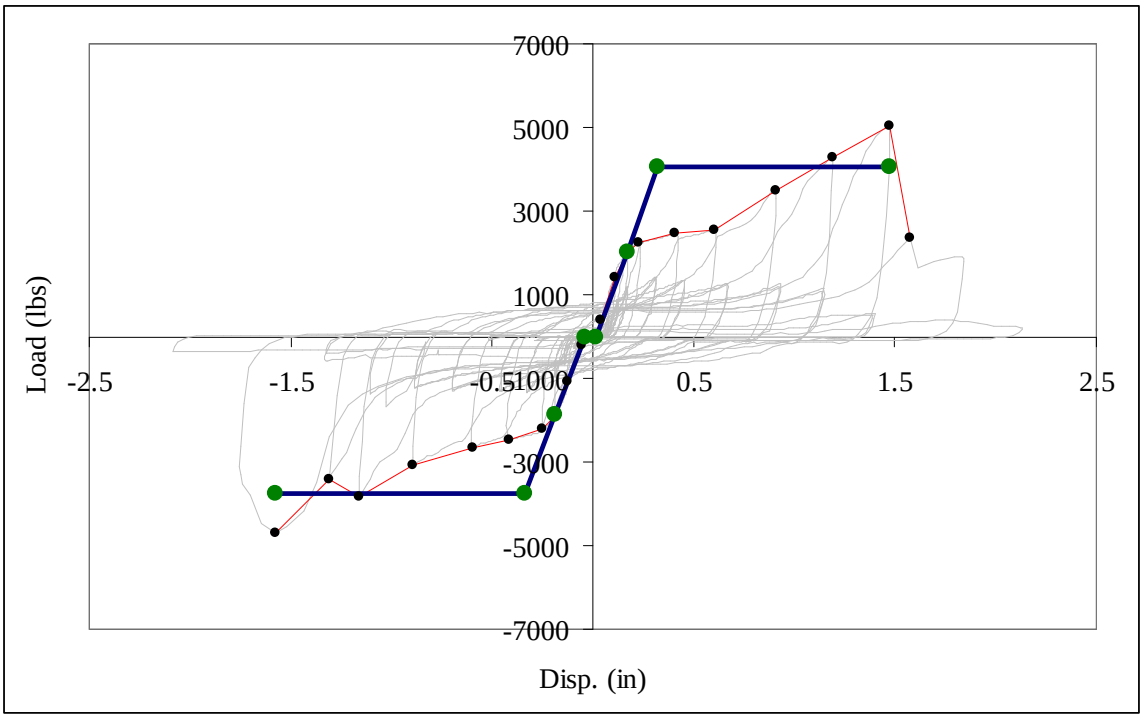

Figure A.24: Load-Deflection plot: C4-1.

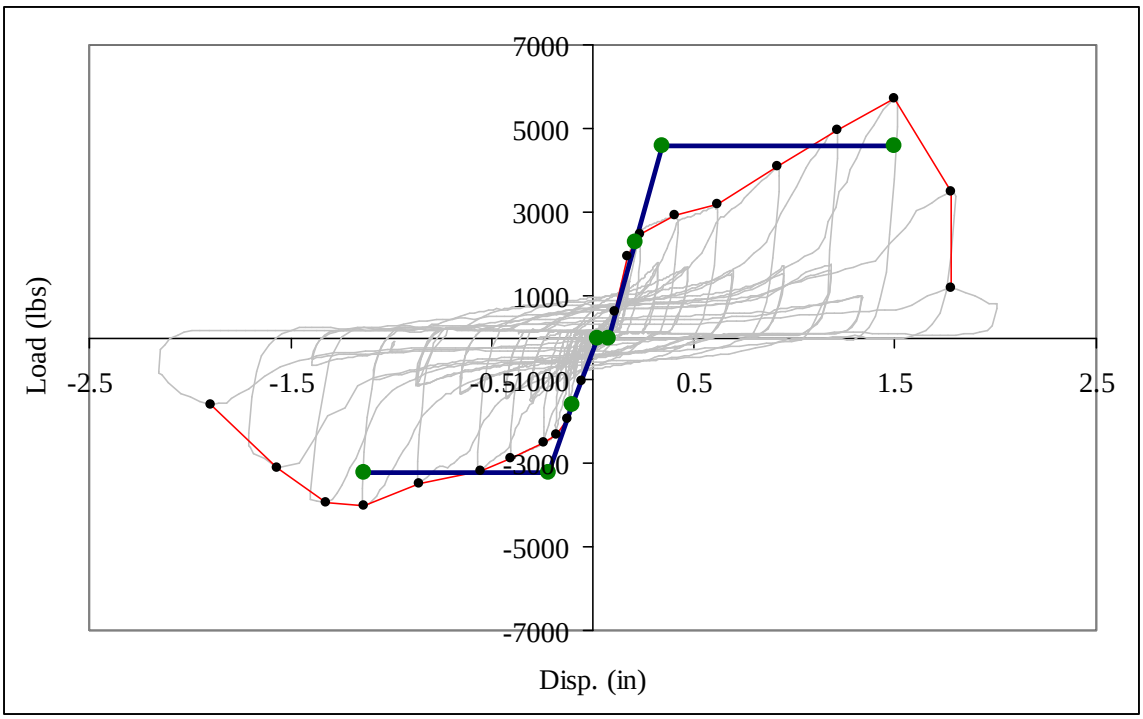

Figure A.25: Load-Deflection plot: C4-2.

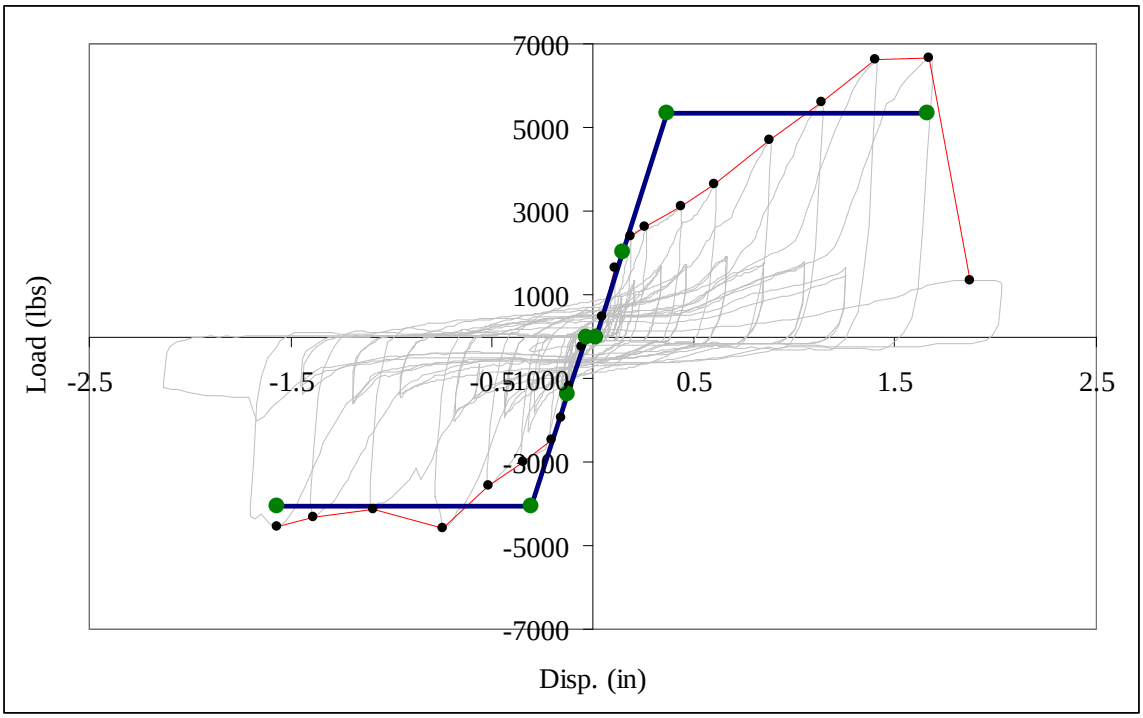

Figure A.26: Load-Deflection plot: C4-3.

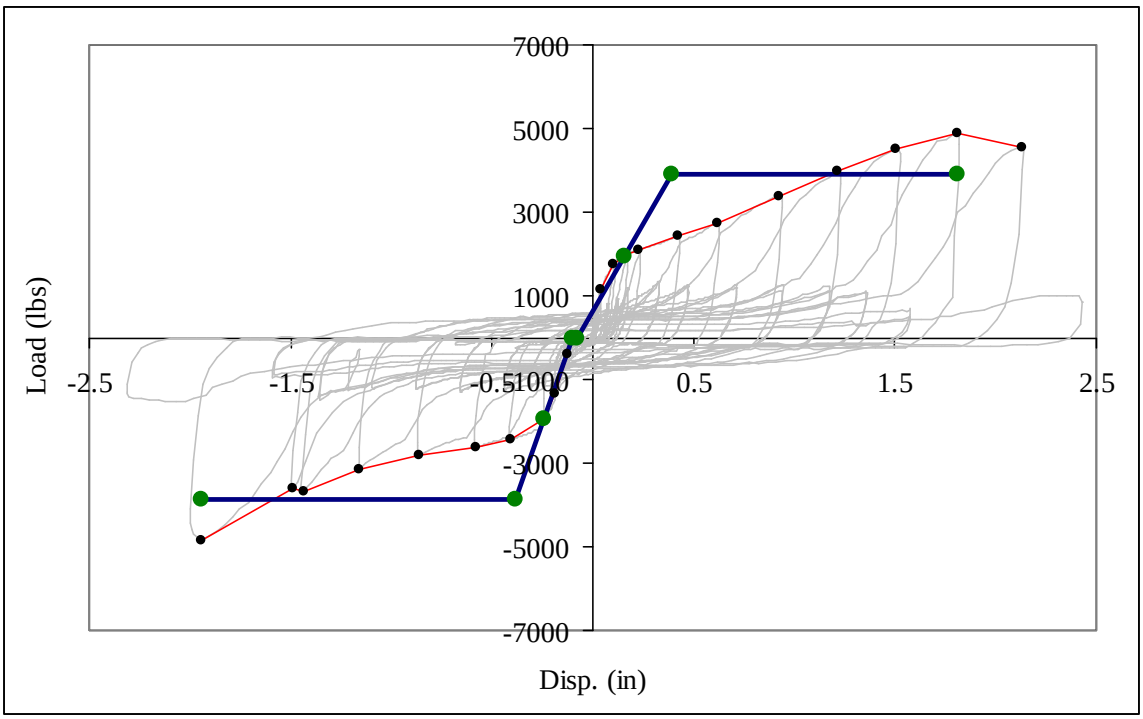

Figure A.27: Load-Deflection plot: C4-4.

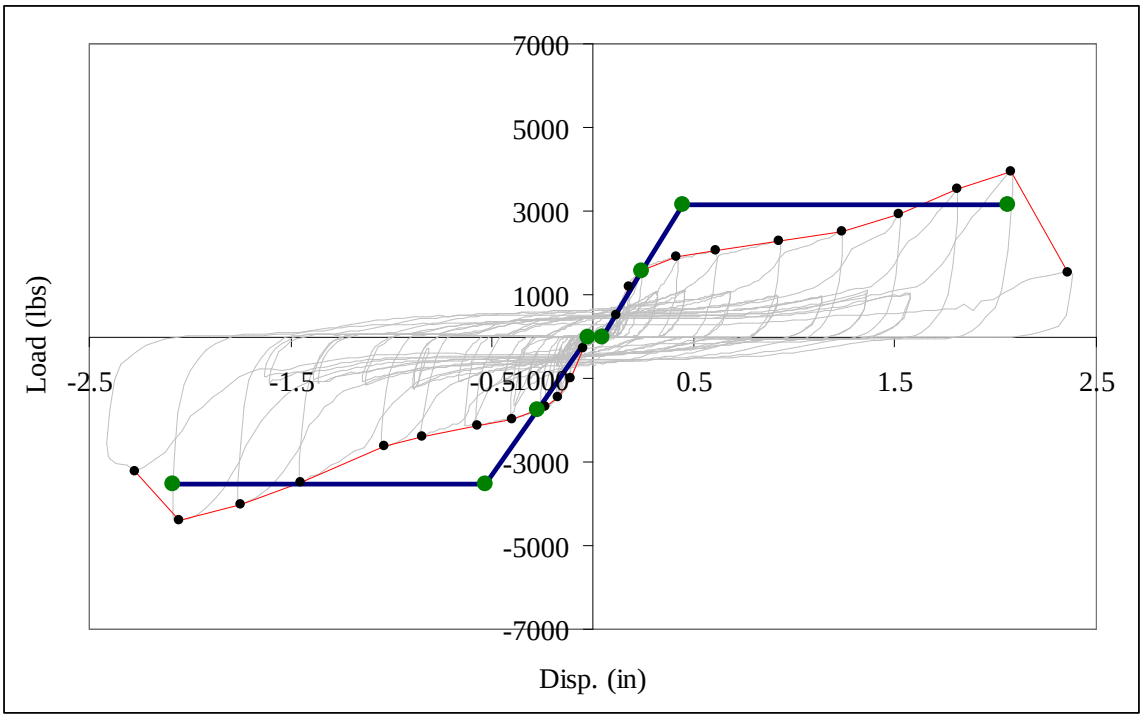

Figure A.28: Load-Deflection plot: C4-5.

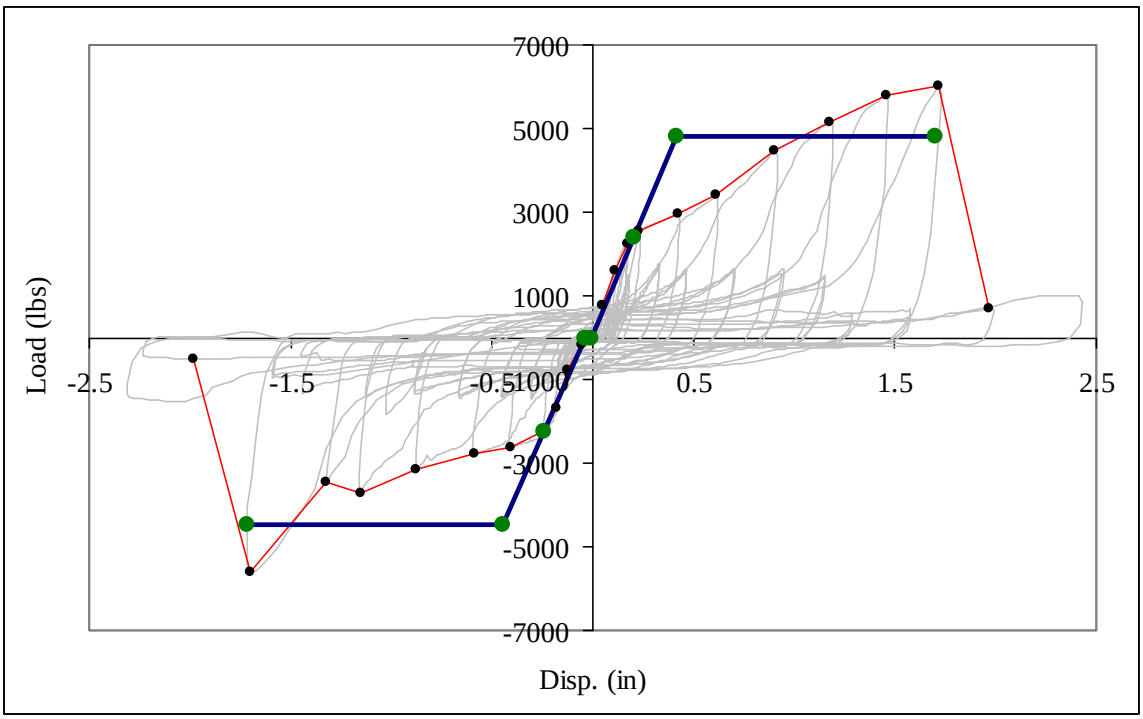

Figure A.29: Load-Deflection plot: C4-6.

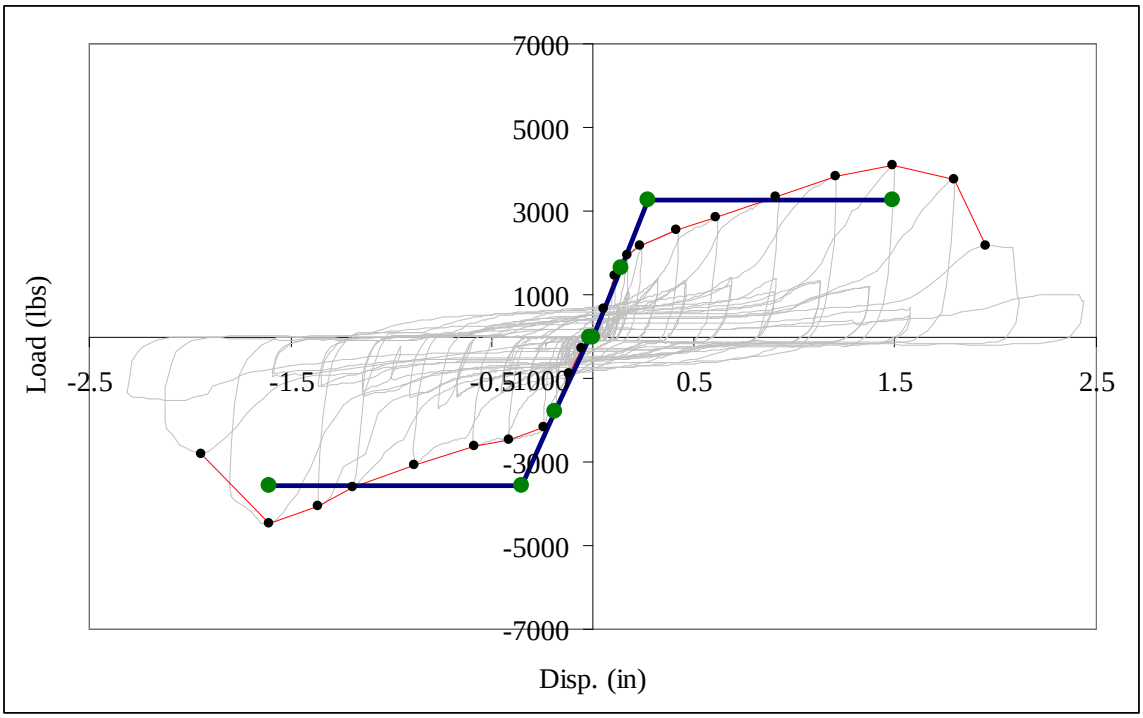

Figure A.30: Load-Deflection plot: C4-7.

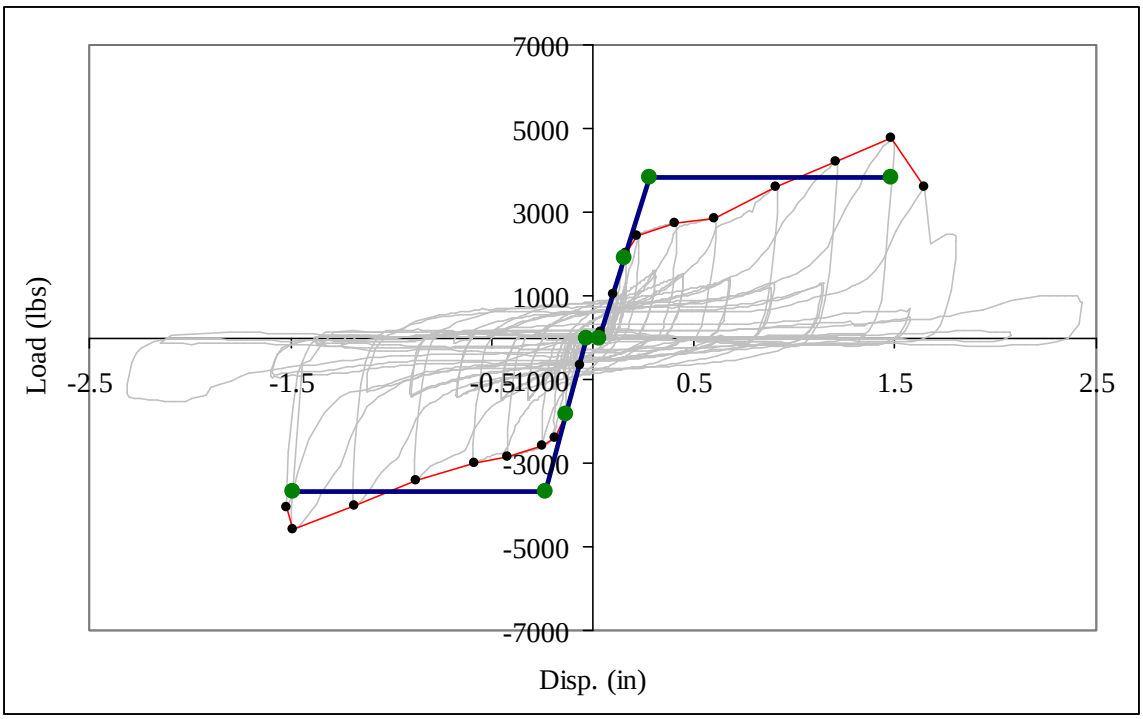

Figure A.31: Load-Deflection plot: C4-8.

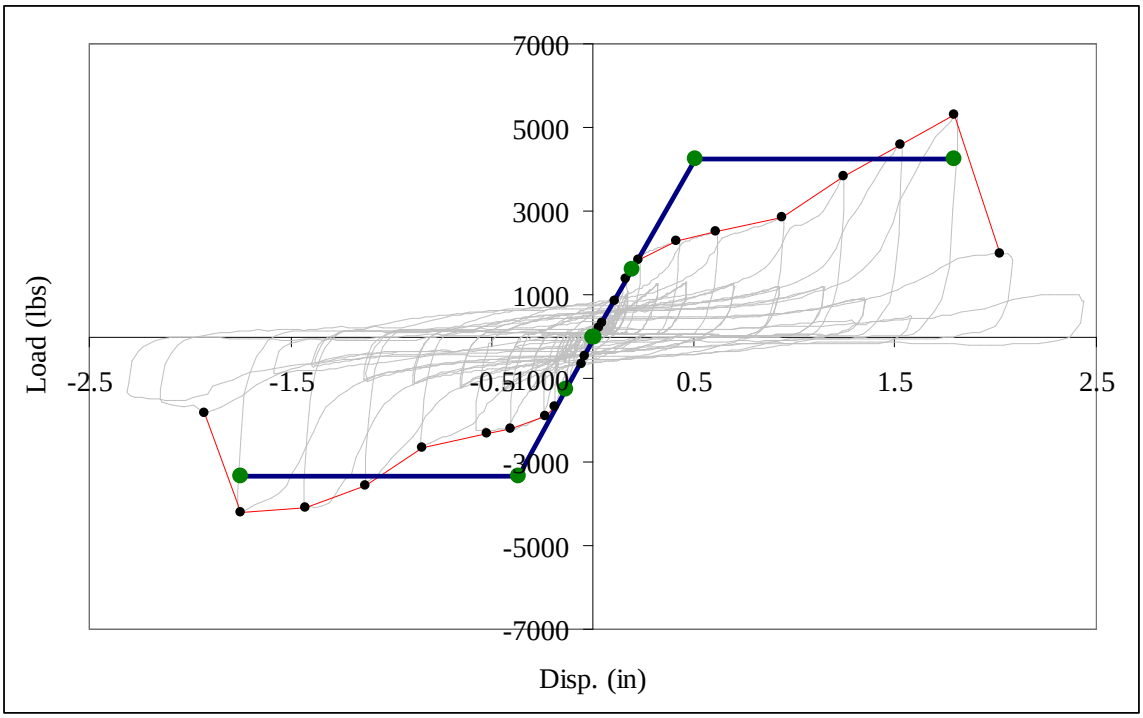

Figure A.32: Load-Deflection plot: C4-9.

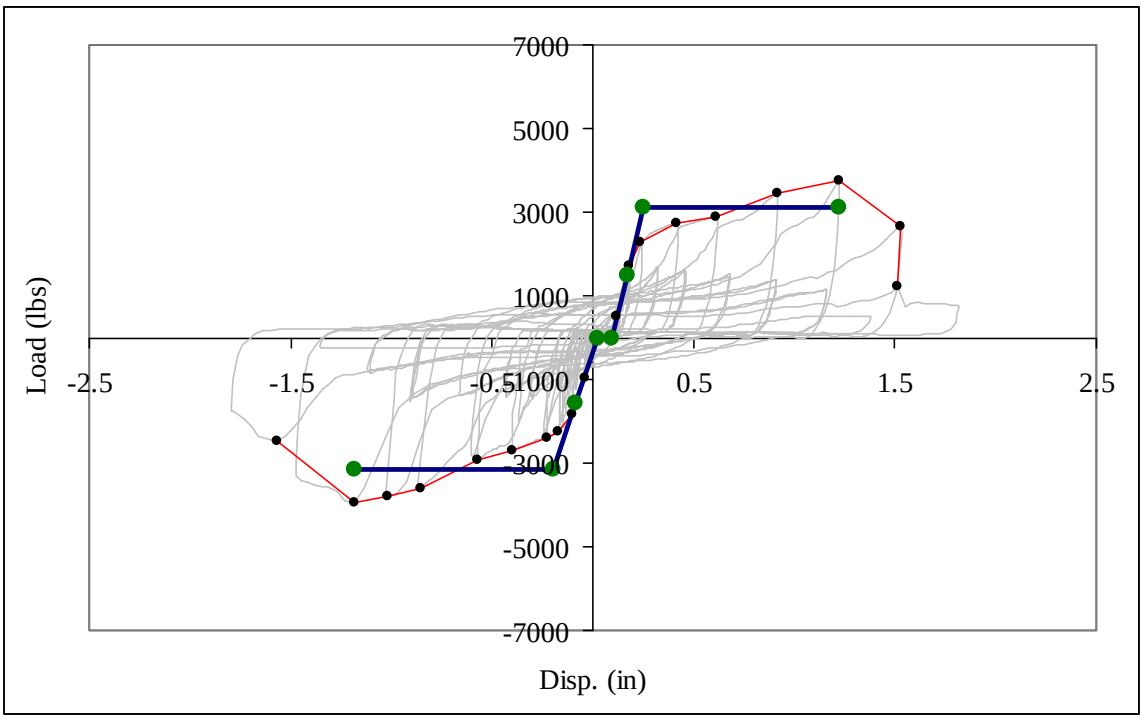

Figure A.33: Load-Deflection plot: C4-10.

Table A.10a: Connection performance properties (SI), Configuration 5.

Connection Performance Properties: Configuration 5

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	24.78	20.05	17.56	25.20	17.88	18.16	23.67	20.42	19.73	15.72	20.32	3.25	0.16
@Displacement (mm)	43.45	38.87	32.93	36.16	39.26	52.50	43.54	44.67	36.51	32.12	40.00	6.18	0.15
Failure Load (kN)	19.83	16.04	14.05	20.16	14.30	14.52	18.94	16.33	15.79	12.57	16.25	2.60	0.16
@Displacement (mm)	43.46	38.87	37.85	36.16	42.77	52.50	44.16	44.67	43.84	32.12	41.64	5.63	0.14
40% Max (kN)	7.43	8.02	7.03	10.08	7.15	7.26	7.10	8.17	7.89	6.29	7.64	1.02	0.13
@Displacement (mm)	3.51	6.41	3.21	4.20	3.64	4.35	3.98	5.08	4.02	3.49	4.19	0.95	0.23
Yield (kN)	19.83	16.04	14.55	20.16	14.48	14.81	18.94	16.33	16.04	12.70	16.39	2.49	0.15
@Displacement (mm)	9.75	14.35	6.07	7.64	6.33	8.72	9.82	9.76	7.52	6.09	8.60	2.52	0.29
5% Offset Yield (kN)	9.89	9.30	7.36	11.27	9.45	8.24	6.59	8.87	6.32	8.50	8.58	1.53	0.18
@Displacement (mm)	4.94	7.36	3.51	4.92	4.80	5.24	3.96	5.80	3.59	4.70	4.88	1.13	0.23
Elastic Stiff. (N/mm)	2059.32	1456.78	2681.40	2931.71	2725.13	1731.65	2036.45	1744.72	2335.61	2465.54	2216.83	489.28	0.22
E.E.P. Energy (N*m)	767.56	520.82	503.42	643.80	565.81	711.79	738.69	647.43	637.58	363.21	610.01	123.48	0.20
Ductility Ratio	4.46	3.22	6.57	4.73	6.76	6.03	4.51	4.58	5.85	5.27	5.20	1.10	0.21
Yield Mode	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV			
Failure Mode	Blt Shr	Blt Shr	Blt Shr	Splitting	Blt Shr	Blt Shr	Blt Shr	Blt Shr	Blt Shr	Splitting			
Governing Member	N.A.	N.A.	N.A.	Both	N.A.	N.A.	N.A.	N.A.	N.A.	Both			

Table A.10b: Connection performance properties (Std.), Configuration 5.

Connection Performance Properties: Configuration 5

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	5571.21	4508.37	3948.29	5666.16	4019.71	4081.50	5321.64	4590.15	4436.50	3533.04	4567.66	729.86	0.16
@ Displacement (in)	1.71	1.53	1.30	1.42	1.55	2.07	1.71	1.76	1.44	1.26	1.57	0.24	0.15
Failure Load (lbs)	4456.97	3606.70	3158.63	4532.93	3215.77	3265.20	4257.31	3672.12	3549.20	2826.43	3654.13	583.88	0.16
@ Displacement (in)	1.71	1.53	1.49	1.42	1.68	2.07	1.74	1.76	1.73	1.26	1.64	0.22	0.14
40% Max (lbs)	1671.36	1803.35	1579.32	2266.46	1607.89	1632.60	1596.49	1836.06	1774.60	1413.21	1718.13	229.43	0.13
@ Displacement (in)	0.14	0.25	0.13	0.17	0.14	0.17	0.16	0.20	0.16	0.14	0.16	0.04	0.23
Yield (lbs)	4456.97	3606.70	3270.66	4532.93	3255.06	3329.03	4257.31	3672.12	3605.63	2854.44	3684.08	560.57	0.15
@ Displacement (in)	0.38	0.57	0.24	0.30	0.25	0.34	0.39	0.38	0.30	0.24	0.34	0.10	0.29
5% Offset Yield (lbs)	2224.36	2089.99	1653.77	2533.87	2125.45	1851.32	1480.94	1993.43	1420.50	1911.70	1928.53	343.70	0.18
@ Displacement (in)	0.19	0.29	0.14	0.19	0.19	0.21	0.16	0.23	0.14	0.19	0.19	0.04	0.23
Elastic Stiff. (lb/in)	11759.04	8318.42	15311.19	16740.48	15560.92	9887.97	11628.45	9962.59	13336.67	14078.61	12658.43	2793.85	0.22
E.E.P. Energy (lb*in)	6793.47	4609.60	4455.61	5698.08	5007.87	6299.85	6537.96	5730.23	5643.09	3214.70	5399.05	1092.87	0.20
Ductility Ratio	4.46	3.22	6.57	4.73	6.76	6.03	4.51	4.58	5.85	5.27	5.20	1.10	0.21
Yield Mode	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV			
Failure Mode	Blt Shr	Blt Shr	Blt Shr	Splitting	Blt Shr	Blt Shr	Blt Shr	Blt Shr	Blt Shr	Splitting			
Governing Member	N.A.	N.A.	N.A.	Both	N.A.	N.A.	N.A.	N.A.	N.A.	Both			

Table A.11a: Member properties (SI), Configuration 5.

Member Properties: Configuration 5

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.41	13.69	14.23	14.07	14.76	15.10	16.81	15.04	14.40	15.16	14.77	0.86	0.06
S.G.	0.51	0.52	0.51	0.59	0.39	0.45	0.45	0.59	0.46	0.46	0.49	0.06	0.13
D.E. 5% Offset Yield (kPa)	46541	43273	44782	56758	31163	40864	34917	44250	30835	37416	41080	7880.69	0.19
D.E. Capacity (kPa)	54710	54952	51991	62592	36476	42332	40319	49463	41795	45318	47995	8123.81	0.17
Side Member													
M.C. (%)	15.29	15.25	16.03	14.27	15.12	16.13	15.28	15.58	15.34	15.82	15.41	0.53	0.03
S.G.	0.52	0.52	0.48	0.57	0.43	0.46	0.47	0.58	0.46	0.45	0.49	0.05	0.10
D.E. 5% Offset Yield (kPa)	38189	38036	26143	45110	27016	36939	31549	33454	25205	30335	33197	6386.34	0.19
D.E. Capacity (kPa)	46749	44775	42581	55399	36956	39162	42411	46432	39223	41552	43524	5250.66	0.12

Table A.11b: Member properties (Std.), Configuration 5.

Member Properties: Configuration 5

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.41	13.69	14.23	14.07	14.76	15.10	16.81	15.04	14.40	15.16	14.77	0.86	0.06
S.G.	0.51	0.52	0.51	0.59	0.39	0.45	0.45	0.59	0.46	0.46	0.49	0.06	0.13
D.E. 5% Offset Yield (psi)	6750.18	6276.19	6494.99	8231.97	4519.73	5926.80	5064.20	6417.88	4472.25	5426.69	5958.09	1142.99	0.19
D.E. Capacity (psi)	7935.00	7970.07	7540.55	9078.13	5290.34	6139.68	5847.77	7173.94	6061.88	6572.71	6961.01	1178.25	0.17
Side Member													
M.C. (%)	15.29	15.25	16.03	14.27	15.12	16.13	15.28	15.58	15.34	15.82	15.41	0.53	0.03
S.G.	0.52	0.52	0.48	0.57	0.43	0.46	0.47	0.58	0.46	0.45	0.49	0.05	0.10
D.E. 5% Offset Yield (psi)	5538.78	5516.61	3791.65	6542.58	3918.29	5357.48	4575.70	4852.06	3655.61	4399.73	4814.85	926.25	0.19
D.E. Capacity (psi)	6780.33	6494.08	6175.79	8034.92	5360.05	5679.86	6151.17	6734.42	5688.72	6026.64	6312.60	761.54	0.12

Table A.12a: Hysteretic connection properties (SI), Configuration 5.

Hysteretic Connection Properties: Configuration 5

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	1.60	1.82	1.14	0.76	0.15	0.20	-0.91	0.69	0.77	-0.86	0.14	0.16
Primary2	2.28	2.13	0.94	1.21	0.05	0.04	-1.31	0.75	0.58	-1.34	0.09	0.07
Primary3	5.96	2.45	0.41	2.79	0.12	0.04	-4.37	1.83	0.42	-2.94	0.12	0.04
Primary4	7.89	3.39	0.43	4.07	0.80	0.20	-7.56	2.52	0.33	-4.28	0.69	0.16
Primary5	8.79	3.80	0.43	5.54	0.91	0.17	-9.39	2.59	0.28	-5.82	0.80	0.14
Primary6	10.99	3.76	0.34	10.22	1.49	0.15	-11.65	1.48	0.13	-9.86	1.34	0.14
Primary7	12.18	4.24	0.35	14.98	1.59	0.11	-12.58	1.78	0.14	-14.24	1.33	0.09
Primary8	14.81	5.07	0.34	22.41	2.61	0.12	-14.31	2.36	0.17	-20.94	1.97	0.09
Primary9	17.34	5.83	0.34	29.76	2.75	0.09	-16.38	2.84	0.17	-27.71	1.92	0.07
Primary10	18.94	6.99	0.37	37.10	2.87	0.08	-18.70	3.48	0.19	-34.81	3.26	0.09
Primary11	15.55	8.81	0.57	43.19	3.23	0.07	-15.82	6.36	0.40	-40.56	4.10	0.10

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	0.99	0.82	0.83	1.05	0.99	0.94	0.18	0.11	0.59	1502.13	1340.60	0.89
Primary2	1.77	1.21	0.68	2.26	1.50	0.66	0.13	0.04	0.33	1393.23	890.26	0.64
Primary3	9.69	2.70	0.28	14.74	2.14	0.14	0.11	0.03	0.30	1803.99	212.79	0.12
Primary4	18.90	7.95	0.42	33.53	11.54	0.34	0.09	0.02	0.19	1828.05	316.29	0.17
Primary5	33.63	12.94	0.38	53.46	17.47	0.33	0.10	0.02	0.19	1571.19	304.76	0.19
Primary6	122.66	33.90	0.28	113.97	22.38	0.20	0.17	0.03	0.15	1151.96	237.69	0.21
Primary7	204.74	30.94	0.15	180.46	29.05	0.16	0.18	0.01	0.06	859.31	174.26	0.20
Primary8	360.43	56.49	0.16	315.60	53.63	0.17	0.18	0.01	0.06	680.42	125.34	0.18
Primary9	468.14	48.72	0.10	484.96	71.92	0.15	0.15	0.01	0.07	590.51	89.87	0.15
Primary10	566.89	60.48	0.11	677.27	125.60	0.19	0.14	0.02	0.12	526.59	93.60	0.18
Primary11	556.32	154.05	0.28	664.30	276.38	0.42	0.15	0.05	0.32	374.25	140.89	0.38

Table A.12b: Hysteretic connection properties (Std.), Configuration 5.

Hysteretic Connection Properties: Configuration 5

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	304.59	262.11	0.86	0.03	0.00	0.14	-284.61	244.32	0.86	-0.03	0.01	0.17
Primary2	440.08	336.83	0.77	0.05	0.00	0.11	-422.59	334.99	0.79	-0.05	0.01	0.20
Primary3	1140.08	585.63	0.51	0.11	0.00	0.04	-1125.95	581.08	0.52	-0.11	0.03	0.24
Primary4	1873.35	675.01	0.36	0.17	0.01	0.05	-1754.36	566.53	0.32	-0.17	0.03	0.17
Primary5	2227.22	763.34	0.34	0.23	0.01	0.04	-2083.83	575.34	0.28	-0.23	0.03	0.15
Primary6	2484.26	988.28	0.40	0.39	0.08	0.20	-2425.79	626.65	0.26	-0.38	0.07	0.19
Primary7	2743.97	1095.19	0.40	0.58	0.09	0.16	-2677.91	623.06	0.23	-0.55	0.09	0.16
Primary8	3411.53	1448.11	0.42	0.86	0.14	0.16	-3086.64	858.29	0.28	-0.81	0.14	0.17
Primary9	3958.73	1754.81	0.44	1.15	0.16	0.14	-3405.64	896.86	0.26	-1.08	0.16	0.15
Primary10	4334.29	2124.29	0.49	1.43	0.18	0.13	-3604.35	951.24	0.26	-1.32	0.17	0.13
Primary11	3669.89	2160.57	0.59	1.65	0.20	0.12	-3522.64	1616.16	0.46	-1.53	0.17	0.11

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	8.38	4.47	0.53	9.58	4.94	0.52	0.14	0.05	0.33	9116.45	4740.38	0.52
Primary2	15.42	7.04	0.46	20.49	7.61	0.37	0.12	0.03	0.27	9022.52	3120.22	0.35
Primary3	86.84	27.42	0.32	127.46	36.63	0.29	0.11	0.02	0.17	10157.62	1783.08	0.18
Primary4	192.81	62.70	0.33	317.10	78.05	0.25	0.10	0.01	0.11	10479.12	1833.51	0.17
Primary5	337.31	98.48	0.29	504.26	108.79	0.22	0.11	0.01	0.11	9299.95	1481.45	0.16
Primary6	1208.67	191.86	0.16	1060.19	131.92	0.12	0.19	0.02	0.08	6305.15	871.94	0.14
Primary7	1910.91	245.24	0.13	1663.77	239.53	0.14	0.20	0.03	0.15	4796.25	778.09	0.16
Primary8	3412.55	403.27	0.12	2994.15	487.42	0.16	0.20	0.03	0.18	3858.97	829.79	0.22
Primary9	4295.41	490.38	0.11	4578.78	728.19	0.16	0.15	0.01	0.07	3375.82	568.24	0.17
Primary10	5115.34	429.76	0.08	6137.13	997.31	0.16	0.14	0.04	0.29	3005.16	502.53	0.17
Primary11	5758.14	1401.65	0.24	6631.92	2249.42	0.34	0.20	0.07	0.36	2382.82	743.32	0.31

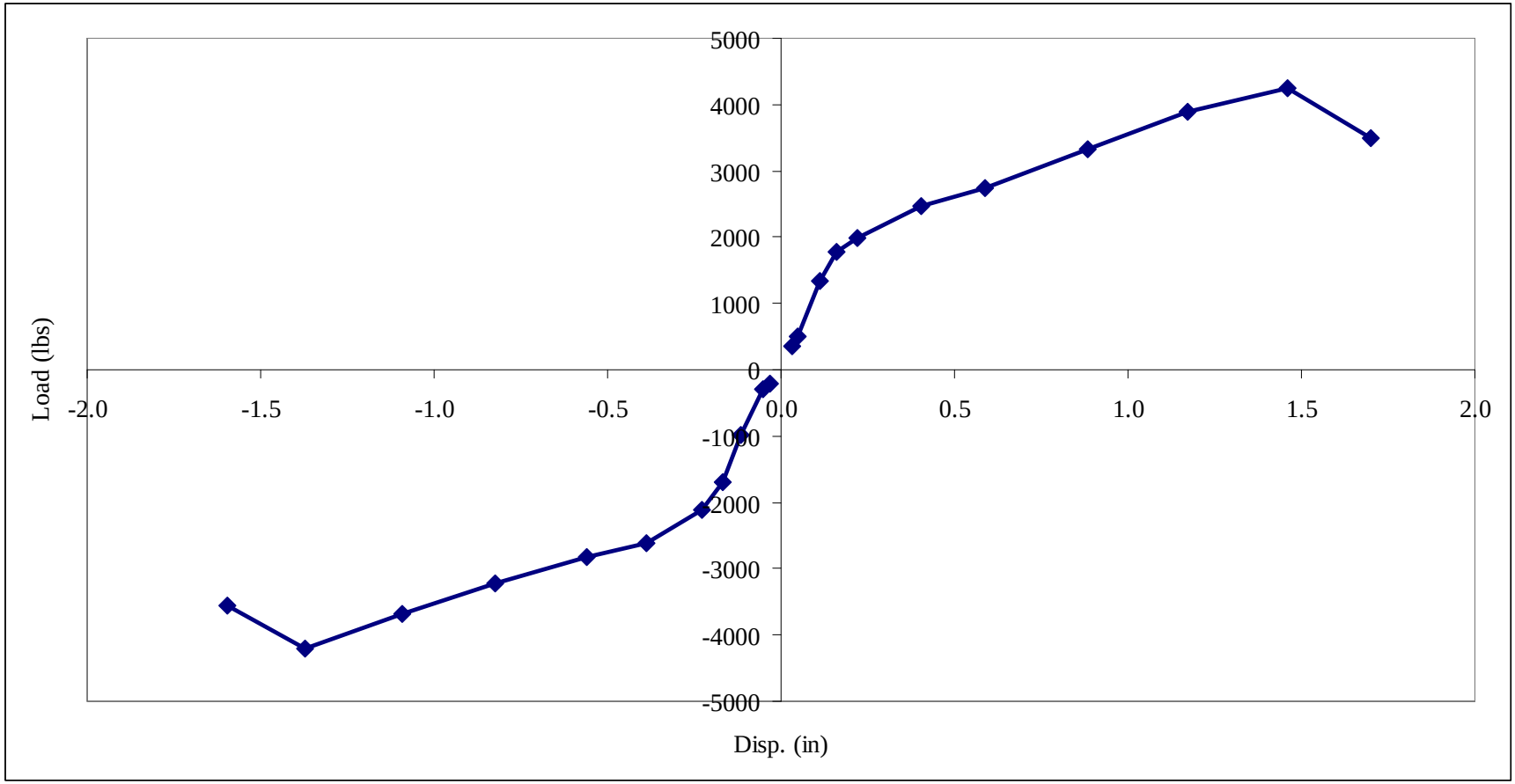

Figure A.34: Mean envelope curve: Configuration 5.

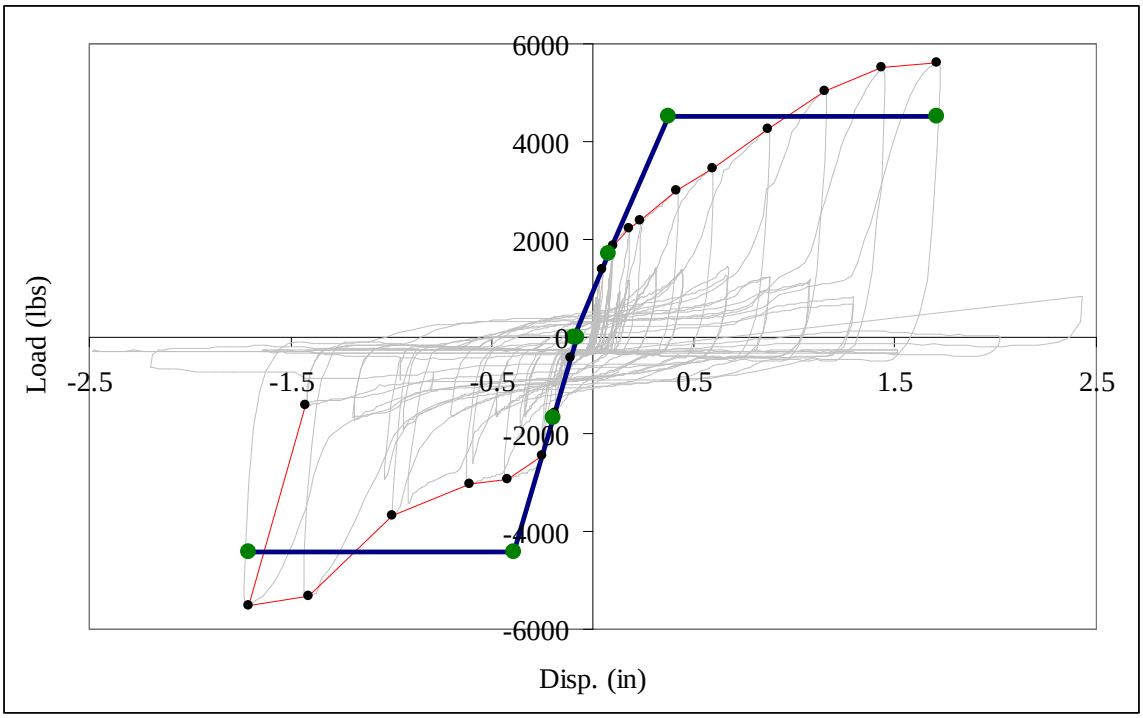

Figure A.35: Load-Deflection plot: C5-1.

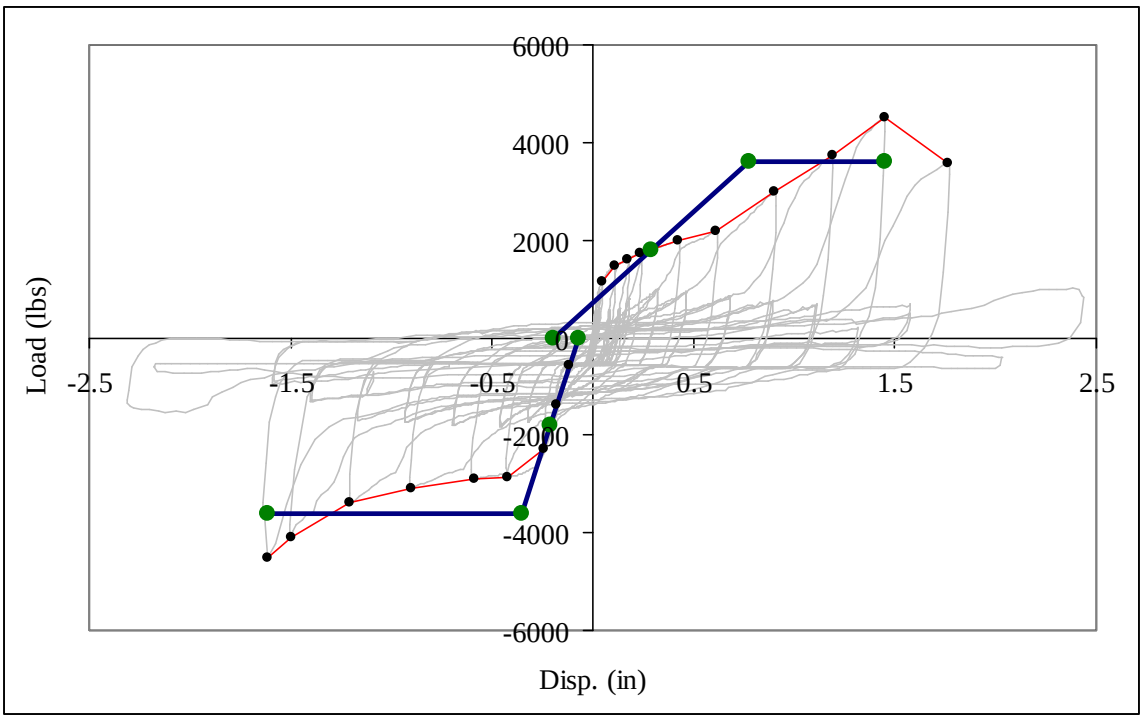

Figure A.36: Load-Deflection plot: C5-2.

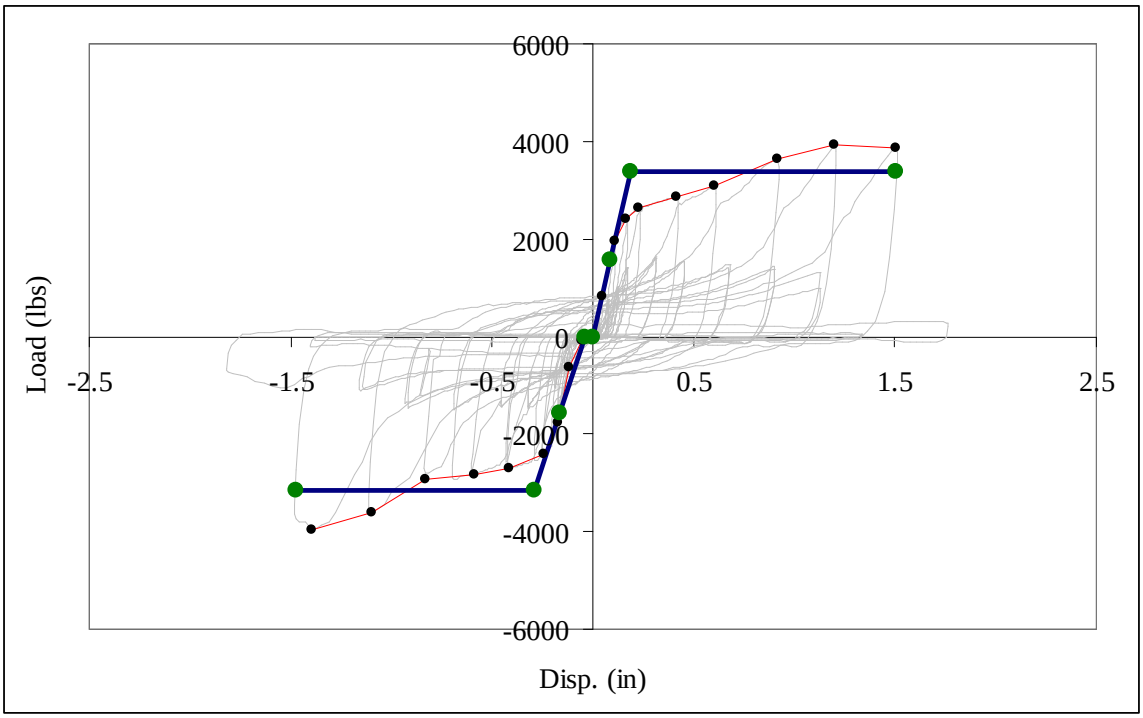

Figure A.37: Load-Deflection plot: C5-3.

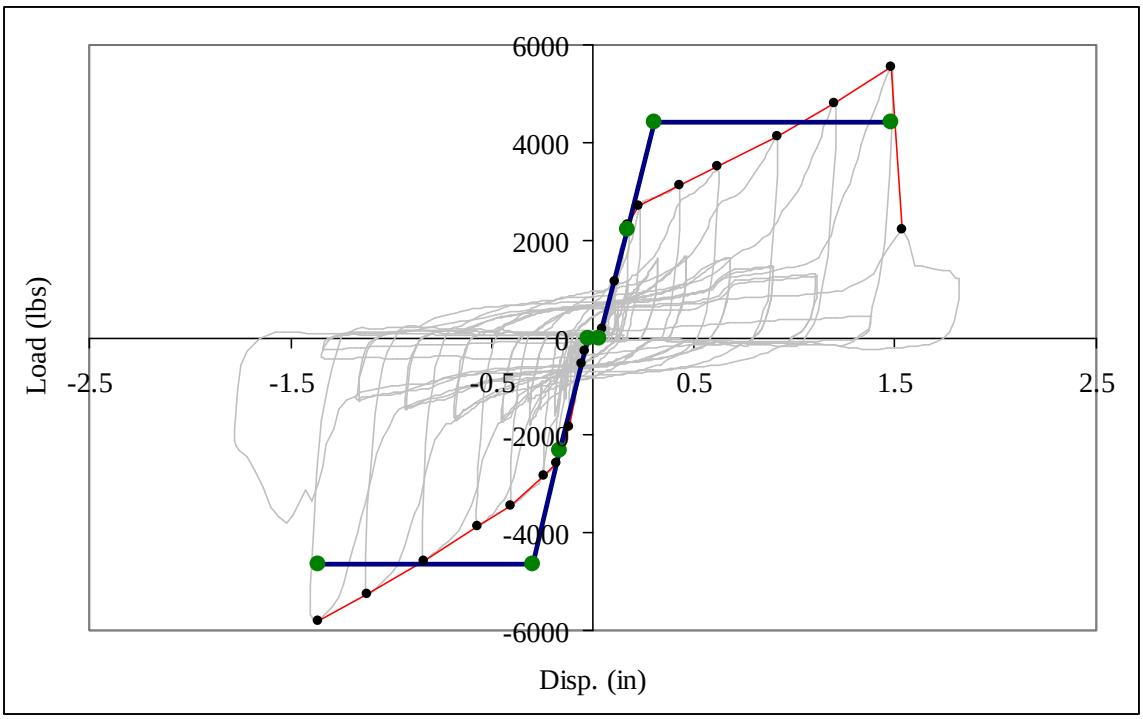

Figure A.38: Load-Deflection plot: C5-4.

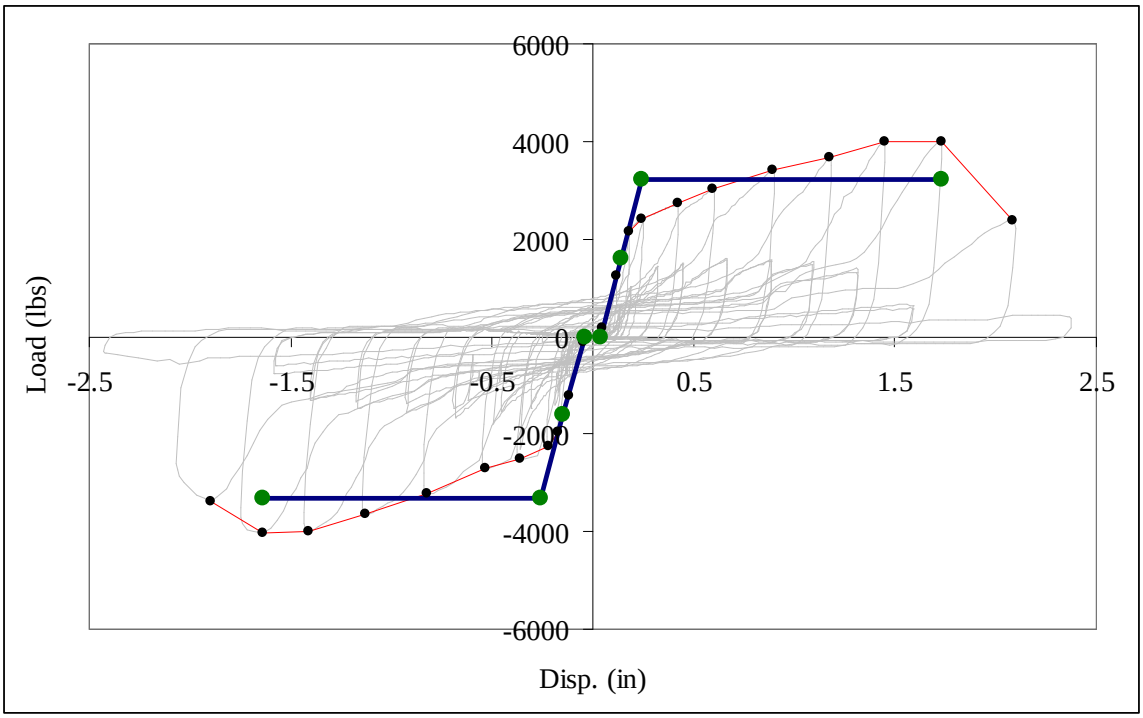

Figure A.39: Load-Deflection plot: C5-5.

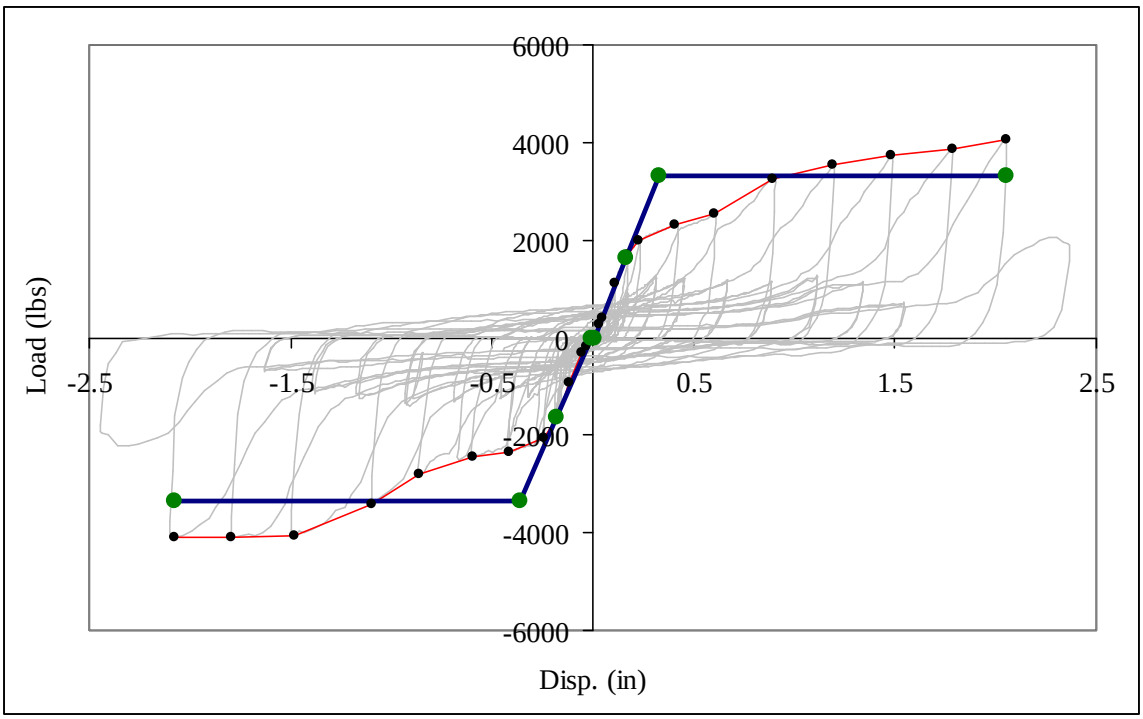

Figure A.40: Load-Deflection plot: C5-6.

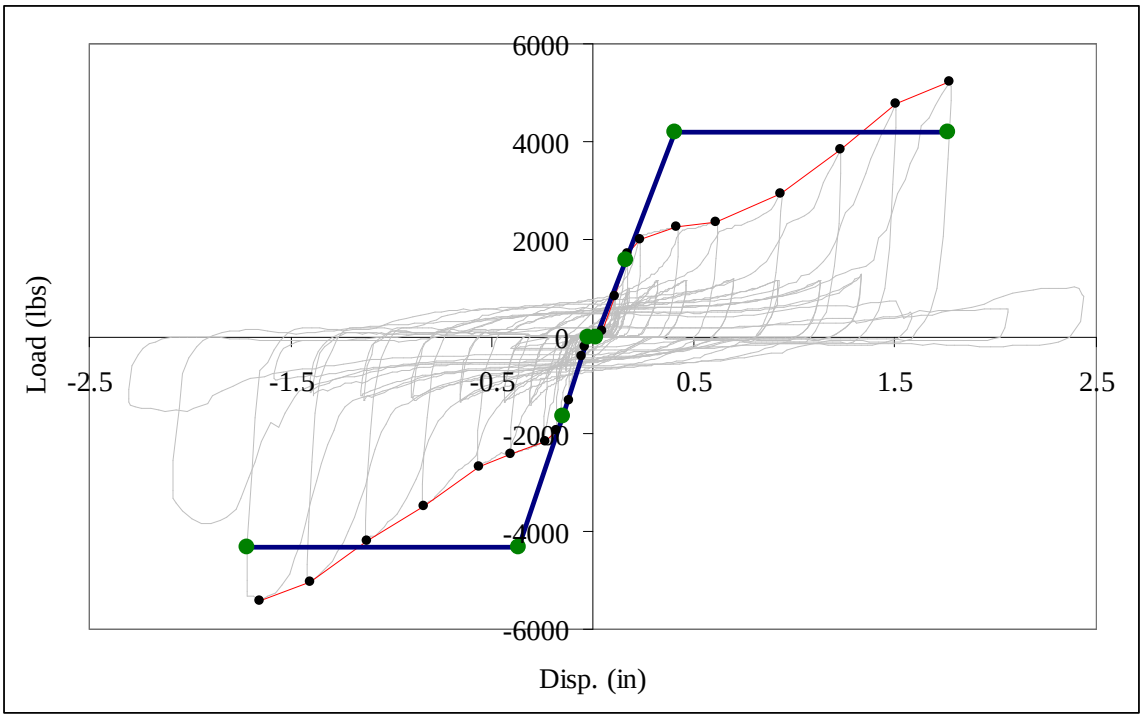

Figure A.41: Load-Deflection plot: C5-7.

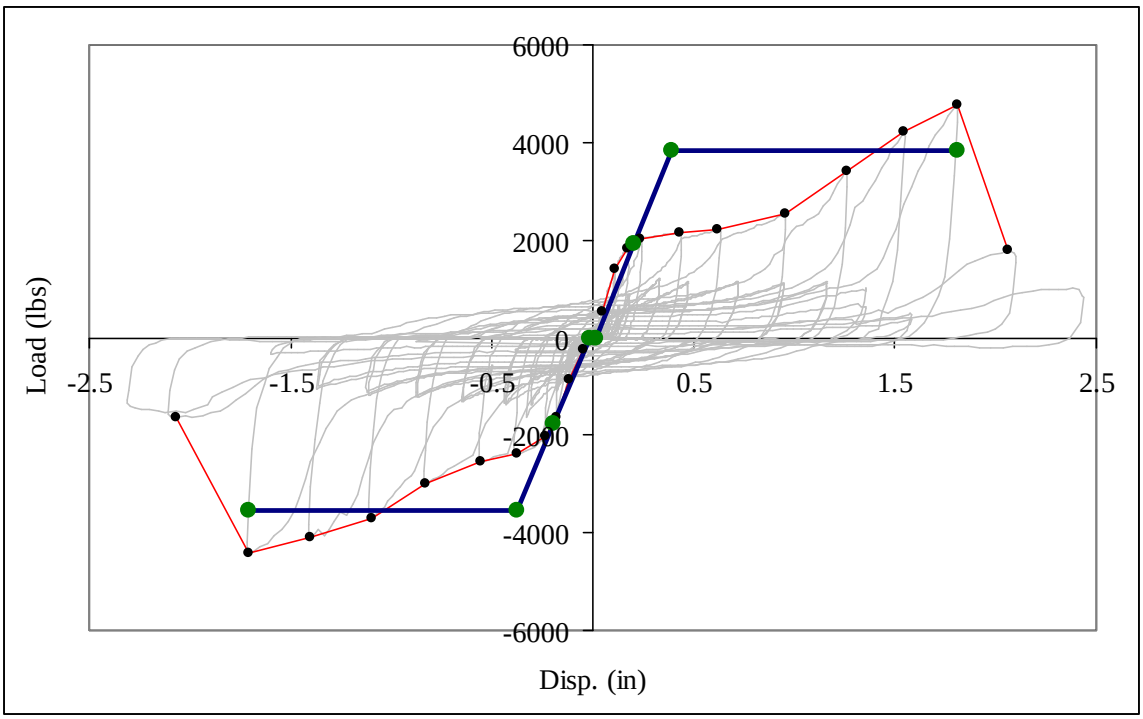

Figure A.42: Load-Deflection plot: C5-8.

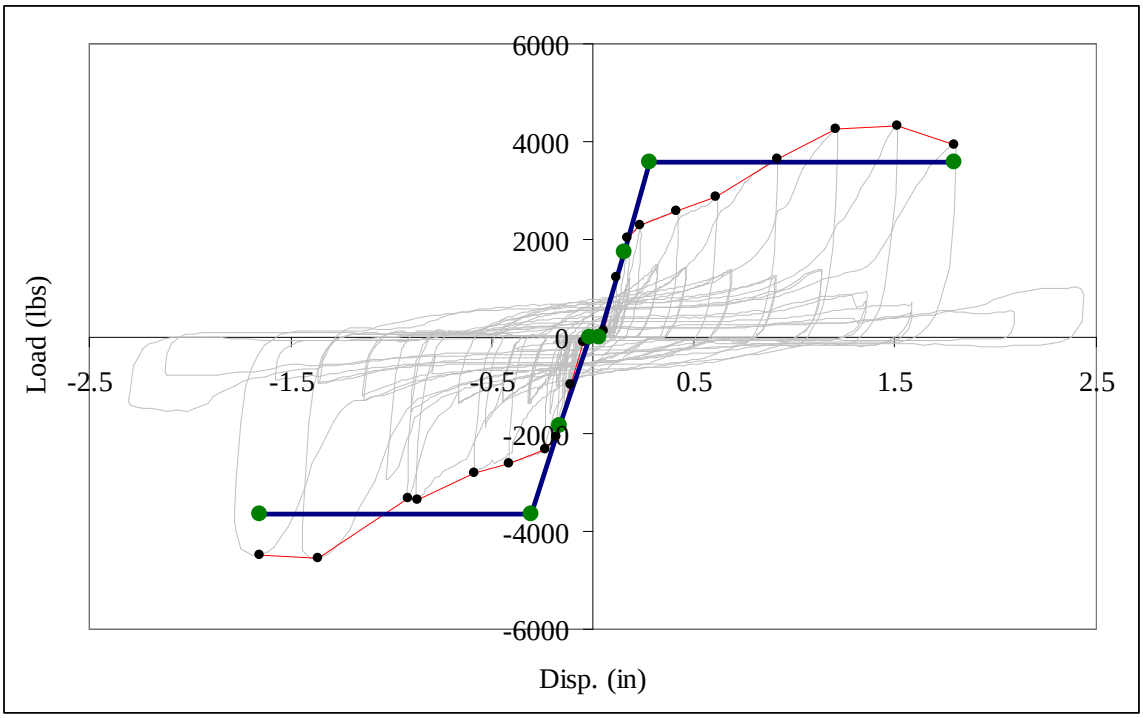

Figure A.43: Load-Deflection plot: C5-9.

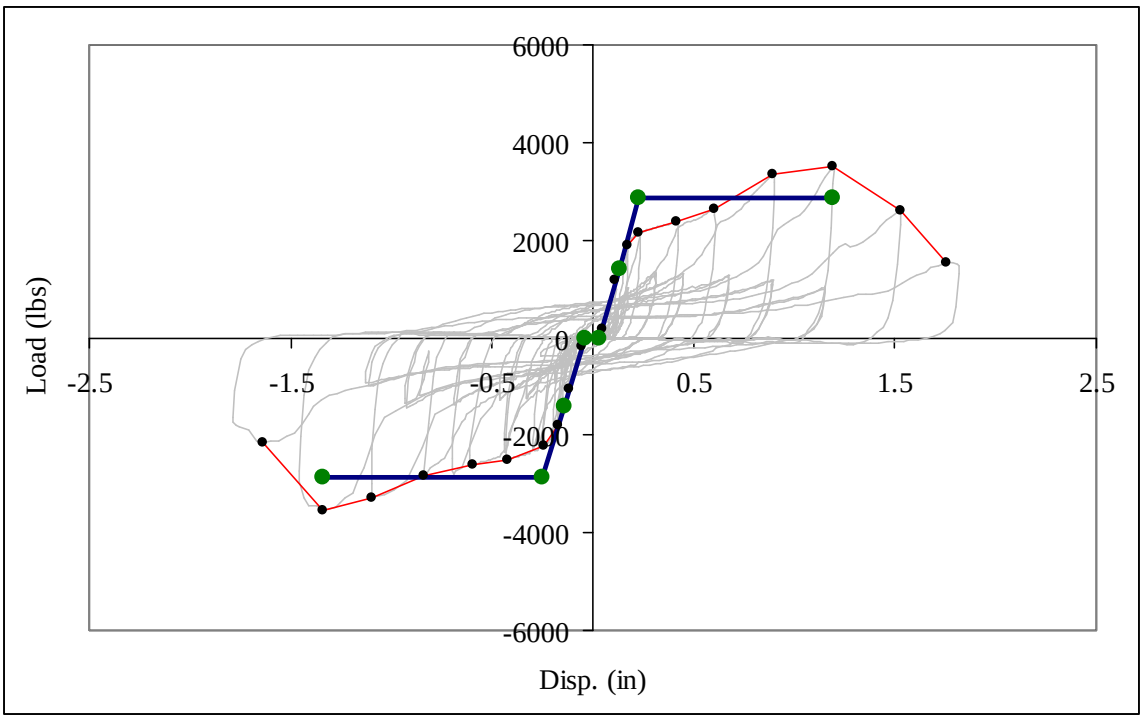

Figure A.44: Load-Deflection plot: C5-10.

Table A.13a: Connection performance properties (SI), Configuration 8.

Connection Performance Properties: Configuration 8

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	39.27	29.71	30.35	28.53	34.73	29.35	34.60	27.32	29.03	31.02	31.39	3.68	0.12
@Displacement (mm)	26.09	10.53	11.61	8.98	11.40	8.76	25.35	9.53	12.15	12.74	13.71	6.47	0.47
Failure Load (kN)	31.42	23.77	24.28	22.83	27.78	23.48	27.68	21.86	23.23	24.81	25.11	2.95	0.12
@Displacement (mm)	36.97	10.53	11.61	8.98	11.40	8.76	25.35	9.53	12.15	12.74	14.80	9.14	0.62
40% Max (kN)	15.71	11.88	12.14	11.41	13.89	11.74	13.84	10.93	11.61	12.41	12.56	1.47	0.12
@Displacement (mm)	4.24	2.86	2.90	2.79	3.19	2.69	3.53	2.95	2.55	2.99	3.07	0.49	0.16
Yield (kN)	34.47	28.40	28.62	27.73	34.29	28.06	31.86	24.97	26.53	29.31	29.42	3.16	0.11
@Displacement (mm)	8.37	5.93	6.12	6.85	4.22	6.23	6.66	5.93	5.14	6.57	6.20	1.09	0.18
5% Offset Yield (kN)	23.71	24.22	24.89	25.59	28.14	25.31	23.74	21.93	21.51	24.23	24.33	1.88	0.08
@Displacement (mm)	6.67	5.55	5.73	6.63	3.69	5.95	5.58	5.60	4.57	5.87	5.58	0.89	0.16
Elastic Stiff. (N/mm)	4541.25	5538.41	5115.24	4029.05	5783.31	4606.31	5764.39	4723.59	5835.74	4765.61	5070.29	631.54	0.12
E.E.P. Energy (N*m)	1117.92	204.86	241.72	155.11	436.71	157.94	685.93	155.96	254.87	272.59	368.36	310.39	0.84
Ductility Ratio	4.43	1.94	1.96	1.32	3.45	1.42	3.82	1.64	2.40	1.97	2.43	1.08	0.44
Yield Mode	IV	IV	IV	III_s-IV	IV	III_s-IV	IV	III_s-IV	IV	IV			
Failure Mode	Balk. Shr.	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Side	Both	Both	Both	Both	Side	Both	Both	Both	Both			

Table A.13b: Connection performance properties (Std.), Configuration 8.

Connection Performance Properties: Configuration 8

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	8828.29	6679.17	6822.78	6414.80	7807.63	6597.61	7778.15	6142.66	6526.49	6972.92	7057.05	827.75	0.12
@ Displacement (in)	1.03	0.41	0.46	0.35	0.45	0.35	1.00	0.38	0.48	0.50	0.54	0.25	0.47
Failure Load (lbs)	7062.63	5343.34	5458.22	5131.84	6246.10	5278.09	6222.52	4914.13	5221.19	5578.33	5645.64	662.20	0.12
@ Displacement (in)	1.46	0.41	0.46	0.35	0.45	0.35	1.00	0.38	0.48	0.50	0.58	0.36	0.62
40% Max (lbs)	3531.31	2671.67	2729.11	2565.92	3123.05	2639.04	3111.26	2457.06	2610.60	2789.17	2822.82	331.10	0.12
@ Displacement (in)	0.17	0.11	0.11	0.11	0.13	0.11	0.14	0.12	0.10	0.12	0.12	0.02	0.16
Yield (lbs)	7750.26	6385.28	6433.73	6233.23	7708.68	6308.16	7161.98	5614.33	5964.66	6588.04	6614.83	709.83	0.11
@ Displacement (in)	0.33	0.23	0.24	0.27	0.17	0.25	0.26	0.23	0.20	0.26	0.24	0.04	0.18
5% Offset Yield (lbs)	5329.46	5445.39	5595.59	5753.81	4285.06	5689.43	5336.61	4931.10	4836.40	5448.17	5265.10	454.51	0.09
@ Displacement (in)	0.26	0.22	0.23	0.26	0.16	0.23	0.22	0.22	0.18	0.23	0.22	0.03	0.14
Elastic Stiff. (lb/in)	25931.21	31625.11	29208.79	23006.48	33023.54	26302.73	32915.54	26972.39	33322.93	27212.34	28952.11	3606.19	0.12
E.E.P. Energy (lb*in)	9894.41	1813.15	2139.38	1372.82	3865.23	1397.87	6071.00	1380.36	2255.81	2412.65	3260.27	2747.14	0.84
Ductility Ratio	4.43	1.94	1.96	1.32	3.45	1.42	3.82	1.64	2.40	1.97	2.43	1.08	0.44
Yield Mode	IV	IV	IV	III_S-IV	IV	III_S-IV	IV	III_S-IV	IV	IV			
Failure Mode	Balk. Shr.	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Side	Both	Both	Both	Both	Side	Both	Both	Both	Both			

Table A.14a: Member properties (SI), Configuration 8.

Member Properties: Configuration 8

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	16.42	15.97	16.15	16.14	16.49	16.44	15.87	15.87	16.05	15.63	16.10	0.28	0.02
S.G.	0.44	0.55	0.48	0.43	0.42	0.43	0.49	0.46	0.45	0.54	0.47	0.05	0.10
D.E. 5% Offset Yield (kPa)	30457	42317	40984	35356	32776	27592	35742	27359	30464	25463	32851	5717.57	0.17
D.E. Capacity (kPa)	35088	51064	46036	40606	39590	36089	41326	37980	41820	42156	41176	4699.64	0.11
Side Member													
M.C. (%)	15.78	15.85	16.19	15.85	15.72	15.66	16.02	16.44	15.50	15.85	15.89	0.27	0.02
S.G.	0.45	0.46	0.53	0.48	0.45	0.49	0.45	0.47	0.51	0.57	0.49	0.04	0.08
D.E. 5% Offset Yield (kPa)	30864	30491	38533	37478	30958	31892	34896	40767	21964	33922	33176	5303.80	0.16
D.E. Capacity (kPa)	37891	43939	51817	43386	42936	41800	38418	44288	28174	44075	41672	6076.55	0.15

Table A.14b: Member properties (Std.), Configuration 8.

Member Properties: Configuration 8

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.41	13.69	14.23	14.07	14.76	15.10	16.81	15.04	14.40	15.16	14.77	0.86	0.06
S.G.	0.51	0.52	0.51	0.59	0.39	0.45	0.45	0.59	0.46	0.46	0.49	0.06	0.13
D.E. 5% Offset Yield (psi)	6750.18	6276.19	6494.99	8231.97	4519.73	5926.80	5064.20	6417.88	4472.25	5426.69	5958.09	1142.99	0.19
D.E. Capacity (psi)	7935.00	7970.07	7540.55	9078.13	5290.34	6139.68	5847.77	7173.94	6061.88	6572.71	6961.01	1178.25	0.17
Side Member													
M.C. (%)	15.29	15.25	16.03	14.27	15.12	16.13	15.28	15.58	15.34	15.82	15.41	0.53	0.03
S.G.	0.52	0.52	0.48	0.57	0.43	0.46	0.47	0.58	0.46	0.45	0.49	0.05	0.10
D.E. 5% Offset Yield (psi)	5538.78	5516.61	3791.65	6542.58	3918.29	5357.48	4575.70	4852.06	3655.61	4399.73	4814.85	926.25	0.19
D.E. Capacity (psi)	6780.33	6494.08	6175.79	8034.92	5360.05	5679.86	6151.17	6734.42	5688.72	6026.64	6312.60	761.54	0.12

Table A.15a: Hysteretic connection properties (SI), Configuration 8.

Hysteretic Connection Properties: Configuration 8

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	3.66	2.22	0.61	0.54	0.13	0.24	-1.27	0.88	0.69	-0.62	0.18	0.29
Primary2	5.11	2.90	0.57	0.90	0.15	0.16	-1.65	1.16	0.71	-0.95	0.28	0.30
Primary3	11.08	4.68	0.42	2.10	0.16	0.08	-4.48	2.29	0.51	-2.10	0.59	0.28
Primary4	17.13	5.77	0.34	3.24	0.26	0.08	-9.37	2.26	0.24	-3.24	0.40	0.12
Primary5	21.91	6.96	0.32	4.23	0.47	0.11	-13.63	2.33	0.17	-3.93	0.52	0.13
Primary6	28.51	8.97	0.31	7.08	0.78	0.11	-23.63	2.67	0.11	-5.81	0.80	0.14
Primary7	30.65	9.61	0.31	10.27	0.91	0.09	-28.09	2.01	0.07	-8.48	1.02	0.12
Primary8	27.97	12.56	0.45	14.18	2.93	0.21	-27.74	2.09	0.08	-10.64	1.85	0.17
Primary9	22.25	12.55	0.56	21.00	2.05	0.10	-19.03	9.94	0.52	-16.89	3.07	0.18
Primary10	25.32	12.36	0.49	25.32	2.43	0.10	-18.99	10.18	0.54	-24.22	1.91	0.08
Primary11	21.60	11.54	0.53	30.17	1.46	0.05	-13.95	11.04	0.79	-27.68	3.32	0.12

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.25	0.68	0.54	1.37	0.73	0.53	0.15	0.04	0.28	4220.55	2193.50	0.52
Primary2	2.28	1.17	0.51	3.08	1.52	0.49	0.12	0.03	0.23	3649.39	1643.95	0.45
Primary3	9.94	3.47	0.35	16.51	3.72	0.23	0.09	0.02	0.17	3709.17	665.80	0.18
Primary4	19.15	2.88	0.15	42.48	3.83	0.09	0.07	0.01	0.11	4094.05	362.93	0.09
Primary5	26.27	2.79	0.11	72.93	7.98	0.11	0.06	0.01	0.11	4358.35	285.90	0.07
Primary6	101.66	13.54	0.13	170.37	21.77	0.13	0.10	0.01	0.10	4059.93	315.97	0.08
Primary7	214.80	22.87	0.11	276.86	27.59	0.10	0.12	0.01	0.06	3148.01	282.10	0.09
Primary8	440.02	84.53	0.19	358.98	116.71	0.33	0.21	0.05	0.23	2239.54	240.88	0.11
Primary9	488.37	220.53	0.45	396.39	230.03	0.58	0.21	0.04	0.21	1089.34	555.87	0.51
Primary10	579.22	256.50	0.44	554.42	298.20	0.54	0.18	0.04	0.20	889.41	422.56	0.48
Primary11	482.00	262.08	0.54	519.02	315.57	0.61	0.15	0.02	0.15	615.39	396.15	0.64

Table A.15b: Hysteretic connection properties (Std.), Configuration 8.

Hysteretic Connection Properties: Configuration 8

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	822.45	498.81	0.61	0.02	0.01	0.24	-284.83	197.81	0.69	-0.02	0.01	0.29
Primary2	1149.46	651.16	0.57	0.04	0.01	0.16	-371.09	261.64	0.71	-0.04	0.01	0.30
Primary3	2491.45	1052.39	0.42	0.08	0.01	0.08	-1008.13	514.76	0.51	-0.08	0.02	0.28
Primary4	3850.82	1296.68	0.34	0.13	0.01	0.08	-2107.15	507.09	0.24	-0.13	0.02	0.12
Primary5	4926.16	1564.48	0.32	0.17	0.02	0.11	-3064.23	524.66	0.17	-0.15	0.02	0.13
Primary6	6409.68	2016.19	0.31	0.28	0.03	0.11	-5311.11	601.08	0.11	-0.23	0.03	0.14
Primary7	6891.19	2160.74	0.31	0.40	0.04	0.09	-6315.65	451.58	0.07	-0.33	0.04	0.12
Primary8	6288.15	2822.67	0.45	0.56	0.12	0.21	-6237.26	470.78	0.08	-0.42	0.07	0.17
Primary9	5002.41	2822.22	0.56	0.83	0.08	0.10	-4277.25	2235.00	0.52	-0.67	0.12	0.18
Primary10	5691.72	2778.89	0.49	1.00	0.10	0.10	-4269.87	2288.92	0.54	-0.95	0.08	0.08
Primary11	4856.42	2594.99	0.53	1.19	0.06	0.05	-3135.52	2482.09	0.79	-1.09	0.13	0.12

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	11.10	6.00	0.54	12.09	6.45	0.53	0.16	0.04	0.28	24099.96	12525.20	0.52
Primary2	20.20	10.40	0.51	27.23	13.46	0.49	0.12	0.03	0.24	20838.55	9387.18	0.45
Primary3	88.02	30.70	0.35	146.16	32.92	0.23	0.10	0.02	0.22	21179.90	3801.82	0.18
Primary4	169.45	25.52	0.15	375.98	33.94	0.09	0.08	0.01	0.17	23377.62	2072.37	0.09
Primary5	232.55	24.68	0.11	645.52	70.62	0.11	0.06	0.01	0.19	24886.84	1632.54	0.07
Primary6	899.78	119.84	0.13	1507.88	192.72	0.13	0.10	0.02	0.19	23182.77	1804.26	0.08
Primary7	1901.18	202.44	0.11	2450.46	244.16	0.10	0.13	0.02	0.15	17975.58	1610.86	0.09
Primary8	3894.50	748.13	0.19	3177.21	1032.94	0.33	0.22	0.05	0.22	12788.12	1375.46	0.11
Primary9	4322.42	1951.84	0.45	3508.36	2035.94	0.58	0.22	0.05	0.23	6220.30	3174.12	0.51
Primary10	5126.52	2270.18	0.44	4907.02	2639.28	0.54	0.18	0.03	0.19	5078.69	2412.86	0.48
Primary11	4266.05	2319.57	0.54	4593.69	2793.03	0.61	0.16	0.02	0.16	3513.97	2262.07	0.64

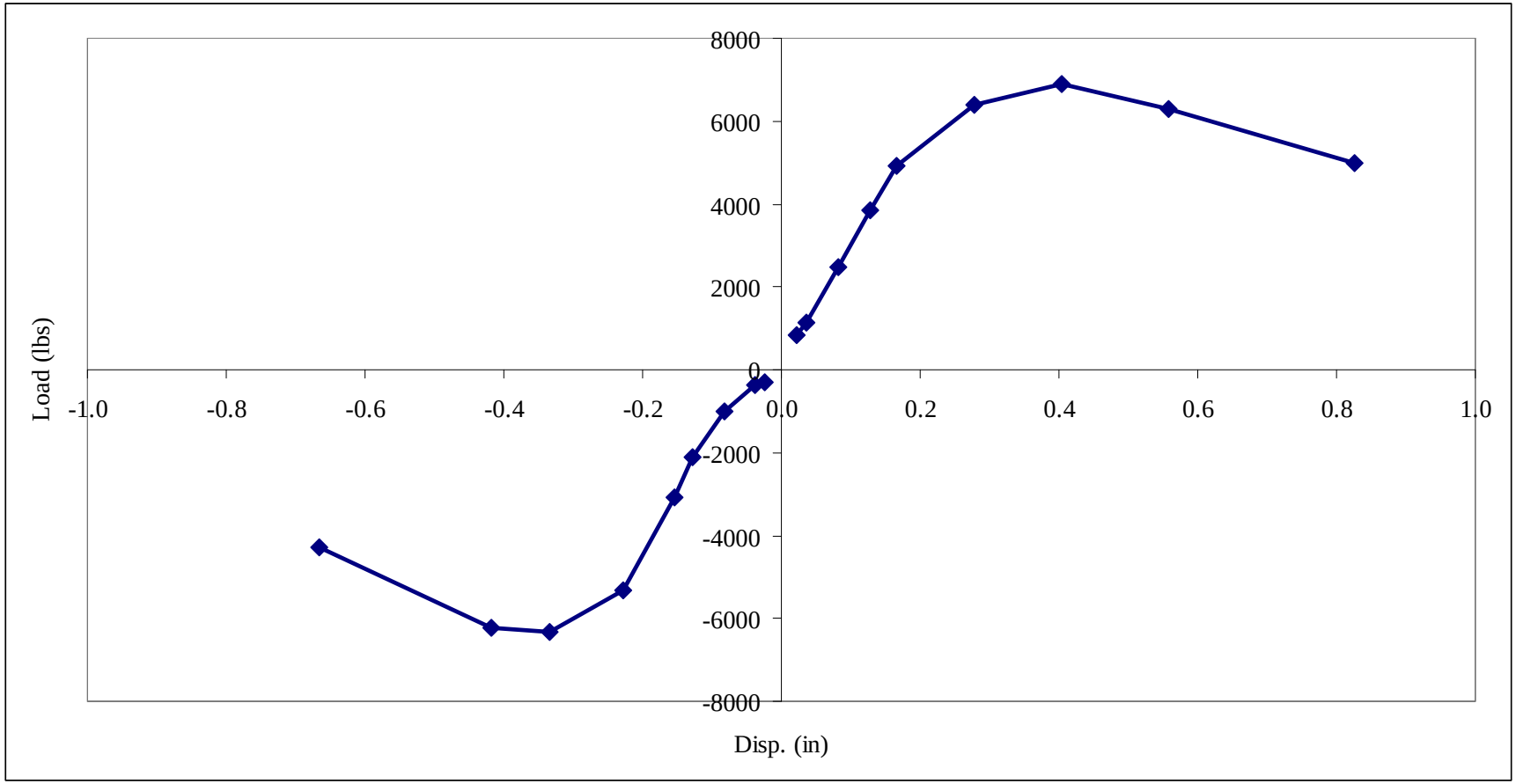

Figure A.45: Mean envelope curve: Configuration 8.

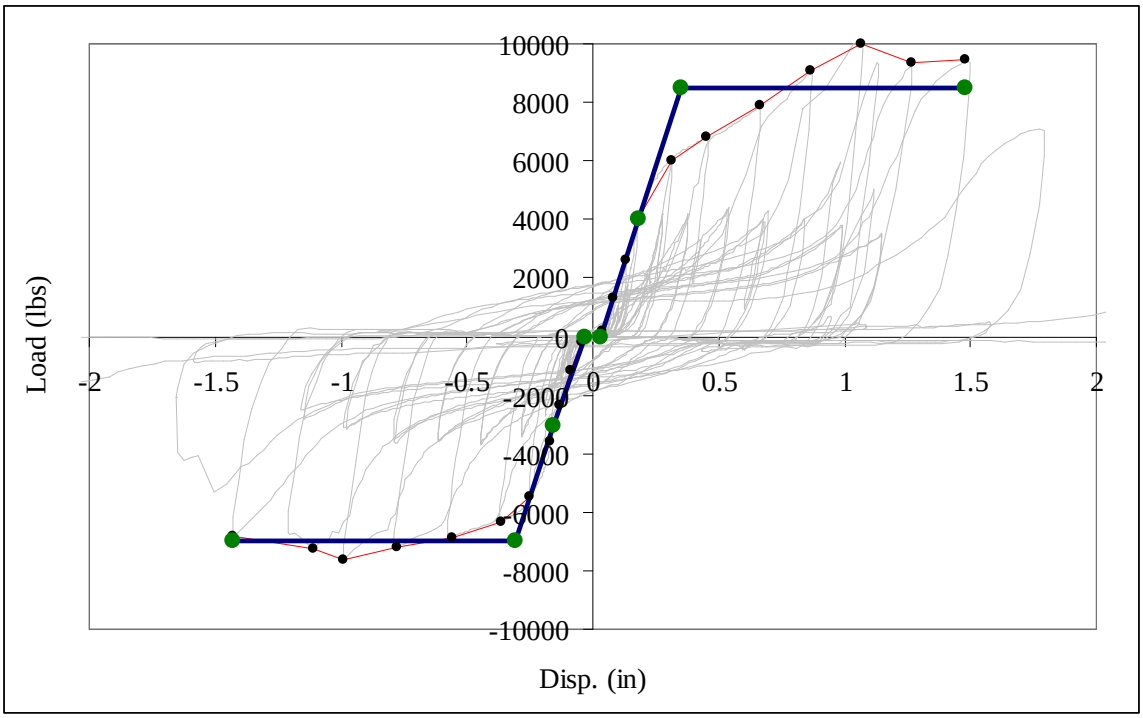

Figure A.46: Load-Deflection plot: C8-1.

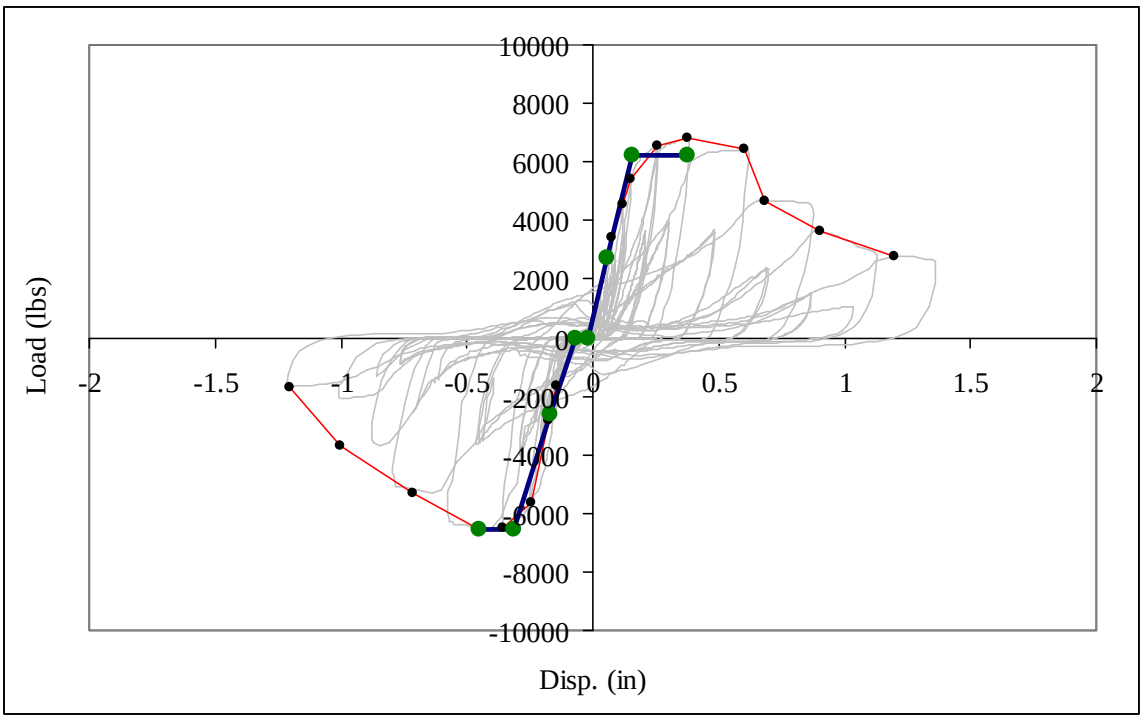

Figure A.47: Load-Deflection plot: C8-2.

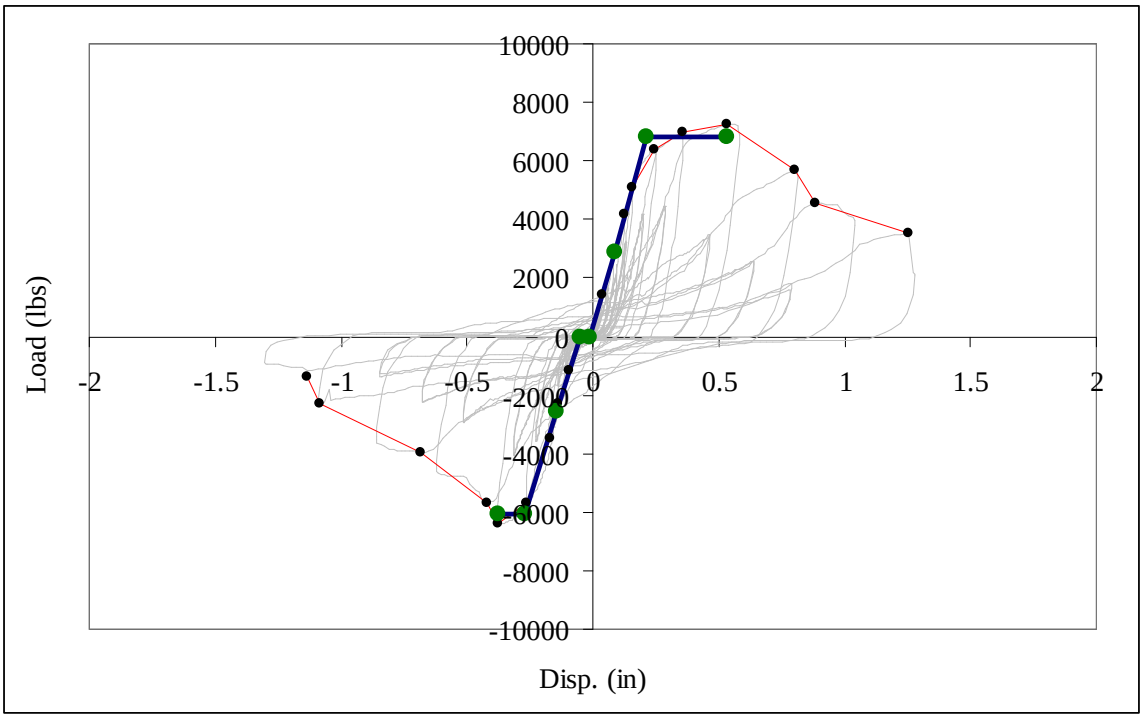

Figure A.48: Load-Deflection plot: C8-3.

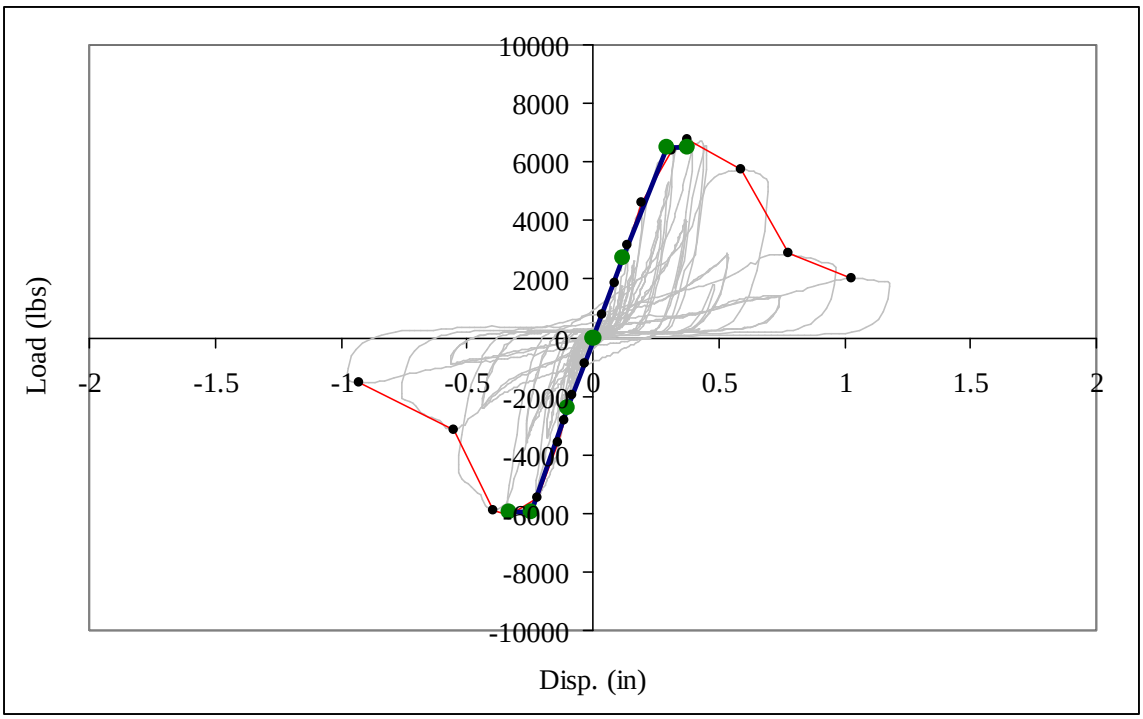

Figure A.49: Load-Deflection plot: C8-4.

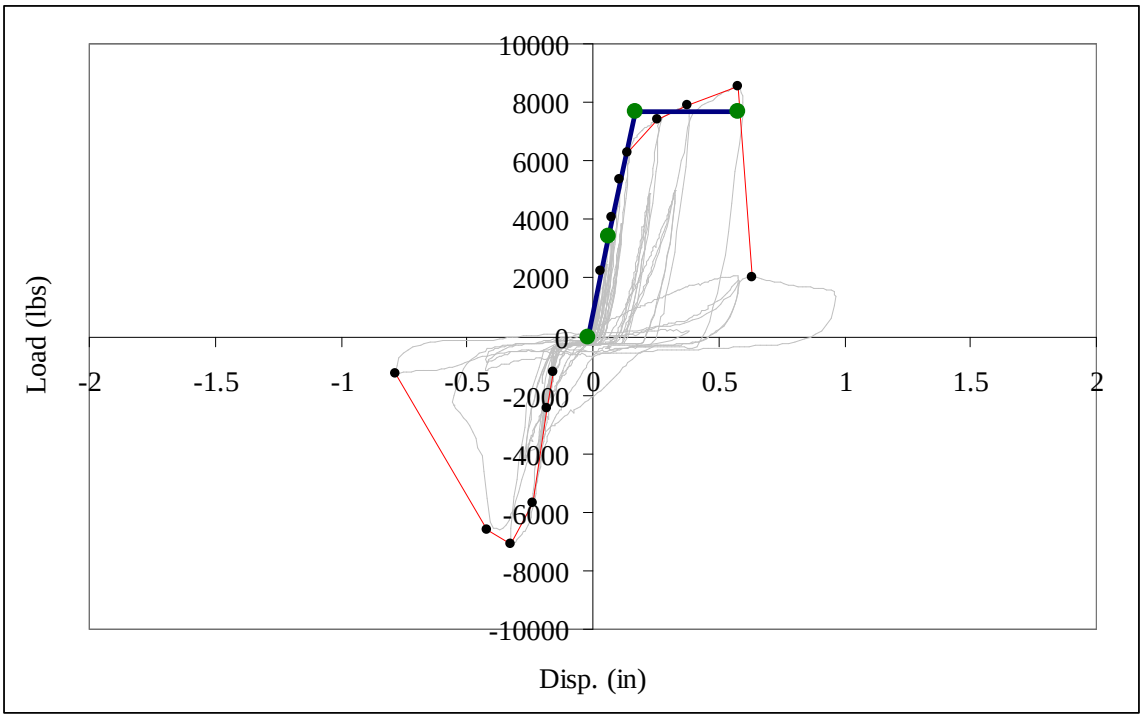

Figure A.50: Load-Deflection plot: C8-5.

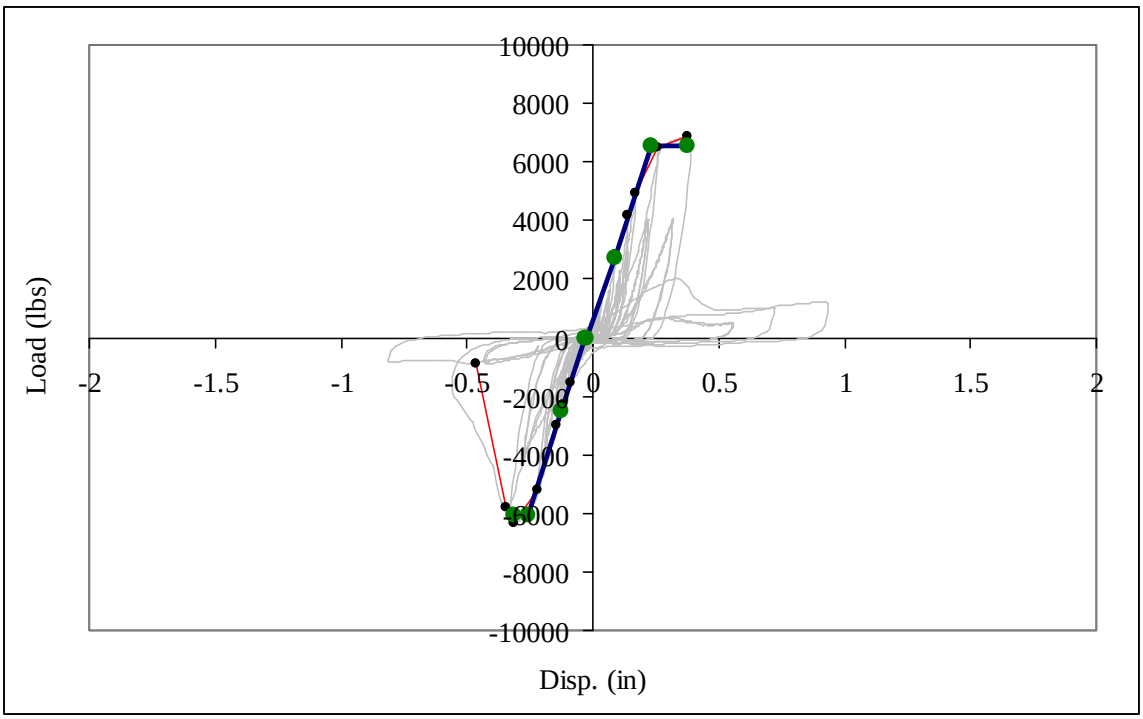

Figure A.51: Load-Deflection plot: C8-6.

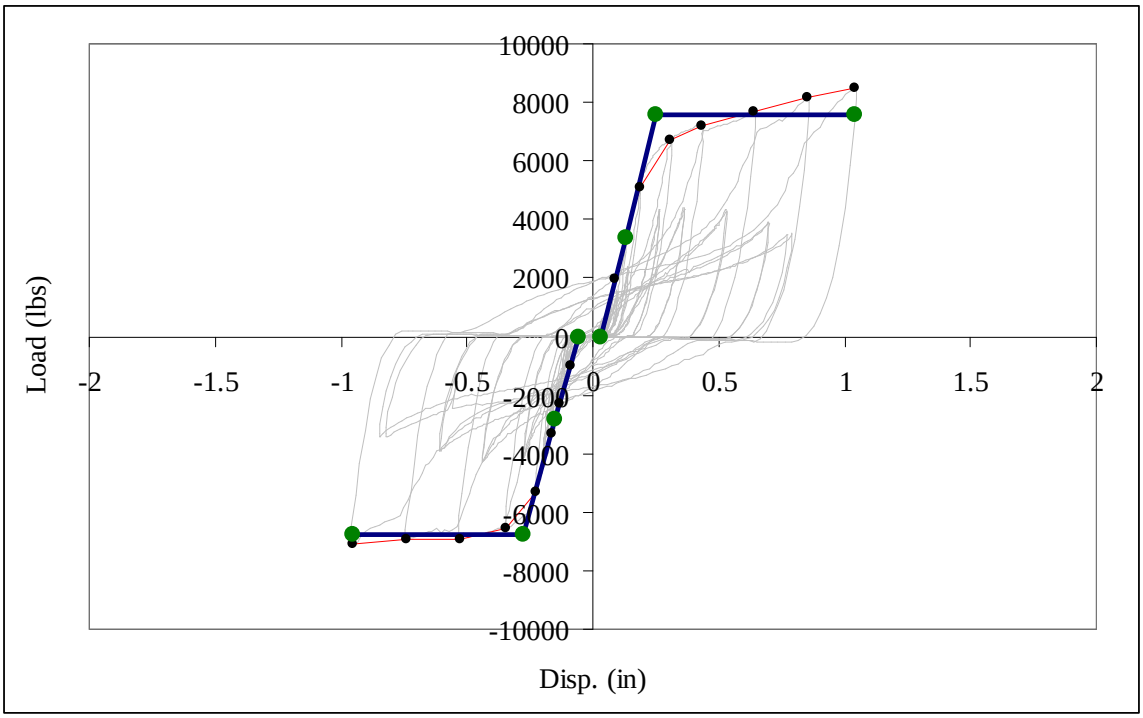

Figure A.52: Load-Deflection plot: C8-7.

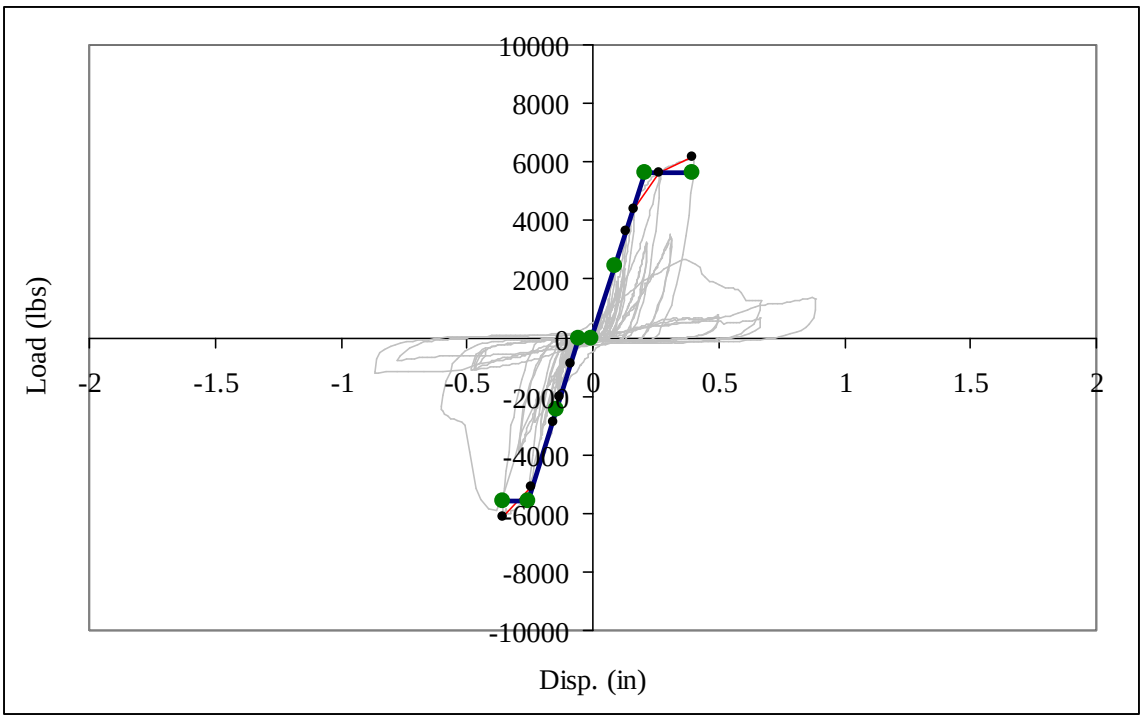

Figure A.53: Load-Deflection plot: C8-8.

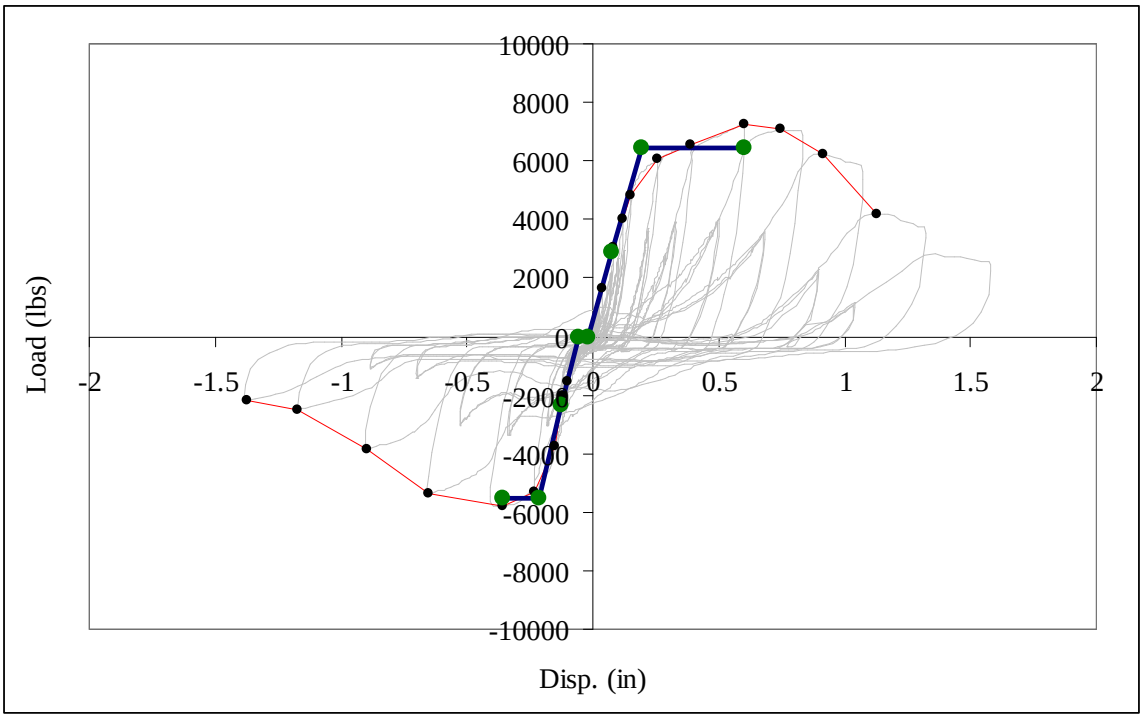

Figure A.54: Load-Deflection plot: C8-9.

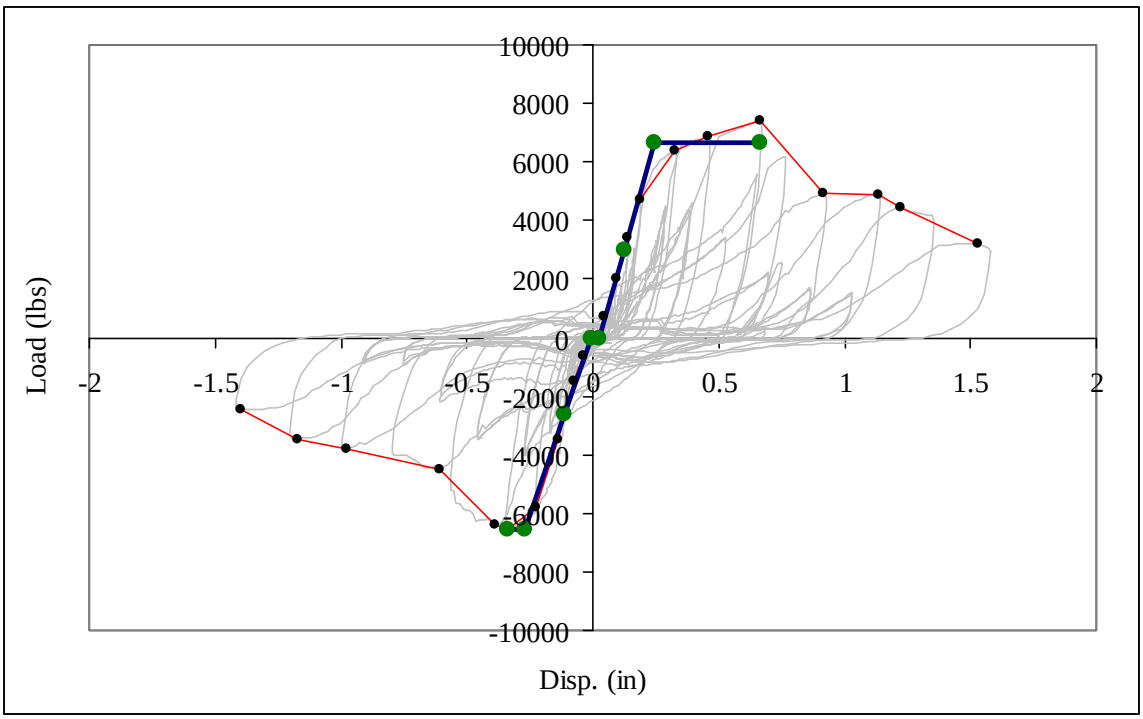

Figure A.55: Load-Deflection plot: C8-10.

Table A.16a: Connection performance properties (SI), Configuration 9.

Connection Performance Properties: Configuration 9

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	29.56	36.81	28.39	27.44	28.09	27.13	32.86	32.00	24.42	42.85	30.95	5.45	0.18
@Displacement (mm)	12.28	16.95	6.95	8.31	8.86	7.81	7.81	7.75	7.16	33.35	11.72	8.20	0.70
Failure Load (kN)	23.65	29.45	22.72	21.95	22.47	21.70	26.29	25.60	19.54	34.28	24.76	4.36	0.18
@Displacement (mm)	12.28	35.78	6.95	8.31	8.86	15.58	19.10	7.75	7.16	33.35	15.51	10.81	0.70
40% Max (kN)	11.82	14.72	11.36	10.98	11.23	10.85	13.15	12.80	9.77	17.14	12.38	2.18	0.18
@Displacement (mm)	3.41	3.50	2.79	2.58	2.98	2.66	2.64	3.04	2.83	3.62	3.00	0.38	0.13
Yield (kN)	27.78	34.70	26.92	25.21	25.78	25.99	30.58	29.06	23.06	37.36	28.64	4.45	0.16
@Displacement (mm)	6.79	6.88	3.58	5.00	5.57	6.10	5.44	5.18	5.64	6.99	5.72	1.04	0.18
5% Offset Yield (kN)	24.44	27.14	25.96	27.44	21.85	24.18	30.02	25.78	23.19	27.85	25.79	2.43	0.09
@Displacement (mm)	6.44	5.92	5.17	8.31	5.19	6.05	5.67	5.07	5.97	5.70	5.95	0.94	0.16
Elastic Stiff. (N/mm)	4881.84	5914.78	7153.91	5970.67	5603.76	4501.52	6239.72	7592.12	4764.08	6009.60	5863.20	995.83	0.17
E.E.P. Energy (N*m)	239.84	1108.25	143.64	140.76	144.25	322.14	493.55	135.70	93.20	1092.52	391.38	392.04	1.00
Ductility Ratio	1.77	5.22	1.99	1.63	1.61	2.60	3.52	1.54	1.25	4.78	2.59	1.43	0.55
Yield Mode	IIIs-IV	IV	IIIs-IV	IV	IV	IV	IV	IV	IIIs-IV	IIIs-IV			
Failure Mode	Splitting	Bolt Shr	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Bolt Shr.			
Governing Member	Both	N.A.	Both	Both	Both	Both	Both	Both	Both	N.A.			

Table A.16b: Connection performance properties (Std.), Configuration 9.

Connection Performance Properties: Configuration 9

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	6645.58	8275.04	6383.39	6168.70	6314.03	6098.14	7387.88	7192.80	5490.14	9632.23	6958.79	1224.08	0.18
@ Displacement (in)	0.48	0.67	0.27	0.33	0.35	0.31	0.31	0.31	0.28	1.31	0.46	0.32	0.70
Failure Load (lbs)	5316.46	6620.03	5106.71	4934.96	5051.23	4878.51	5910.30	5754.24	4392.11	7705.78	5567.03	979.27	0.18
@ Displacement (in)	0.48	1.41	0.27	0.33	0.35	0.61	0.75	0.31	0.28	1.31	0.61	0.43	0.70
40% Max (lbs)	2658.23	3310.02	2553.36	2467.48	2525.61	2439.25	2955.15	2877.12	2196.05	3852.89	2783.52	489.63	0.18
@ Displacement (in)	0.13	0.14	0.11	0.10	0.12	0.10	0.10	0.12	0.11	0.14	0.12	0.01	0.13
Yield (lbs)	6244.66	7853.14	6051.87	5667.58	5795.90	5843.81	6874.63	6532.34	5183.92	8398.89	6444.68	1009.12	0.16
@ Displacement (in)	0.27	0.29	0.14	0.20	0.22	0.24	0.21	0.20	0.22	0.28	0.23	0.04	0.19
5% Offset Yield (lbs)	5495.14	4486.00	5835.11	6168.70	4913.12	5436.82	6747.98	5796.65	5212.63	6261.46	5635.36	671.71	0.12
@ Displacement (in)	0.25	0.18	0.20	0.33	0.20	0.24	0.22	0.20	0.24	0.22	0.23	0.04	0.18
Elastic Stiff. (lb/in)	27876.03	29852.83	40849.85	34093.38	31998.31	25704.33	35629.70	43352.11	27203.60	34315.71	33087.59	5797.89	0.18
E.E.P. Energy (lb*in)	2122.73	9845.06	1271.36	1245.80	1276.76	2851.16	4368.30	1201.01	824.87	9669.63	3467.67	3477.20	1.00
Ductility Ratio	1.77	4.89	1.99	1.63	1.61	2.60	3.52	1.54	1.25	4.78	2.56	1.36	0.53
Yield Mode	IIIs-IV	IV	IIIs-IV	IV	IV	IV	IV	IV	IIIs-IV	IIIs-IV			
Failure Mode	Splitting	Bolt Shr	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Bolt Shr.			
Governing Member	Both	N.A.	Both	Both	Both	Both	Both	Both	Both	N.A.			

Table A.17a: Member properties (SI), Configuration 9.

Member Properties: Configuration 9

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	16.28	15.38	15.56	15.45	16.18	15.74	15.52	16.30	15.69	15.65	15.78	0.35	0.02
S.G.	0.45	0.51	0.51	0.48	0.48	0.45	0.56	0.46	0.45	0.50	0.49	0.04	0.07
D.E. 5% Offset Yield (kPa)	24865	34282	37554	42322	24117	28864	41219	32344	36264	39287	34112	6474.66	0.19
D.E. Capacity (kPa)	35765	45637	47849	45250	35076	37637	48434	42790	41865	48489	42879	5167.04	0.12
Side Member													
M.C. (%)	16.74	15.62	16.19	16.62	15.58	14.50	16.25	17.46	16.35	17.29	16.26	0.87	0.05
S.G.	0.44	0.51	0.55	0.53	0.43	0.41	0.59	0.49	0.35	0.48	0.48	0.07	0.15
D.E. 5% Offset Yield (kPa)	29653	30491	38143	37127	34146	33293	42523	32622	21964	34808	33477	5537.70	0.17
D.E. Capacity (kPa)	37984	43939	50534	50363	40591	37838	52047	44857	28174	40995	42732	7286.88	0.17

Table A.17b: Member properties (Std.), Configuration 9.

Member Properties: Configuration 9

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	16.28	15.38	15.56	15.45	16.18	15.74	15.52	16.30	15.69	15.65	15.78	0.35	0.02
S.G.	0.45	0.51	0.51	0.48	0.48	0.45	0.56	0.46	0.45	0.50	0.49	0.04	0.07
D.E. 5% Offset Yield (psi)	3606.31	4972.12	5446.72	6138.32	3497.84	4186.29	5978.20	4691.14	5259.68	5698.13	4947.47	939.06	0.19
D.E. Capacity (psi)	5187.25	6619.06	6939.87	6562.89	5087.27	5458.70	7024.78	6206.16	6071.91	7032.72	6219.06	749.41	0.12
Side Member													
M.C. (%)	16.74	15.62	16.19	16.62	15.58	14.50	16.25	17.46	16.35	17.29	16.26	0.87	0.05
S.G.	0.44	0.51	0.55	0.53	0.43	0.41	0.59	0.49	0.35	0.48	0.48	0.07	0.15
D.E. 5% Offset Yield (psi)	4300.82	4422.36	5532.08	5384.80	4952.49	4828.74	6167.37	4731.42	3185.54	5048.46	4855.41	803.17	0.17
D.E. Capacity (psi)	5509.01	6372.71	7329.32	7304.50	5887.18	5487.96	7548.68	6505.95	4086.20	5945.83	6197.73	1056.87	0.17

Table A.18a: Hysteretic connection properties (SI), Configuration 9.

Hysteretic Connection Properties: Configuration 9

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	1.90	1.80	0.95	0.41	0.13	0.32	-1.73	1.10	0.63	-0.48	0.08	0.16
Primary2	2.80	2.54	0.91	0.68	0.16	0.24	-2.40	1.49	0.62	-0.76	0.11	0.15
Primary3	8.11	5.84	0.72	1.90	0.16	0.08	-6.46	3.42	0.53	-1.99	0.23	0.12
Primary4	14.00	6.91	0.49	3.10	0.26	0.08	-11.71	3.97	0.34	-3.11	0.39	0.13
Primary5	20.67	7.72	0.37	4.25	0.72	0.17	-17.30	2.37	0.14	-3.96	0.66	0.17
Primary6	28.54	9.53	0.33	6.81	1.00	0.15	-26.70	2.24	0.08	-5.90	0.75	0.13
Primary7	29.44	10.53	0.36	9.69	1.28	0.13	-27.95	2.82	0.10	-7.88	0.50	0.06
Primary8	27.40	12.68	0.46	14.66	2.41	0.16	-24.18	8.54	0.35	-12.21	2.25	0.18
Primary9	25.19	14.65	0.58	20.91	1.74	0.08	-21.92	9.70	0.44	-18.64	2.15	0.12
Primary10	24.59	15.63	0.64	26.64	1.80	0.07	-18.59	9.94	0.53	-23.81	2.65	0.11
Primary11	24.87	16.78	0.67	32.04	1.97	0.06	-18.58	9.36	0.50	-29.11	0.98	0.03

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	0.77	0.33	0.43	0.85	0.44	0.52	0.16	0.06	0.34	4177.81	2169.26	0.52
Primary2	1.41	0.55	0.39	1.93	0.90	0.47	0.12	0.02	0.20	3638.46	1558.56	0.43
Primary3	7.59	2.75	0.36	14.22	3.58	0.25	0.08	0.01	0.18	3735.34	742.18	0.20
Primary4	16.37	4.28	0.26	39.22	7.45	0.19	0.07	0.01	0.12	4135.16	565.27	0.14
Primary5	25.58	5.27	0.21	77.52	8.29	0.11	0.05	0.01	0.18	4634.09	518.04	0.11
Primary6	104.71	25.67	0.25	176.07	21.75	0.12	0.09	0.02	0.20	4374.57	563.44	0.13
Primary7	226.36	23.55	0.10	252.95	37.21	0.15	0.15	0.03	0.18	3282.57	479.16	0.15
Primary8	425.08	112.44	0.26	357.85	140.58	0.39	0.21	0.06	0.27	1892.97	538.33	0.28
Primary9	515.02	200.43	0.39	462.67	207.16	0.45	0.19	0.03	0.18	1201.10	563.16	0.47
Primary10	571.96	267.33	0.47	543.34	282.34	0.52	0.18	0.04	0.24	862.28	473.89	0.55
Primary11	607.10	302.83	0.50	664.12	346.46	0.52	0.15	0.03	0.19	715.59	399.15	0.56

Table A.18b: Hysteretic connection properties (Std.), Configuration 9.

Hysteretic Connection Properties: Configuration 9

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	426.64	404.90	0.95	0.02	0.01	0.32	-388.28	246.36	0.63	-0.02	0.00	0.16
Primary2	629.64	571.22	0.91	0.03	0.01	0.24	-539.27	334.80	0.62	-0.03	0.00	0.15
Primary3	1823.18	1313.68	0.72	0.07	0.01	0.08	-1453.12	768.62	0.53	-0.08	0.01	0.12
Primary4	3146.98	1553.32	0.49	0.12	0.01	0.08	-2633.63	891.83	0.34	-0.12	0.02	0.13
Primary5	4647.73	1734.49	0.37	0.17	0.03	0.17	-3890.28	531.68	0.14	-0.16	0.03	0.17
Primary6	6417.05	2141.54	0.33	0.27	0.04	0.15	-6002.13	503.31	0.08	-0.23	0.03	0.13
Primary7	6618.11	2366.33	0.36	0.38	0.05	0.13	-6283.47	633.48	0.10	-0.31	0.02	0.06
Primary8	6159.93	2849.67	0.46	0.58	0.09	0.16	-5436.85	1919.94	0.35	-0.48	0.09	0.18
Primary9	5663.74	3293.32	0.58	0.82	0.07	0.08	-4927.96	2181.31	0.44	-0.73	0.08	0.12
Primary10	5527.57	3513.00	0.64	1.05	0.07	0.07	-4178.85	2235.05	0.53	-0.94	0.10	0.11
Primary11	5590.12	3771.89	0.67	1.26	0.08	0.06	-4177.87	2103.24	0.50	-1.15	0.04	0.03

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	6.83	2.92	0.43	7.54	3.93	0.52	0.16	0.06	0.34	23855.89	12386.81	0.52
Primary2	12.49	4.86	0.39	17.05	7.96	0.47	0.12	0.02	0.20	20776.13	8899.60	0.43
Primary3	67.22	24.35	0.36	125.89	31.66	0.25	0.08	0.01	0.18	21329.33	4237.98	0.20
Primary4	144.93	37.90	0.26	347.12	65.93	0.19	0.07	0.01	0.12	23612.40	3227.79	0.14
Primary5	226.43	46.62	0.21	686.12	73.34	0.11	0.05	0.01	0.18	26461.36	2958.10	0.11
Primary6	926.73	227.18	0.25	1558.37	192.52	0.12	0.09	0.02	0.20	24979.44	3217.34	0.13
Primary7	2003.46	208.46	0.10	2238.83	329.33	0.15	0.15	0.03	0.18	18743.94	2736.05	0.15
Primary8	3762.25	995.17	0.26	3167.20	1244.25	0.39	0.21	0.06	0.27	10809.12	3073.95	0.28
Primary9	4558.32	1774.00	0.39	4094.99	1833.56	0.45	0.19	0.03	0.18	6858.45	3215.70	0.47
Primary10	5062.26	2366.09	0.47	4808.93	2498.93	0.52	0.18	0.04	0.24	4923.77	2706.00	0.55
Primary11	5373.26	2680.26	0.50	5878.00	3066.44	0.52	0.15	0.03	0.19	4086.13	2279.18	0.56

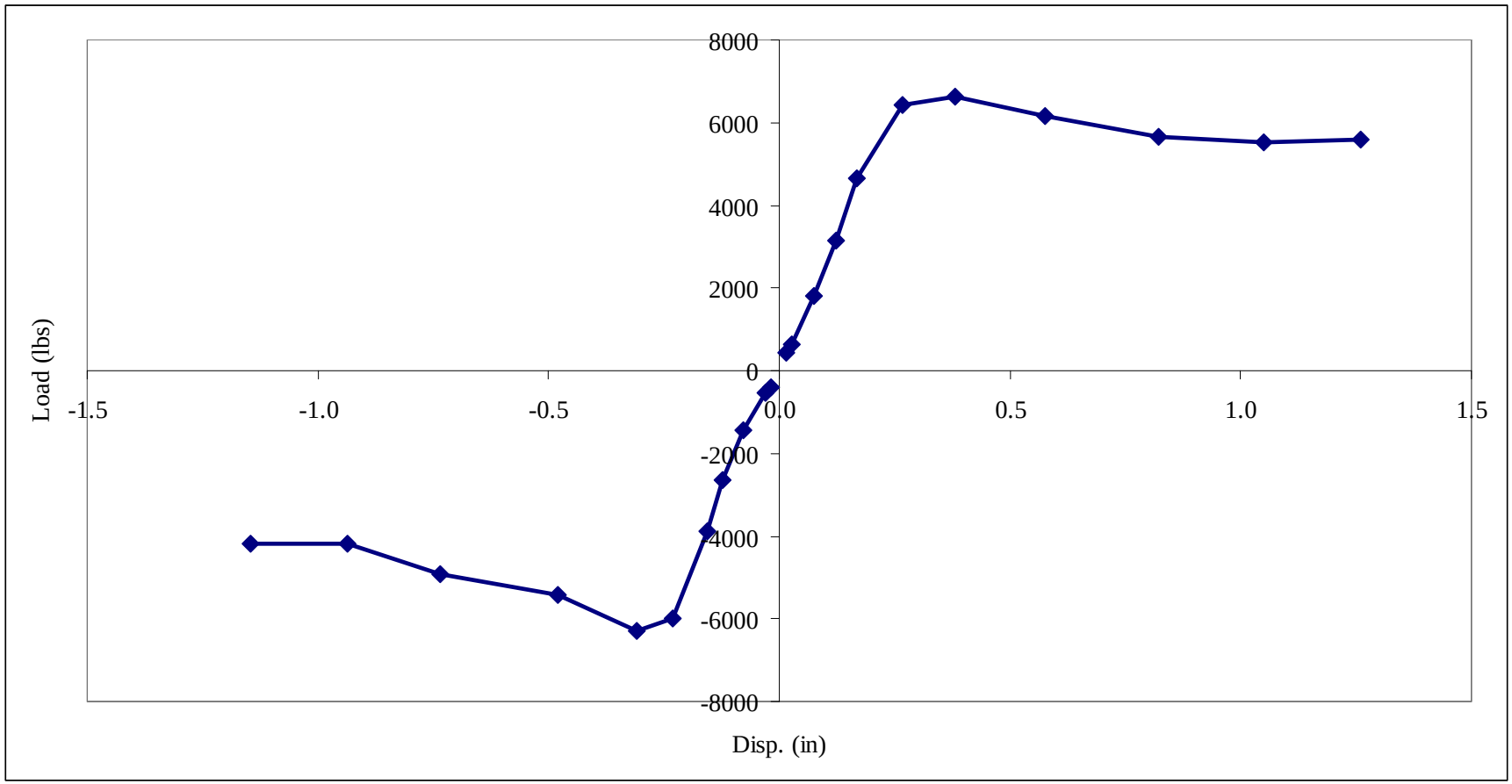

Figure A.56: Mean envelope curve: Configuration 9.

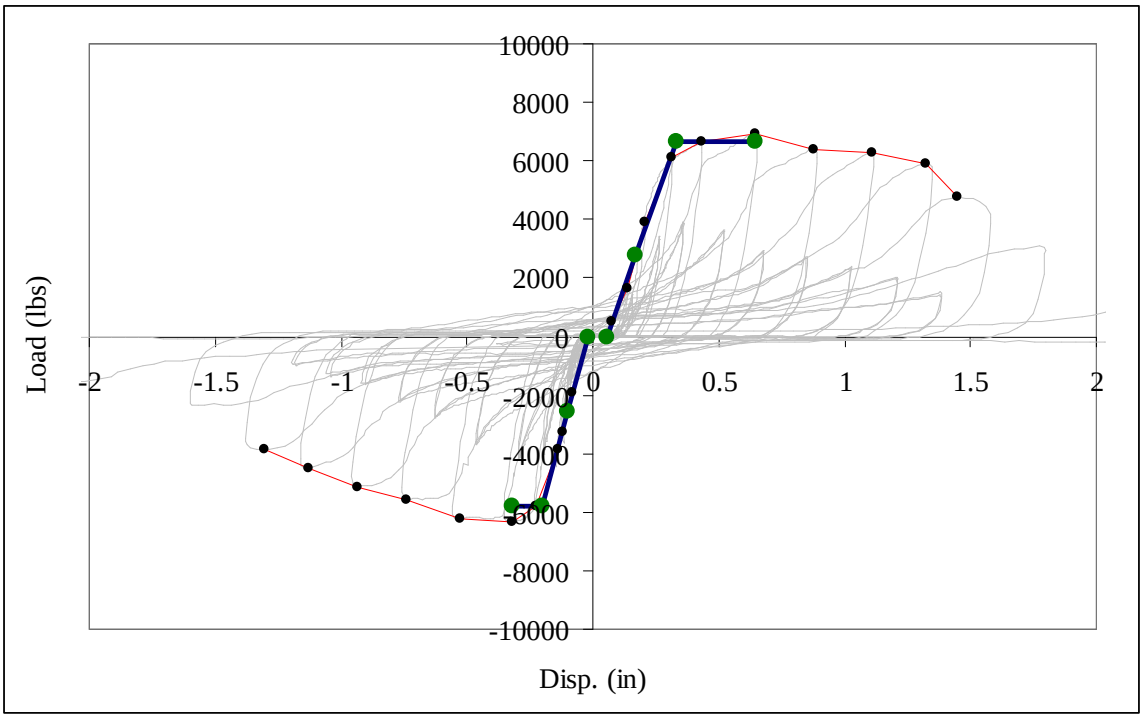

Figure A.57: Load-Deflection plot: C9-1.

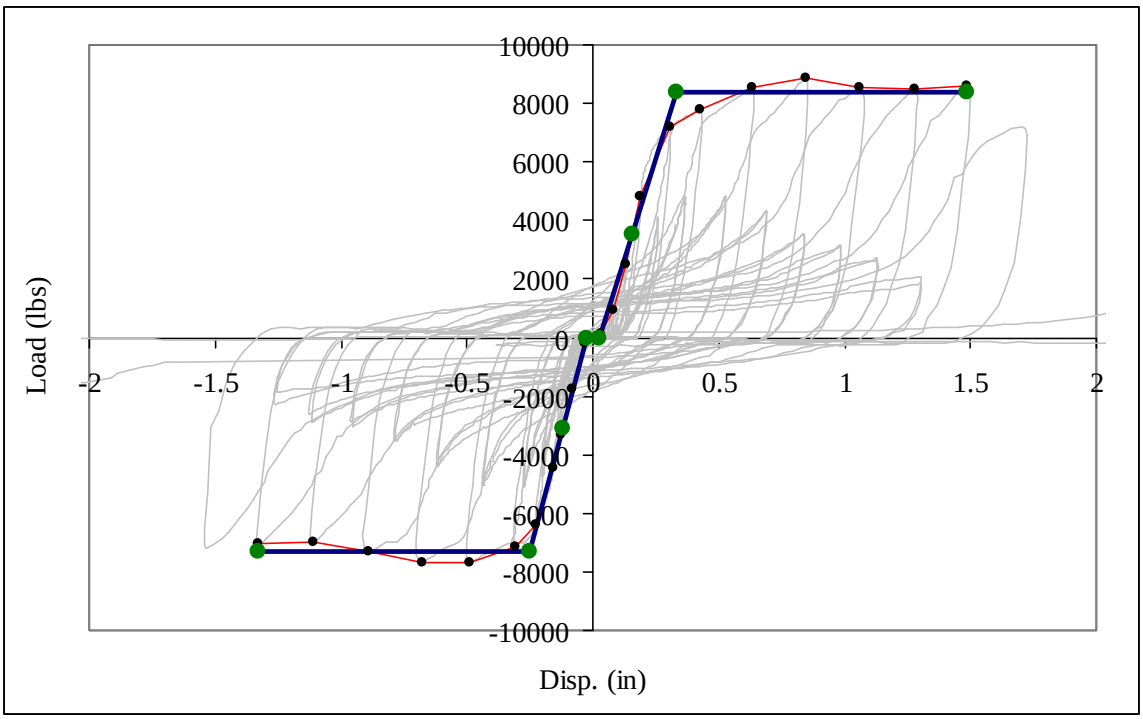

Figure A.58: Load-Deflection plot: C9-2.

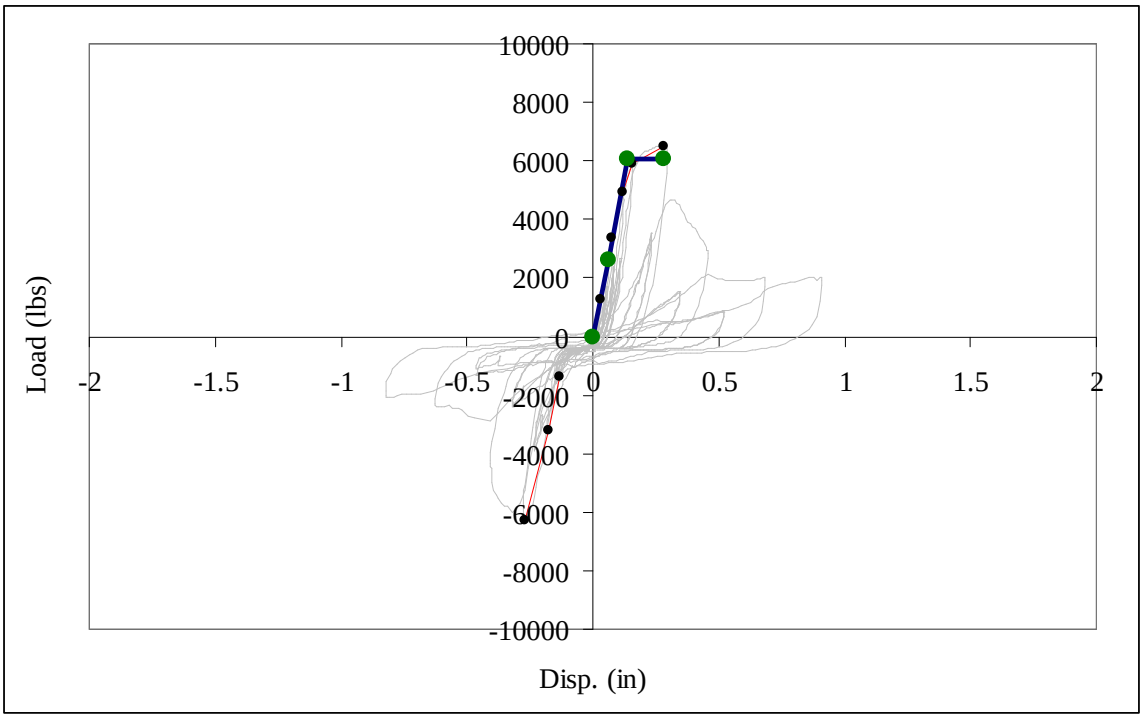

Figure A.59: Load-Deflection plot: C9-3.

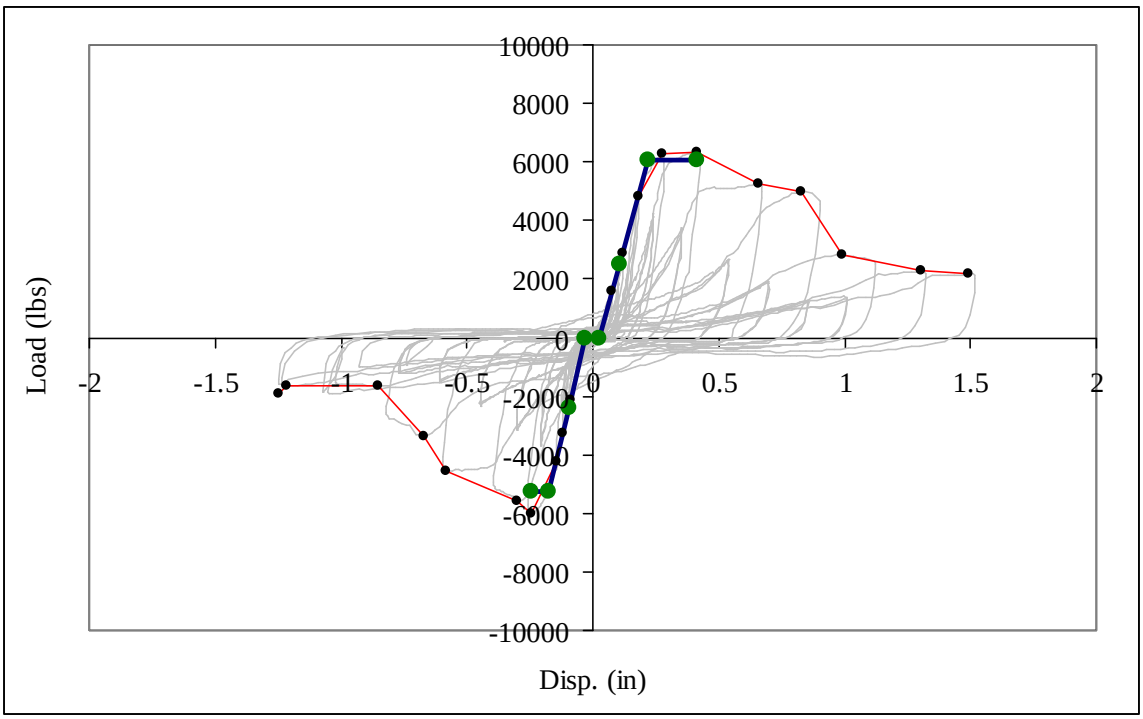

Figure A.60: Load-Deflection plot: C9-4.

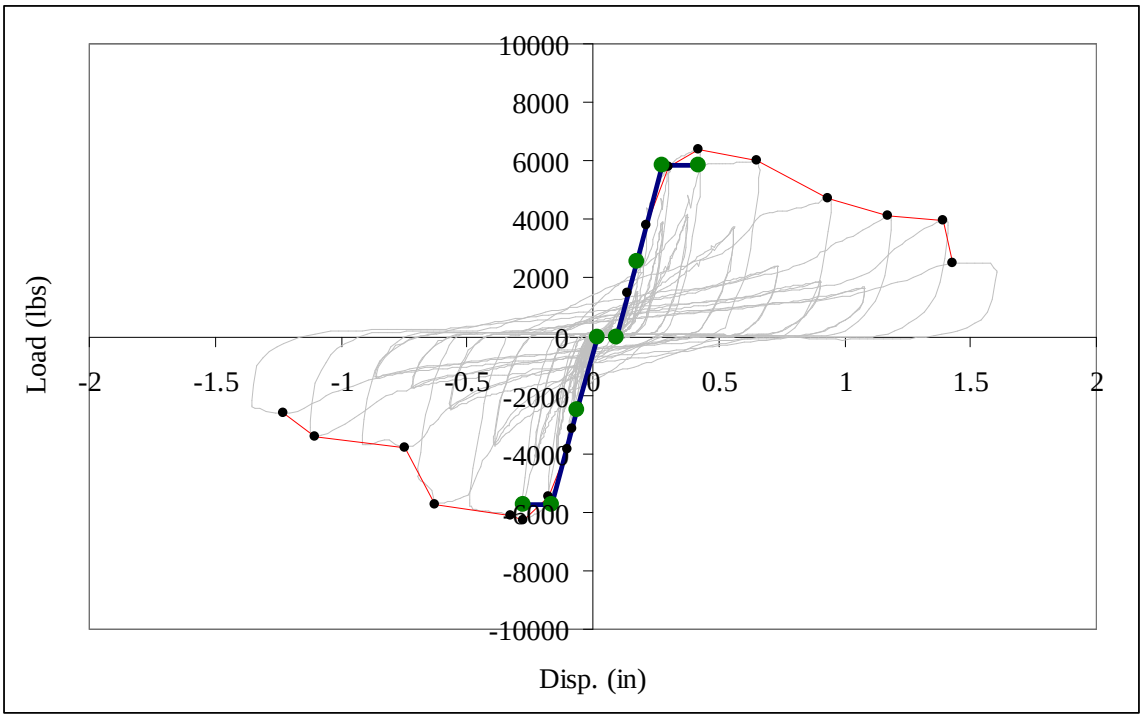

Figure A.61: Load-Deflection plot: C9-5.

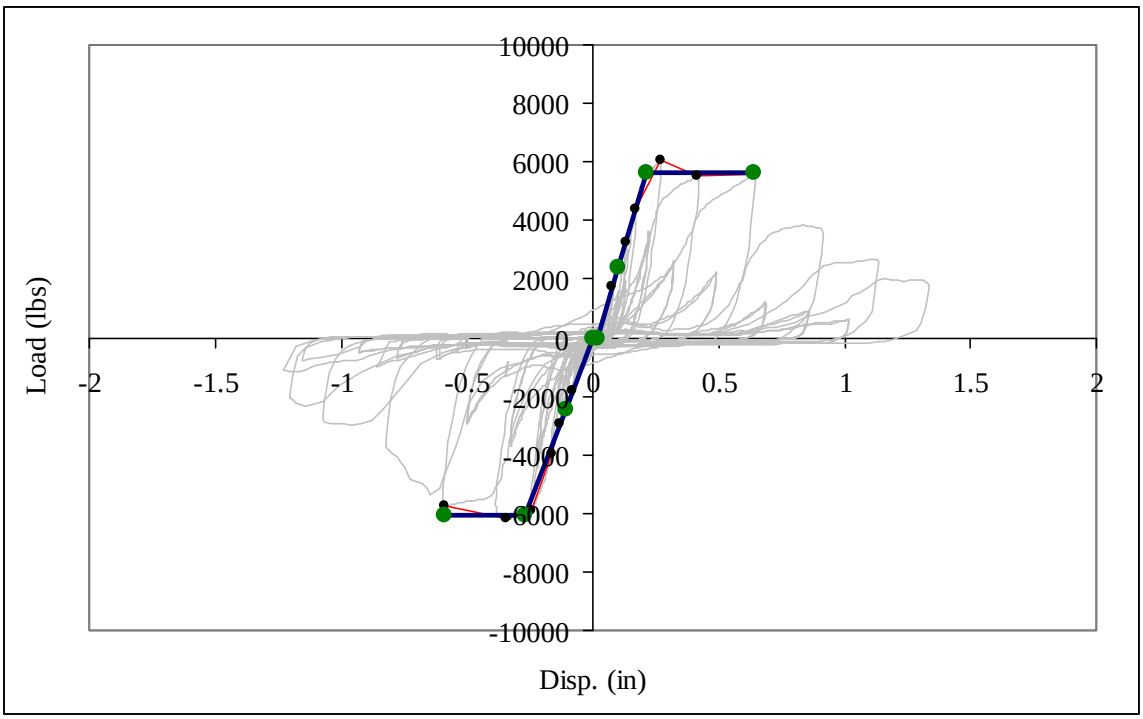

Figure A.62: Load-Deflection plot: C9-6.

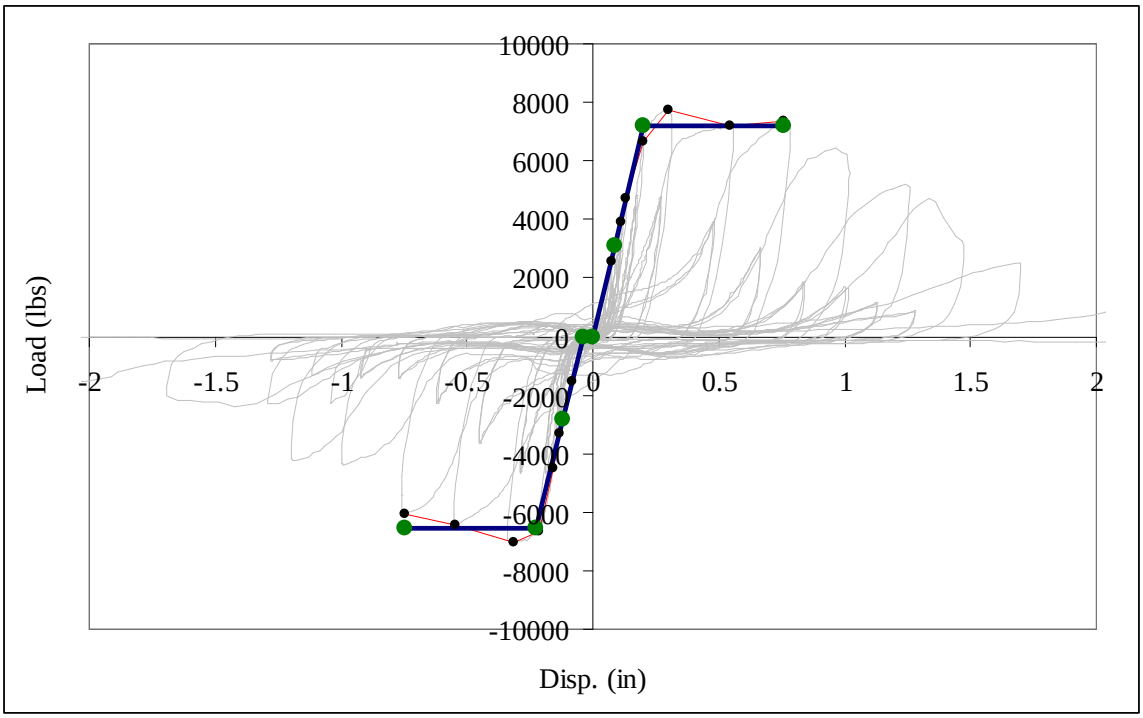

Figure A.63: Load-Deflection plot: C9-7.

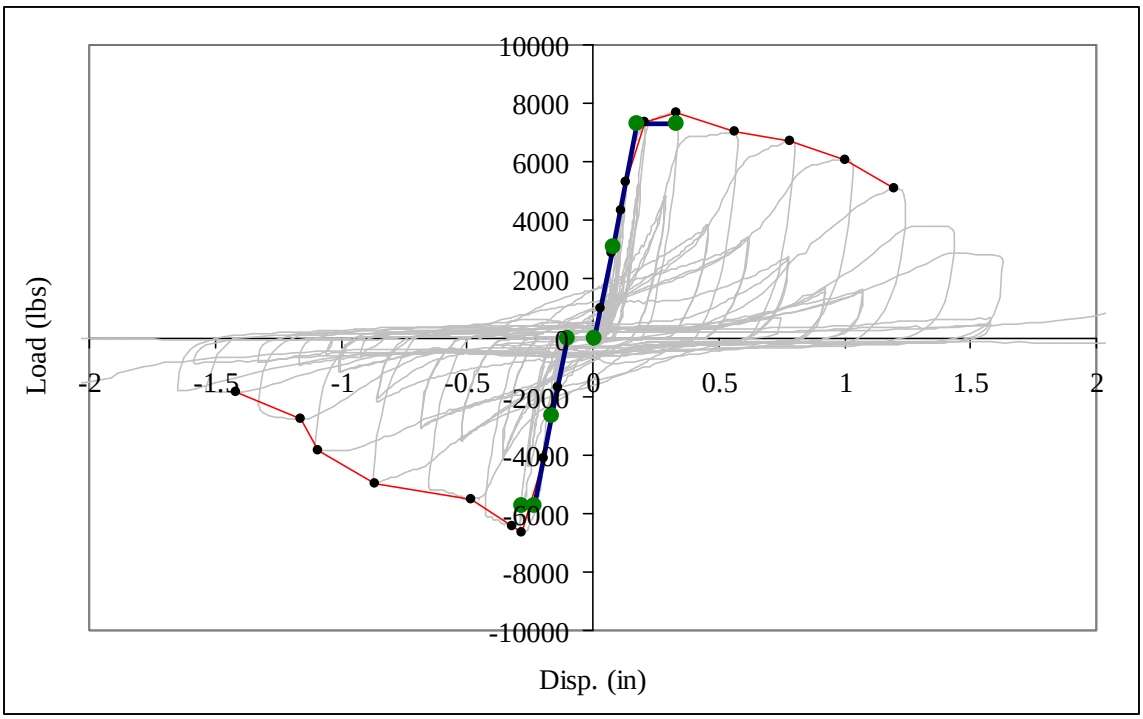

Figure A.64: Load-Deflection plot: C9-8.

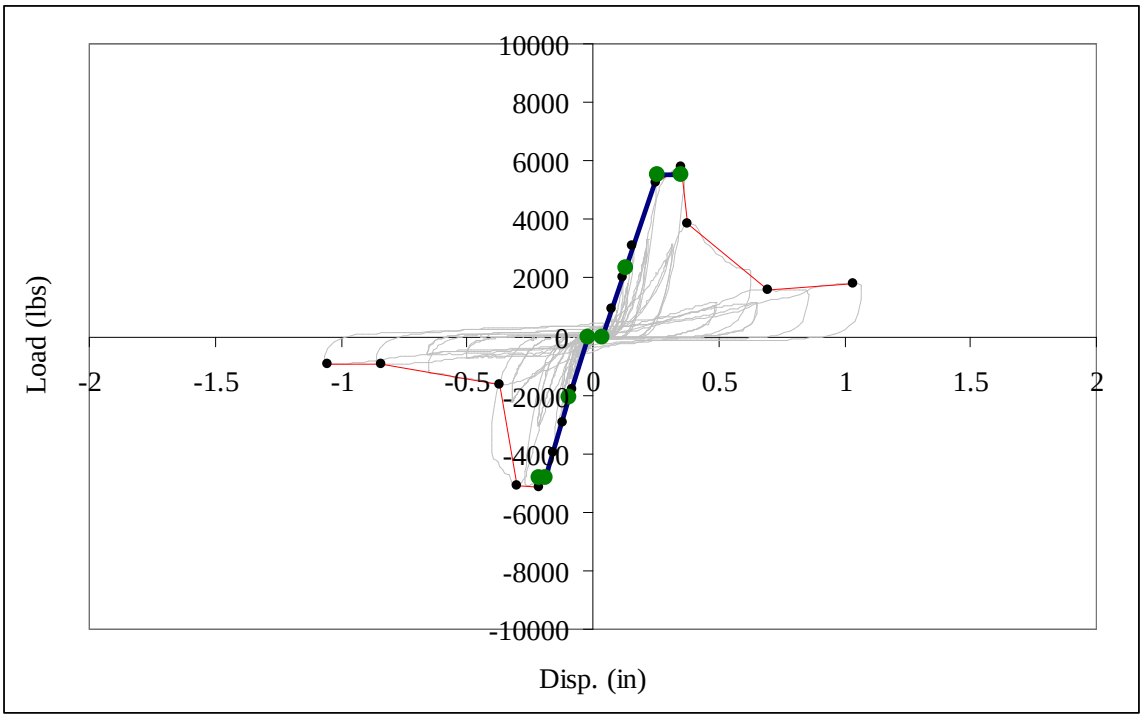

Figure A.65: Load-Deflection plot: C9-9.

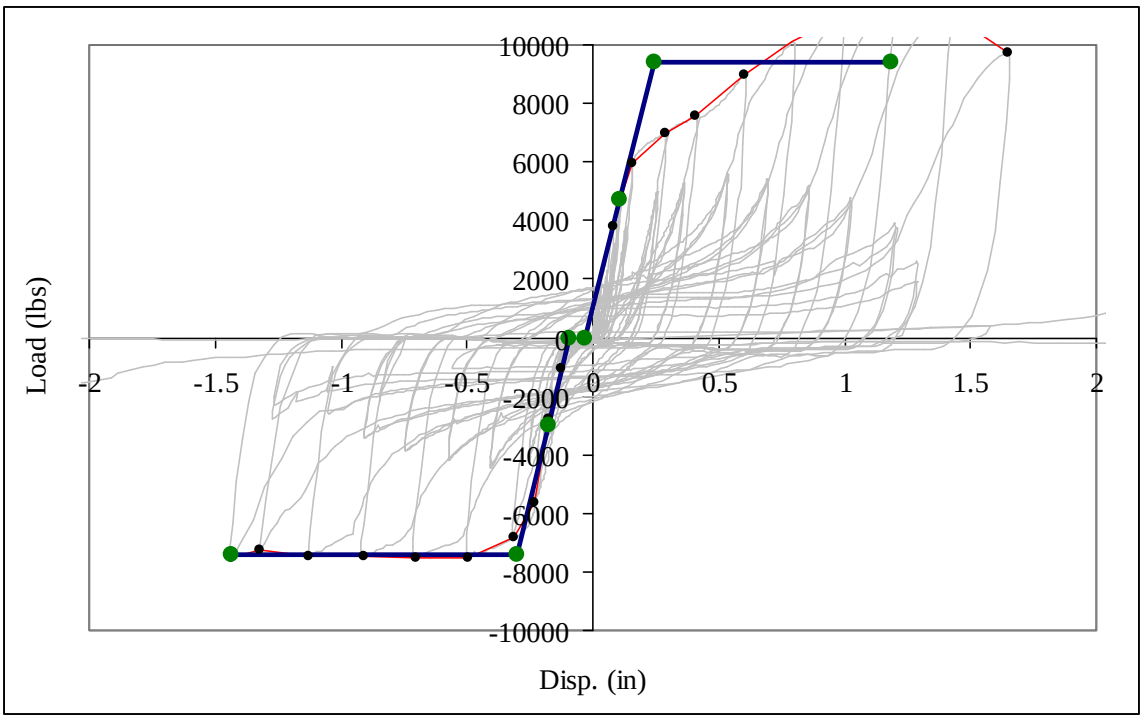

Figure A.66: Load-Deflection plot: C9-10.

A1.2 - Predicted Yield Mode III_s Configurations

Table A.19a: Connection performance properties (SI), Configuration 11.

Connection Performance Properties: Configuration 11

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	11.42	11.79	11.00	11.34	10.66	9.49	13.32	11.81	10.43	12.90	11.42	1.13	0.10
@Displacement (mm)	12.32	16.59	18.14	15.14	16.32	10.39	16.34	13.98	10.06	19.72	14.90	3.20	0.21
Failure Load (kN)	9.14	9.43	8.80	9.07	8.53	7.59	10.66	9.44	8.34	10.32	9.13	0.91	0.10
@Displacement (mm)	12.32	16.59	18.31	15.14	16.70	10.39	16.34	13.98	10.06	19.72	14.96	3.24	0.22
40% Max (kN)	4.57	4.72	4.40	4.53	4.27	3.80	5.33	4.72	4.17	5.16	4.57	0.45	0.10
@Displacement (mm)	4.63	4.66	5.01	5.22	4.44	4.43	4.50	4.68	3.78	5.42	4.68	0.46	0.10
Yield (kN)	10.14	10.08	9.39	9.61	8.83	7.92	11.43	10.63	8.93	11.19	9.81	1.10	0.11
@Displacement (mm)	7.71	7.90	8.49	8.60	7.40	7.21	8.35	7.74	5.97	9.53	7.89	0.95	0.12
5% Offset Yield (kN)	8.97	7.45	6.76	8.50	6.57	9.49	8.58	10.07	7.49	8.39	8.23	1.15	0.14
@Displacement (mm)	7.79	6.90	7.28	8.63	6.55	10.39	7.31	10.08	5.94	8.26	7.91	1.45	0.18
Elastic Stiff. (N/mm)	1828.16	1687.53	1455.21	1490.55	1553.22	1535.21	1778.58	1951.85	2183.66	1467.77	1693.17	241.77	0.14
E.E.P. Energy (N*m)	76.33	121.02	125.58	96.40	108.16	46.28	137.80	95.91	55.06	157.36	101.99	35.49	0.35
Ductility Ratio	1.63	2.09	2.15	1.77	2.25	1.48	1.94	1.91	1.82	2.10	1.91	0.24	0.13
Yield Mode	III_s	III_s	III_s	III_s	III_s	III_s	III_s	III_s	III_s	III_s			
Failure Mode	Splitting	Splitting	Plug Shr	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Plug Shr			
Governing Member	Main	Side	Side	Side	Side	Main	Side	Side	Side	Side			

Table A.19b: Connection performance properties (Std.), Configuration 11.

Connection Performance Properties: Configuration 11

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	2567.13	2651.28	2472.70	2548.77	2397.24	2133.72	2995.52	2653.92	2344.07	2900.31	2566.47	254.92	0.10
@ Displacement (in)	0.49	0.65	0.71	0.60	0.64	0.41	0.64	0.55	0.40	0.78	0.59	0.13	0.21
Failure Load (lbs)	2053.71	2121.03	1978.16	2039.01	1917.79	1706.98	2396.42	2123.13	1875.26	2320.25	2053.17	203.94	0.10
@ Displacement (in)	0.49	0.65	0.72	0.60	0.66	0.41	0.64	0.55	0.40	0.78	0.59	0.13	0.22
40% Max (lbs)	1026.85	1060.51	989.08	1019.51	958.90	853.49	1198.21	1061.57	937.63	1160.13	1026.59	101.97	0.10
@ Displacement (in)	0.18	0.18	0.20	0.21	0.17	0.17	0.18	0.18	0.15	0.21	0.18	0.02	0.10
Yield (lbs)	2279.27	2265.40	2112.05	2160.49	1985.96	1781.46	2569.28	2388.99	2006.67	2514.64	2206.42	246.96	0.11
@ Displacement (in)	0.30	0.31	0.33	0.34	0.29	0.28	0.33	0.30	0.24	0.38	0.31	0.04	0.12
5% Offset Yield (lbs)	2016.36	1674.35	1519.00	1911.58	1477.10	2133.72	1929.46	2264.36	1683.59	1885.58	1849.51	257.86	0.14
@ Displacement (in)	0.31	0.27	0.29	0.34	0.26	0.41	0.29	0.40	0.23	0.33	0.31	0.06	0.18
Elastic Stiff. (lb/in)	10439.07	9636.05	8309.47	8511.25	8869.12	8766.27	10155.93	11145.35	12469.01	8381.18	9668.27	1380.53	0.14
E.E.P. Energy (lb*in)	675.59	1071.13	1111.51	853.22	957.29	409.59	1219.62	848.85	487.36	1392.75	902.69	314.14	0.35
Ductility Ratio	1.63	2.09	2.15	1.77	2.25	1.48	1.94	1.91	1.82	2.10	1.91	0.24	0.13
Yield Mode	III_s	III_s	III_s	III_s	III_s	III_s	III_s	III_s	III_s	III_s			
Failure Mode	Splitting	Splitting	Plug Shr	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Plug Shr			
Governing Member	Main	Side	Side	Side	Side	Main	Side	Side	Side	Side			

Table A.20a: Member properties (SI), Configuration 11.

Member Properties: Configuration 11

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	17.14	15.03	16.76	16.20	16.87	15.31	16.91	15.91	16.36	16.39	16.29	0.70	0.04
S.G.	0.45	0.42	0.41	0.44	0.44	0.57	0.55	0.48	0.49	0.50	0.48	0.05	0.11
D.E. 5% Offset Yield (kPa)	24503	20843	24176	23084	18378	34293	31142	25464	28379	27465	25773	4732.43	0.18
D.E. Capacity (kPa)	24503	22197	25258	24165	19577	34293	32480	29948	29549	27630	26960	4645.88	0.17
Side Member													
M.C. (%)	13.98	14.14	14.31	14.57	14.19	14.97	14.78	14.76	14.41	15.55	14.57	0.47	0.03
S.G.	0.51	0.50	0.57	0.44	0.42	0.43	0.45	0.50	0.50	0.51	0.48	0.05	0.10
D.E. 5% Offset Yield (kPa)	33942	32154	30158	31404	25352	25787	30008	30185	31935	29987	30091	2692.06	0.09
D.E. Capacity (kPa)	33942	32740	30428	31404	25352	25931	31335	30314	31935	29987	30337	2745.77	0.09

Table A.20b: Member properties (Std.), Configuration 11.

Member Properties: Configuration 11

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	17.14	15.03	16.76	16.20	16.87	15.31	16.91	15.91	16.36	16.39	16.29	0.70	0.04
S.G.	0.45	0.42	0.41	0.44	0.44	0.57	0.55	0.48	0.49	0.50	0.48	0.05	0.11
D.E. 5% Offset Yield (psi)	3553.90	3022.93	3506.43	3348.03	2665.49	4973.78	4516.76	3693.22	4116.05	3983.51	3738.01	686.38	0.18
D.E. Capacity (psi)	3553.90	3219.37	3663.36	3504.80	2839.44	4973.78	4710.79	4343.55	4285.64	4007.41	3910.20	673.82	0.17
Side Member													
M.C. (%)	13.98	14.14	14.31	14.57	14.19	14.97	14.78	14.76	14.41	15.55	14.57	0.47	0.03
S.G.	0.51	0.50	0.57	0.44	0.42	0.43	0.45	0.50	0.50	0.51	0.48	0.05	0.10
D.E. 5% Offset Yield (psi)	4922.85	4663.46	4374.08	4554.70	3676.99	3740.02	4352.25	4377.99	4631.78	4349.26	4364.34	390.45	0.09
D.E. Capacity (psi)	4922.85	4748.55	4413.22	4554.70	3676.99	3760.94	4544.67	4396.64	4631.78	4349.26	4399.96	398.24	0.09

Table A.21a: Hysteretic connection properties (SI), Configuration 11.

Hysteretic Connection Properties: Configuration 11

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.21	0.21	0.99	0.52	0.31	0.60	-0.19	0.27	1.43	-0.30	0.52	1.75
Primary2	0.30	0.40	1.32	0.85	0.50	0.58	-0.39	0.66	1.70	-0.84	0.42	0.50
Primary3	1.08	0.97	0.90	2.21	0.96	0.44	-1.67	1.89	1.13	-2.23	1.04	0.47
Primary4	3.51	2.09	0.59	4.05	0.16	0.04	-3.73	2.34	0.63	-4.07	0.13	0.03
Primary5	5.05	2.33	0.46	5.21	0.84	0.16	-5.42	2.55	0.47	-5.15	0.76	0.15
Primary6	9.59	3.15	0.33	9.06	1.35	0.15	-8.86	2.29	0.26	-8.87	1.19	0.13
Primary7	10.34	4.37	0.42	12.20	2.39	0.20	-9.58	2.73	0.28	-11.63	2.02	0.17
Primary8	9.75	5.50	0.56	16.48	4.17	0.25	-6.21	5.40	0.87	-12.73	4.86	0.38
Primary9	3.29	2.71	0.83	14.60	6.02	0.41	-8.10	5.03	0.62	-16.77	2.92	0.17

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.20	0.15	0.77	0.12	0.13	1.11	0.33	0.15	0.47	364.09	333.89	0.92
Primary2	0.42	0.39	0.94	0.36	0.46	1.26	0.25	0.11	0.46	373.26	408.50	1.09
Primary3	2.26	1.75	0.77	3.42	1.90	0.55	0.10	0.02	0.24	644.66	397.78	0.62
Primary4	7.95	2.42	0.30	14.72	2.20	0.15	0.08	0.02	0.18	891.90	130.88	0.15
Primary5	13.27	5.14	0.39	28.13	9.57	0.34	0.07	0.01	0.15	977.73	268.83	0.27
Primary6	60.42	16.88	0.28	83.89	19.19	0.23	0.11	0.01	0.13	1032.70	81.21	0.08
Primary7	92.64	24.06	0.26	123.28	35.61	0.29	0.12	0.01	0.10	835.59	128.96	0.15
Primary8	124.31	71.62	0.58	137.07	84.13	0.61	0.17	0.06	0.37	512.33	252.81	0.49
Primary9	90.94	85.36	0.94	97.99	72.71	0.74	0.12	0.05	0.39	372.66	223.50	0.60

Table A.21b: Hysteretic connection properties (Std.), Configuration 11.

Hysteretic Connection Properties: Configuration 11

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	47.58	46.95	0.99	0.02	0.01	0.60	-43.15	61.56	1.43	-0.01	0.02	1.75
Primary2	67.74	89.58	1.32	0.03	0.02	0.58	-87.28	148.80	1.70	-0.03	0.02	0.50
Primary3	241.71	217.99	0.90	0.09	0.04	0.44	-374.37	424.17	1.13	-0.09	0.04	0.47
Primary4	789.05	469.22	0.59	0.16	0.01	0.04	-839.00	526.03	0.63	-0.16	0.00	0.03
Primary5	1134.51	524.02	0.46	0.21	0.03	0.16	-1218.77	573.45	0.47	-0.20	0.03	0.15
Primary6	2155.80	707.74	0.33	0.36	0.05	0.15	-1991.10	513.74	0.26	-0.35	0.05	0.13
Primary7	2324.61	982.29	0.42	0.48	0.09	0.20	-2152.94	612.95	0.28	-0.46	0.08	0.17
Primary8	2190.77	1237.56	0.56	0.65	0.16	0.25	-1395.75	1214.06	0.87	-0.50	0.19	0.38
Primary9	738.58	609.65	0.83	0.57	0.24	0.41	-1820.97	1129.90	0.62	-0.66	0.11	0.17

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.74	1.34	0.77	1.03	1.14	1.11	0.33	0.15	0.47	2079.00	1906.56	0.92
Primary2	3.67	3.46	0.94	3.22	4.05	1.26	0.23	0.14	0.60	2131.35	2332.60	1.09
Primary3	20.04	15.51	0.77	30.28	16.81	0.55	0.08	0.07	0.86	3681.12	2271.41	0.62
Primary4	70.37	21.44	0.30	130.33	19.48	0.15	0.10	0.03	0.31	5092.86	747.36	0.15
Primary5	117.47	45.50	0.39	248.94	84.72	0.34	0.08	0.03	0.33	5582.96	1535.07	0.27
Primary6	534.78	149.44	0.28	742.52	169.86	0.23	0.12	0.03	0.25	5896.86	463.74	0.08
Primary7	819.94	212.95	0.26	1091.10	315.13	0.29	0.12	0.02	0.13	4771.32	736.39	0.15
Primary8	1100.22	633.89	0.58	1213.16	744.60	0.61	0.18	0.09	0.49	2925.46	1443.56	0.49
Primary9	804.89	755.54	0.94	867.29	643.54	0.74	0.12	0.05	0.39	2127.95	1276.22	0.60

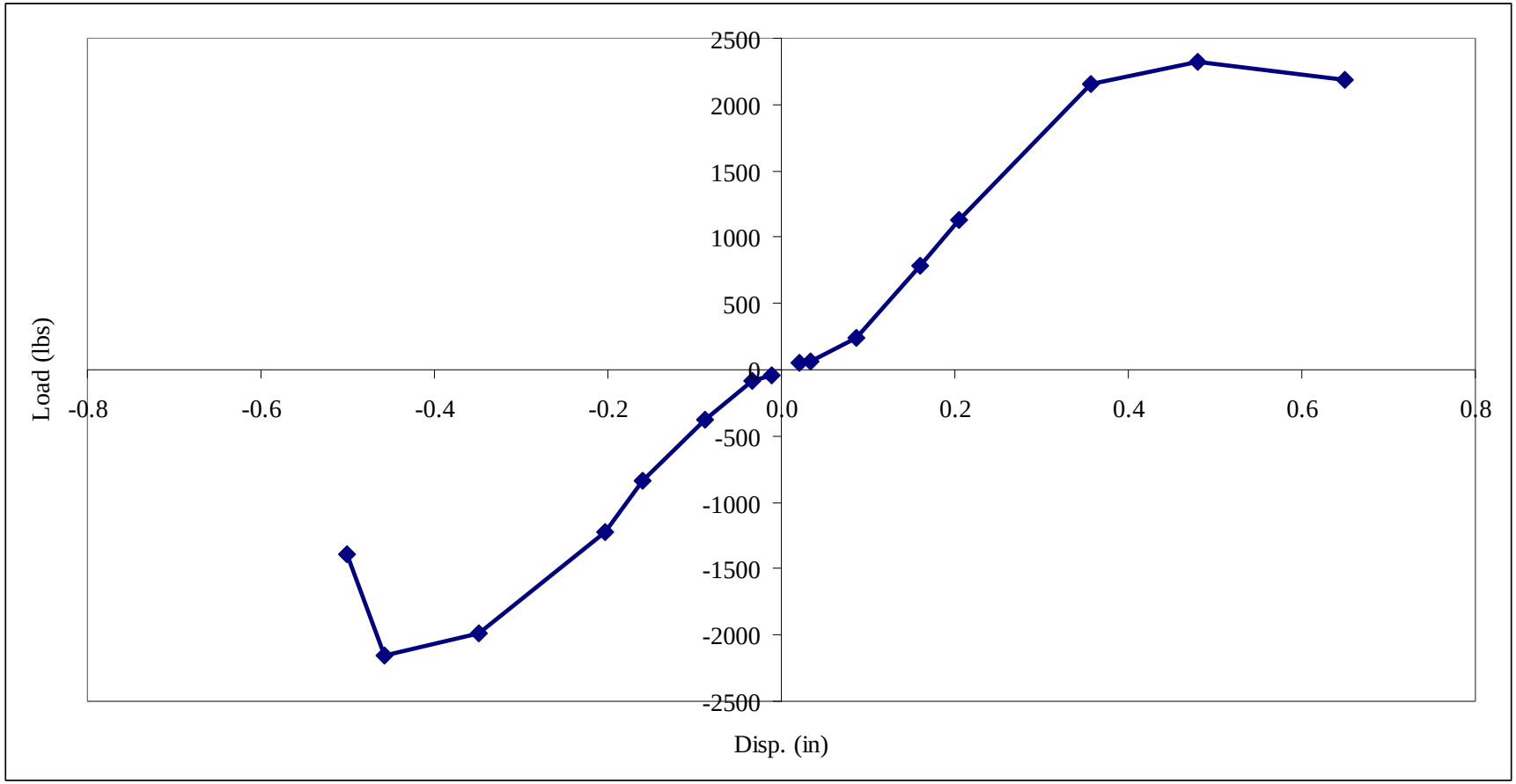

Figure A.67: Mean envelope curve: Configuration 11.

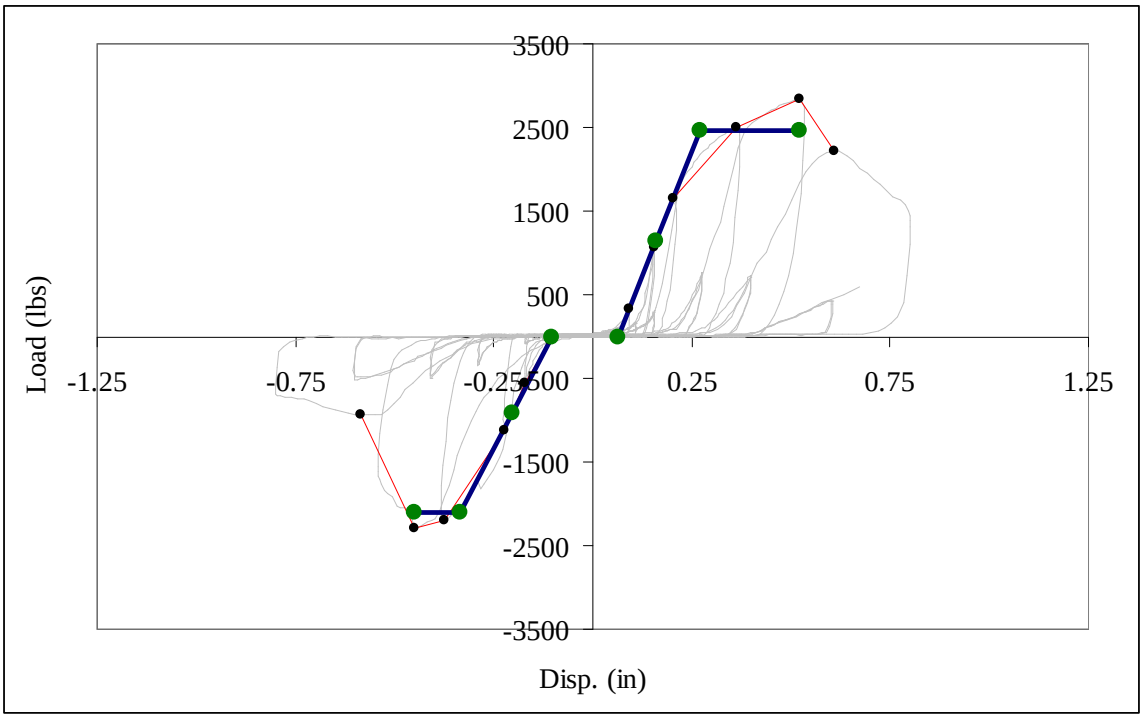

Figure A.68: Load-Deflection plot: C11-1.

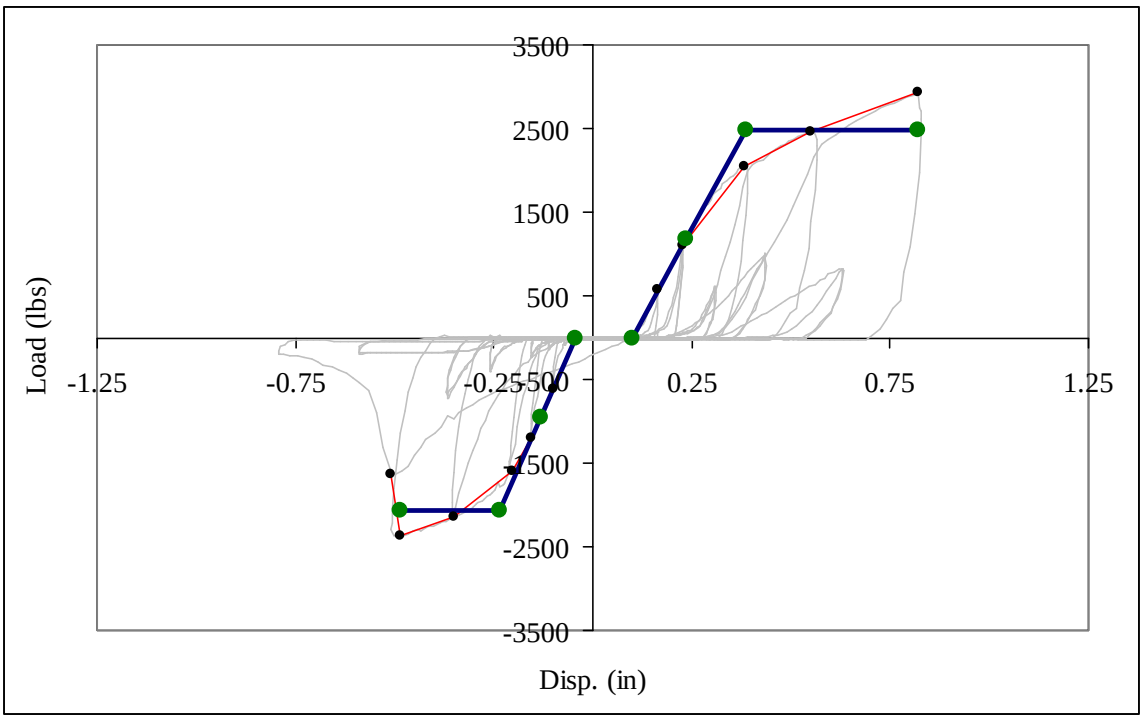

Figure A.69: Load-Deflection plot: C11-2.

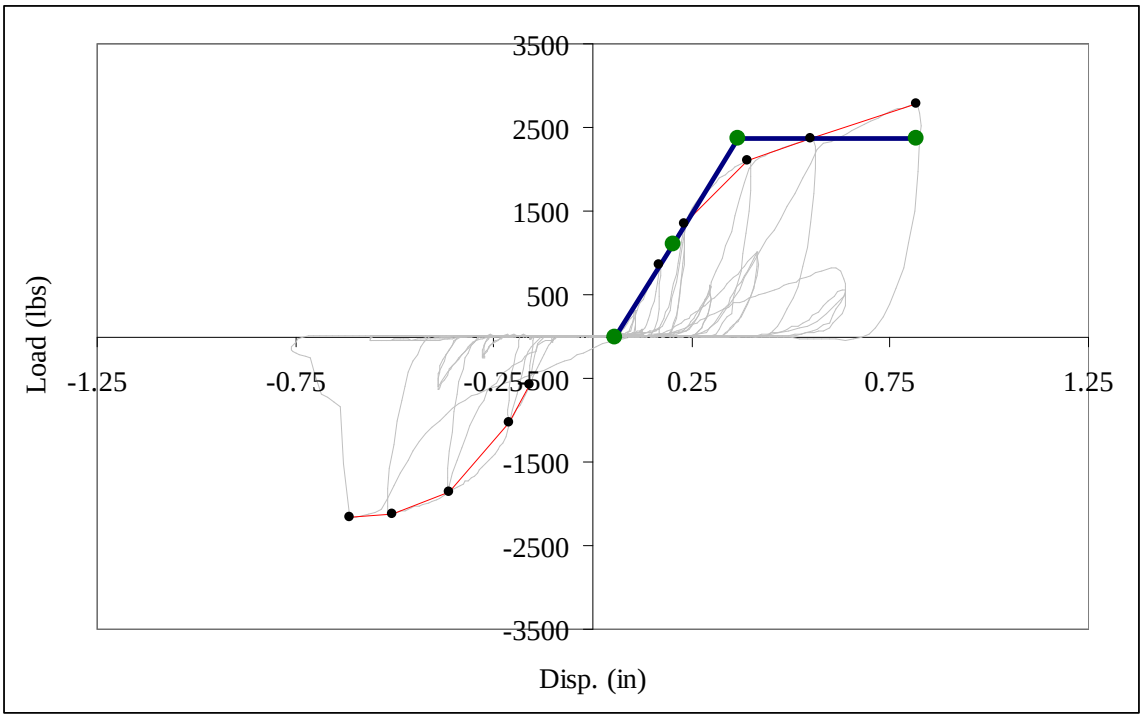

Figure A.70: Load-Deflection plot: C11-3.

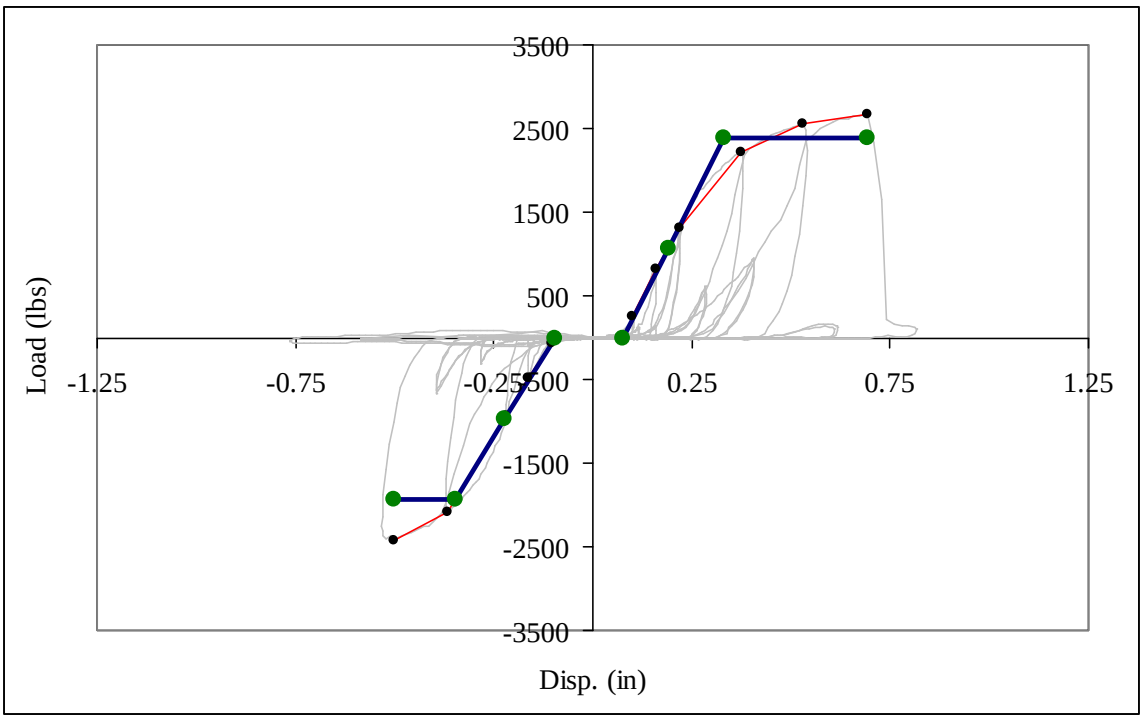

Figure A.71: Load-Deflection plot: C11-4.

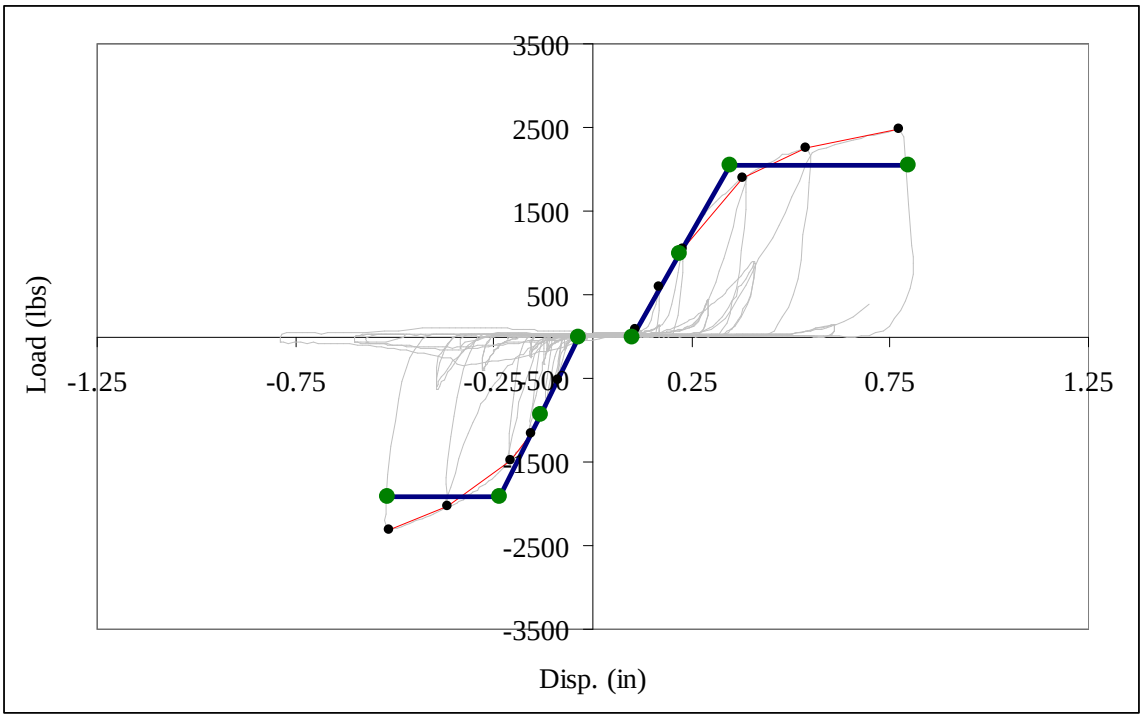

Figure A.72: Load-Deflection plot: C11-5.

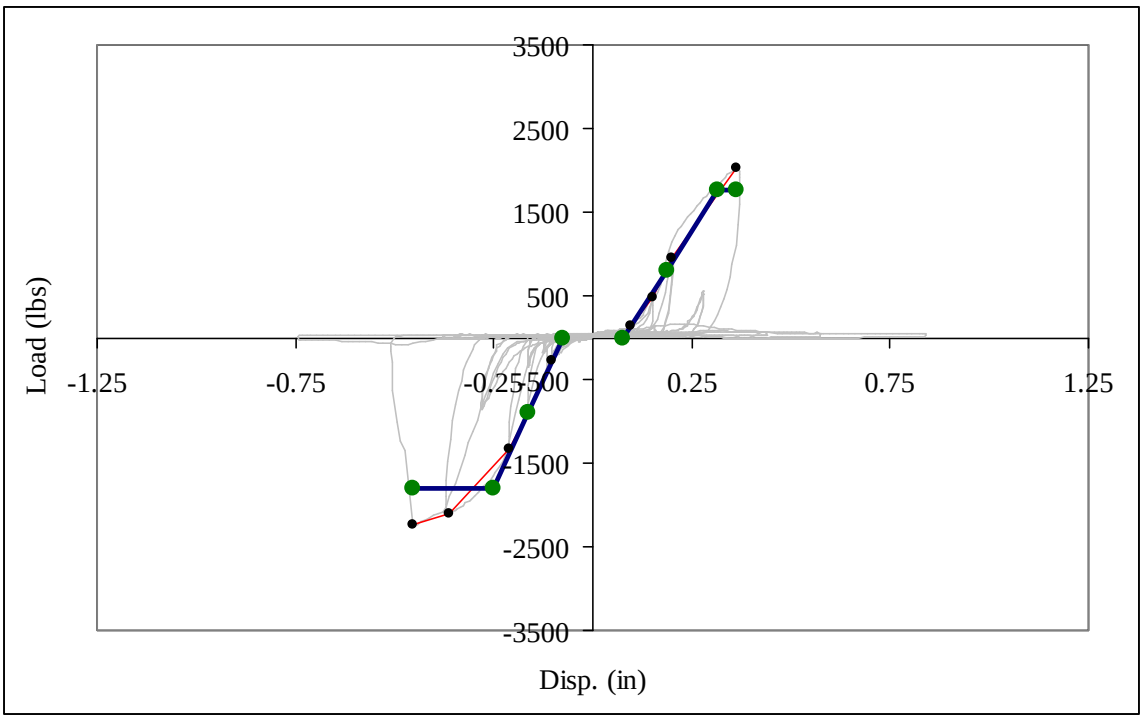

Figure A.73: Load-Deflection plot: C11-6.

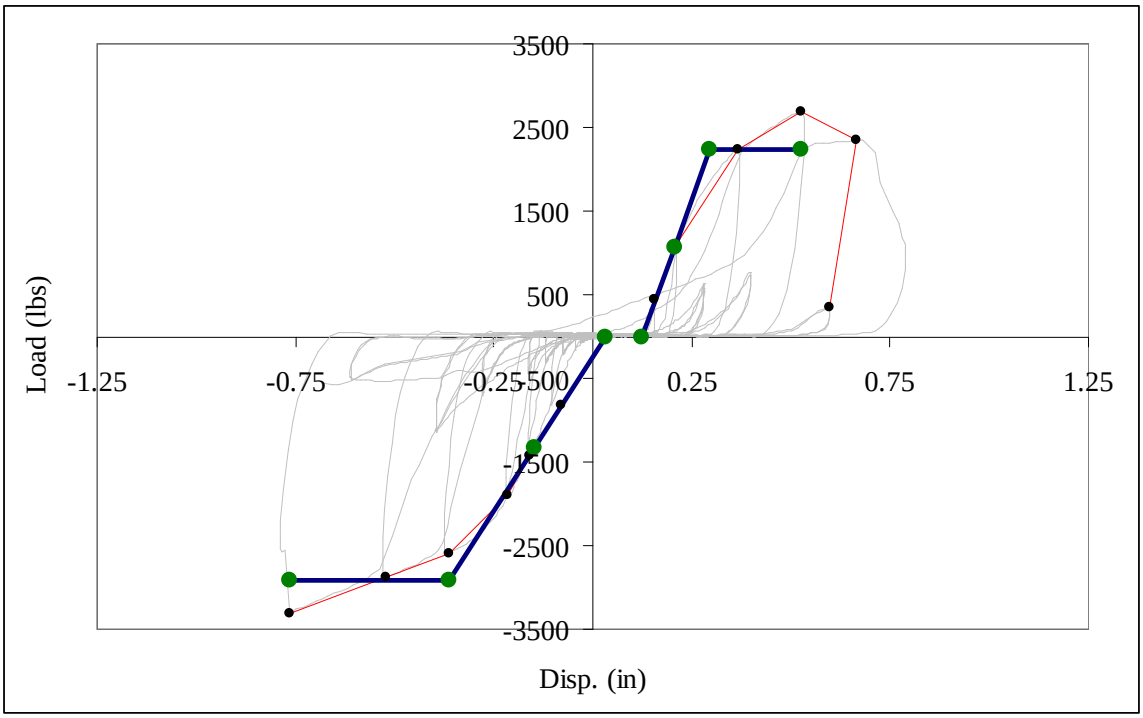

Figure A.74: Load-Deflection plot: C11-7.

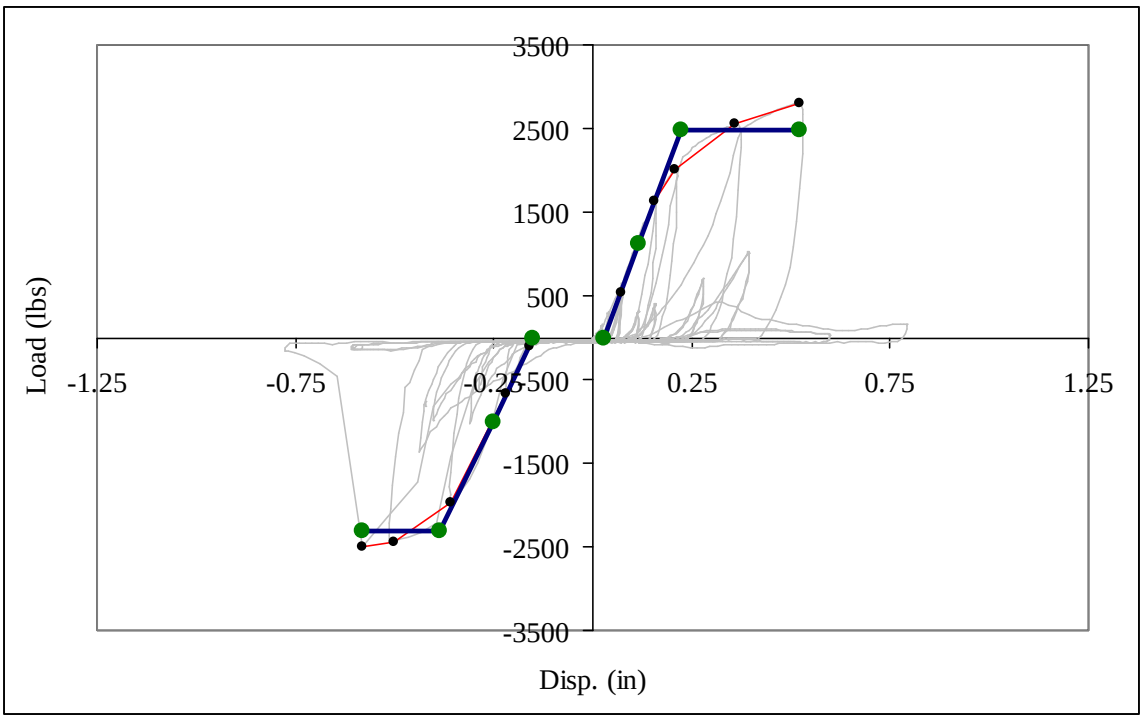

Figure A.75: Load-Deflection plot: C11-8.

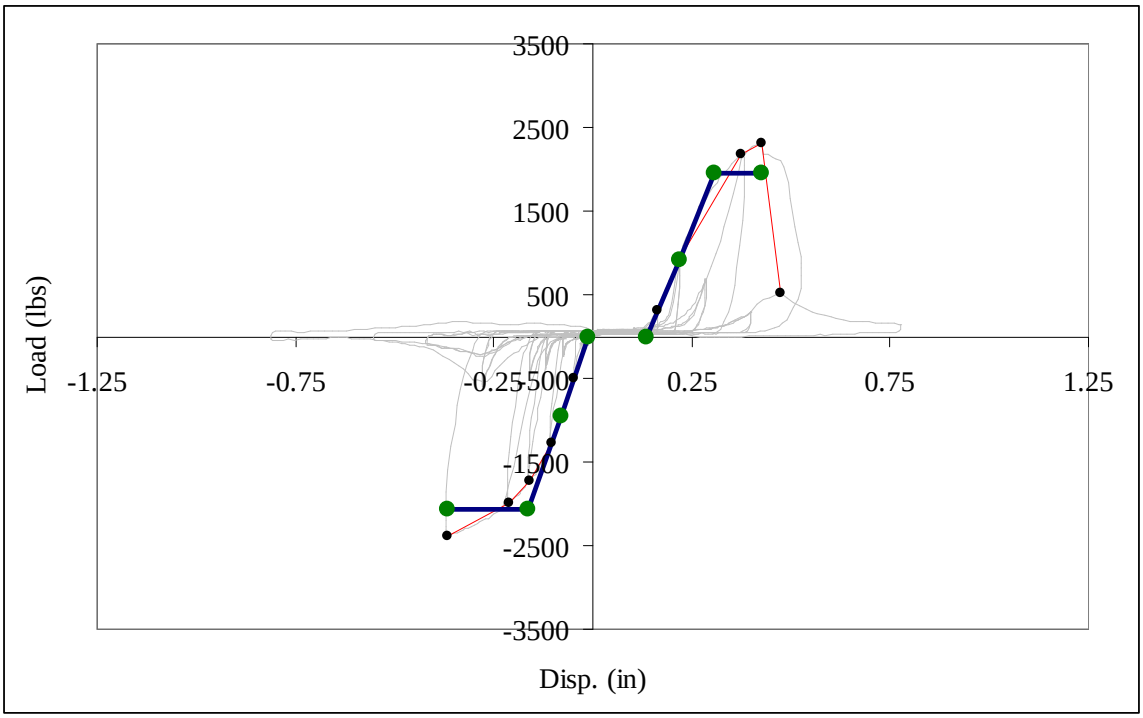

Figure A.76: Load-Deflection plot: C11-9.

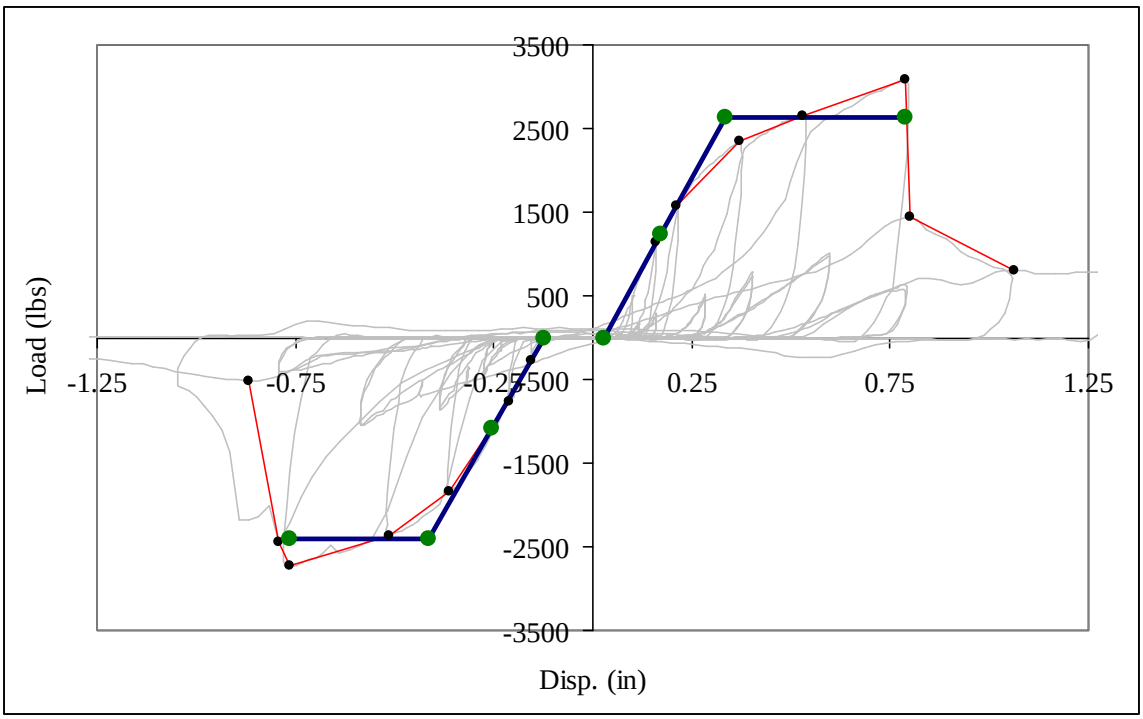

Figure A.77: Load-Deflection plot: C11-10.

Table A.22a: Connection performance properties (SI), Configuration 12.

Connection Performance Properties: Configuration 12

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	23.74	28.21	25.44	31.28	22.69	20.67	29.65		28.84	27.82	26.48	3.54	0.13
@Displacement (mm)	8.43	10.73	7.56	10.15	8.37	6.74	9.53		11.56	9.19	9.14	1.54	0.17
Failure Load (kN)	18.99	22.56	20.35	25.03	18.15	16.54	23.72		23.07	22.25	21.18	2.83	0.13
@Displacement (mm)	8.43	10.73	7.56	10.15	8.37	6.74	9.53		11.56	9.19	9.14	1.54	0.17
40% Max (kN)	9.50	11.28	10.17	12.51	9.08	8.27	11.86		11.54	11.13	10.59	1.42	0.13
@Displacement (mm)	4.39	4.85	4.02	4.43	4.31	3.94	4.31		4.90	4.17	4.37	0.33	0.08
Yield (kN)	21.16	25.04	23.54	28.08	20.56	18.68	25.58	Censored	26.16	24.63	23.71	3.02	0.13
@Displacement (mm)	7.27	8.37	6.91	8.03	7.24	6.05	7.03		8.73	7.32	7.44	0.82	0.11
5% Offset Yield (kN)	23.74	24.48	25.44	28.04	22.69	20.11	24.48		25.44	24.94	24.37	2.16	0.09
@Displacement (mm)	8.43	8.88	7.56	8.65	8.37	6.97	7.44		9.19	7.75	8.14	0.74	0.09
Elastic Stiff. (N/mm)	4147.08	3952.53	4613.98	4319.71	3926.44	4961.44	5045.04		3878.14	4282.11	4347.38	437.79	0.10
E.E.P. Energy (N*m)	80.56	139.03	75.52	150.28	77.70	48.86	129.33		164.58	120.44	109.59	39.94	0.36
Ductility Ratio	1.20	1.31	1.10	1.27	1.16	1.11	1.36		1.34	1.26	1.23	0.10	0.08
Yield Mode	III_s	III_s	III_s	III_s	II-III_s	II-III_s	II-III_s		III_s	III_s			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting		Splitting	Splitting			
Governing Member	Main	Main	Main	Side	Side	Main	Side		Side	Side			

Table A.22b: Connection performance properties (Std.), Configuration 12.

Connection Performance Properties: Configuration 12

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	5336.83	6340.77	5718.21	7032.64	5100.81	4647.10	6665.09		6483.52	6253.53	5953.17	795.39	0.13
@ Displacement (in)	0.33	0.42	0.30	0.40	0.33	0.27	0.38		0.46	0.36	0.36	0.06	0.17
Failure Load (lbs)	4269.46	5072.61	4574.57	5626.11	4080.65	3717.68	5332.07		5186.82	5002.83	4762.53	636.32	0.13
@ Displacement (in)	0.33	0.42	0.30	0.40	0.33	0.27	0.38		0.46	0.36	0.36	0.06	0.17
40% Max (lbs)	2134.73	2536.31	2287.28	2813.06	2040.32	1858.84	2666.03		2593.41	2501.41	2381.27	318.16	0.13
@ Displacement (in)	0.17	0.19	0.16	0.17	0.17	0.16	0.17		0.19	0.16	0.17	0.01	0.08
Yield (lbs)	4757.31	5629.70	5291.81	6312.55	4620.98	4198.62	5751.53	Censored	5881.12	5537.57	5331.24	679.33	0.13
@ Displacement (in)	0.29	0.33	0.27	0.32	0.28	0.24	0.28		0.34	0.29	0.29	0.03	0.11
5% Offset Yield (lbs)	5336.83	5503.15	5718.21	6303.83	5100.81	4520.79	5502.59		5720.19	5606.51	5479.21	486.64	0.09
@ Displacement (in)	0.33	0.35	0.30	0.34	0.33	0.27	0.29		0.36	0.31	0.32	0.03	0.09
Elastic Stiff. (lb/in)	23680.42	22569.53	26346.51	24666.15	22420.52	28330.53	28807.93		22144.76	24451.46	24824.20	2499.87	0.10
E.E.P. Energy (lb*in)	713.04	1230.48	668.40	1330.08	687.69	432.42	1144.70		1456.66	1065.95	969.94	353.51	0.36
Ductility Ratio	1.20	1.31	1.10	1.27	1.16	1.11	1.36		1.34	1.26	1.23	0.10	0.08
Yield Mode	III_s	III_s	III_s	III_s	$II\text{-}III_s$	$II\text{-}III_s$	$II\text{-}III_s$		III_s	III_s			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting		Splitting	Splitting			
Governing Member	Main	Main	Main	Side	Side	Main	Side		Side	Side			

Table A.23a: Member properties (SI), Configuration 12.

Member Properties: Configuration 12

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.08	16.64	16.86	16.20	16.62	16.33	16.32		16.41	15.21	14.57	5.15	0.35
S.G.	0.43	0.41	0.48	0.53	0.45	0.46	0.48		0.43	0.44	0.41	0.15	0.36
D.E. 5% Offset Yield (kPa)	28236	27221	31055	28776	28291	27780	28590		26082	27746	25378	9006.56	0.35
D.E. Capacity (kPa)	29436	27789	32620	31346	30461	28736	29766		27532	28243	26593	9480.05	0.36
Side Member													
M.C. (%)	14.09	14.37	14.94	14.73	14.14	13.82	13.59		12.65	15.27	12.76	4.54	0.36
S.G.	0.46	0.44	0.58	0.58	0.48	0.45	0.44		0.41	0.47	0.43	0.16	0.37
D.E. 5% Offset Yield (kPa)	31445	29462	39871	36237	30349	30462	30902		27484	29483	28569	10677.00	0.37
D.E. Capacity (kPa)	31445	29744	39871	37285	30543	30721	31778		27643	30290	28932	10805.66	0.37

Table A.23b: Member properties (Std), Configuration 12

Member Properties: Configuration 12

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.08	16.64	16.86	16.20	16.62	16.33	16.32		16.41	15.21	16.19	0.62	0.04
S.G.	0.43	0.41	0.48	0.53	0.45	0.46	0.48		0.43	0.44	0.46	0.04	0.08
D.E. 5% Offset Yield (psi)	4095.32	3948.07	4504.14	4173.60	4103.29	4029.05	4146.66		3782.85	4024.13	4089.68	195.08	0.05
D.E. Capacity (psi)	4269.31	4030.44	4731.12	4546.33	4417.99	4167.72	4317.10		3993.19	4096.29	4285.50	246.37	0.06
Side Member													
M.C. (%)	14.09	14.37	14.94	14.73	14.14	13.82	13.59		12.65	15.27	14.18	0.78	0.06
S.G.	0.46	0.44	0.58	0.58	0.48	0.45	0.44		0.41	0.47	0.48	0.06	0.12
D.E. 5% Offset Yield (psi)	4560.61	4273.10	5782.72	5255.66	4401.79	4418.15	4481.87		3986.12	4276.09	4604.01	559.58	0.12
D.E. Capacity (psi)	4560.61	4314.02	5782.72	5407.68	4429.91	4455.73	4608.96		4009.26	4393.12	4662.44	563.58	0.12

Table A.24a: Hysteretic connection properties (SI), Configuration 12.

Hysteretic Connection Properties: Configuration 12

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.45	0.37	0.83	0.36	0.15	0.42	-0.45	0.46	1.04	-0.50	0.10	0.20
Primary2	0.56	0.58	1.04	0.63	0.14	0.22	-0.69	0.78	1.12	-0.79	0.15	0.19
Primary3	2.09	2.28	1.09	2.03	0.12	0.06	-3.40	2.60	0.76	-2.06	0.21	0.10
Primary4	5.25	4.20	0.80	3.31	0.22	0.07	-6.92	3.20	0.46	-3.10	0.36	0.12
Primary5	9.35	5.15	0.55	4.49	0.62	0.14	-10.92	3.59	0.33	-4.09	0.62	0.15
Primary6	21.66	7.88	0.36	7.65	1.09	0.14	-19.35	7.27	0.38	-6.39	1.21	0.19
Primary7	23.13	11.57	0.50	9.62	1.86	0.19	-21.03	9.48	0.45	-8.02	1.68	0.21
Primary8	12.34	10.18	0.83	10.61	2.79	0.26	-8.63	7.84	0.91	-9.01	1.48	0.16
Primary9	5.03	4.35	0.86	14.85	7.54	0.51	-3.57	2.97	0.83	-12.73	7.41	0.58

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.35	0.18	0.52	0.18	0.14	0.79	0.35	0.10	0.28	1113.14	1023.55	0.92
Primary2	0.62	0.34	0.55	0.44	0.40	0.90	0.29	0.10	0.35	890.78	813.47	0.91
Primary3	4.01	1.76	0.44	5.65	2.09	0.37	0.11	0.02	0.22	1343.12	528.99	0.39
Primary4	9.56	2.69	0.28	19.36	5.25	0.27	0.08	0.01	0.13	1885.65	381.33	0.20
Primary5	18.37	5.58	0.30	43.77	12.60	0.29	0.07	0.01	0.08	2333.27	408.71	0.18
Primary6	79.10	24.94	0.32	148.39	46.16	0.31	0.09	0.03	0.35	2889.92	423.64	0.15
Primary7	133.59	56.61	0.42	204.19	95.86	0.47	0.12	0.04	0.38	2475.84	791.08	0.32
Primary8	125.79	83.50	0.66	110.81	82.81	0.75	0.22	0.09	0.42	1073.53	776.91	0.72
Primary9	85.08	51.16	0.60	71.71	62.24	0.87	0.22	0.07	0.31	297.89	168.85	0.57

Table A.24b: Hysteretic connection properties (Std.), Configuration 12.

Hysteretic Connection Properties: Configuration 12

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	100.11	83.06	0.83	0.01	0.01	0.42	-100.85	104.52	1.04	-0.02	0.00	0.20
Primary2	125.97	131.44	1.04	0.02	0.01	0.22	-155.97	175.31	1.12	-0.03	0.01	0.19
Primary3	470.71	511.71	1.09	0.08	0.00	0.06	-765.21	585.31	0.76	-0.08	0.01	0.10
Primary4	1180.26	944.99	0.80	0.13	0.01	0.07	-1556.53	719.67	0.46	-0.12	0.01	0.12
Primary5	2102.54	1156.78	0.55	0.18	0.02	0.14	-2453.98	806.35	0.33	-0.16	0.02	0.15
Primary6	4869.74	1770.49	0.36	0.30	0.04	0.14	-4349.14	1635.19	0.38	-0.25	0.05	0.19
Primary7	5198.80	2599.93	0.50	0.38	0.07	0.19	-4727.76	2131.32	0.45	-0.32	0.07	0.21
Primary8	2773.23	2288.65	0.83	0.42	0.11	0.26	-1939.66	1761.67	0.91	-0.35	0.06	0.16
Primary9	1130.31	977.60	0.86	0.58	0.30	0.51	-801.78	666.81	0.83	-0.50	0.29	0.58

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	3.09	1.62	0.52	1.61	1.27	0.79	0.35	0.10	0.28	6356.21	5844.63	0.92
Primary2	5.50	3.05	0.55	3.92	3.53	0.90	0.29	0.10	0.35	5086.48	4645.04	0.91
Primary3	35.45	15.60	0.44	50.05	18.50	0.37	0.11	0.02	0.22	7669.42	3020.60	0.39
Primary4	84.62	23.82	0.28	171.34	46.46	0.27	0.08	0.01	0.13	10767.36	2177.45	0.20
Primary5	162.62	49.38	0.30	387.39	111.52	0.29	0.07	0.01	0.08	13323.34	2333.81	0.18
Primary6	700.05	220.73	0.32	1313.37	408.55	0.31	0.09	0.03	0.35	16501.85	2419.07	0.15
Primary7	1182.40	501.01	0.42	1807.23	848.45	0.47	0.12	0.04	0.38	14137.40	4517.21	0.32
Primary8	1113.32	739.03	0.66	980.79	732.93	0.75	0.22	0.09	0.42	6130.00	4436.26	0.72
Primary9	753.04	452.76	0.60	634.69	550.83	0.87	0.22	0.07	0.31	1701.01	964.17	0.57

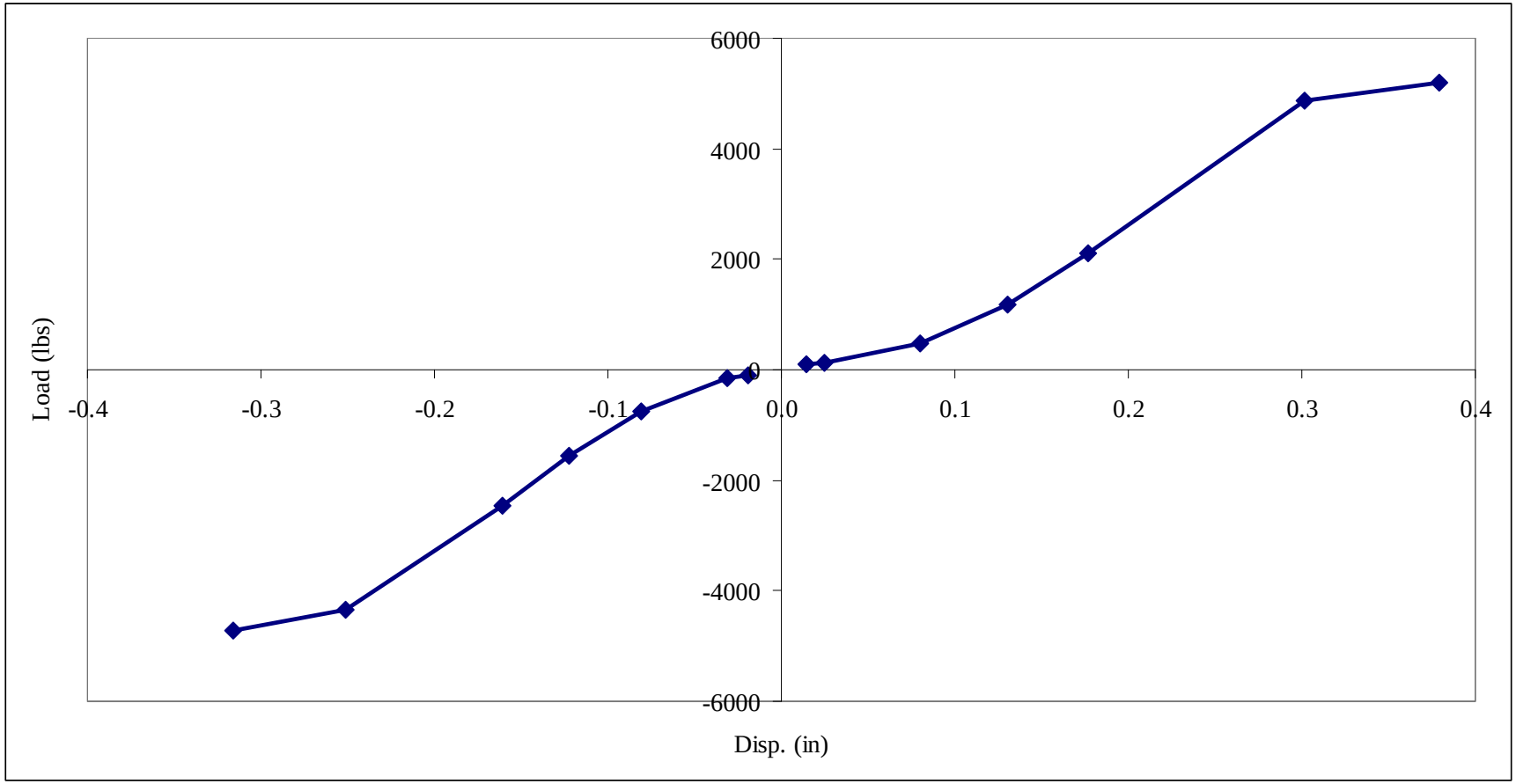

Figure A.78: Mean envelope curve: Configuration 12.

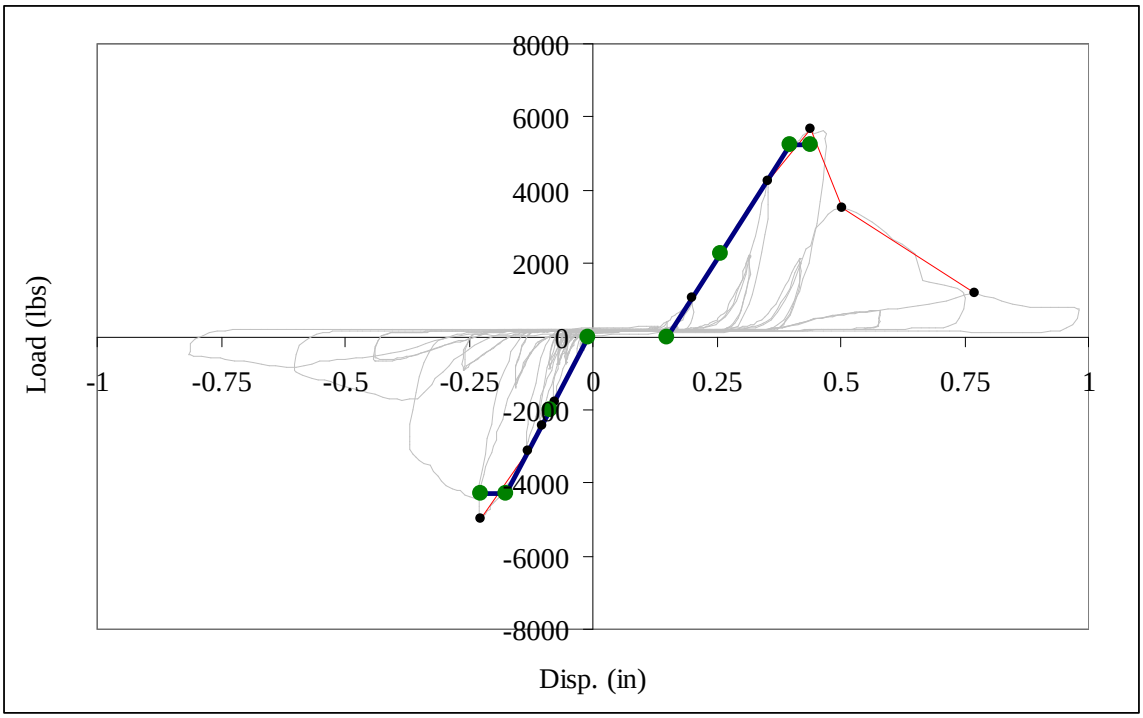

Figure A.79: Load-Deflection plot: C12-1.

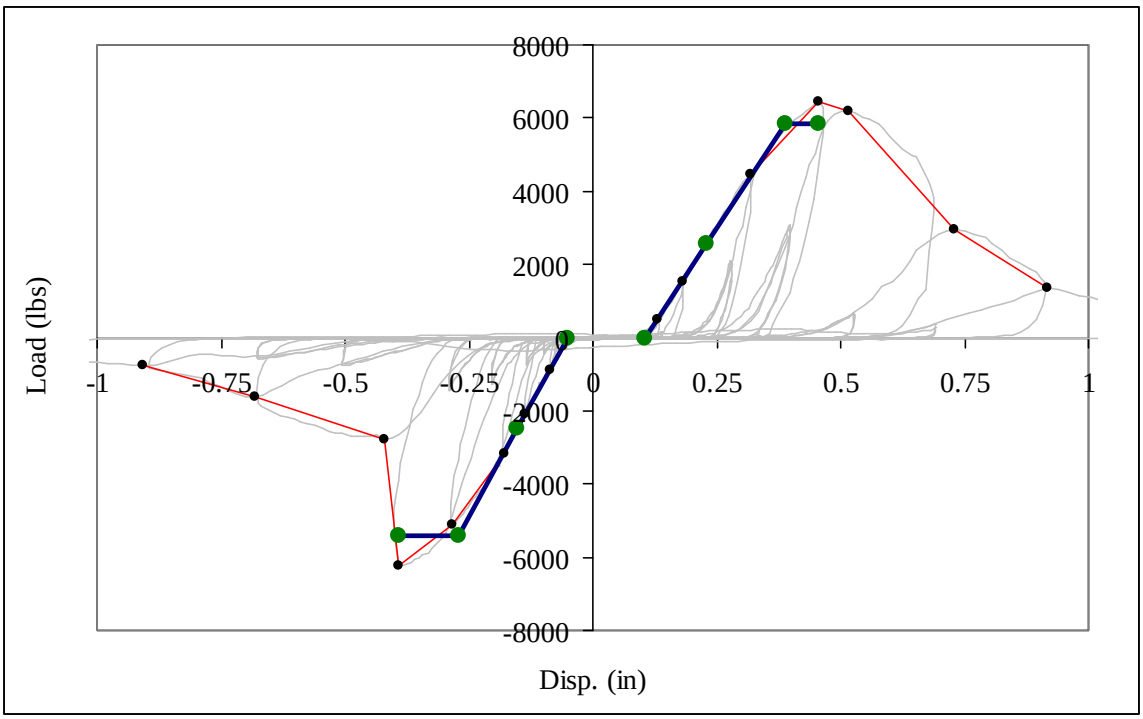

Figure A.80: Load-Deflection plot: C12-2.

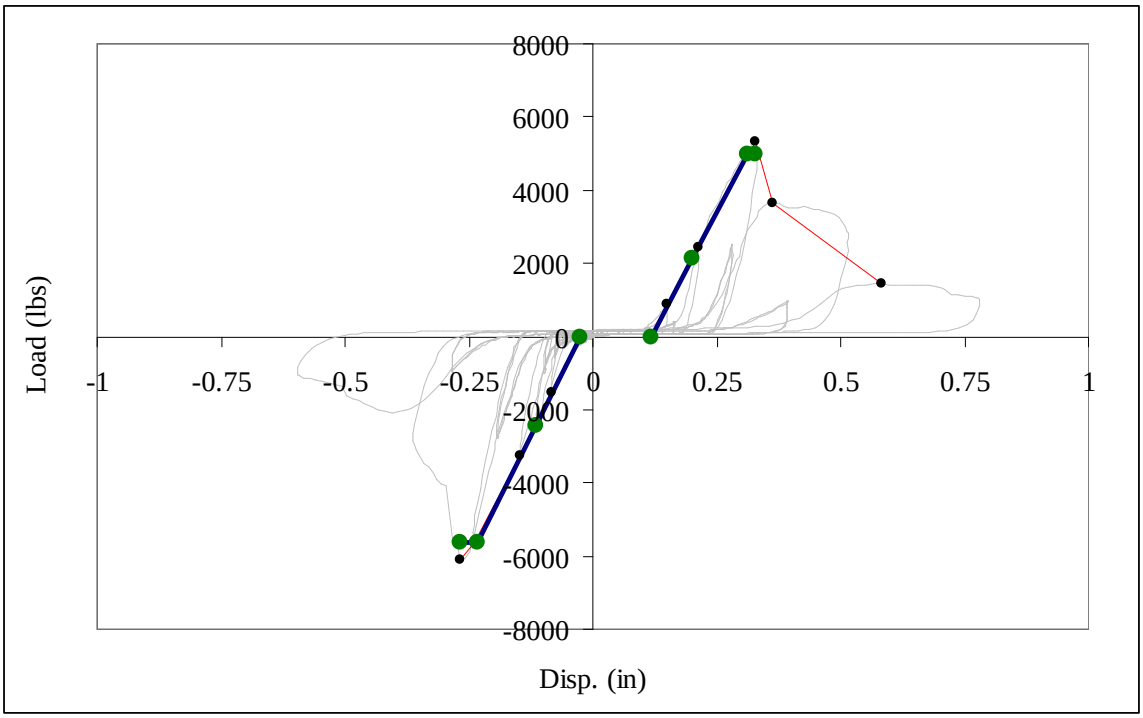

Figure A.81: Load-Deflection plot: C12-3.

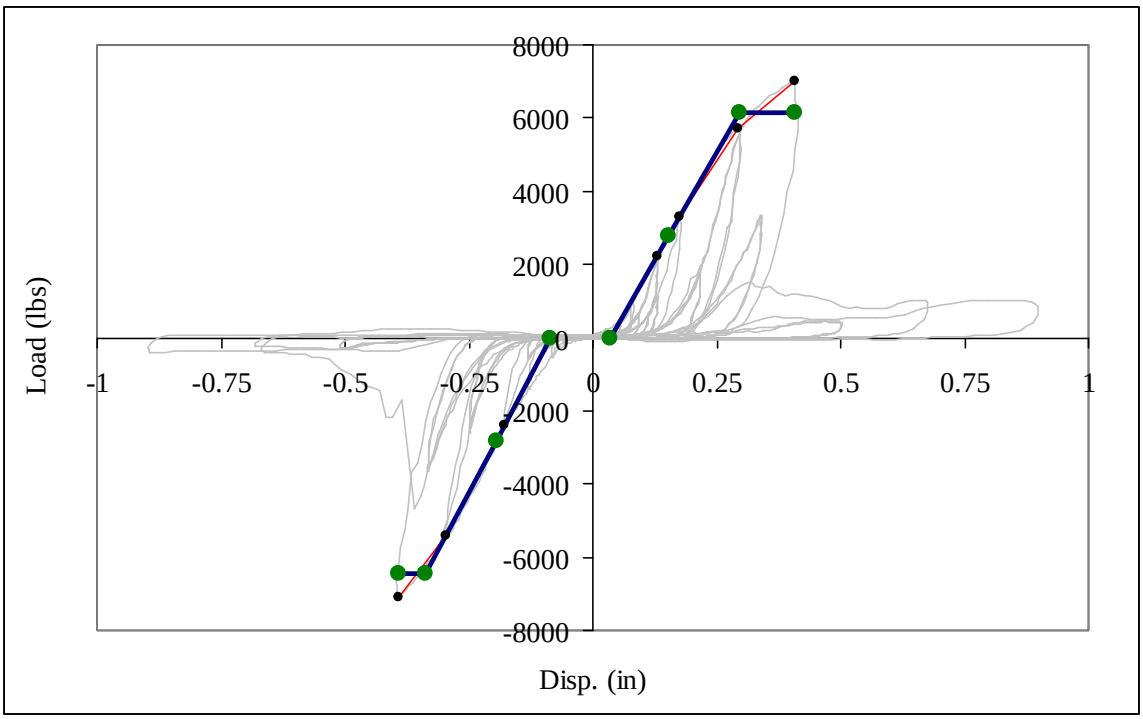

Figure A.82: Load-Deflection plot: C12-4.

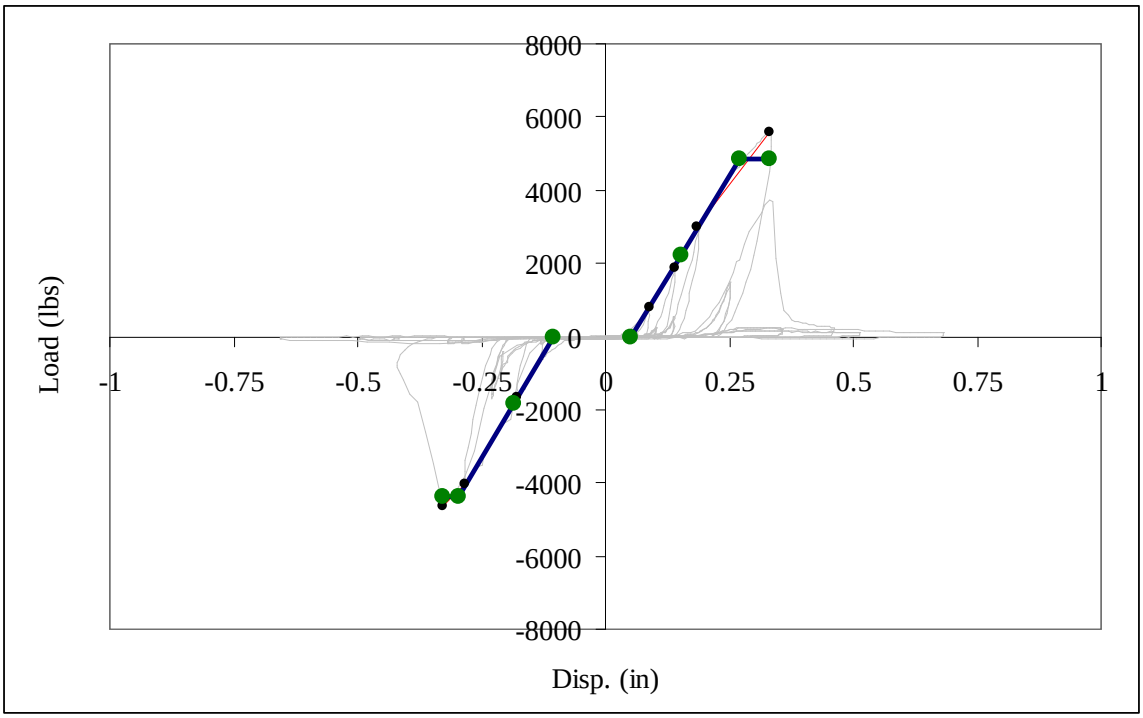

Figure A.83: Load-Deflection plot: C12-5.

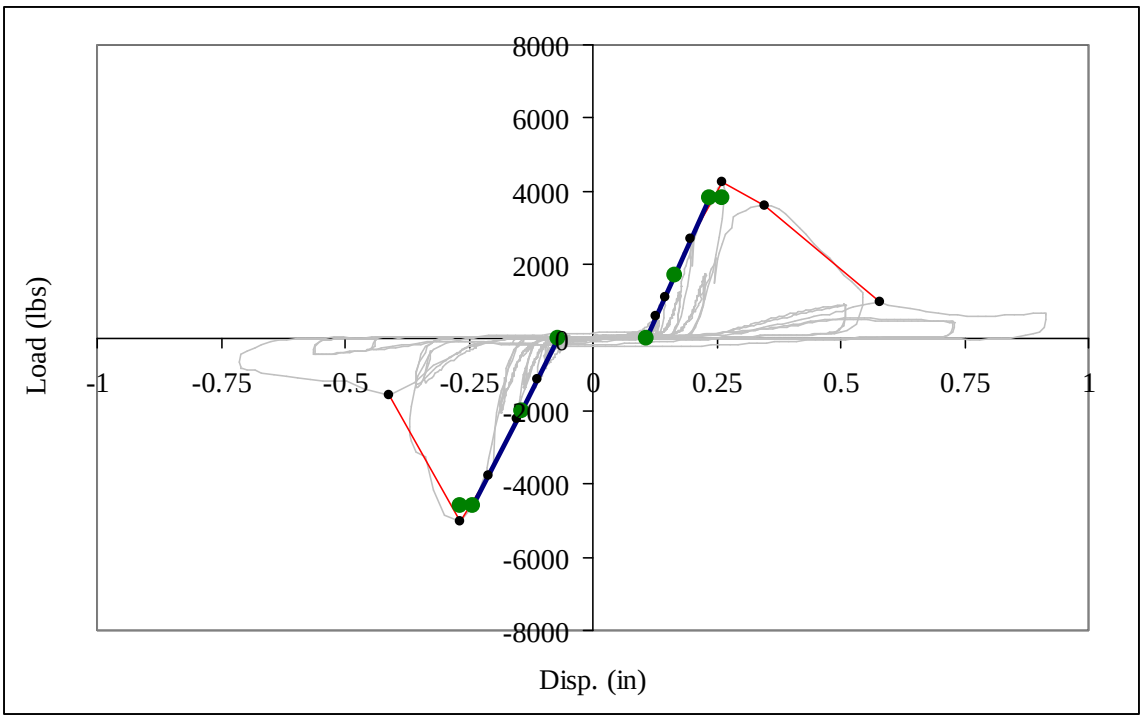

Figure A.84: Load-Deflection plot: C12-6.

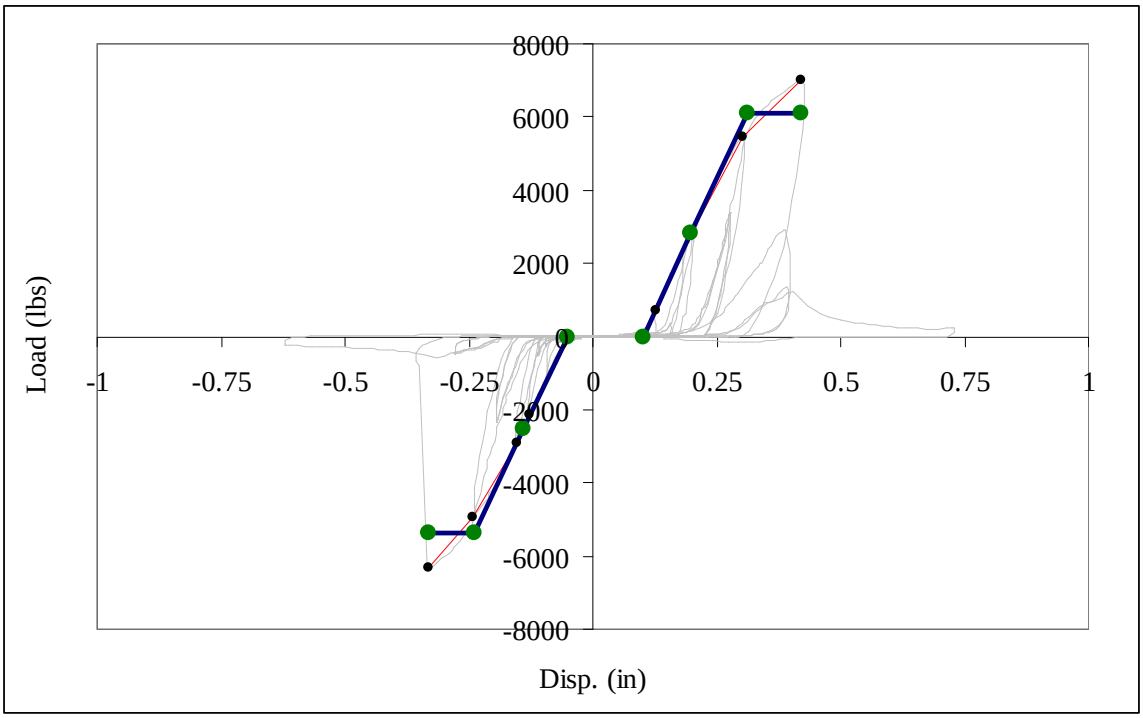

Figure A.85: Load-Deflection plot: C12-7.

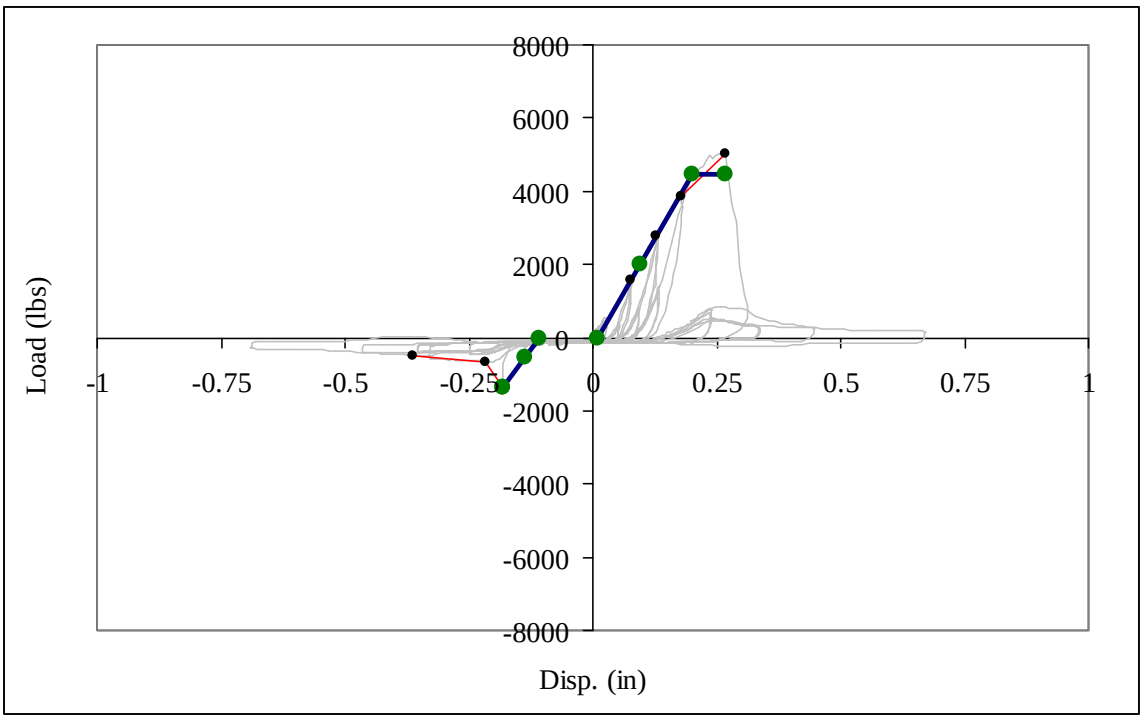

Figure A.86: Load-Deflection plot: C12-8.

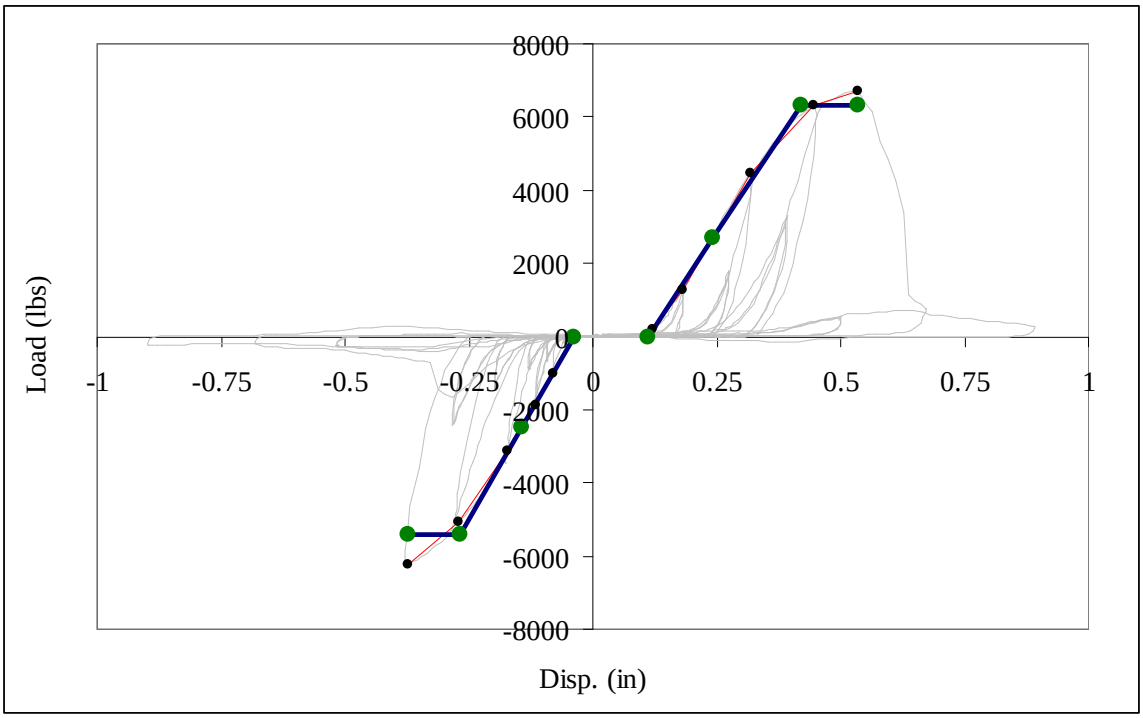

Figure A.87: Load-Deflection plot: C12-9.

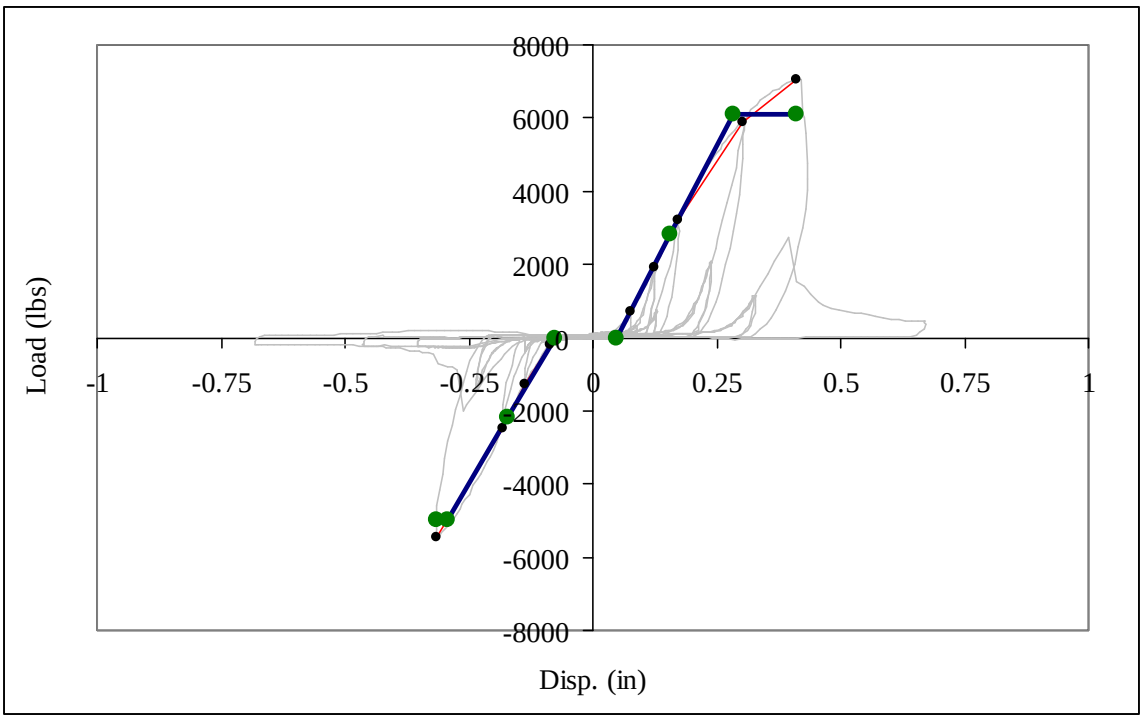

Figure A.88: Load-Deflection plot: C12-10.

Table A.25a: Connection performance properties (SI), Configuration 14.

Connection Performance Properties: Configuration 14

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	32.98	29.90	34.14	35.07	24.78	23.65	28.67	23.39	31.21	32.36	29.61	4.35	0.15
@Displacement (mm)	16.65	15.79	21.01	23.10	15.10	10.01	13.37	17.39	15.58	17.97	16.60	3.68	0.22
Failure Load (kN)	26.38	23.92	27.31	28.05	19.83	18.92	22.93	18.71	24.96	25.89	23.69	3.48	0.15
@Displacement (mm)	16.65	23.22	21.01	23.10	15.10	32.84	13.37	19.84	15.58	17.97	19.87	5.66	0.28
40% Max (kN)	13.19	11.96	13.66	14.03	9.91	9.46	11.47	9.35	12.48	12.94	11.85	1.74	0.15
@Displacement (mm)	5.57	4.88	5.92	5.27	5.61	4.54	4.79	5.10	6.02	5.46	5.32	0.49	0.09
Yield (kN)	28.94	27.93	30.63	31.28	23.23	22.13	26.02	21.39	26.70	28.51	26.68	3.46	0.13
@Displacement (mm)	9.87	8.58	11.56	9.38	10.34	7.70	8.69	8.92	10.40	9.99	9.54	1.11	0.12
5% Offset Yield (kN)	25.31	23.61	24.09	22.06	20.21	20.46	23.47	18.65	21.60	23.10	22.26	2.04	0.09
@Displacement (mm)	9.52	8.21	10.01	7.87	9.57	7.93	8.63	8.62	9.43	9.04	8.88	0.74	0.08
Elastic Stiff. (N/mm)	3666.32	4314.64	3016.53	4195.60	2829.88	4113.71	3742.75	3185.01	3306.92	3499.14	3587.05	511.45	0.14
E.E.P. Energy (N*m)	313.07	509.78	446.01	558.34	216.26	618.21	217.01	312.87	250.91	348.81	379.13	145.20	0.38
Ductility Ratio	1.71	2.70	1.82	2.51	1.44	4.33	1.52	2.19	1.50	1.80	2.15	0.88	0.41
Yield Mode	III_s	III_s	III_s	III_s-IV	III_s	III_s	III_s	III_s	III_s	III_s-IV			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Both	Both	Main	Side	Side	Side	Side	Side	Both	Side			

Table A.25b: Connection performance properties (Std.), Configuration 14.

Connection Performance Properties: Configuration 14

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	7414.38	6722.53	7675.59	7883.18	5571.62	5315.96	6444.33	5257.34	7015.33	7274.49	6657.48	978.06	0.15
@ Displacement (in)	0.66	0.62	0.83	0.91	0.59	0.39	0.53	0.68	0.61	0.71	0.65	0.14	0.22
Failure Load (lbs)	5931.51	5378.02	6140.47	6306.54	4457.30	4252.77	5155.46	4205.87	5612.26	5819.59	5325.98	782.45	0.15
@ Displacement (in)	0.66	0.91	0.83	0.91	0.59	1.29	0.53	0.78	0.61	0.71	0.78	0.22	0.28
40% Max (lbs)	2965.75	2689.01	3070.24	3153.27	2228.65	2126.39	2577.73	2102.94	2806.13	2909.80	2662.99	391.22	0.15
@ Displacement (in)	0.22	0.19	0.23	0.21	0.22	0.18	0.19	0.20	0.24	0.22	0.21	0.02	0.09
Yield (lbs)	6506.32	6278.99	6885.56	7031.22	5223.19	4974.55	5849.67	4808.00	6002.84	6410.19	5997.05	778.07	0.13
@ Displacement (in)	0.39	0.34	0.45	0.37	0.41	0.30	0.34	0.35	0.41	0.39	0.38	0.04	0.12
5% Offset Yield (lbs)	5689.97	5307.59	5416.61	4958.46	4542.66	4599.76	5276.85	4192.63	4856.88	5192.42	5003.38	459.61	0.09
@ Displacement (in)	0.37	0.32	0.39	0.31	0.38	0.31	0.34	0.34	0.37	0.36	0.35	0.03	0.08
Elastic Stiff. (lb/in)	20935.25	24637.23	17224.82	23957.49	16159.05	23489.87	21371.66	18186.88	18882.99	19980.61	20482.58	2920.47	0.14
E.E.P. Energy (lb*in)	2770.91	4511.96	3947.48	4941.74	1914.09	5471.63	1920.69	2769.12	2220.75	3087.23	3355.56	1285.11	0.38
Ductility Ratio	1.71	2.70	1.82	2.51	1.44	4.33	1.52	2.19	1.50	1.80	2.15	0.88	0.41
Yield Mode	III_s	III_s	III_s	III_s-IV	III_s	III_s	III_s	III_s	III_s	III_s-IV			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Both	Both	Main	Side	Side	Side	Side	Side	Both	Side			

Table A.26a: Member properties (SI), Configuration 14.

Member Properties: Configuration 14

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.96	14.83	15.60	15.91	15.46	15.97	15.64	16.12	15.76	15.82	15.61	0.42	0.03
S.G.	0.45	0.43	0.42	0.46	0.42	0.50	0.52	0.40	0.38	0.46	0.44	0.04	0.10
D.E. 5% Offset Yield (kPa)	26357	24119	23525	21556	26251	29593	28340	18651	20530	28317	24724	3666.51	0.15
D.E. Capacity (kPa)	26413	24167	23659	21921	27318	29668	28625	20177	21035	28849	25183	3459.77	0.14
Side Member													
M.C. (%)	15.24	15.55	16.02	17.02	16.06	16.34	16.28	16.32	16.02	15.66	16.05	0.49	0.03
S.G.	0.46	0.47	0.57	0.59	0.40	0.39	0.43	0.44	0.56	0.54	0.48	0.07	0.15
D.E. 5% Offset Yield (kPa)	29132	26237	36014	34101	24874	24061	24365	26207	33874	34019	29288	4733.81	0.16
D.E. Capacity (kPa)	29475	27230	36079	34493	25404	24516	25624	26405	34113	34258	29760	4507.20	0.15

Table A.26b: Member properties (Std.), Configuration 14.

Member Properties: Configuration 14

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.96	14.83	15.60	15.91	15.46	15.97	15.64	16.12	15.76	15.82	15.61	0.42	0.03
S.G.	0.45	0.43	0.42	0.46	0.42	0.50	0.52	0.40	0.38	0.46	0.44	0.04	0.10
D.E. 5% Offset Yield (psi)	3822.67	3498.16	3411.92	3126.37	3807.33	4292.06	4110.28	2705.12	2977.68	4106.98	3585.86	531.78	0.15
D.E. Capacity (psi)	3830.89	3505.11	3431.39	3179.34	3962.10	4302.89	4151.75	2926.42	3050.89	4184.13	3652.49	501.79	0.14
Side Member													
M.C. (%)	15.24	15.55	16.02	17.02	16.06	16.34	16.28	16.32	16.02	15.66	16.05	0.49	0.03
S.G.	0.46	0.47	0.57	0.59	0.40	0.39	0.43	0.44	0.56	0.54	0.48	0.07	0.15
D.E. 5% Offset Yield (psi)	4225.28	3805.37	5223.29	4945.88	3607.69	3489.71	3533.80	3800.94	4913.02	4934.04	4247.90	686.58	0.16
D.E. Capacity (psi)	4274.92	3949.28	5232.84	5002.76	3684.54	3555.73	3716.49	3829.69	4947.60	4968.72	4316.26	653.71	0.15

Table A.27a: Hysteretic connection properties (SI), Configuration 14.

Hysteretic Connection Properties: Configuration 14

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.20	0.20	0.99	0.40	0.11	0.28	-0.34	0.32	0.94	-0.47	0.16	0.33
Primary2	0.27	0.21	0.78	0.67	0.16	0.23	-0.75	0.72	0.96	-0.81	0.25	0.31
Primary3	1.35	1.36	1.00	1.94	0.18	0.09	-2.56	2.17	0.85	-2.10	0.08	0.04
Primary4	4.14	3.12	0.75	3.20	0.24	0.08	-5.55	3.15	0.57	-3.28	0.21	0.06
Primary5	8.59	4.71	0.55	4.50	0.15	0.03	-9.13	3.64	0.40	-4.35	0.26	0.06
Primary6	19.95	7.58	0.38	8.08	0.40	0.05	-18.77	2.97	0.16	-7.09	0.65	0.09
Primary7	26.39	9.21	0.35	11.61	0.72	0.06	-23.96	2.64	0.11	-9.56	0.94	0.10
Primary8	30.56	10.52	0.34	16.97	1.22	0.07	-26.72	4.54	0.17	-13.83	1.58	0.11
Primary9	30.21	11.35	0.38	21.30	2.18	0.10	-24.27	9.76	0.40	-17.88	1.92	0.11
Primary10	23.10	12.59	0.55	24.38	3.24	0.13	-17.63	9.74	0.55	-19.64	8.28	0.42
Primary11	21.32	6.47	0.30	31.40	2.58	0.08	-12.66	4.71	0.37	-28.47	4.37	0.15

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.15	0.15	1.01	0.13	0.11	0.89	0.19	0.04	0.23	615.84	497.94	0.81
Primary2	0.38	0.34	0.89	0.43	0.34	0.80	0.16	0.05	0.33	663.41	483.40	0.73
Primary3	2.70	1.57	0.58	4.01	1.69	0.42	0.10	0.02	0.20	959.00	346.26	0.36
Primary4	7.91	3.13	0.40	15.78	4.77	0.30	0.08	0.02	0.21	1483.51	337.59	0.23
Primary5	16.11	4.68	0.29	39.24	9.33	0.24	0.07	0.01	0.21	1992.57	354.62	0.18
Primary6	78.14	19.79	0.25	148.00	29.73	0.20	0.08	0.01	0.13	2541.50	333.07	0.13
Primary7	157.69	38.69	0.25	269.42	47.52	0.18	0.09	0.01	0.15	2372.92	198.30	0.08
Primary8	352.74	108.71	0.31	446.18	84.37	0.19	0.13	0.04	0.29	1863.84	239.67	0.13
Primary9	428.90	108.01	0.25	543.27	148.37	0.27	0.13	0.03	0.22	1393.05	324.71	0.23
Primary10	398.39	195.11	0.49	483.12	226.18	0.47	0.14	0.03	0.23	937.50	350.65	0.37
Primary11	479.10	189.45	0.40	516.45	168.36	0.33	0.15	0.02	0.12	567.81	168.63	0.30

Table A.27b: Hysteretic connection properties (Std.), Configuration 14.

Hysteretic Connection Properties: Configuration 14

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	45.62	45.01	0.99	0.02	0.00	0.28	-76.78	72.35	0.94	-0.02	0.01	0.33
Primary2	61.52	48.14	0.78	0.03	0.01	0.23	-168.86	162.83	0.96	-0.03	0.01	0.31
Primary3	304.60	305.34	1.00	0.08	0.01	0.09	-575.92	487.12	0.85	-0.08	0.00	0.04
Primary4	930.44	701.53	0.75	0.13	0.01	0.08	-1247.83	707.77	0.57	-0.13	0.01	0.06
Primary5	1932.10	1059.83	0.55	0.18	0.01	0.03	-2051.97	818.09	0.40	-0.17	0.01	0.06
Primary6	4485.93	1704.88	0.38	0.32	0.02	0.05	-4218.74	667.25	0.16	-0.28	0.03	0.09
Primary7	5932.97	2070.09	0.35	0.46	0.03	0.06	-5386.38	593.88	0.11	-0.38	0.04	0.10
Primary8	6869.85	2364.53	0.34	0.67	0.05	0.07	-6006.20	1019.73	0.17	-0.54	0.06	0.11
Primary9	6791.48	2551.81	0.38	0.84	0.09	0.10	-5455.32	2193.17	0.40	-0.70	0.08	0.11
Primary10	5192.05	2830.04	0.55	0.96	0.13	0.13	-3962.30	2189.40	0.55	-0.77	0.33	0.42
Primary11	4792.70	1453.74	0.30	1.24	0.10	0.08	-2846.84	1058.33	0.37	-1.12	0.17	0.15

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.30	1.31	1.01	1.13	1.01	0.89	0.19	0.04	0.21	3516.56	2843.33	0.81
Primary2	3.35	2.99	0.89	3.76	3.01	0.80	0.17	0.05	0.30	3788.18	2760.30	0.73
Primary3	23.89	13.88	0.58	35.46	14.96	0.42	0.12	0.03	0.24	5476.02	1977.22	0.36
Primary4	70.04	27.68	0.40	139.66	42.18	0.30	0.09	0.02	0.26	8471.06	1927.70	0.23
Primary5	142.59	41.42	0.29	347.27	82.59	0.24	0.07	0.02	0.26	11377.89	2024.94	0.18
Primary6	691.61	175.18	0.25	1309.88	263.13	0.20	0.09	0.02	0.27	14512.34	1901.86	0.13
Primary7	1395.66	342.47	0.25	2384.55	420.63	0.18	0.10	0.02	0.20	13549.69	1132.30	0.08
Primary8	3121.99	962.16	0.31	3949.00	746.73	0.19	0.13	0.04	0.28	10642.78	1368.55	0.13
Primary9	3796.10	955.95	0.25	4808.35	1313.15	0.27	0.13	0.03	0.19	7954.53	1854.17	0.23
Primary10	3526.05	1726.86	0.49	4276.00	2001.84	0.47	0.13	0.04	0.28	5353.28	2002.27	0.37
Primary11	4240.41	1676.76	0.40	4570.98	1490.11	0.33	0.16	0.03	0.21	3242.28	962.93	0.30

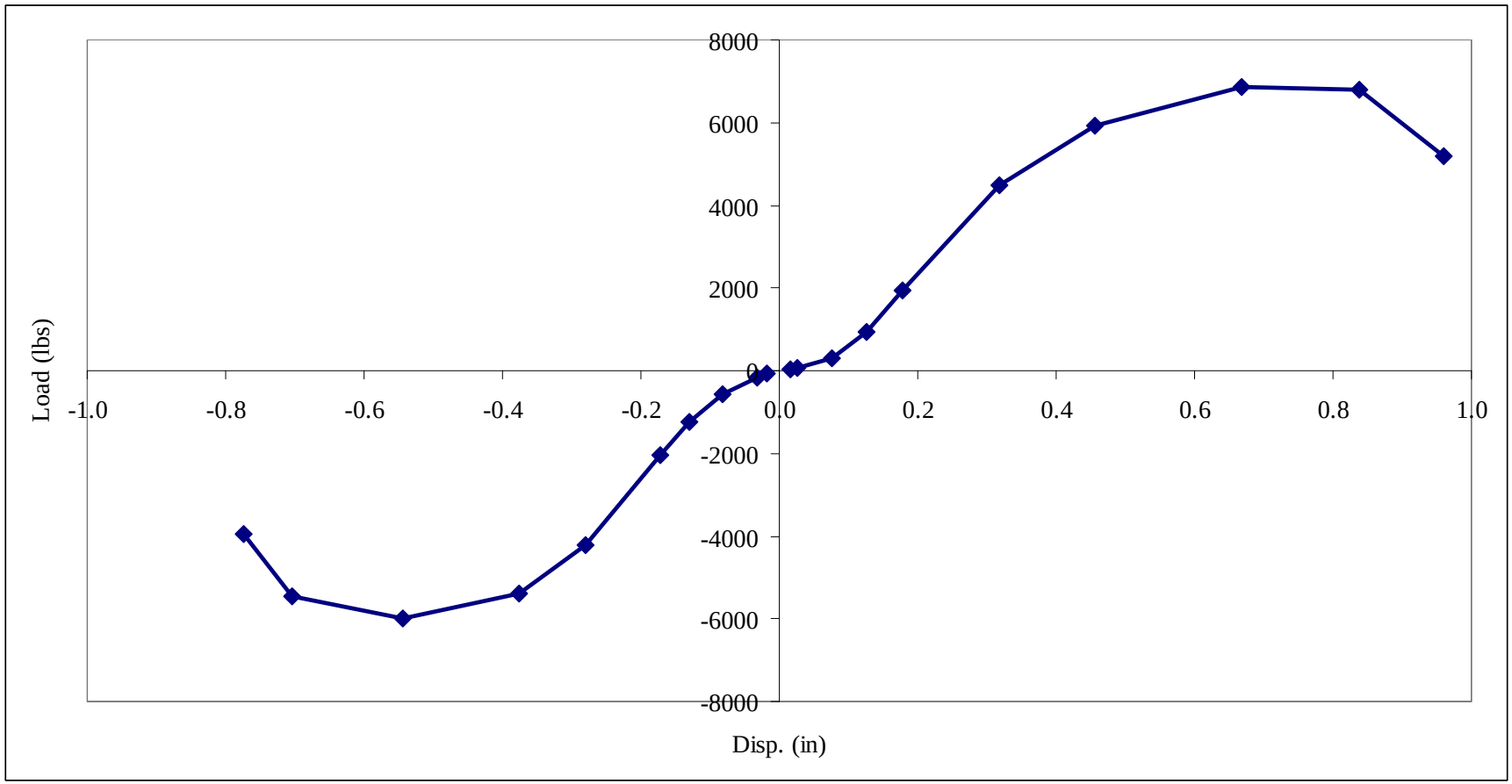

Figure A.89: Mean envelope curve: Configuration 14.

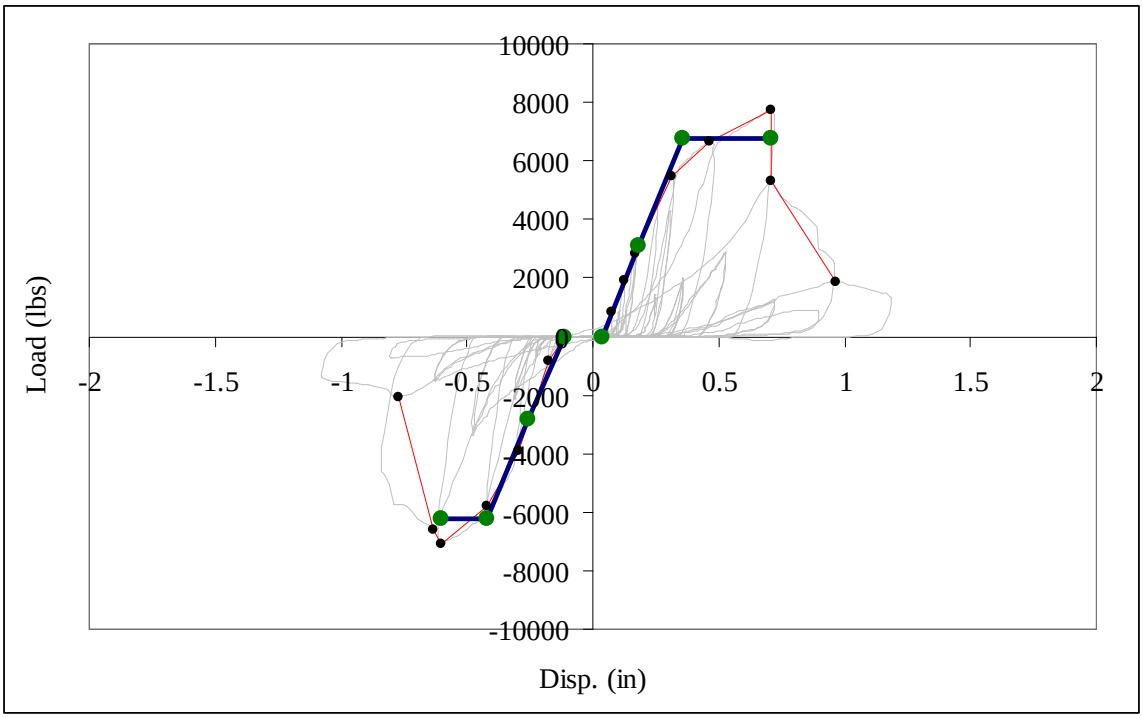

Figure A.90: Load-Deflection plot: C14-1.

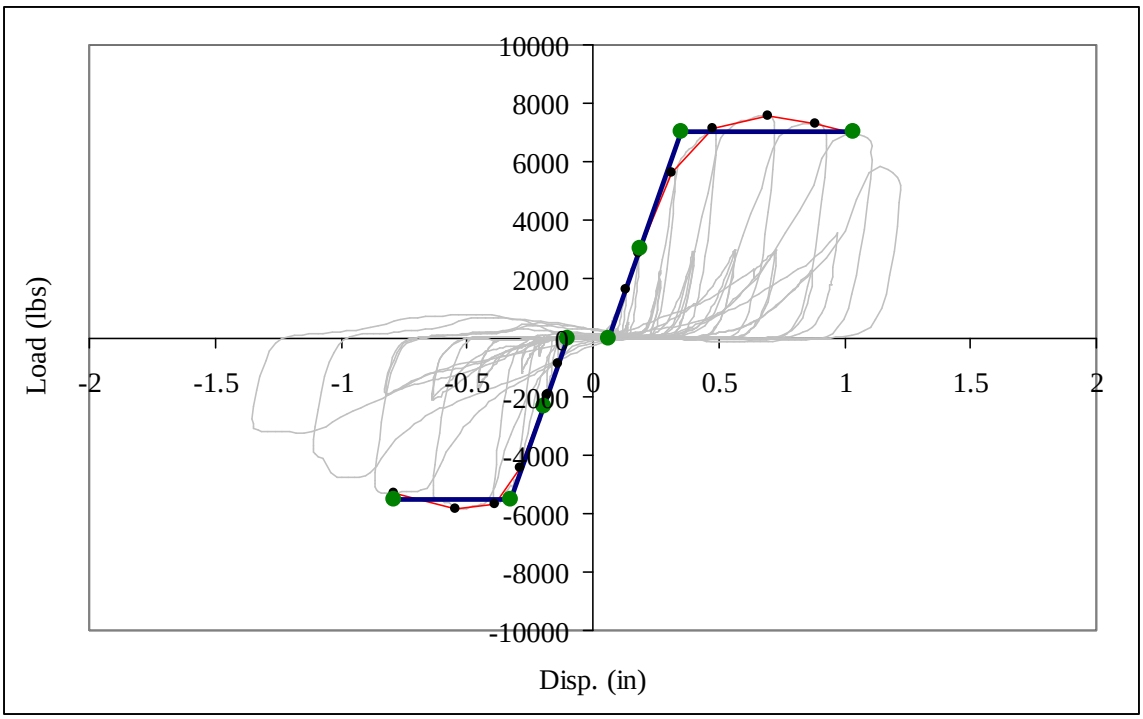

Figure A.91: Load-Deflection plot: C14-2.

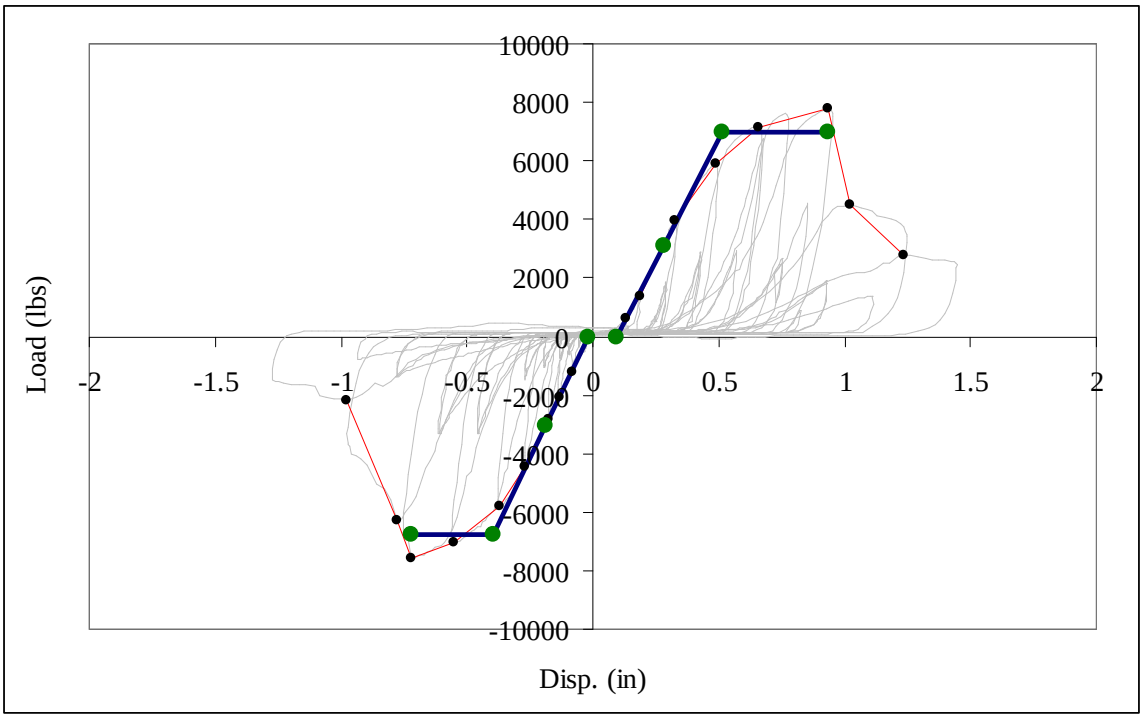

Figure A.92: Load-Deflection plot: C14-3.

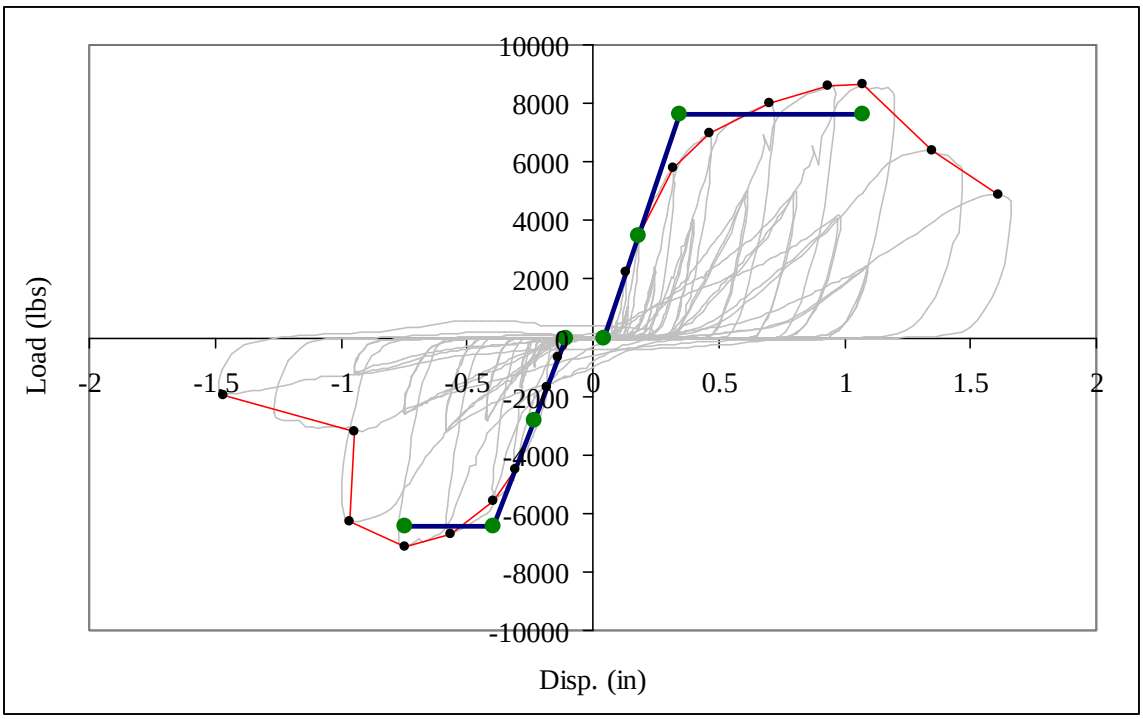

Figure A.93: Load-Deflection plot: C14-4.

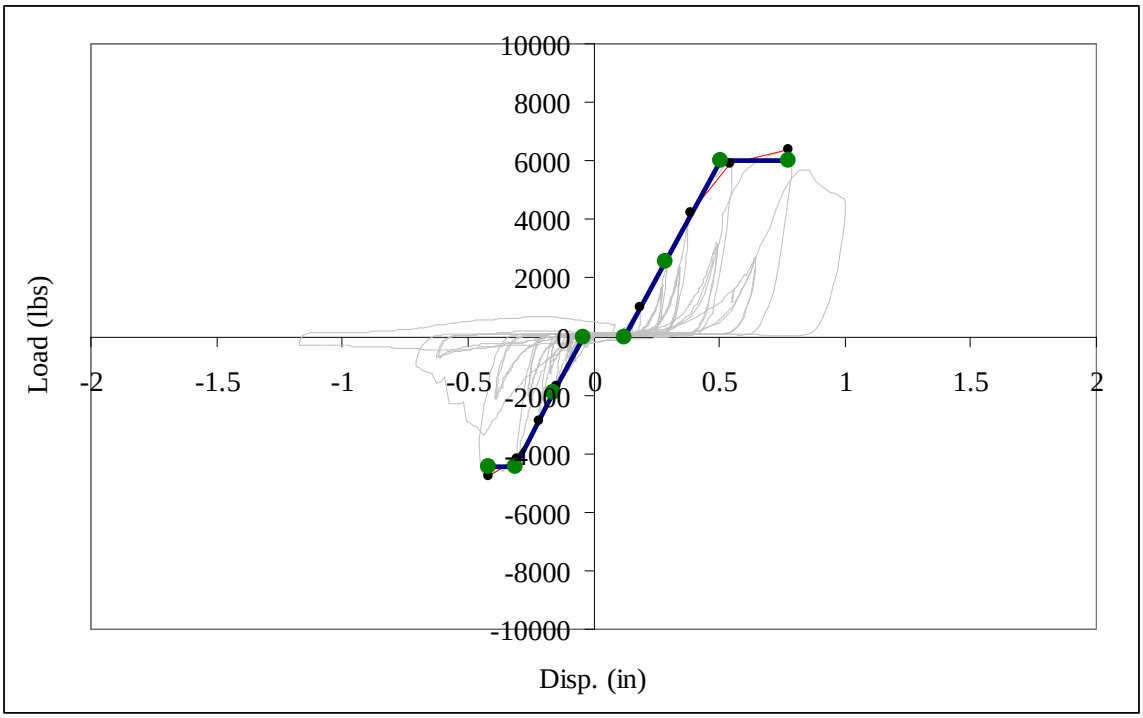

Figure A.94: Load-Deflection plot: C14-5.

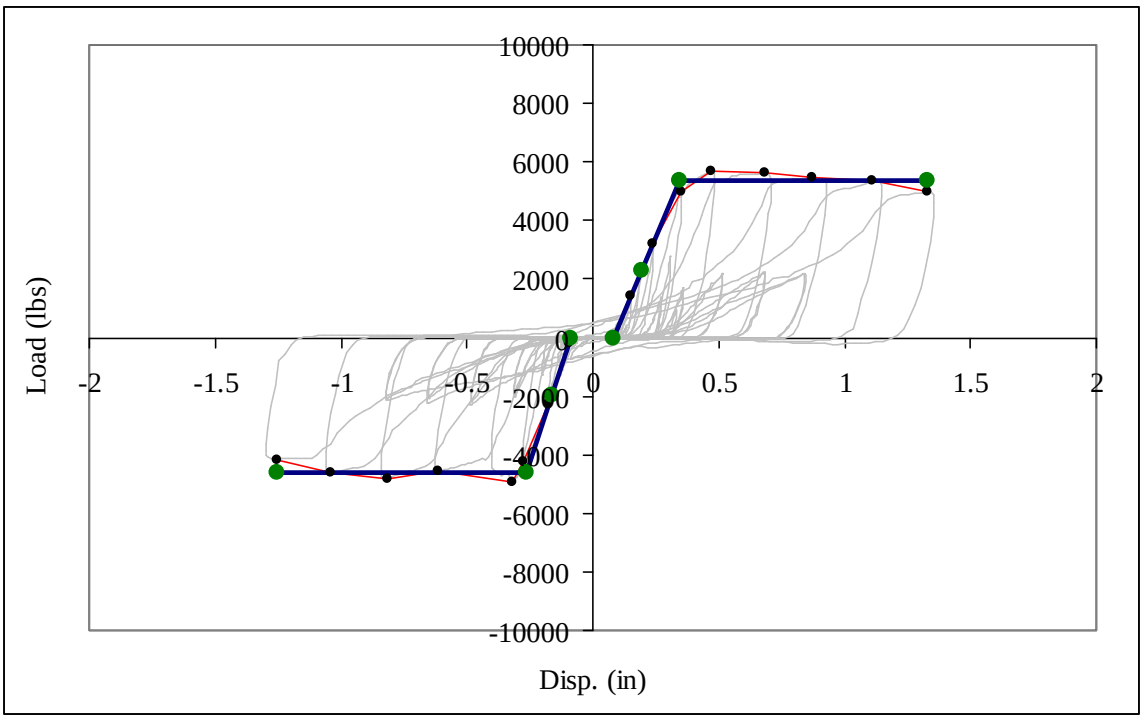

Figure A.95: Load-Deflection plot: C14-6.

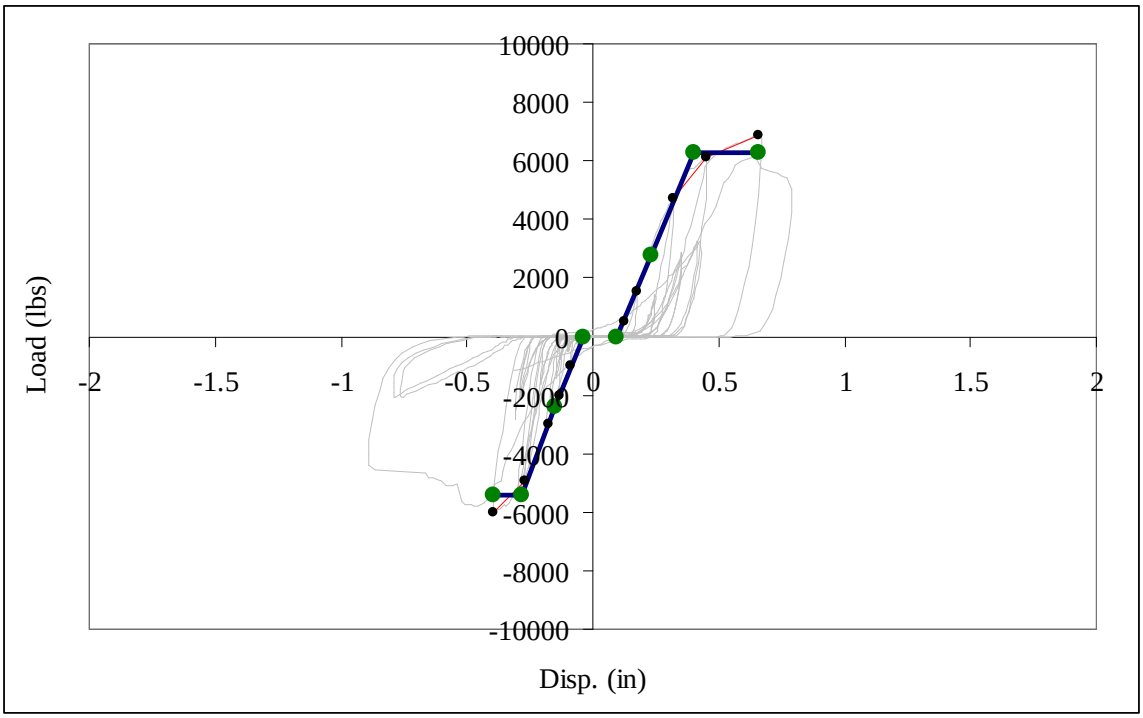

Figure A.96: Load-Deflection plot: C14-7.

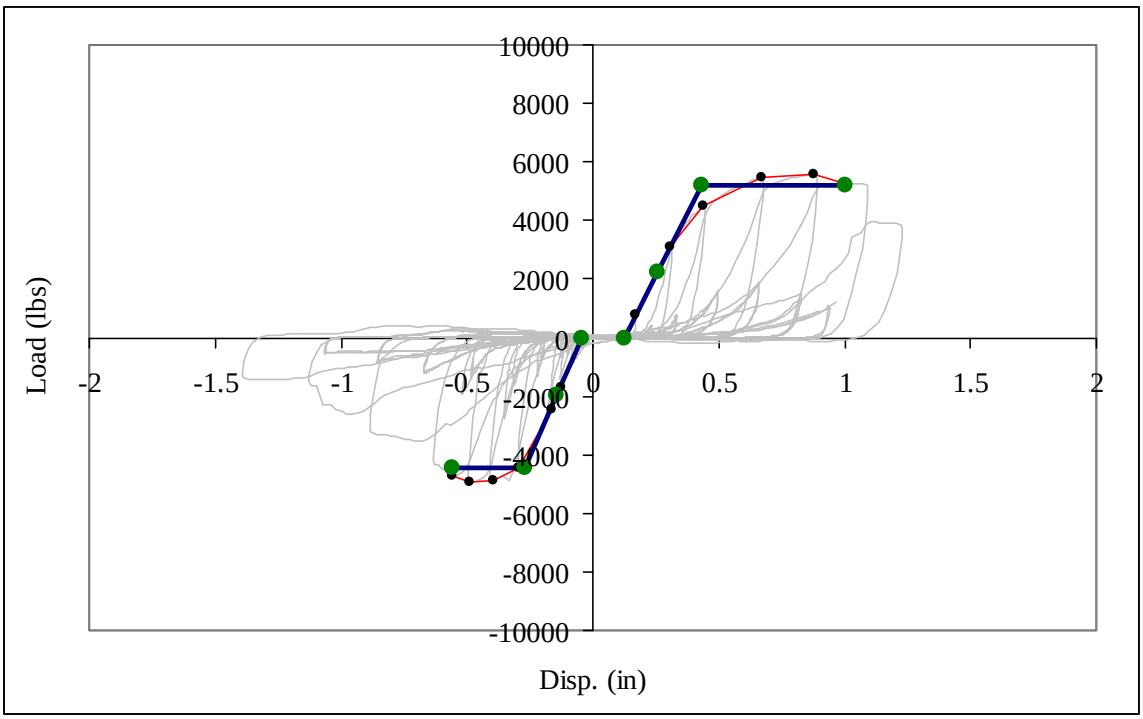

Figure A.97: Load-Deflection plot: C14-8.

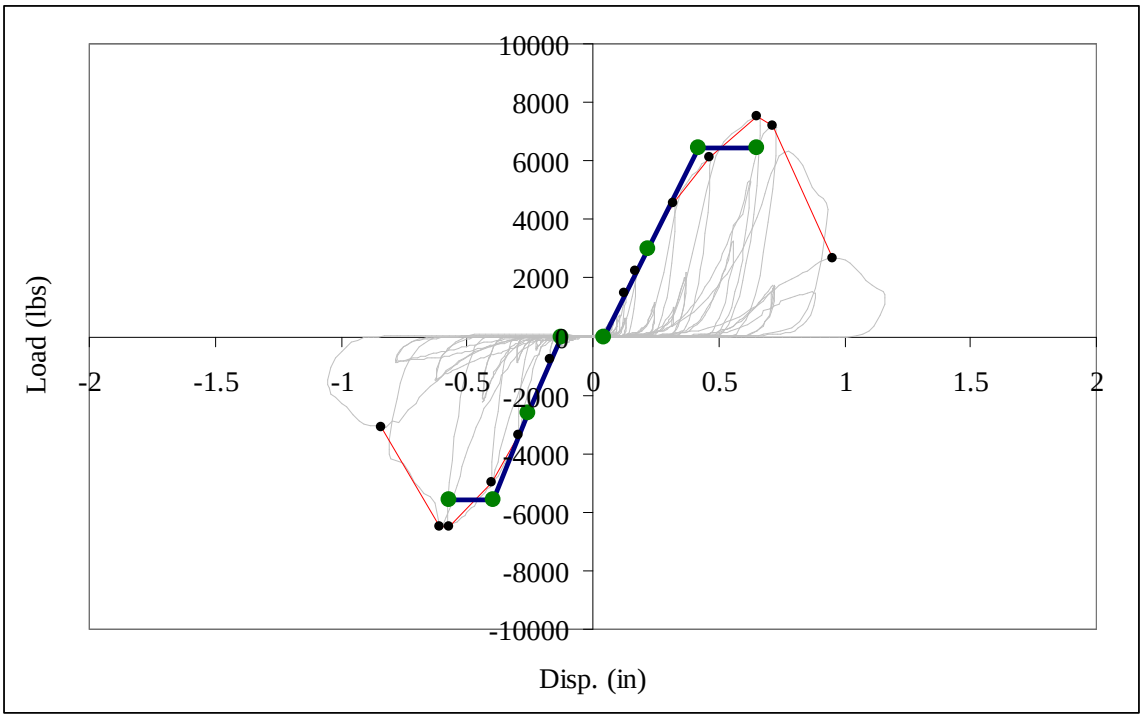

Figure A.98: Load-Deflection plot: C14-9.

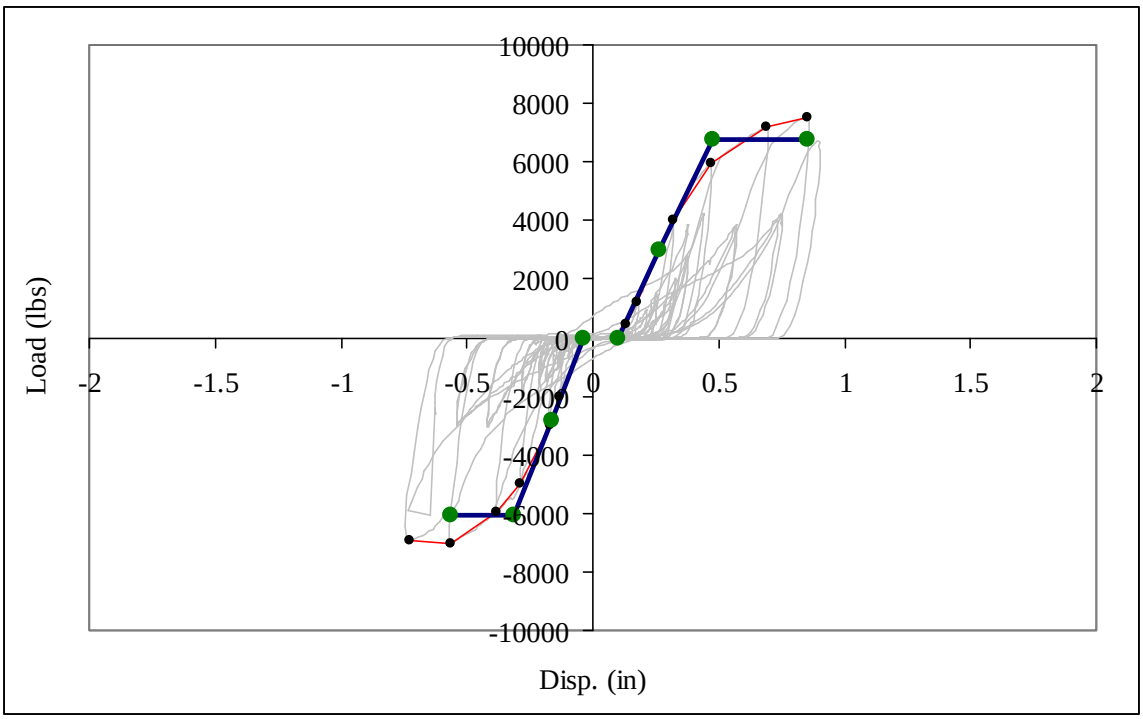

Figure A.99: Load-Deflection plot: C14-10.

Table A.28a: Connection performance properties (SI), Configuration 15.

Connection Performance Properties: Configuration 15

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	32.43	36.28	43.51	31.93	33.26	36.58	29.53	33.79	39.67	35.84	35.28	4.06	0.12
@Displacement (mm)	17.02	23.39	31.01	19.81	14.43	21.18	21.16	23.94	25.08	18.99	21.60	4.62	0.21
Failure Load (kN)	25.94	29.02	34.81	25.54	26.61	29.26	23.62	27.03	31.74	28.67	28.22	3.25	0.12
@Displacement (mm)	17.02	23.39	31.01	19.81	14.43	21.18	21.16	23.94	25.08	18.99	21.60	4.62	0.21
40% Max (kN)	12.97	14.51	17.40	12.77	13.31	14.63	11.81	13.52	15.87	14.33	14.11	1.63	0.12
@Displacement (mm)	5.56	6.47	7.13	7.67	5.02	6.13	6.63	6.25	6.80	5.73	6.34	0.78	0.12
Yield (kN)	29.63	32.82	38.56	29.95	29.70	32.13	26.99	29.86	34.47	30.76	31.49	3.22	0.10
@Displacement (mm)	10.07	12.65	14.15	10.77	9.64	11.04	12.92	11.46	12.16	10.41	11.53	1.42	0.12
5% Offset Yield (kN)	24.82	26.34	28.17	25.46	24.83	24.48	22.63	23.43	23.57	23.78	24.75	1.61	0.07
@Displacement (mm)	9.40	11.08	11.32	10.57	9.00	9.49	11.72	10.07	9.65	9.01	10.13	0.98	0.10
Elastic Stiff. (N/mm)	3699.23	2978.18	3022.79	Censored	3575.75	3602.86	2420.11	3133.45	3482.88	3551.55	3274.09	418.36	0.13
E.E.P. Energy (N*m)	330.17	547.01	903.16	356.25	269.68	473.95	379.41	522.62	619.03	405.04	480.63	183.32	0.38
Ductility Ratio	1.66	1.83	2.19	1.86	1.53	1.92	1.67	2.10	2.06	1.81	1.86	0.21	0.11
Yield Mode	IIIs	IIIs	IV	IIIs	IIIs	IIIs	IIIs-IV	IIIs-IV	IV	IIIs			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Both	Both	Both	Side	Both	Side	Main	Both	Both	Side			

Table A.28b: Connection performance properties (Std.), Configuration 15.

Connection Performance Properties: Configuration 15

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	7290.31	8155.30	9781.30	7177.79	7477.83	8223.56	6638.31	7596.35	8918.02	8056.03	7931.48	913.82	0.12
@ Displacement (in)	0.67	0.92	1.22	0.78	0.57	0.83	0.83	0.94	0.99	0.75	0.85	0.18	0.21
Failure Load (lbs)	5832.24	6524.24	7825.04	5742.23	5982.26	6578.85	5310.64	6077.08	7134.42	6444.82	6345.18	731.05	0.12
@ Displacement (in)	0.67	0.92	1.22	0.78	0.57	0.83	0.83	0.94	0.99	0.75	0.85	0.18	0.21
40% Max (lbs)	2916.12	3262.12	3912.52	2871.12	2991.13	3289.43	2655.32	3038.54	3567.21	3222.41	3172.59	365.53	0.12
@ Displacement (in)	0.22	0.25	0.28	0.30	0.20	0.24	0.26	0.25	0.27	0.23	0.25	0.03	0.12
Yield (lbs)	6662.21	7377.18	8669.42	6733.03	6675.72	7223.02	6067.26	6712.24	7749.73	6916.24	7078.61	724.92	0.10
@ Displacement (in)	0.40	0.50	0.56	0.42	0.38	0.43	0.51	0.45	0.48	0.41	0.45	0.06	0.12
5% Offset Yield (lbs)	5580.05	5921.27	6333.42	5723.36	5581.33	5503.40	5086.39	5267.62	5299.56	5346.12	5564.25	362.50	0.07
@ Displacement (in)	0.37	0.44	0.45	0.42	0.35	0.37	0.46	0.40	0.38	0.35	0.40	0.04	0.10
Elastic Stiff. (lb/in)	21123.12	17005.85	17260.57	Censored	20418.06	20572.87	13819.20	17892.48	19887.76	20279.87	18695.53	2388.88	0.13
E.E.P. Energy (lb*in)	2922.23	4841.44	7993.61	3153.04	2386.85	4194.83	3358.05	4625.58	5478.86	3584.88	4253.94	1622.55	0.38
Ductility Ratio	1.66	1.83	2.19	1.86	1.53	1.92	1.67	2.10	2.06	1.81	1.86	0.21	0.11
Yield Mode	IIIs	IIIs	IV	IIIs	IIIs	IIIs	IIIs-IV	IIIs-IV	IV	IIIs			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Both	Both	Both	Side	Both	Side	Main	Both	Both	Side			

Table A.29a: Member properties (SI), Configuration 15.

Member Properties: Configuration 15

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.08	16.42	16.18	16.60	15.15	15.25	16.20	15.48	16.08	15.29	15.77	0.58	0.04
S.G.	0.51	0.40	0.36	0.39	0.46	0.47	0.45	0.43	0.43	0.43	0.43	0.04	0.09
D.E. 5% Offset Yield (kPa)	25736	21730	22552	18864	26366	26464	21079	24831	21664	25308	23459	2620.00	0.11
D.E. Capacity (kPa)	26639	22648	23002	20086	26831	26601	22593	28025	24853	26481	24776	2558.93	0.10
Side Member													
M.C. (%)	15.96	16.30	15.52	15.05	15.05	14.92	16.64	16.48	15.80	15.23	15.69	0.64	0.04
S.G.	0.50	0.50	0.56	0.58	0.50	0.55	0.44	0.42	0.56	0.59	0.52	0.06	0.11
D.E. 5% Offset Yield (kPa)	26511	25730	31596	32561	28612	31642	18964	21214	34756	37331	28892	5842.40	0.20
D.E. Capacity (kPa)	28893	27358	31697	33112	29812	31642	20111	23589	35293	38798	30030	5454.82	0.18

Table A.29b: Member properties (Std.), Configuration 15.

Member Properties: Configuration 15

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.08	16.42	16.18	16.60	15.15	15.25	16.20	15.48	16.08	15.29	15.77	0.58	0.04
S.G.	0.51	0.40	0.36	0.39	0.46	0.47	0.45	0.43	0.43	0.43	0.43	0.04	0.09
D.E. 5% Offset Yield (psi)	3732.74	3151.62	3270.87	2735.99	3824.07	3838.23	3057.26	3601.36	3142.06	3670.59	3402.48	380.00	0.11
D.E. Capacity (psi)	3863.64	3284.85	3336.07	2913.21	3891.55	3858.13	3276.81	4064.70	3604.63	3840.66	3593.43	371.14	0.10
Side Member													
M.C. (%)	15.96	16.30	15.52	15.05	15.05	14.92	16.64	16.48	15.80	15.23	15.69	0.64	0.04
S.G.	0.50	0.50	0.56	0.58	0.50	0.55	0.44	0.42	0.56	0.59	0.52	0.06	0.11
D.E. 5% Offset Yield (psi)	3845.10	3731.73	4582.60	4722.48	4149.76	4589.26	2750.52	3076.80	5040.90	5414.42	4190.36	847.36	0.20
D.E. Capacity (psi)	4190.58	3967.86	4597.19	4802.44	4323.81	4589.26	2916.88	3421.29	5118.75	5627.13	4355.52	791.15	0.18

Table A.30a: Hysteretic connection properties (SI), Configuration 15.

Hysteretic Connection Properties: Configuration 15

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.66	0.56	0.85	0.59	0.12	0.20	-0.27	0.23	0.86	-0.77	0.11	0.14
Primary2	1.07	0.90	0.84	0.97	0.17	0.17	-0.46	0.40	0.88	-1.14	0.08	0.07
Primary3	3.11	2.23	0.72	2.28	0.12	0.05	-1.95	1.75	0.90	-2.45	0.09	0.04
Primary4	6.29	3.38	0.54	3.50	0.17	0.05	-4.31	2.98	0.69	-3.63	0.17	0.05
Primary5	10.03	4.39	0.44	4.72	0.20	0.04	-7.36	3.98	0.54	-4.67	0.27	0.06
Primary6	21.44	6.80	0.32	8.31	0.21	0.03	-16.48	4.30	0.26	-7.44	0.61	0.08
Primary7	28.01	8.89	0.32	11.59	0.41	0.04	-24.36	3.07	0.13	-9.94	0.83	0.08
Primary8	34.03	10.87	0.32	17.00	0.66	0.04	-30.18	2.25	0.07	-14.33	1.40	0.10
Primary9	36.76	12.09	0.33	22.29	1.02	0.05	-30.90	4.10	0.13	-18.70	1.20	0.06
Primary10	34.47	12.74	0.37	26.96	1.56	0.06	-27.11	8.04	0.30	-23.69	2.25	0.09
Primary11	29.06	13.17	0.45	30.71	3.62	0.12	-22.89	9.15	0.40	-28.83	1.90	0.07

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.40	0.25	0.63	0.30	0.19	0.64	0.23	0.09	0.41	694.46	479.65	0.69
Primary2	0.81	0.50	0.62	0.79	0.48	0.61	0.18	0.09	0.48	720.43	442.60	0.61
Primary3	4.38	1.88	0.43	5.96	2.30	0.39	0.13	0.05	0.40	1069.06	426.55	0.40
Primary4	10.26	3.68	0.36	18.73	6.70	0.36	0.10	0.03	0.35	1492.02	545.08	0.37
Primary5	18.44	6.30	0.34	40.73	13.83	0.34	0.08	0.01	0.20	1855.25	631.70	0.34
Primary6	75.07	21.87	0.29	150.18	20.50	0.14	0.08	0.02	0.24	2411.76	333.10	0.14
Primary7	133.95	19.97	0.15	283.50	27.51	0.10	0.08	0.01	0.13	2437.54	224.45	0.09
Primary8	346.93	36.48	0.11	505.13	35.22	0.07	0.11	0.01	0.09	2057.97	205.56	0.10
Primary9	509.72	25.66	0.05	699.84	83.16	0.12	0.12	0.02	0.14	1650.83	153.29	0.09
Primary10	571.28	70.57	0.12	781.05	178.34	0.23	0.12	0.02	0.15	1225.78	309.23	0.25
Primary11	556.66	144.20	0.26	782.92	267.69	0.34	0.12	0.03	0.22	873.29	272.00	0.31

Table A.30b: Hysteretic connection properties (Std.), Configuration 15.

Hysteretic Connection Properties: Configuration 15

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	148.26	126.03	0.85	0.02	0.00	0.20	-60.91	52.41	0.86	-0.03	0.00	0.14
Primary2	239.68	202.43	0.84	0.04	0.01	0.17	-103.06	90.43	0.88	-0.04	0.00	0.07
Primary3	698.81	501.98	0.72	0.09	0.00	0.05	-438.51	394.02	0.90	-0.10	0.00	0.04
Primary4	1413.17	758.90	0.54	0.14	0.01	0.05	-967.87	669.33	0.69	-0.14	0.01	0.05
Primary5	2255.75	985.85	0.44	0.19	0.01	0.04	-1654.12	895.72	0.54	-0.18	0.01	0.06
Primary6	4820.46	1528.04	0.32	0.33	0.01	0.03	-3704.91	967.59	0.26	-0.29	0.02	0.08
Primary7	6297.37	1998.23	0.32	0.46	0.02	0.04	-5475.81	689.76	0.13	-0.39	0.03	0.08
Primary8	7650.82	2443.97	0.32	0.67	0.03	0.04	-6785.46	505.19	0.07	-0.56	0.06	0.10
Primary9	8263.92	2719.06	0.33	0.88	0.04	0.05	-6947.04	921.66	0.13	-0.74	0.05	0.06
Primary10	7748.37	2863.53	0.37	1.06	0.06	0.06	-6095.46	1807.62	0.30	-0.93	0.09	0.09
Primary11	6533.26	2961.03	0.45	1.21	0.14	0.12	-5145.70	2057.85	0.40	-1.14	0.07	0.07

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	3.54	2.24	0.63	2.62	1.68	0.64	0.27	0.12	0.44	3965.47	2738.86	0.69
Primary2	7.13	4.45	0.62	7.00	4.24	0.61	0.25	0.11	0.46	4113.78	2527.31	0.61
Primary3	38.78	16.64	0.43	52.77	20.34	0.39	0.19	0.10	0.53	6104.52	2435.64	0.40
Primary4	90.84	32.57	0.36	165.73	59.33	0.36	0.14	0.08	0.55	8519.67	3112.51	0.37
Primary5	163.23	55.76	0.34	360.47	122.40	0.34	0.11	0.05	0.41	10593.75	3607.12	0.34
Primary6	664.43	193.60	0.29	1329.19	181.42	0.14	0.10	0.04	0.35	13771.50	1902.02	0.14
Primary7	1185.52	176.74	0.15	2509.18	243.49	0.10	0.08	0.01	0.17	13918.73	1281.65	0.09
Primary8	3070.63	322.90	0.11	4470.77	311.68	0.07	0.11	0.01	0.09	11751.30	1173.76	0.10
Primary9	4511.40	227.12	0.05	6194.08	736.02	0.12	0.12	0.02	0.13	9426.50	875.33	0.09
Primary10	5056.28	624.63	0.12	6912.84	1578.43	0.23	0.12	0.02	0.15	6999.39	1765.73	0.25
Primary11	4926.90	1276.32	0.26	6929.43	2369.24	0.34	0.12	0.03	0.22	4986.61	1553.17	0.31

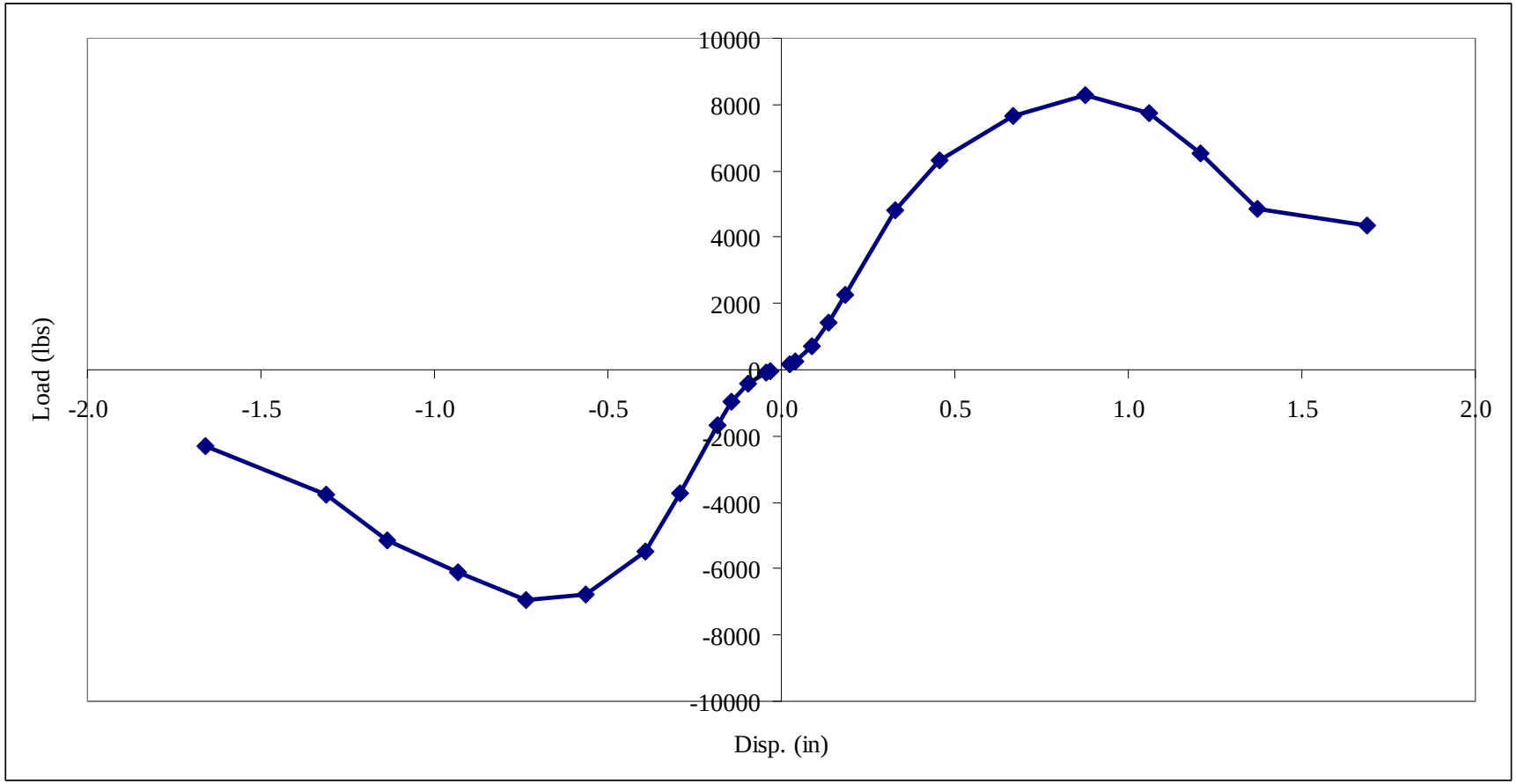

Figure A.100: Mean envelope curve: Configuration 15.

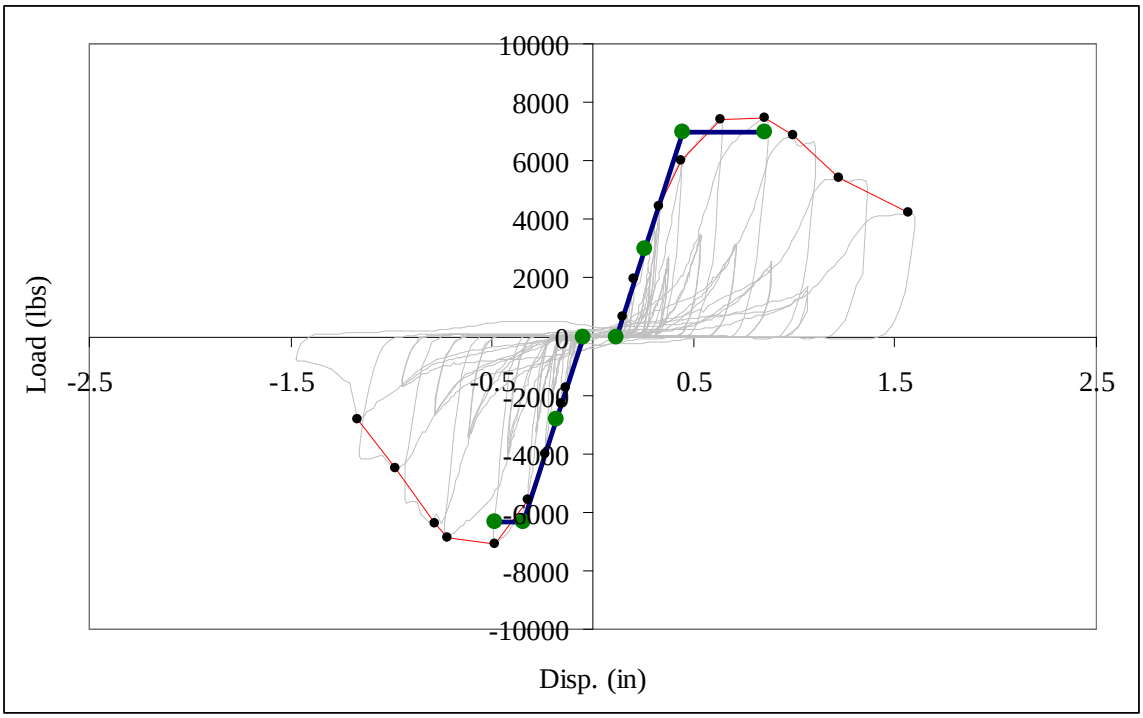

Figure A.101: Load-Deflection plot: C15-1.

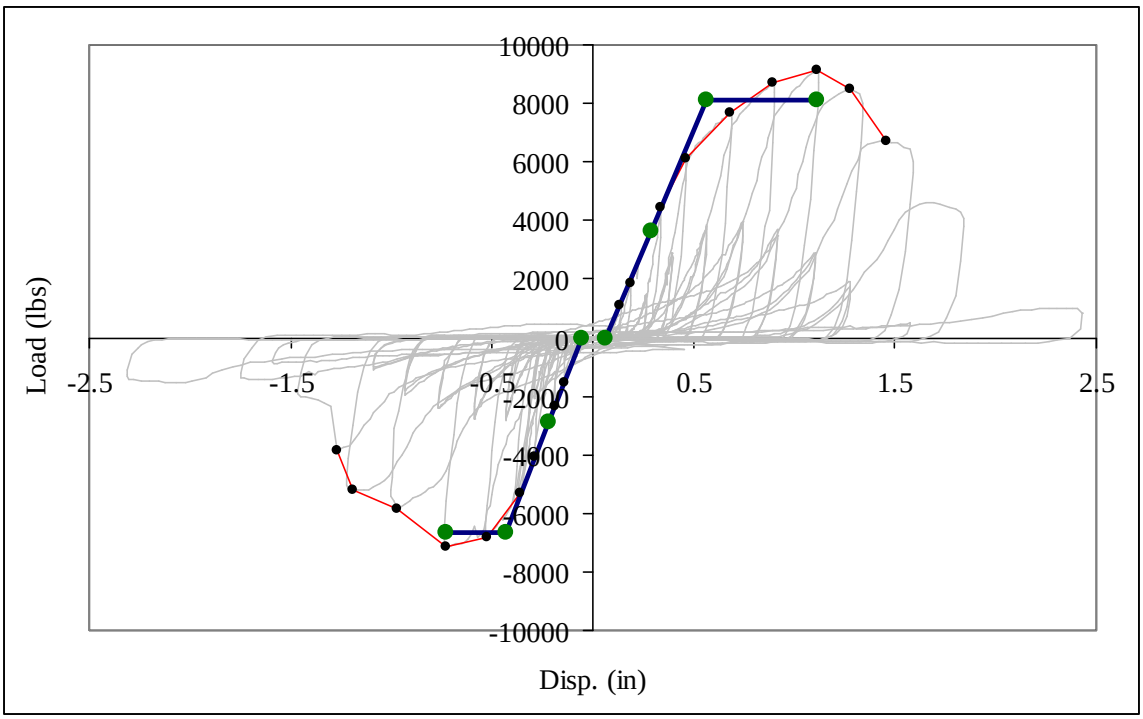

Figure A.102: Load-Deflection plot: C15-2.

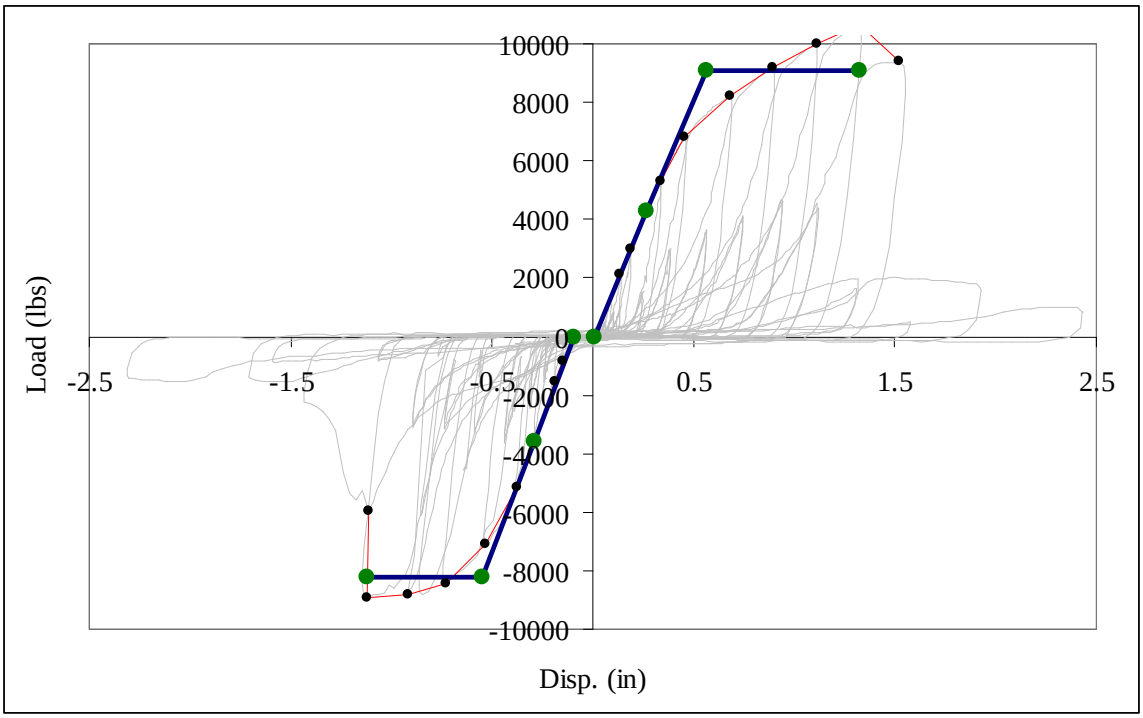

Figure A.103: Load-Deflection plot: C15-3.

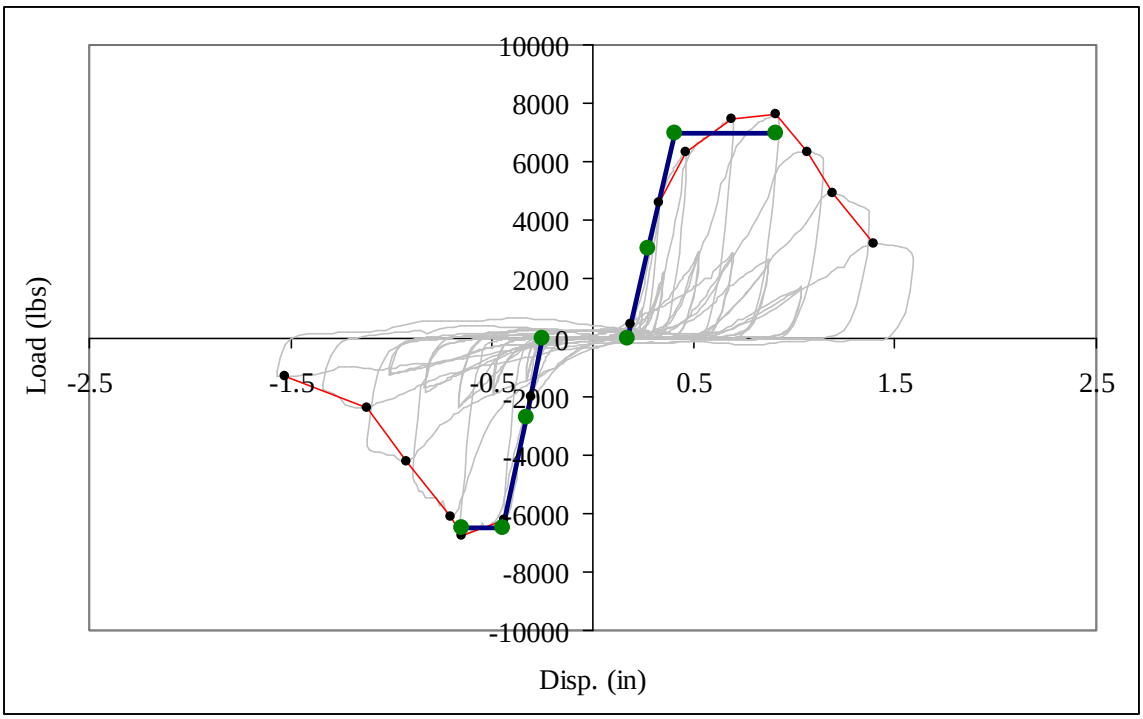

Figure A.104: Load-Deflection plot: C15-4.

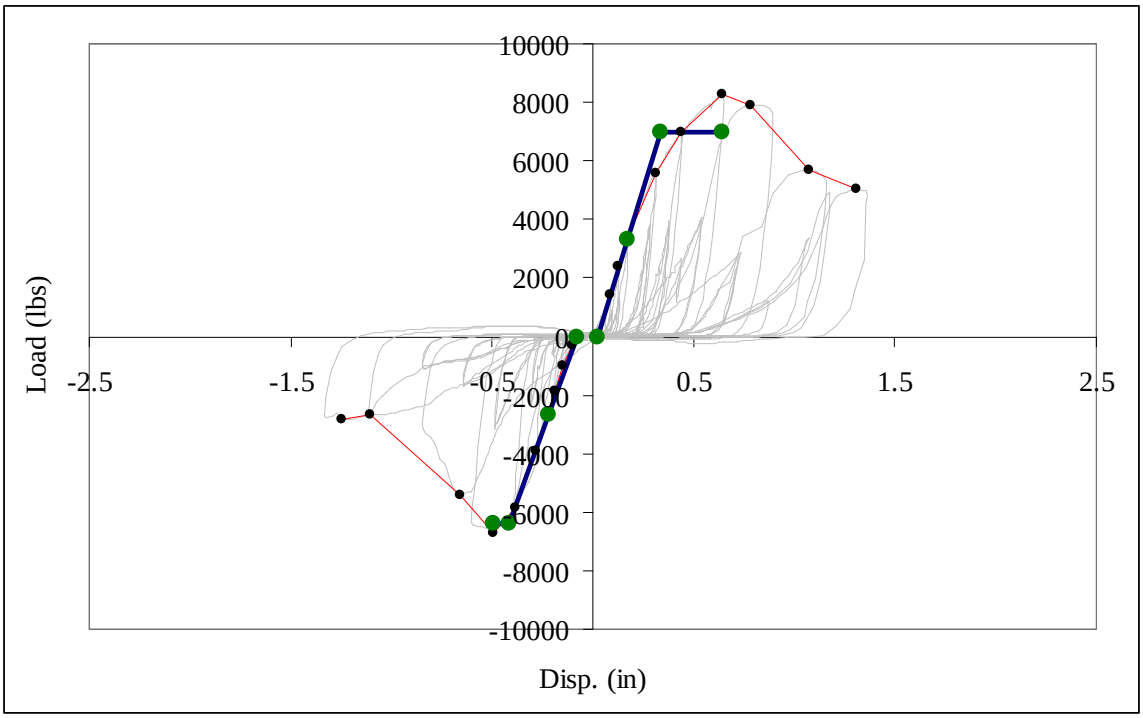

Figure A.105: Load-Deflection plot: C15-5.

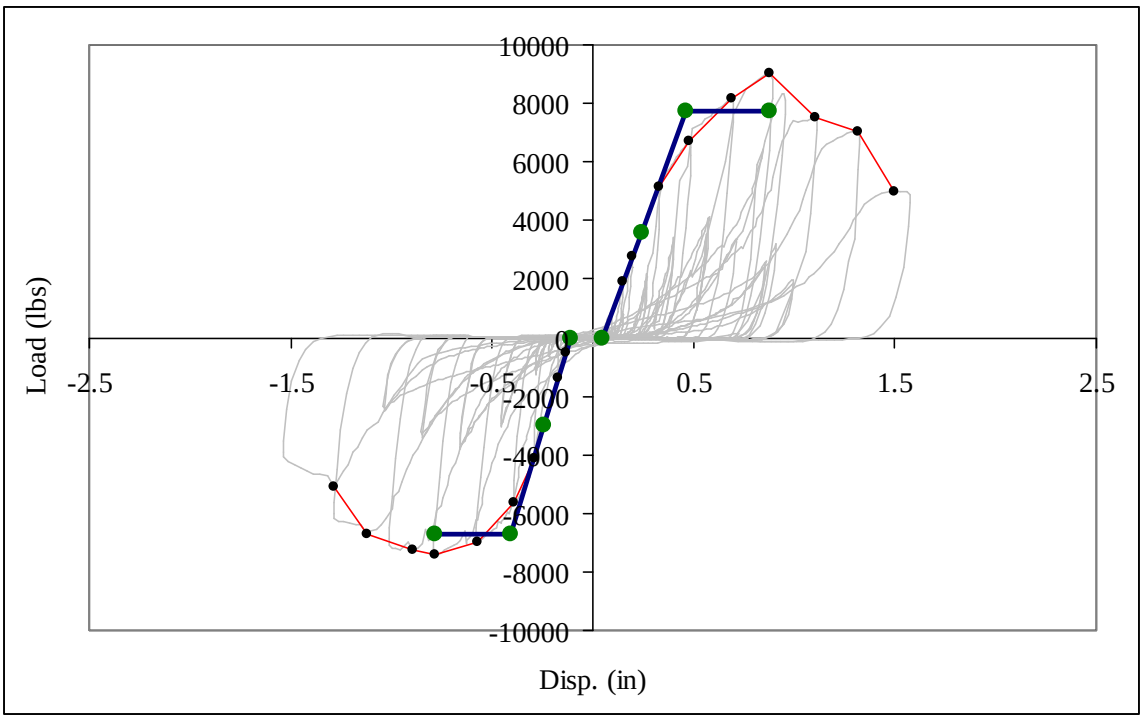

Figure A.106: Load-Deflection plot: C15-6.

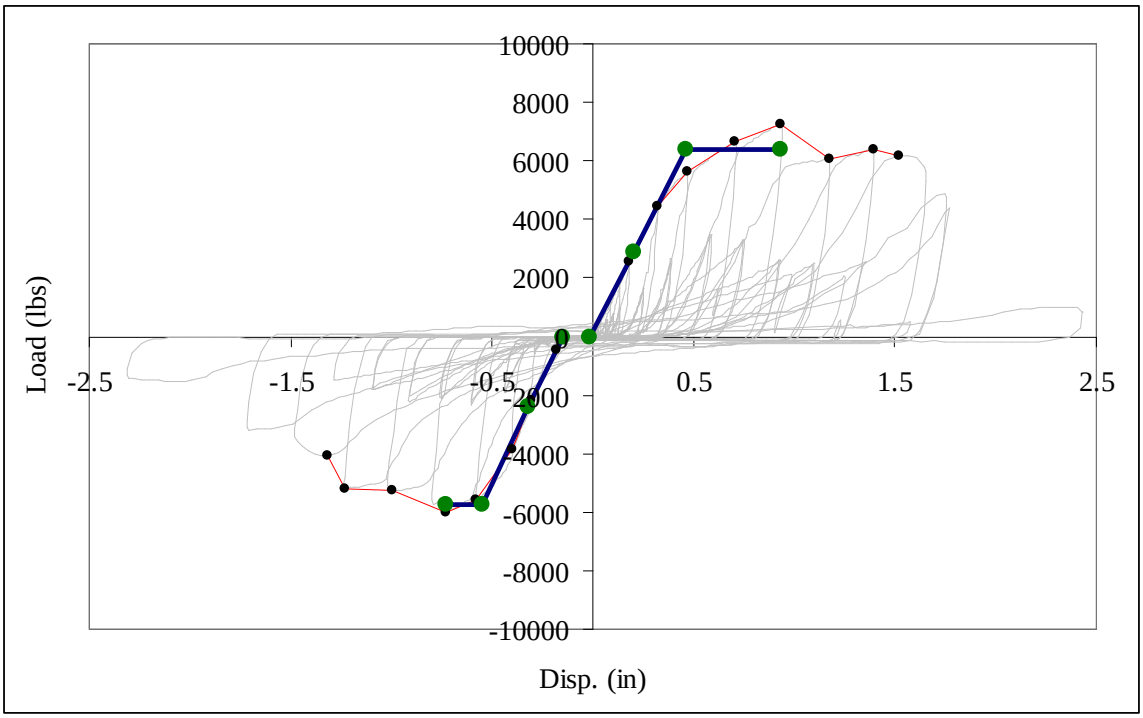

Figure A.107: Load-Deflection plot: C15-7.

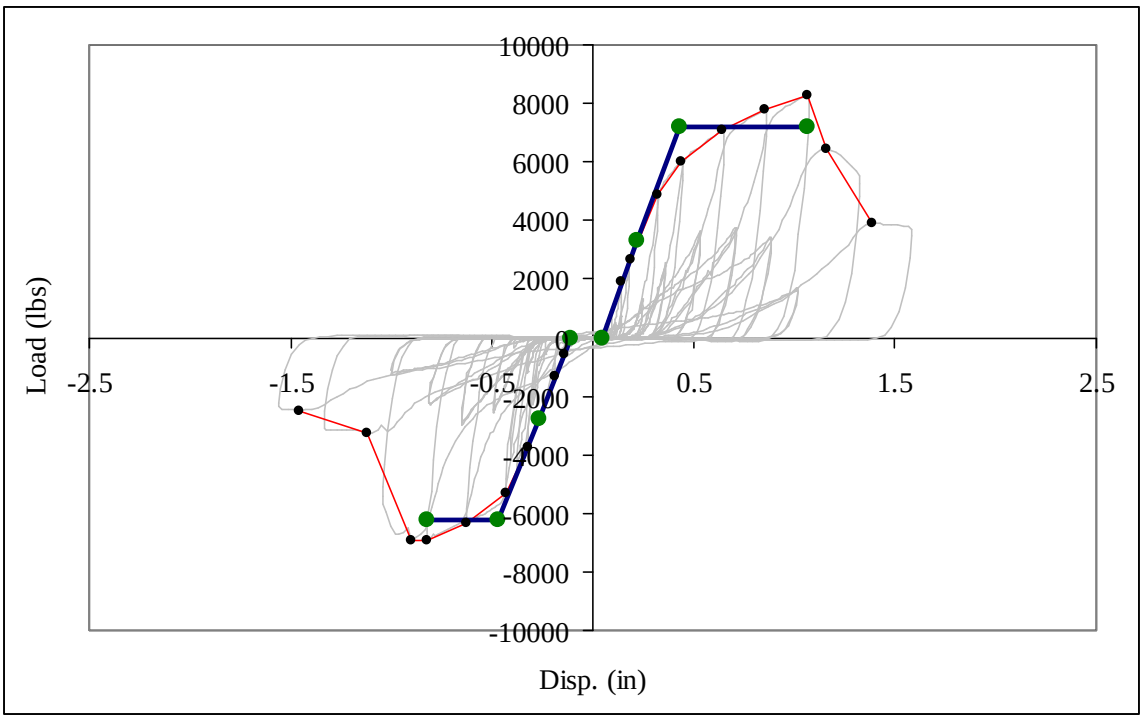

Figure A.108: Load-Deflection plot: C15-8.

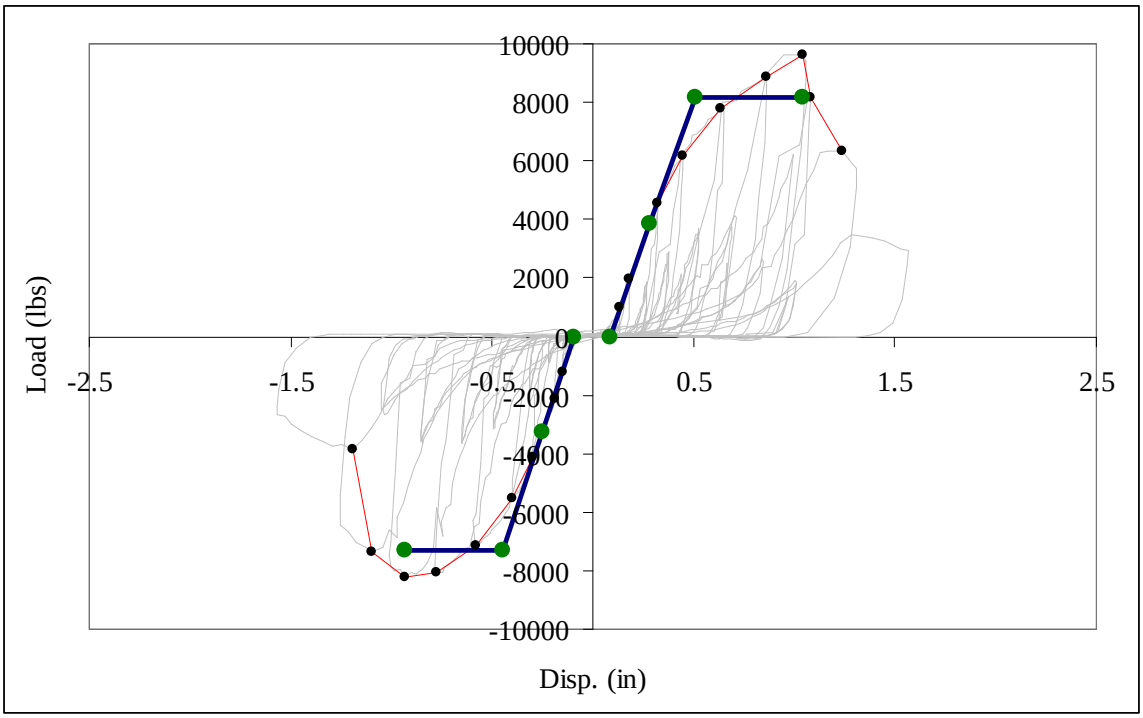

Figure A.109: Load-Deflection plot: C15-9.

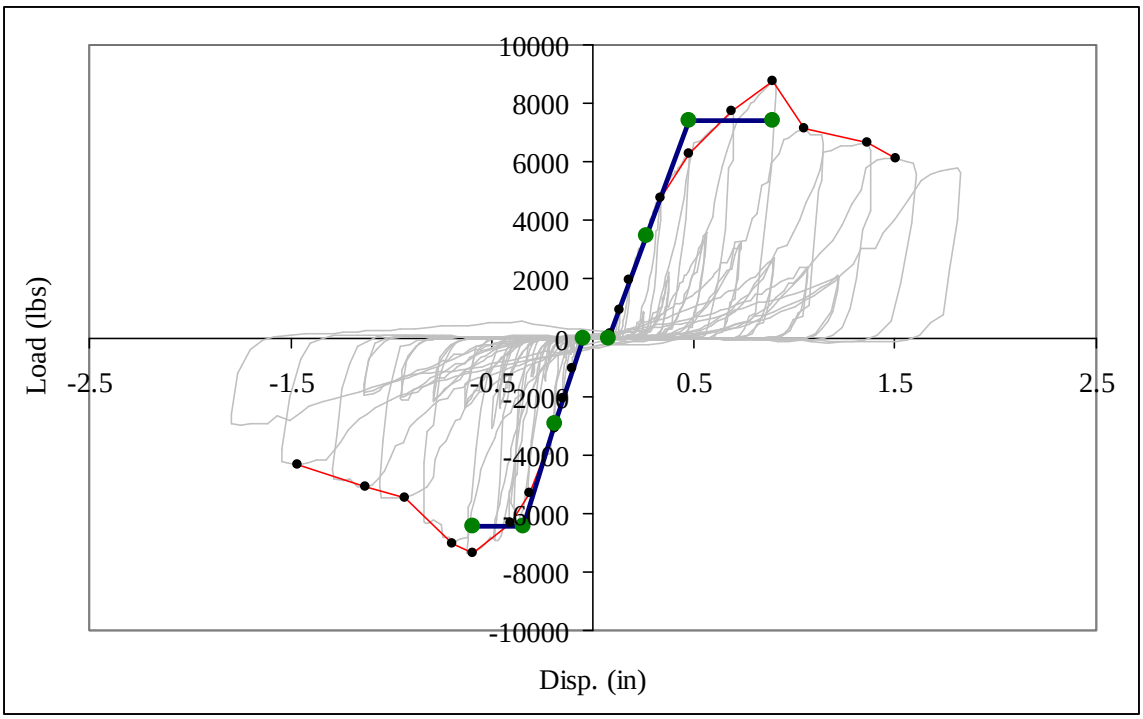

Figure A.110: Load-Deflection plot: C15-10.

Table A.31a: Connection performance properties (SI), Configuration 16.

Connection Performance Properties: Configuration 16

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	32.78	31.30	32.73	43.81	38.14	33.93	29.82	36.81	36.33	35.11	35.08	4.00	0.11
@Displacement (mm)	25.45	18.53	26.54	27.91	28.19	25.31	13.83	21.09	18.82	20.26	22.59	4.79	0.21
Failure Load (kN)	26.22	25.04	26.18	35.05	30.51	27.14	23.86	29.45	29.07	28.09	28.06	3.20	0.11
@Displacement (mm)	25.45	18.53	27.74	27.91	28.19	25.31	13.83	21.09	18.82	20.26	22.71	4.91	0.22
40% Max (kN)	13.11	12.52	14.74	17.53	15.26	13.57	11.93	14.72	14.53	14.04	14.20	1.58	0.11
@Displacement (mm)	6.03	5.64	8.48	6.67	6.42	5.41	4.85	5.62	5.55	5.91	6.06	0.99	0.16
Yield (kN)	28.51	28.42	29.14	39.65	33.68	29.63	26.58	34.78	31.09	31.50	31.30	3.85	0.12
@Displacement (mm)	11.77	11.03	15.73	15.71	13.16	10.68	9.25	12.86	9.73	12.46	12.24	2.23	0.18
5% Offset Yield (kN)	20.54	23.67	25.44	32.18	25.27	20.74	23.38	31.00	23.47	25.75	25.14	3.84	0.15
@Displacement (mm)	9.44	10.00	14.50	13.29	10.71	8.41	8.94	12.12	8.44	10.94	10.68	2.08	0.19
Elastic Stiff. (N/mm)	2693.25	2959.39	2044.80	2446.37	2749.78	3038.85	3347.97	2781.84	3958.17	2667.91	2868.83	516.80	0.18
E.E.P. Energy (N*m)	541.28	350.75	518.00	803.11	713.73	568.66	227.18	505.43	404.63	431.00	506.37	168.16	0.33
Ductility Ratio	2.16	1.73	1.74	1.78	2.20	2.46	1.55	1.66	1.95	1.64	1.89	0.30	0.16
Yield Mode	IIIs	IIIs	IIIs-IV	IIIs	IIIs	IIIs	IIIs	IIIs	IIIs	IIIs			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Balk. Shr.	Balk. Shr.			
Governing Member	Side	Both	Side	Both	Side	Side	Both	Side	Side	Side			

Table A.31b: Connection performance properties (Std.), Configuration 16.

Connection Performance Properties: Configuration 16

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	7369.13	7036.03	7357.16	9849.77	8574.07	7627.72	6704.75	8274.68	8168.20	7892.46	7885.40	900.12	0.11
@ Displacement (in)	1.00	0.73	1.05	1.10	1.11	1.00	0.54	0.83	0.74	0.80	0.89	0.19	0.21
Failure Load (lbs)	5895.30	5628.82	5885.72	7879.82	6859.26	6102.17	5363.80	6619.74	6534.56	6313.97	6308.32	720.10	0.11
@ Displacement (in)	1.00	0.73	1.09	1.10	1.11	1.00	0.54	0.83	0.74	0.80	0.89	0.19	0.22
40% Max (lbs)	2947.65	2814.41	3313.34	3939.91	3429.63	3051.09	2681.90	3309.87	3267.28	3156.99	3191.21	354.91	0.11
@ Displacement (in)	0.24	0.22	0.33	0.26	0.25	0.21	0.19	0.22	0.22	0.23	0.24	0.04	0.16
Yield (lbs)	6409.47	6388.70	6551.23	8914.64	7570.99	6661.10	5976.09	7817.91	6988.39	7081.54	7036.01	865.49	0.12
@ Displacement (in)	0.46	0.43	0.62	0.62	0.52	0.42	0.36	0.51	0.38	0.49	0.48	0.09	0.18
5% Offset Yield (lbs)	4617.54	5322.34	5720.17	7234.95	5679.92	4662.02	5257.03	6968.08	5276.21	5787.74	5652.60	863.95	0.15
@ Displacement (in)	0.37	0.39	0.57	0.52	0.42	0.33	0.35	0.48	0.33	0.43	0.42	0.08	0.19
Elastic Stiff. (lb/in)	15378.85	16898.55	11676.13	13969.15	15701.67	17352.29	19117.38	15884.74	22601.71	15234.18	16381.47	2951.01	0.18
E.E.P. Energy (lb*in)	4790.70	3104.37	4584.65	7108.10	6317.05	5033.04	2010.67	4473.43	3581.26	3814.68	4481.80	1488.30	0.33
Ductility Ratio	2.16	1.73	1.74	1.78	2.20	2.46	1.55	1.66	1.95	1.64	1.89	0.30	0.16
Yield Mode	IIIs	IIIs	IIIs-IV	IIIs	IIIs	IIIs	IIIs	IIIs	IIIs	IIIs			
Failure Mode	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting	Balk. Shr.	Balk. Shr.			
Governing Member	Side	Both	Side	Both	Side	Side	Both	Side	Side	Side			

Table A.32a: Member properties (SI), Configuration 16.

Member Properties: Configuration 16

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.21	15.23	16.06	15.56	15.53	14.18	15.06	15.83	16.26	16.26	15.52	0.64	0.04
S.G.	0.50	0.58	0.51	0.52	0.53	0.55	0.62	0.51	0.51	0.46	0.53	0.04	0.08
D.E. 5% Offset Yield (kPa)	22336	32755	20645	25781	25869	28742	32774	24888	20930	20851	25557	4627.08	0.18
D.E. Capacity (kPa)	26914	36099	23821	27729	28617	29574	35363	26101	25854	22726	28280	4430.06	0.16
Side Member													
M.C. (%)	16.47	13.17	14.36	16.29	14.63	16.72	16.07	15.55	15.95	14.57	15.38	1.14	0.07
S.G.	0.48	0.45	0.46	0.55	0.43	0.49	0.44	0.59	0.51	0.47	0.49	0.05	0.10
D.E. 5% Offset Yield (kPa)	24351	24030	24616	27708	24264	22713	24300	28074	25870	30286	25621	2342.64	0.09
D.E. Capacity (kPa)	25927	24030	24616	27708	24264	22713	24300	28074	25870	30286	25779	2300.33	0.09

Table A.32b: Member properties (Std.), Configuration 16.

Member Properties: Configuration 16

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.21	15.23	16.06	15.56	15.53	14.18	15.06	15.83	16.26	16.26	15.52	0.64	0.04
S.G.	0.50	0.58	0.51	0.52	0.53	0.55	0.62	0.51	0.51	0.46	0.53	0.04	0.08
D.E. 5% Offset Yield (psi)	3239.52	4750.66	2994.26	3739.25	3751.89	4168.59	4753.48	3609.74	3035.69	3024.21	3706.73	671.10	0.18
D.E. Capacity (psi)	3903.56	5235.75	3454.91	4021.78	4150.54	4289.36	5128.91	3785.54	3749.83	3296.15	4101.63	642.52	0.16
Side Member													
M.C. (%)	16.47	13.17	14.36	16.29	14.63	16.72	16.07	15.55	15.95	14.57	15.38	1.14	0.07
S.G.	0.48	0.45	0.46	0.55	0.43	0.49	0.44	0.59	0.51	0.47	0.49	0.05	0.10
D.E. 5% Offset Yield (psi)	3531.82	3485.27	3570.28	4018.65	3519.24	3294.16	3524.43	4071.77	3752.13	4392.58	3716.03	339.77	0.09
D.E. Capacity (psi)	3760.39	3485.27	3570.28	4018.65	3519.24	3294.16	3524.43	4071.77	3752.13	4392.58	3738.89	333.63	0.09

Table A.33a: Hysteretic connection properties (SI), Configuration 16.

Hysteretic Connection Properties: Configuration 16

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	1.69	1.26	0.74	0.32	0.15	0.47	-1.50	0.72	0.48	-0.35	0.11	0.31
Primary2	2.40	1.63	0.68	0.59	0.18	0.30	-2.13	0.99	0.46	-0.70	0.14	0.21
Primary3	4.16	2.82	0.68	1.84	0.10	0.05	-4.07	1.53	0.38	-1.78	0.22	0.12
Primary4	6.46	3.81	0.59	3.04	0.15	0.05	-7.42	2.46	0.33	-3.05	0.14	0.05
Primary5	9.39	4.36	0.46	4.29	0.24	0.06	-9.94	2.61	0.26	-4.06	0.25	0.06
Primary6	17.93	6.37	0.36	7.69	0.39	0.05	-16.51	2.68	0.16	-6.60	0.61	0.09
Primary7	24.46	8.09	0.33	10.52	0.67	0.06	-22.44	2.93	0.13	-8.99	0.69	0.08
Primary8	30.46	9.97	0.33	15.32	0.68	0.04	-29.03	2.59	0.09	-12.70	1.42	0.11
Primary9	33.19	11.09	0.33	20.21	1.29	0.06	-32.51	3.57	0.11	-17.26	1.50	0.09
Primary10	33.26	11.45	0.34	25.39	1.50	0.06	-33.03	5.55	0.17	-21.77	1.75	0.08
Primary11	28.82	12.67	0.44	30.17	2.69	0.09	-28.36	10.86	0.38	-25.32	2.50	0.10

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**	**Mean**	**StDev**	**COV**
Primary1	0.66	0.34	0.53	0.61	0.36	0.59	0.17	0.04	0.22	4544.61	2084.91	0.46
Primary2	1.42	0.67	0.47	1.54	0.74	0.48	0.14	0.02	0.17	3428.82	1478.98	0.43
Primary3	6.00	3.27	0.55	7.42	2.87	0.39	0.12	0.04	0.30	2267.11	778.55	0.34
Primary4	13.61	4.25	0.31	20.96	3.41	0.16	0.10	0.02	0.21	2283.13	407.95	0.18
Primary5	20.97	4.29	0.20	39.97	4.54	0.11	0.08	0.01	0.14	2313.74	243.49	0.11
Primary6	71.02	13.42	0.19	122.70	11.28	0.09	0.09	0.02	0.22	2418.38	310.62	0.13
Primary7	119.61	21.55	0.18	228.79	13.24	0.06	0.08	0.01	0.16	2417.05	304.42	0.13
Primary8	286.42	43.61	0.15	417.52	32.83	0.08	0.11	0.01	0.11	2134.89	244.41	0.11
Primary9	460.42	48.45	0.11	617.16	79.61	0.13	0.12	0.01	0.08	1758.17	187.24	0.11
Primary10	604.08	75.76	0.13	781.97	124.13	0.16	0.12	0.01	0.08	1407.66	214.40	0.15
Primary11	635.43	175.95	0.28	803.72	283.15	0.35	0.13	0.03	0.23	1022.49	305.78	0.30

Table A.33b: Hysteretic connection properties (Std.), Configuration 16.

Hysteretic Connection Properties: Configuration 16

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	380.94	283.73	0.74	0.01	0.01	0.47	-336.52	161.80	0.48	-0.01	0.00	0.31
Primary2	539.85	366.04	0.68	0.02	0.01	0.30	-479.28	221.48	0.46	-0.03	0.01	0.21
Primary3	935.79	634.90	0.68	0.07	0.00	0.05	-915.25	344.01	0.38	-0.07	0.01	0.12
Primary4	1453.10	857.18	0.59	0.12	0.01	0.05	-1667.23	552.53	0.33	-0.12	0.01	0.05
Primary5	2110.62	979.44	0.46	0.17	0.01	0.06	-2235.28	585.97	0.26	-0.16	0.01	0.06
Primary6	4029.79	1433.08	0.36	0.30	0.02	0.05	-3712.49	602.63	0.16	-0.26	0.02	0.09
Primary7	5498.56	1818.04	0.33	0.41	0.03	0.06	-5044.04	658.99	0.13	-0.35	0.03	0.08
Primary8	6848.49	2241.95	0.33	0.60	0.03	0.04	-6526.66	582.00	0.09	-0.50	0.06	0.11
Primary9	7462.08	2493.09	0.33	0.80	0.05	0.06	-7308.02	801.98	0.11	-0.68	0.06	0.09
Primary10	7477.13	2574.88	0.34	1.00	0.06	0.06	-7424.48	1248.75	0.17	-0.86	0.07	0.08
Primary11	6479.92	2848.37	0.44	1.19	0.11	0.09	-6374.98	2442.20	0.38	-1.00	0.10	0.10

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	5.80	3.05	0.53	5.37	3.17	0.59	0.19	0.06	0.34	25950.41	11905.12	0.46
Primary2	12.61	5.95	0.47	13.60	6.52	0.48	0.17	0.06	0.36	19579.05	8445.19	0.43
Primary3	53.15	28.98	0.55	65.64	25.40	0.39	0.14	0.07	0.46	12945.51	4445.64	0.34
Primary4	120.44	37.64	0.31	185.47	30.14	0.16	0.11	0.03	0.30	13037.01	2329.45	0.18
Primary5	185.62	37.97	0.20	353.74	40.18	0.11	0.09	0.02	0.27	13211.78	1390.38	0.11
Primary6	628.60	118.78	0.19	1085.98	99.82	0.09	0.09	0.02	0.20	13809.28	1773.70	0.13
Primary7	1058.61	190.72	0.18	2025.01	117.23	0.06	0.09	0.01	0.10	13801.69	1738.29	0.13
Primary8	2535.06	385.97	0.15	3695.39	290.60	0.08	0.11	0.01	0.10	12190.56	1395.62	0.11
Primary9	4075.06	428.82	0.11	5462.36	704.61	0.13	0.12	0.01	0.11	10039.38	1069.15	0.11
Primary10	5346.57	670.58	0.13	6921.06	1098.68	0.16	0.13	0.02	0.14	8037.96	1224.25	0.15
Primary11	5624.06	1557.26	0.28	7113.49	2506.08	0.35	0.13	0.03	0.23	5838.55	1746.05	0.30

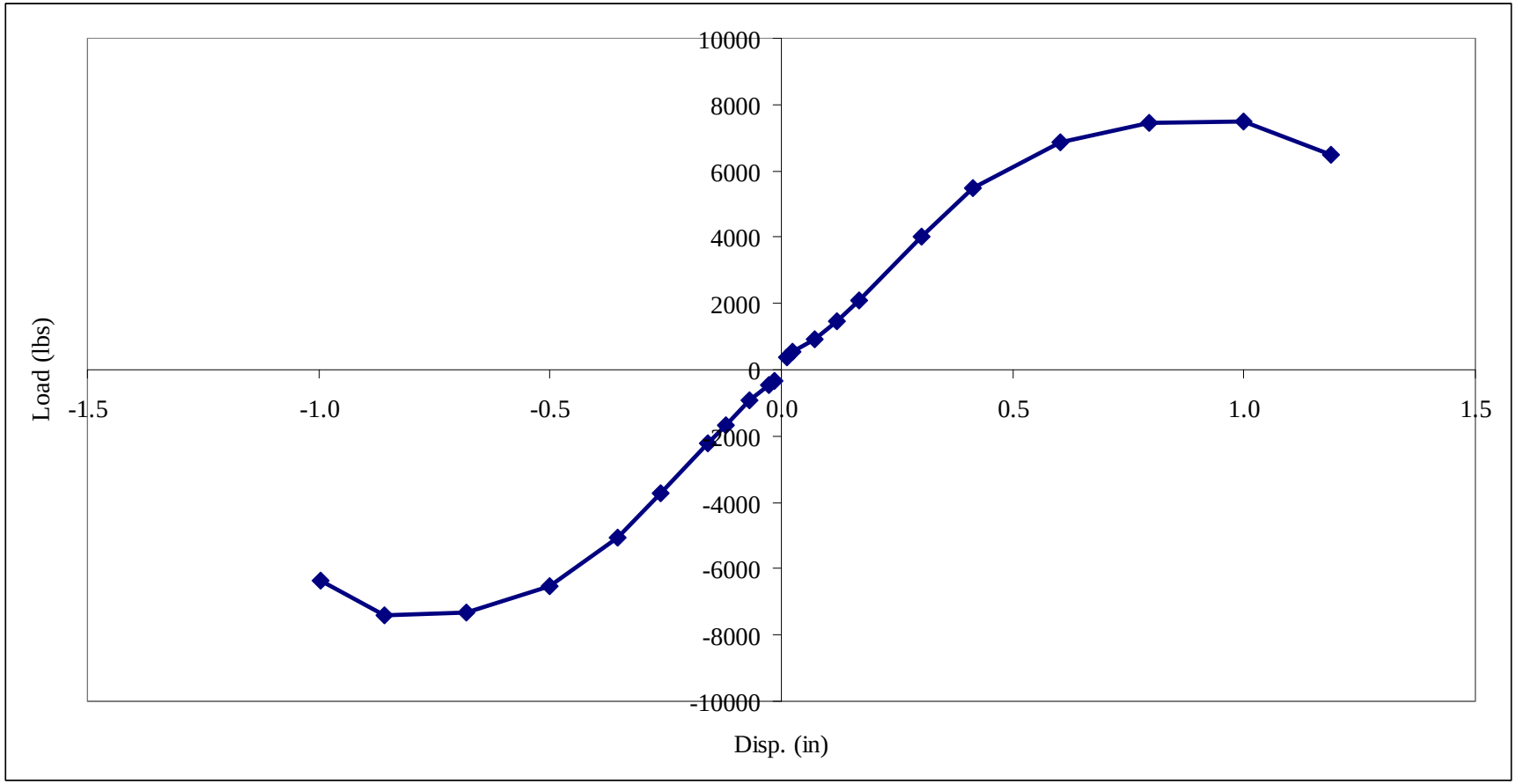

Figure A.111: Mean envelope curve: Configuration 16.

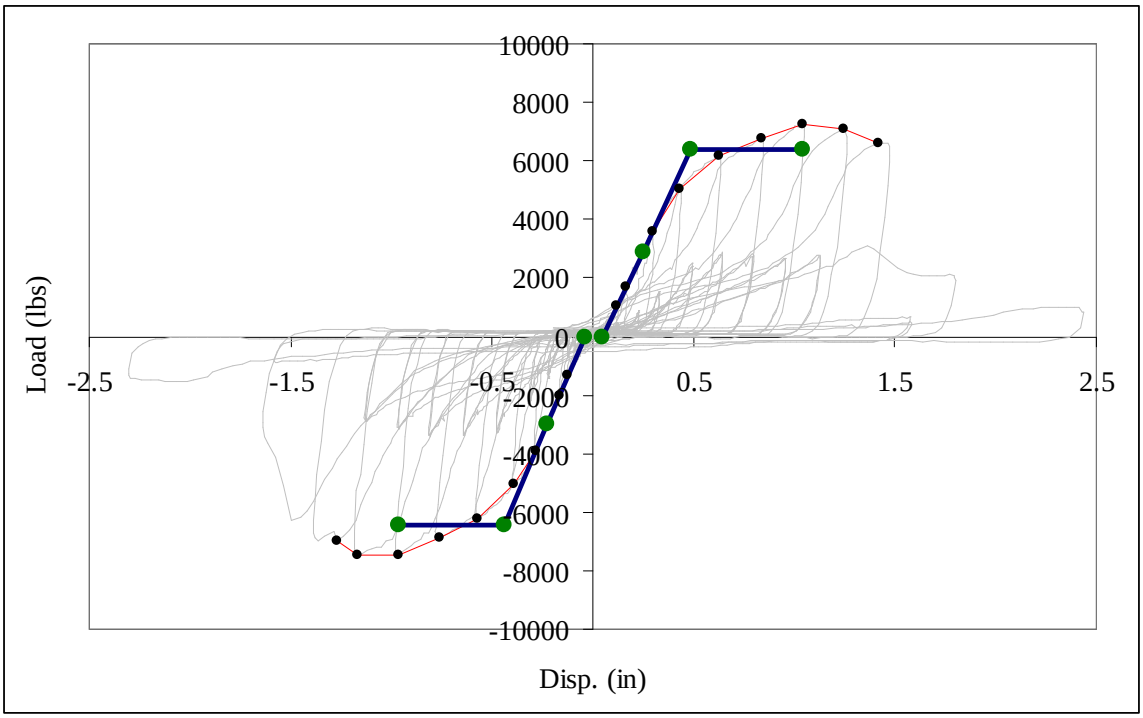

Figure A.112: Load-Deflection plot: C16-1.

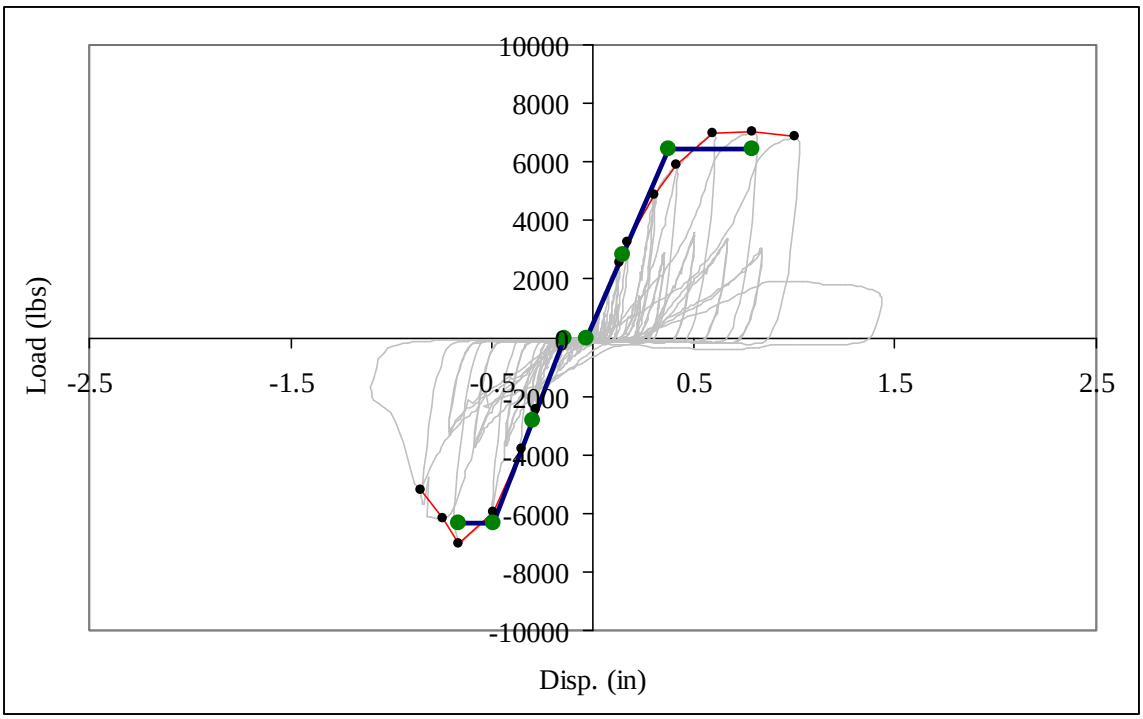

Figure A.113: Load-Deflection plot: C16-2.

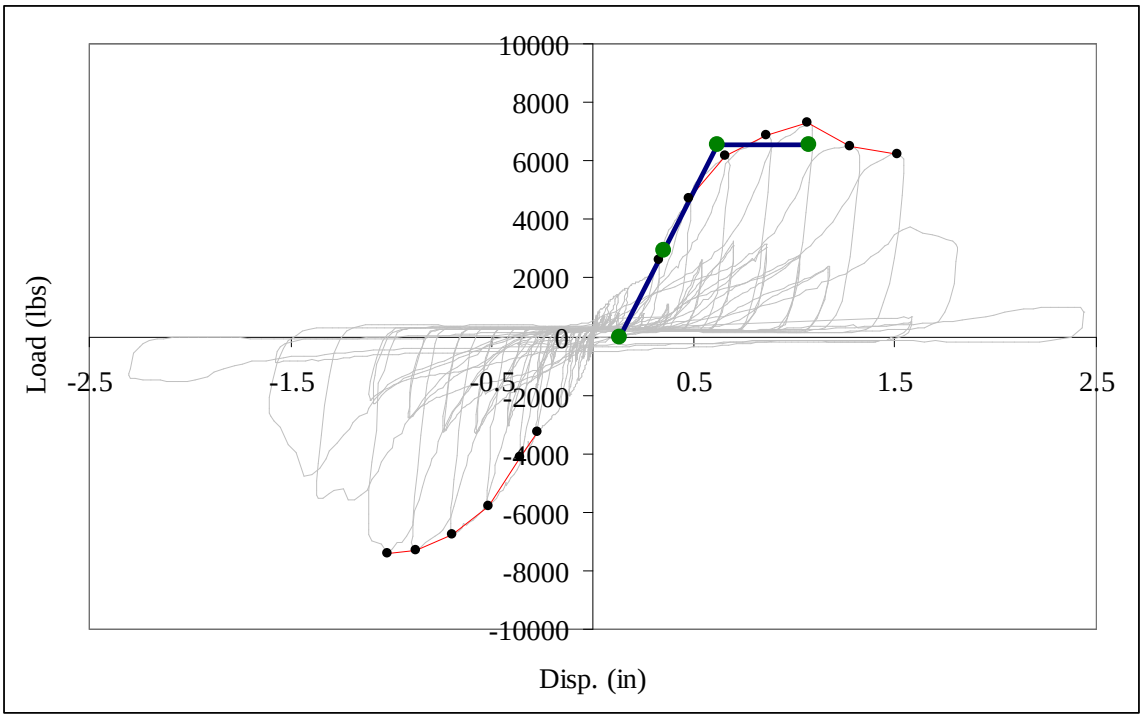

Figure A.114: Load-Deflection plot: C16-3.

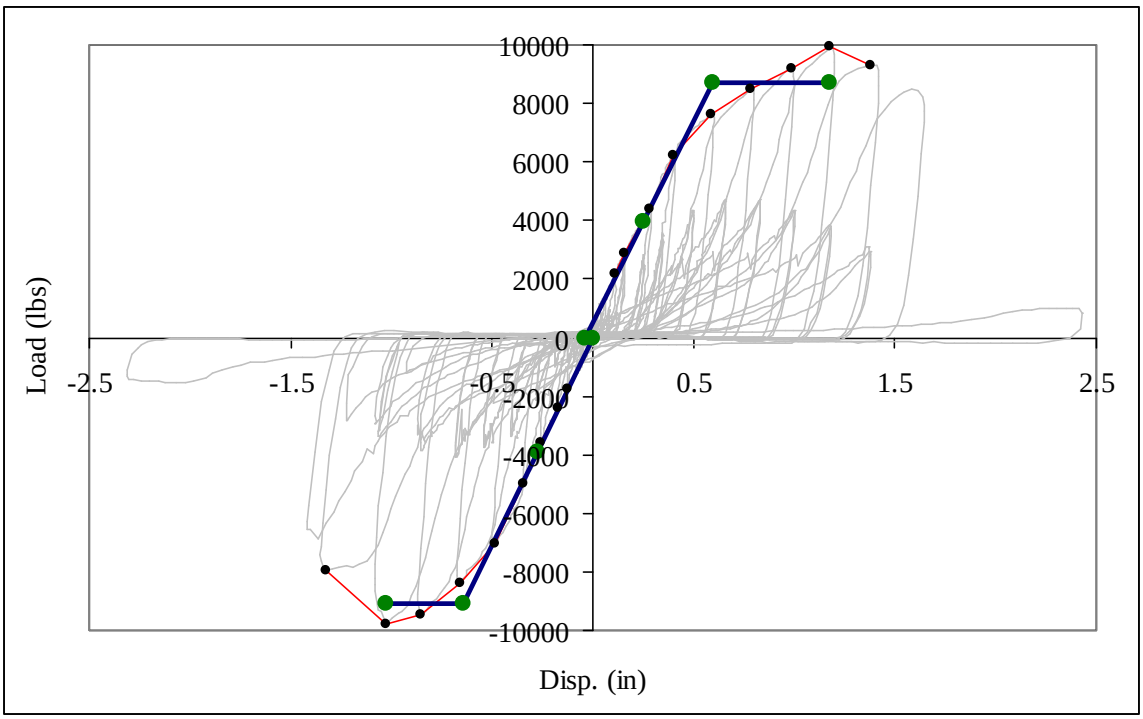

Figure A.115: Load-Deflection plot: C16-4.

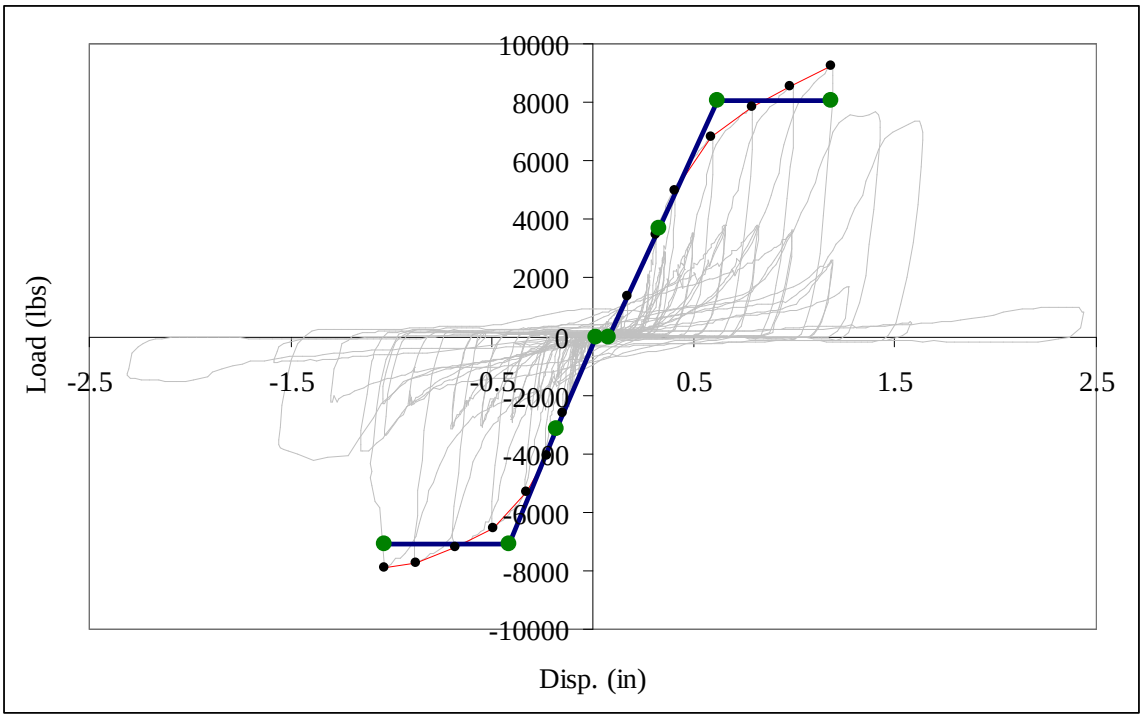

Figure A.116: Load-Deflection plot: C16-5.

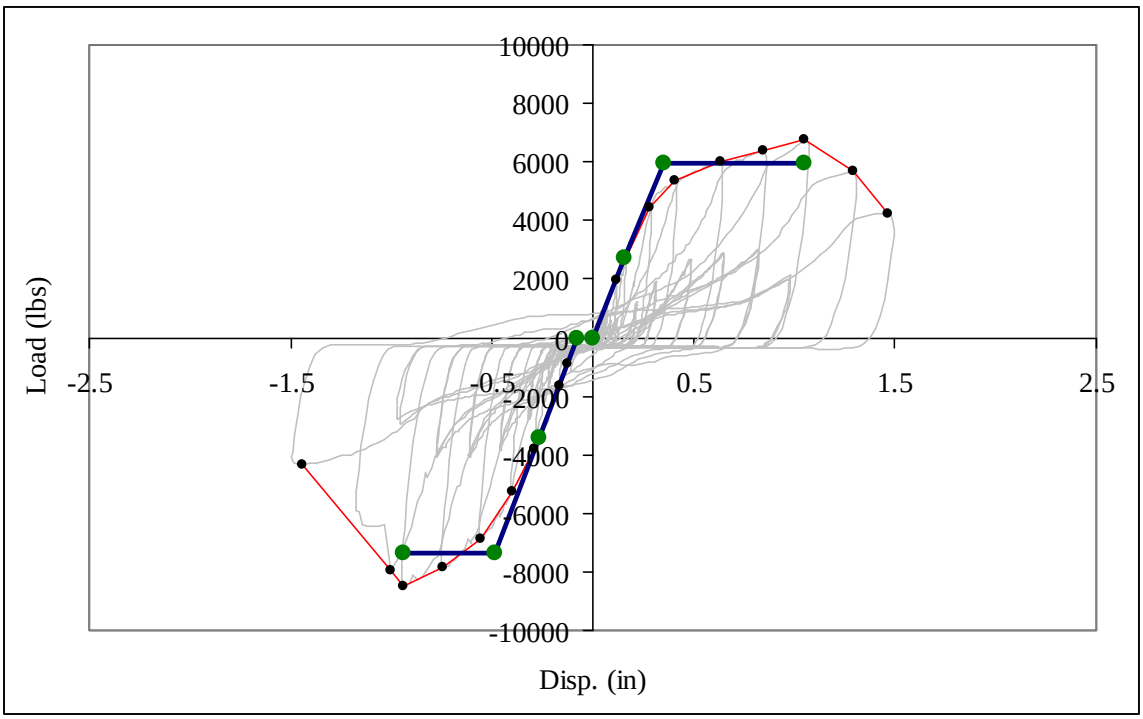

Figure A.117: Load-Deflection plot: C16-6.

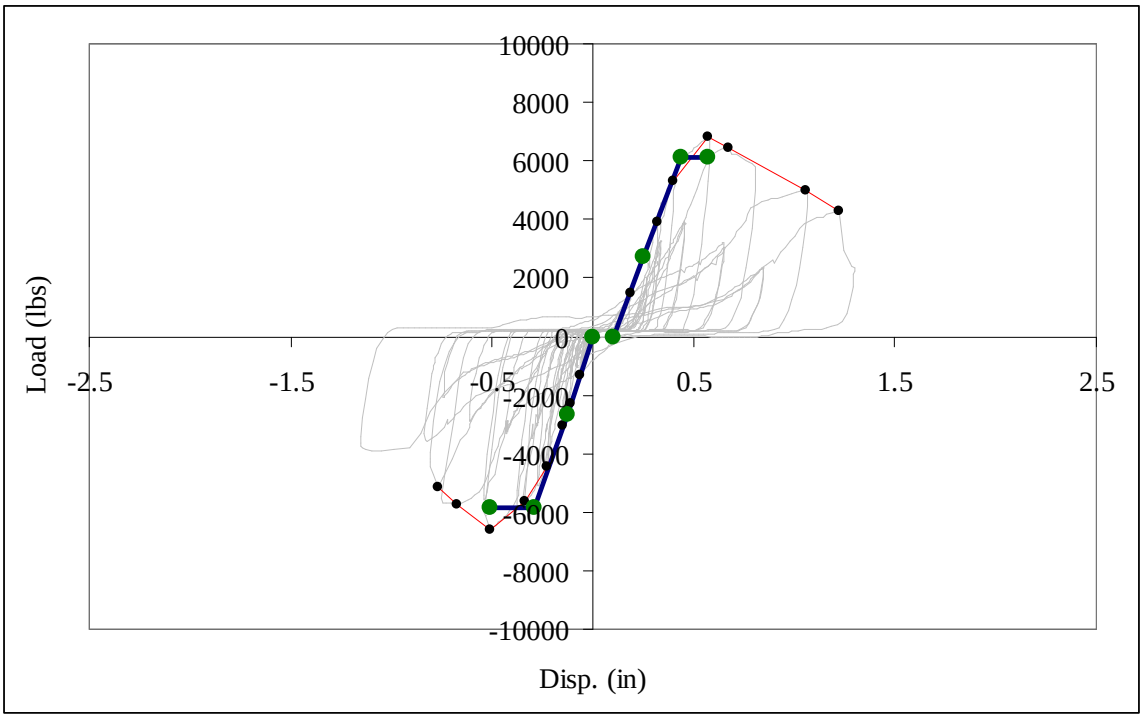

Figure A.118: Load-Deflection plot: C16-7.

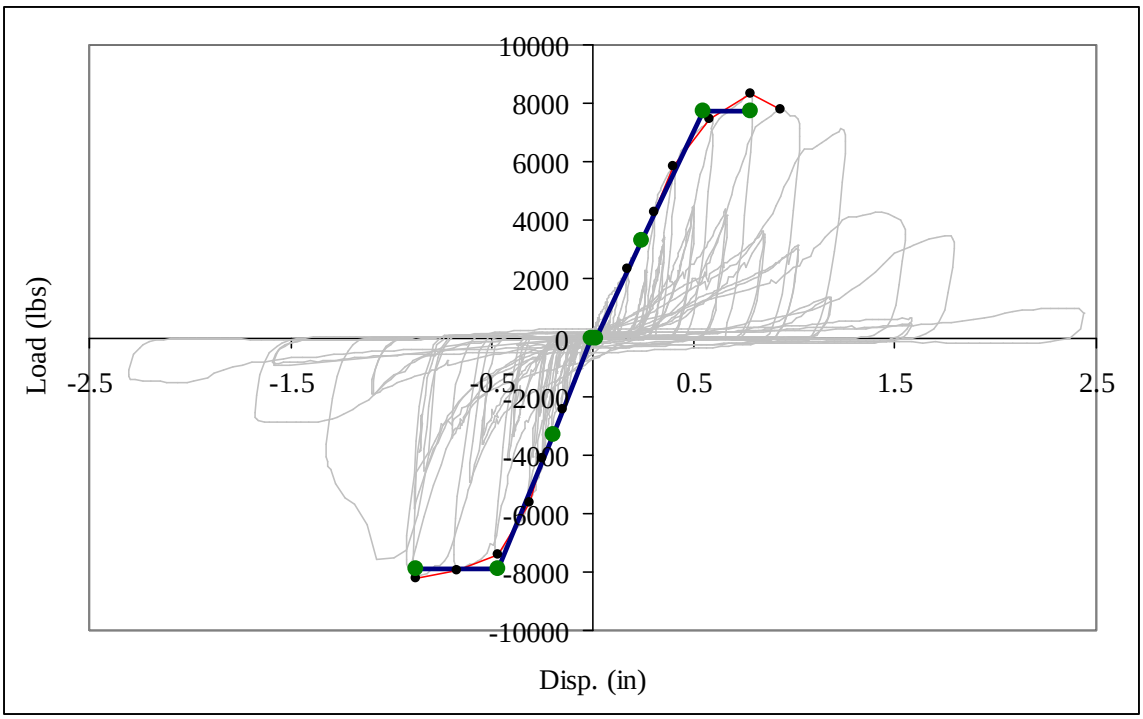

Figure A.119: Load-Deflection plot: C16-8.

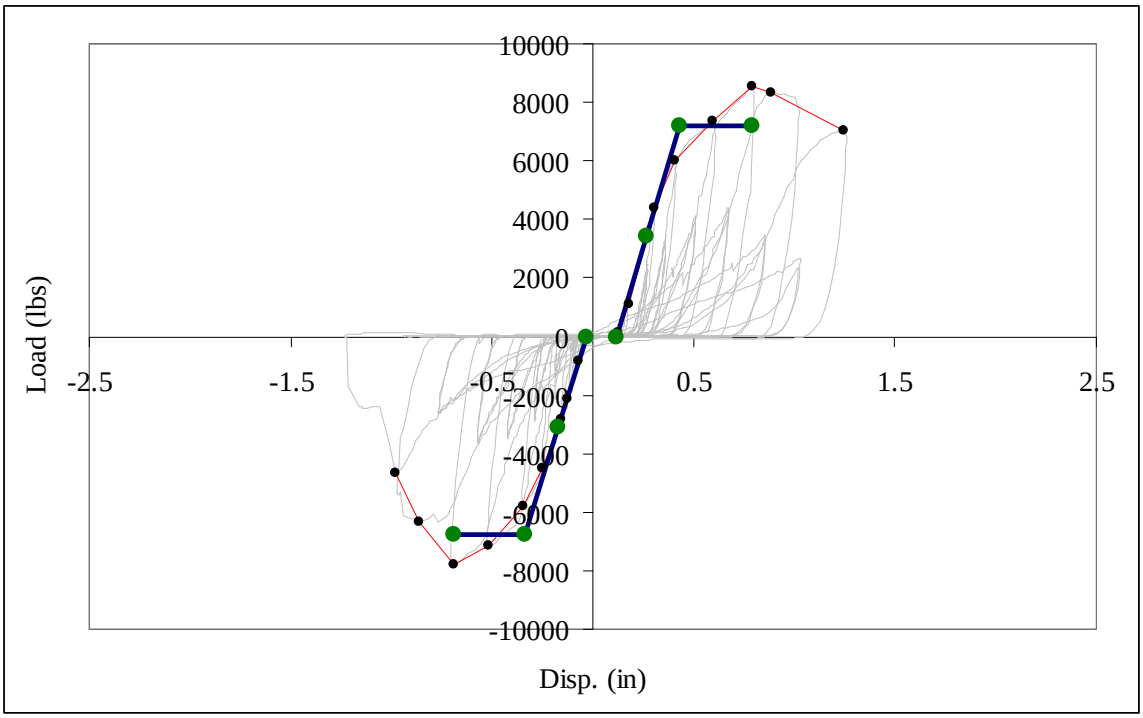

Figure A.120: Load-Deflection plot: C16-9.

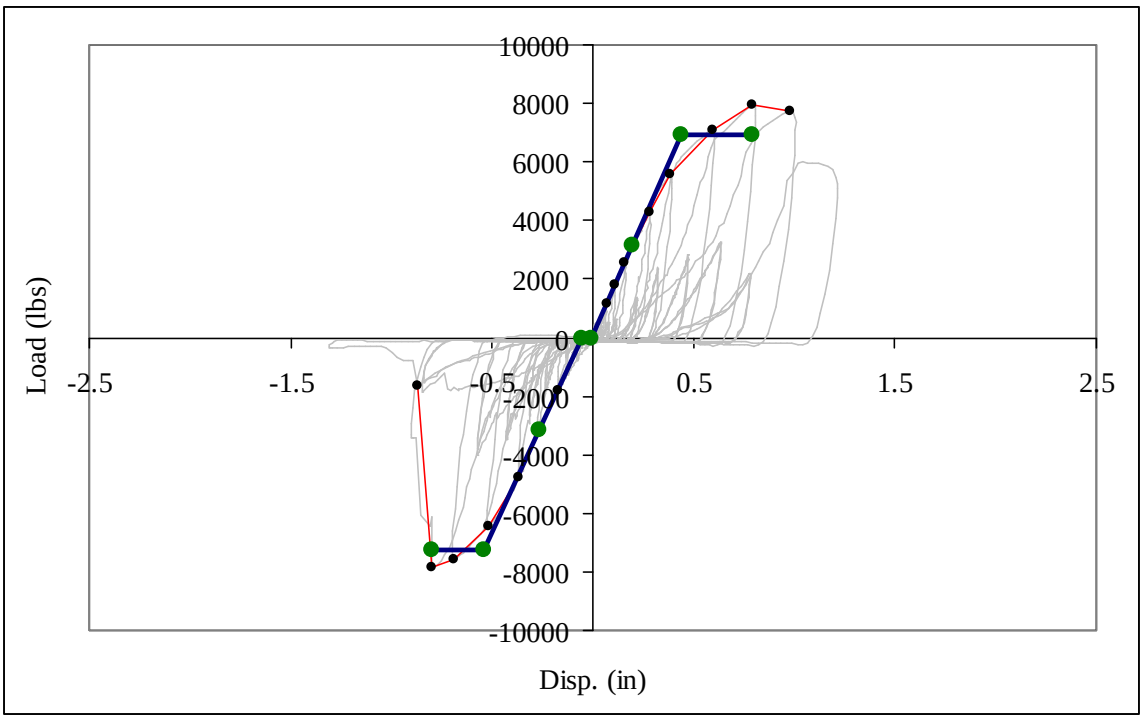

Figure A.121: Load-Deflection plot: C16-10.

Table A.34a: Connection performance properties (SI), Configuration 18.

Connection Performance Properties: Configuration 18

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	71.72	70.98	79.40	80.01	67.86	72.10	71.03	56.48	78.58	74.82	72.30	6.91	0.10
@Displacement (mm)	8.92	10.13	11.39	9.02	8.71	12.87	10.80	7.56	10.68	7.66	9.77	1.70	0.17
Failure Load (kN)	57.38	56.78	63.52	64.01	54.28	57.68	56.83	45.18	62.87	59.85	57.84	5.53	0.10
@Displacement (mm)	8.92	10.13	11.39	9.02	8.71	12.87	10.80	7.56	10.68	7.66	9.77	1.70	0.17
40% Max (kN)	28.69	28.39	31.76	32.00	27.14	28.84	28.41	22.59	31.43	29.93	28.92	2.76	0.10
@Displacement (mm)	3.78	4.07	4.06	4.91	3.84	4.34	4.04	3.36	4.07	3.34	3.98	0.46	0.11
Yield (kN)	62.47	68.18	72.75	71.53	62.02	67.70	63.00	62.48	72.15	67.98	67.03	4.28	0.06
@Displacement (mm)	6.99	8.22	7.60	6.96	7.22	8.81	7.64	7.87	7.26	5.98	7.45	0.77	0.10
5% Offset Yield (kN)	65.72	68.12	65.39	67.83	63.17	61.94	59.19	56.48	66.71	65.71	64.03	3.82	0.06
@Displacement (mm)	7.95	8.81	7.66	7.41	7.99	8.75	7.88	7.56	7.44	6.45	7.79	0.68	0.09
Elastic Stiff. (N/mm)	10472.54	9840.27	11532.60	Censored	10539.95	8801.21	9608.21	9028.16	12855.72	16607.53	11031.80	2440.73	0.22
E.E.P. Energy (N*m)	335.64	382.00	536.94	285.18	278.57	559.09	438.45	332.53	465.55	277.43	389.14	105.74	0.27
Ductility Ratio	1.27	1.23	1.48	1.30	1.23	1.44	1.38	1.22	1.46	1.43	1.34	0.11	0.08
Yield Mode	II-III_s	II-III_s	III_s	III_s	II-III_s	III_s	III_s	III_s	III_s	III_s			
Failure Mode	Splitting	Splitting	Balk. Shr.	Balk. Shr.	Splitting	Balk. Shr.	Ten Rup	Balk. Shr.	Balk. Shr.	Balk. Shr.			
Governing Member	Side	Side	Side	Side	Side	Side	Side	Side	Side	Side			

Table A.34b: Connection performance properties (Std.), Configuration 18.

Connection Performance Properties: Configuration 18

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	16123.12	15956.12	17850.36	17986.14	15254.56	16208.43	15968.92	12696.94	17666.57	16819.44	16253.06	1552.94	0.10
@ Displacement (in)	0.35	0.40	0.45	0.36	0.34	0.51	0.43	0.30	0.42	0.30	0.38	0.07	0.17
Failure Load (lbs)	12898.50	12764.89	14280.28	14388.91	12203.65	12966.74	12775.13	10157.55	14133.26	13455.55	13002.45	1242.35	0.10
@ Displacement (in)	0.35	0.40	0.45	0.36	0.34	0.51	0.43	0.30	0.42	0.30	0.38	0.07	0.17
40% Max (lbs)	6449.25	6382.45	7140.14	7194.46	6101.82	6483.37	6387.57	5078.78	7066.63	6727.78	6501.22	621.17	0.10
@ Displacement (in)	0.15	0.16	0.16	0.19	0.15	0.17	0.16	0.13	0.16	0.13	0.16	0.02	0.11
Yield (lbs)	14044.75	15327.12	16354.43	16079.52	13942.68	15219.34	14163.37	14046.56	16219.39	15281.88	15067.90	961.17	0.06
@ Displacement (in)	0.28	0.32	0.30	0.27	0.28	0.35	0.30	0.31	0.29	0.24	0.29	0.03	0.10
5% Offset Yield (lbs)	14774.46	15312.92	14699.25	15248.52	14201.36	13925.47	13305.97	12696.94	14997.17	14772.32	14393.44	858.94	0.06
@ Displacement (in)	0.31	0.35	0.30	0.29	0.31	0.34	0.31	0.30	0.29	0.25	0.31	0.03	0.09
Elastic Stiff. (lb/in)	59799.76	56189.40	65852.85	Censored	60184.64	50256.18	54864.28	51552.09	73408.02	94831.42	62993.18	13936.94	0.22
E.E.P. Energy (lb*in)	2970.70	3380.97	4752.32	2524.06	2465.58	4948.34	3880.62	2943.15	4120.48	2455.45	3444.17	935.87	0.27
Ductility Ratio	1.27	1.23	1.48	1.30	1.23	1.44	1.38	1.22	1.46	1.43	1.34	0.11	0.08
Yield Mode	II-III_s	II-III_s	III_s	III_s	II-III_s	III_s	III_s	III_s	III_s	III_s			
Failure Mode	Splitting	Splitting	Balk. Shr.	Balk. Shr.	Splitting	Balk. Shr.	Ten Rup	Balk. Shr.	Balk. Shr.	Balk. Shr.			
Governing Member	Side	Side	Side	Side	Side	Side	Side	Side	Side	Side			

Table A.35a: Member properties (SI), Configuration 18.

Member Properties: Configuration 18

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.92	15.02	14.05	16.03	16.17	14.41	15.47	15.10	14.80	15.45	15.14	0.66	0.04
S.G.	0.47	0.47	0.40	0.39	0.42	0.42	0.49	0.50	0.49	0.47	0.45	0.04	0.09
D.E. 5% Offset Yield (kPa)	25497	26214	22626	23256	22213	26115	23285	27735	30401	32380	25972	3399.73	0.13
D.E. Capacity (kPa)	26975	27461	24015	24136	25554	26346	26486	29198	31773	32759	27470	2956.66	0.11
Side Member													
M.C. (%)	15.03	17.17	13.56	15.61	14.94	17.15	17.04	15.94	17.03	17.07	16.05	1.25	0.08
S.G.	0.44	0.47	0.50	0.46	0.47	0.40	0.49	0.50	0.57	0.55	0.49	0.05	0.10
D.E. 5% Offset Yield (kPa)	30348	27575	33206	25064	23458	23373	28838	23617	26998	27138	26962	3237.48	0.12
D.E. Capacity (kPa)	31327	30546	33206	26005	25434	24450	29129	25899	27200	27597	28079	2872.40	0.10

Table A.35b: Member properties (Std.), Configuration 18.

Member Properties: Configuration 18

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.92	15.02	14.05	16.03	16.17	14.41	15.47	15.10	14.80	15.45	15.14	0.66	0.04
S.G.	0.47	0.47	0.40	0.39	0.42	0.42	0.49	0.50	0.49	0.47	0.45	0.04	0.09
D.E. 5% Offset Yield (psi)	3698.05	3802.04	3281.56	3372.96	3221.71	3787.62	3377.15	4022.55	4409.33	4696.33	3766.93	493.09	0.13
D.E. Capacity (psi)	3912.37	3982.89	3483.02	3500.65	3706.25	3821.15	3841.42	4234.85	4608.20	4751.29	3984.21	428.82	0.11
Side Member													
M.C. (%)	15.03	17.17	13.56	15.61	14.94	17.15	17.04	15.94	17.03	17.07	16.05	1.25	0.08
S.G.	0.44	0.47	0.50	0.46	0.47	0.40	0.49	0.50	0.57	0.55	0.49	0.05	0.10
D.E. 5% Offset Yield (psi)	4401.61	3999.46	4816.16	3635.15	3402.31	3390.01	4182.56	3425.39	3915.77	3935.98	3910.44	469.55	0.12
D.E. Capacity (psi)	4543.58	4430.32	4816.16	3771.69	3688.80	3546.16	4224.81	3756.31	3945.03	4002.63	4072.55	416.60	0.10

Table A.36a: Hysteretic connection properties (SI), Configuration 18.

Hysteretic Connection Properties: Configuration 18

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.53	1.29	0.84	0.12	0.08	0.69	-1.25	0.74	0.59	-0.16	0.06	0.36
Primary2	2.06	1.77	0.86	0.28	0.10	0.36	-1.89	1.62	0.86	-0.33	0.14	0.43
Primary3	4.65	3.57	0.77	1.16	0.07	0.06	-5.17	4.07	0.79	-0.92	0.56	0.61
Primary4	8.31	5.92	0.71	1.97	0.10	0.05	-9.62	6.49	0.67	-1.86	0.22	0.12
Primary5	13.53	8.27	0.61	2.73	0.14	0.05	-14.90	8.09	0.54	-2.51	0.32	0.13
Primary6	35.24	13.12	0.37	4.79	0.32	0.07	-32.44	8.43	0.26	-4.16	0.62	0.15
Primary7	53.36	18.44	0.35	6.41	0.67	0.10	-46.62	5.73	0.12	-5.37	0.87	0.16
Primary8	71.84	24.05	0.33	8.84	1.11	0.13	-58.96	10.16	0.17	-6.79	1.22	0.18
Primary9	75.73	26.50	0.35	11.06	1.63	0.15	-60.32	22.50	0.37	-7.89	3.33	0.42
Primary10	65.83	24.83	0.38	14.31	1.90	0.13	-25.14	32.74	1.30	-7.96	7.20	0.90
Primary11	42.49	28.12	0.66	17.91	2.65	0.15	-20.65	26.94	1.30	-11.57	7.09	0.61

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.31	0.17	0.53	0.21	0.15	0.70	0.31	0.15	0.47	11832.59	11851.74	1.00
Primary2	0.78	0.53	0.69	0.62	0.45	0.72	0.24	0.10	0.43	6717.28	3863.97	0.58
Primary3	4.35	1.80	0.41	5.37	2.20	0.41	0.13	0.02	0.17	4431.03	2013.69	0.45
Primary4	9.64	3.47	0.36	16.52	5.74	0.35	0.09	0.01	0.11	4752.16	1789.84	0.38
Primary5	15.60	5.73	0.37	36.18	10.58	0.29	0.07	0.01	0.18	5479.73	1677.62	0.31
Primary6	58.39	19.38	0.33	150.80	24.41	0.16	0.06	0.02	0.30	7581.40	1212.16	0.16
Primary7	90.65	25.56	0.28	296.06	28.62	0.10	0.05	0.01	0.27	8545.60	935.22	0.11
Primary8	219.78	41.63	0.19	521.29	51.57	0.10	0.07	0.02	0.27	8431.50	1094.19	0.13
Primary9	502.73	137.18	0.27	685.58	159.18	0.23	0.12	0.05	0.42	7232.40	1327.25	0.18
Primary10	458.63	222.14	0.48	623.33	221.70	0.36	0.12	0.04	0.32	4085.52	1541.17	0.38
Primary11	403.74	92.20	0.23	532.57	129.25	0.24	0.13	0.04	0.30	2244.73	848.74	0.38

Table A.36b: Hysteretic connection properties (Std.), Configuration 18.

Hysteretic Connection Properties: Configuration 18

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	345.00	289.18	0.84	0.00	0.00	0.69	-280.33	165.57	0.59	-0.01	0.00	0.36
Primary2	462.25	397.60	0.86	0.01	0.00	0.36	-424.26	364.08	0.86	-0.01	0.01	0.43
Primary3	1045.57	802.16	0.77	0.05	0.00	0.06	-1163.18	913.98	0.79	-0.04	0.02	0.61
Primary4	1867.26	1330.35	0.71	0.08	0.00	0.05	-2163.18	1459.99	0.67	-0.07	0.01	0.12
Primary5	3041.89	1858.61	0.61	0.11	0.01	0.05	-3350.52	1818.67	0.54	-0.10	0.01	0.13
Primary6	7921.91	2949.15	0.37	0.19	0.01	0.07	-7292.62	1894.61	0.26	-0.16	0.02	0.15
Primary7	11995.86	4144.48	0.35	0.25	0.03	0.10	-10481.43	1289.09	0.12	-0.21	0.03	0.16
Primary8	16150.05	5405.80	0.33	0.35	0.04	0.13	-13254.81	2284.64	0.17	-0.27	0.05	0.18
Primary9	17025.82	5956.91	0.35	0.44	0.06	0.15	-13561.12	5057.93	0.37	-0.31	0.13	0.42
Primary10	14799.04	5583.11	0.38	0.56	0.07	0.13	-5652.54	7360.84	1.30	-0.31	0.28	0.90
Primary11	9551.81	6320.99	0.66	0.71	0.10	0.15	-4642.87	6056.31	1.30	-0.46	0.28	0.61

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	2.79	1.49	0.53	1.84	1.29	0.70	0.31	0.15	0.47	67565.82	67675.16	1.00
Primary2	6.89	4.73	0.69	5.47	3.95	0.72	0.24	0.10	0.43	38356.66	22063.85	0.58
Primary3	38.50	15.90	0.41	47.49	19.45	0.41	0.14	0.03	0.22	25301.82	11498.48	0.45
Primary4	85.28	30.70	0.36	146.24	50.78	0.35	0.09	0.01	0.11	27135.51	10220.26	0.38
Primary5	138.11	50.68	0.37	320.23	93.62	0.29	0.07	0.01	0.18	31290.09	9579.46	0.31
Primary6	516.75	171.49	0.33	1334.70	216.02	0.16	0.06	0.02	0.30	43290.90	6921.60	0.16
Primary7	802.29	226.25	0.28	2620.35	253.33	0.10	0.05	0.01	0.27	48796.65	5340.27	0.11
Primary8	1945.23	368.46	0.19	4613.78	456.43	0.10	0.07	0.02	0.27	48145.09	6247.98	0.13
Primary9	4449.54	1214.17	0.27	6067.88	1408.89	0.23	0.12	0.05	0.42	41298.07	7578.80	0.18
Primary10	4059.18	1966.14	0.48	5516.91	1962.19	0.36	0.12	0.04	0.32	23328.94	8800.30	0.38
Primary11	3573.38	816.02	0.23	4713.68	1143.93	0.24	0.13	0.04	0.30	12817.74	4846.45	0.38

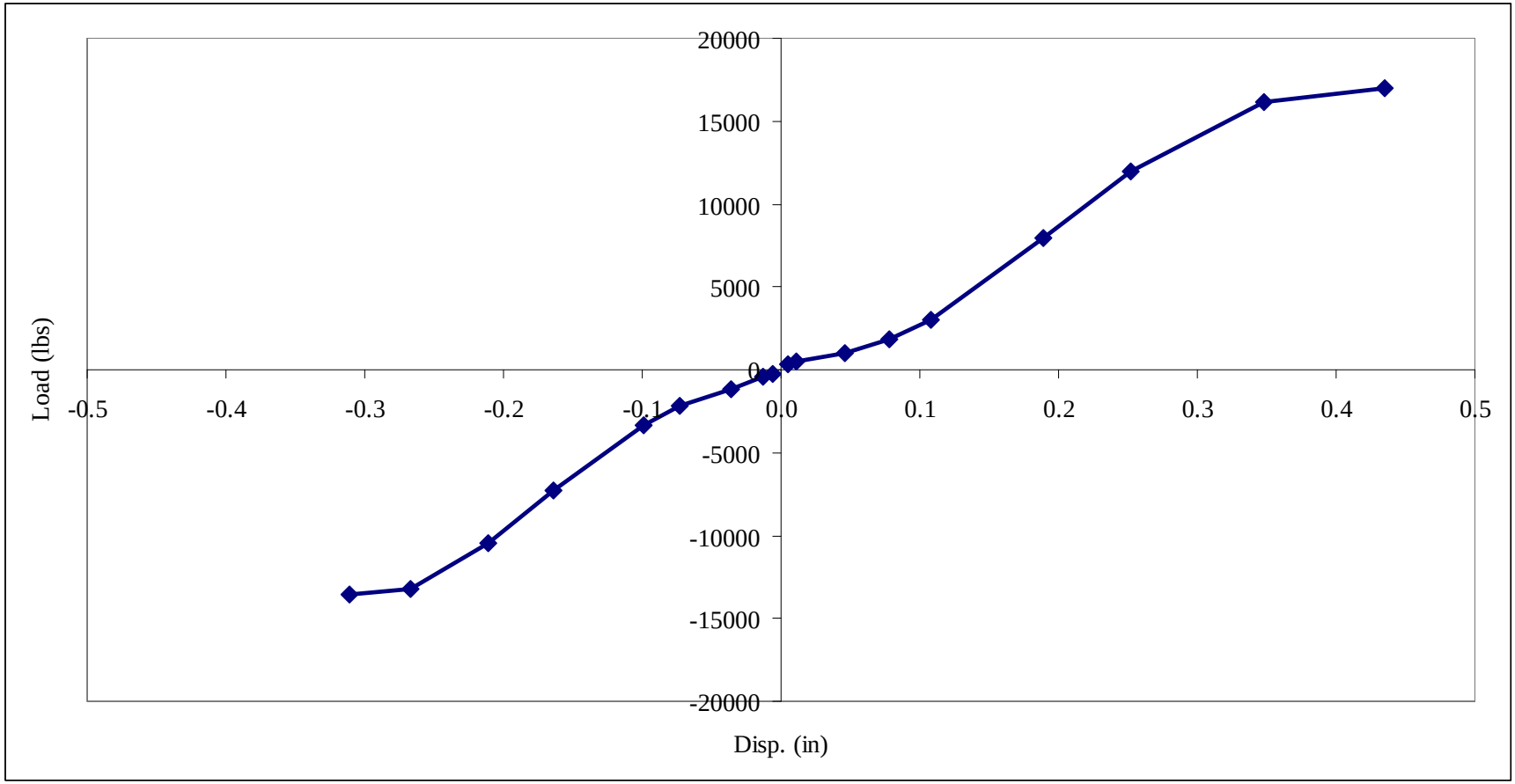

Figure A.122: Mean envelope curve: Configuration 18.

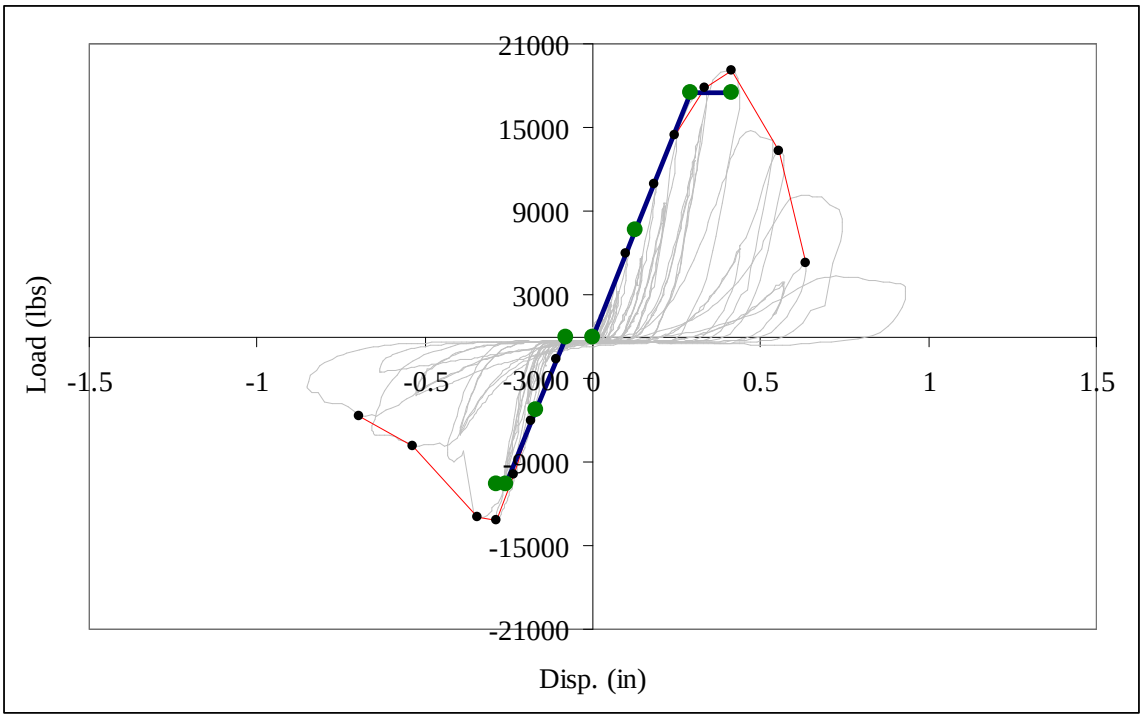

Figure A.123: Load-Deflection plot: C18-1.

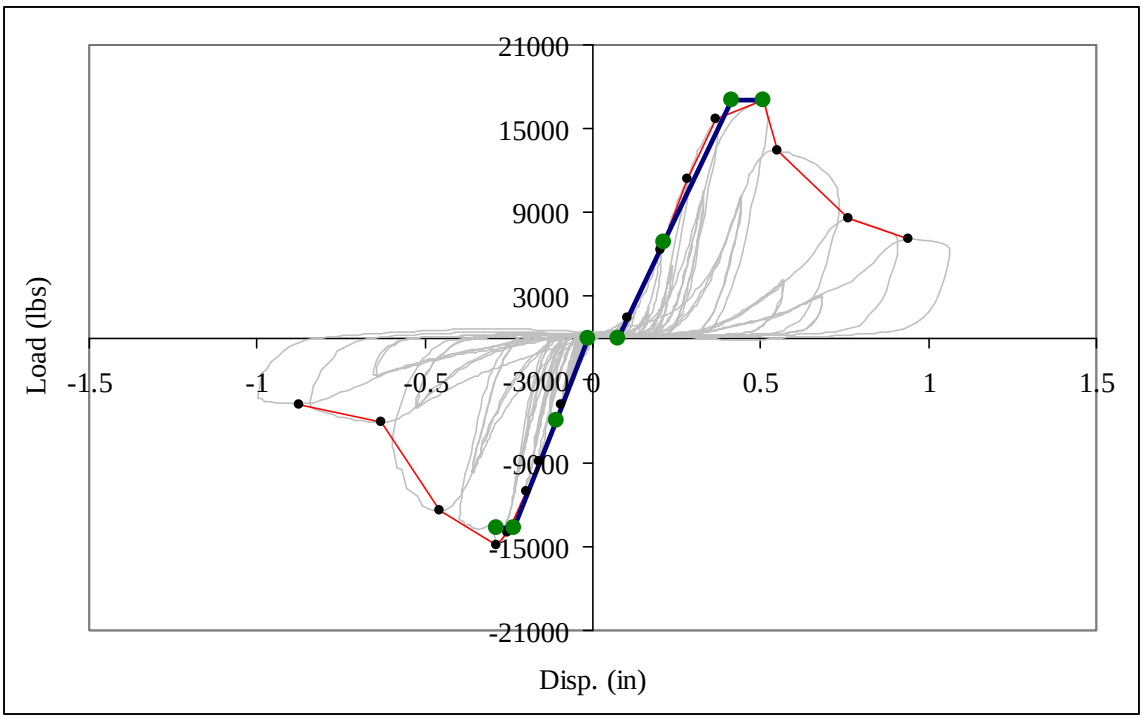

Figure A.124: Load-Deflection plot: C18-2.

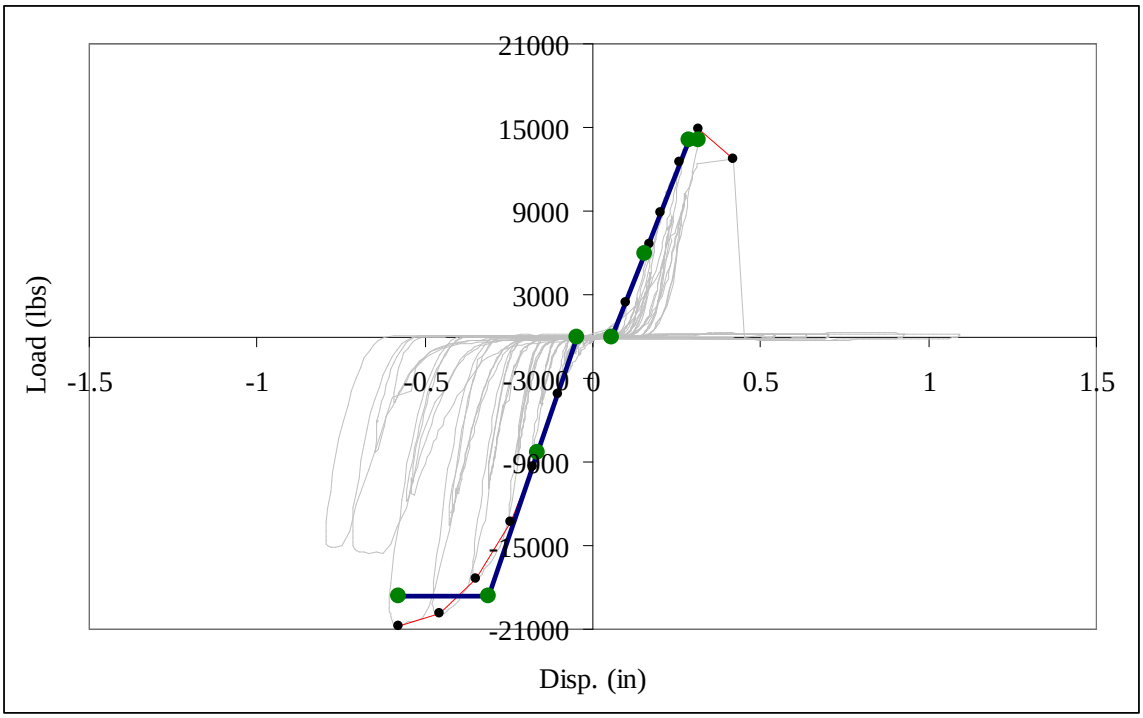

Figure A.125: Load-Deflection plot: C18-3.

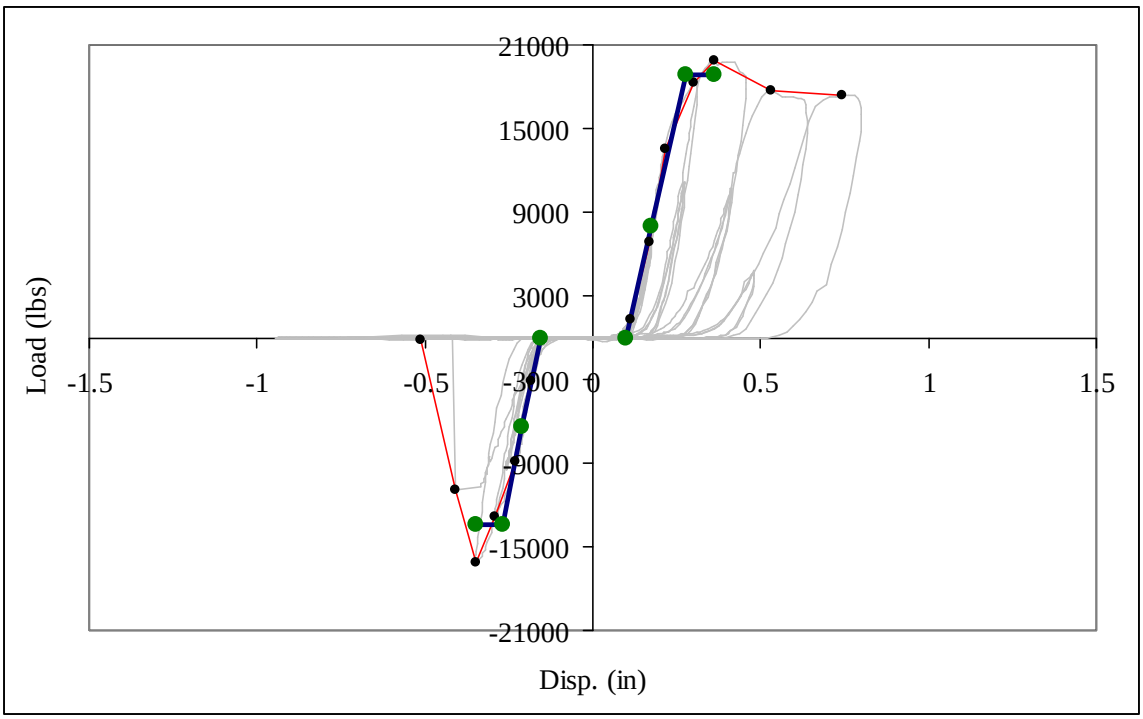

Figure A.126: Load-Deflection plot: C18-4.

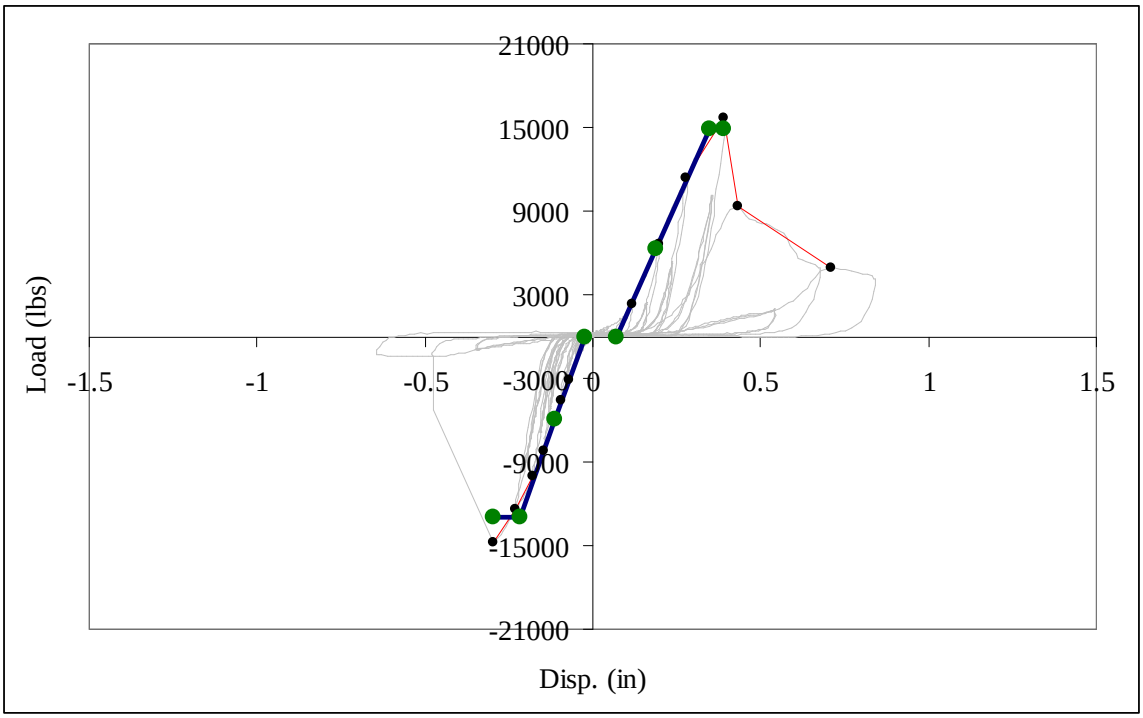

Figure A.127: Load-Deflection plot: C18-5.

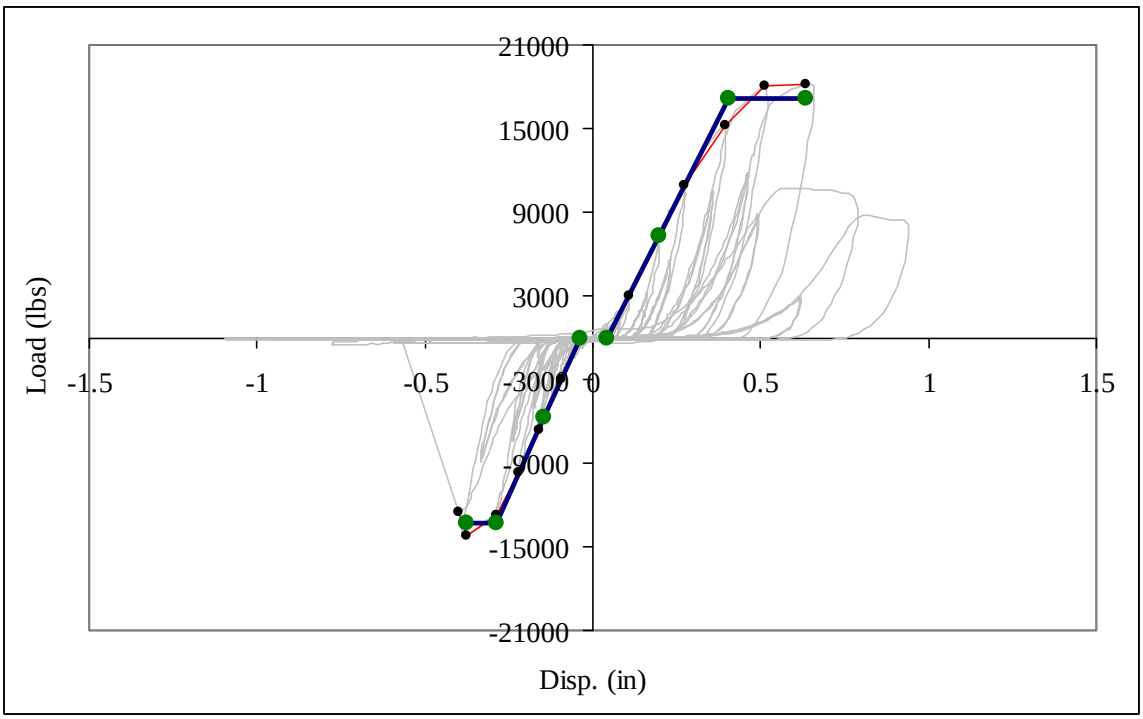

Figure A.128: Load-Deflection plot: C18-6.

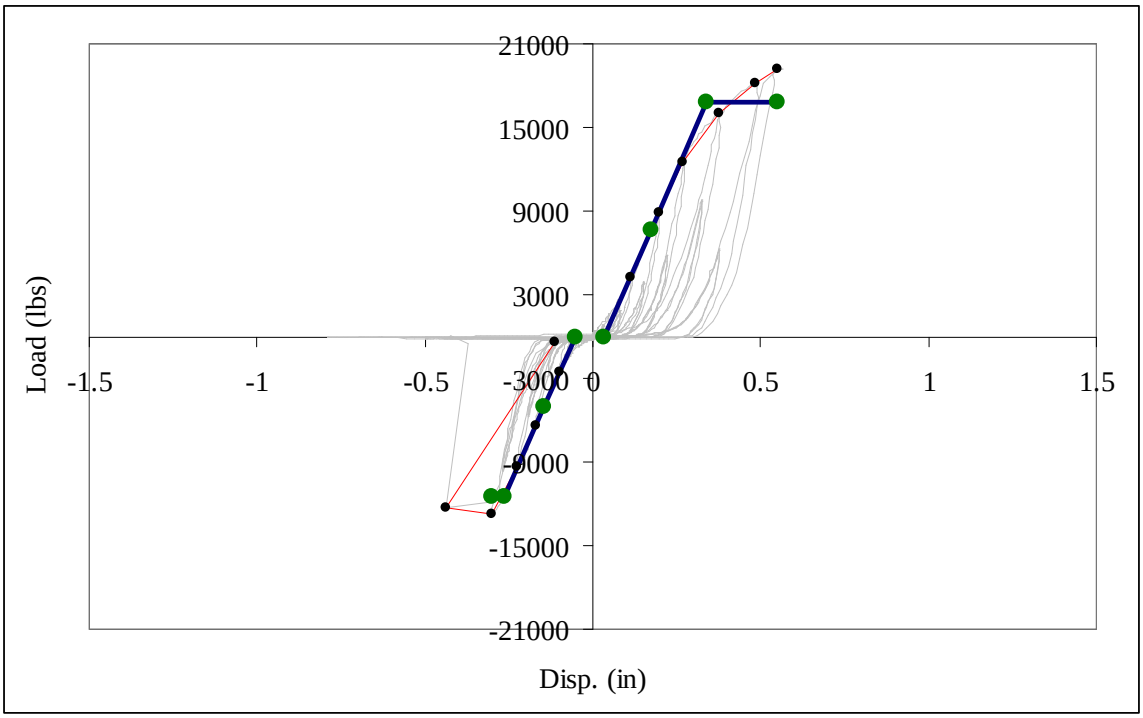

Figure A.129: Load-Deflection plot: C18-7.

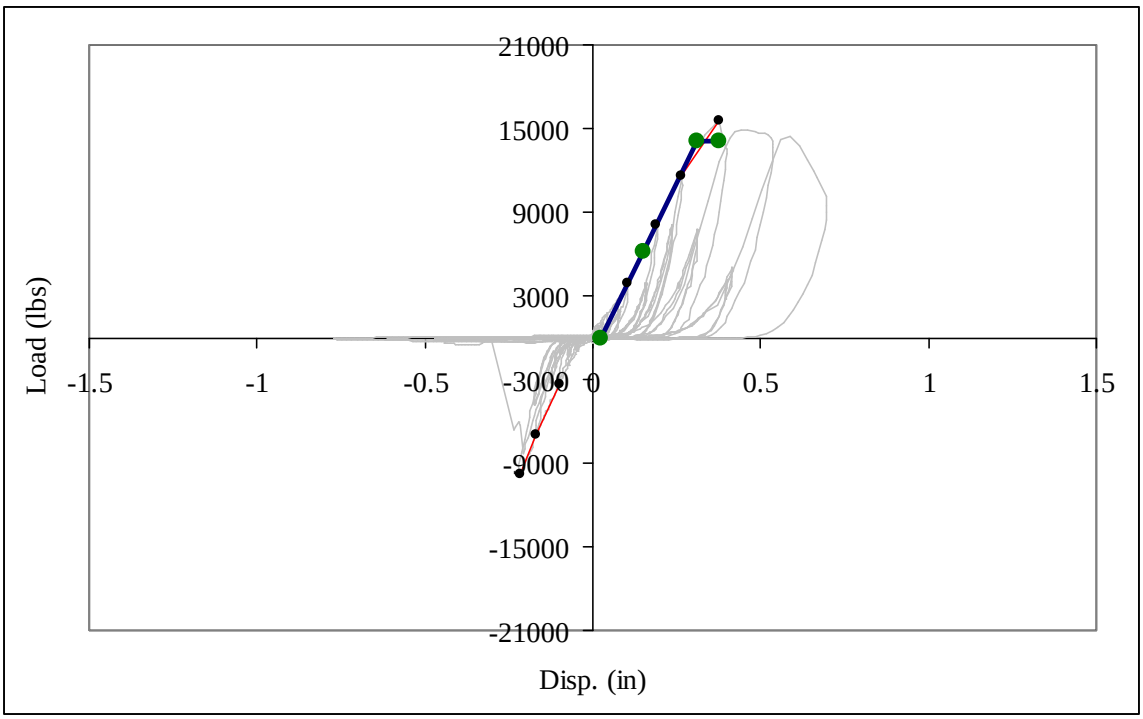

Figure A.130: Load-Deflection plot: C18-8.

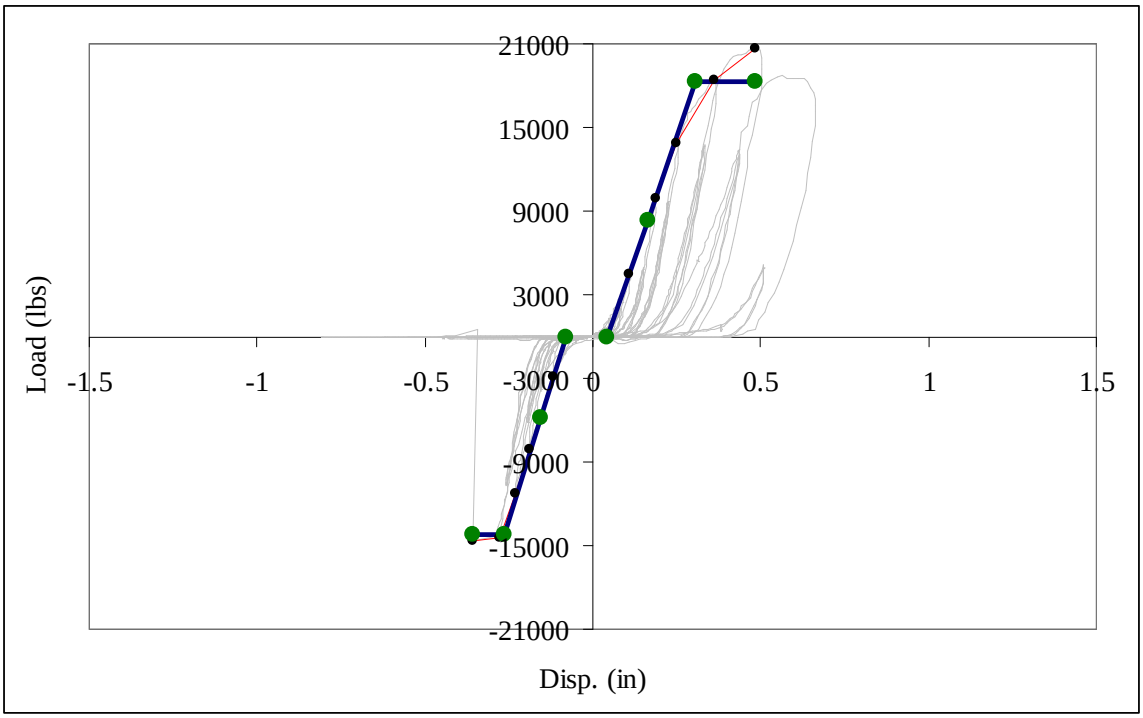

Figure A.131: Load-Deflection plot: C18-9.

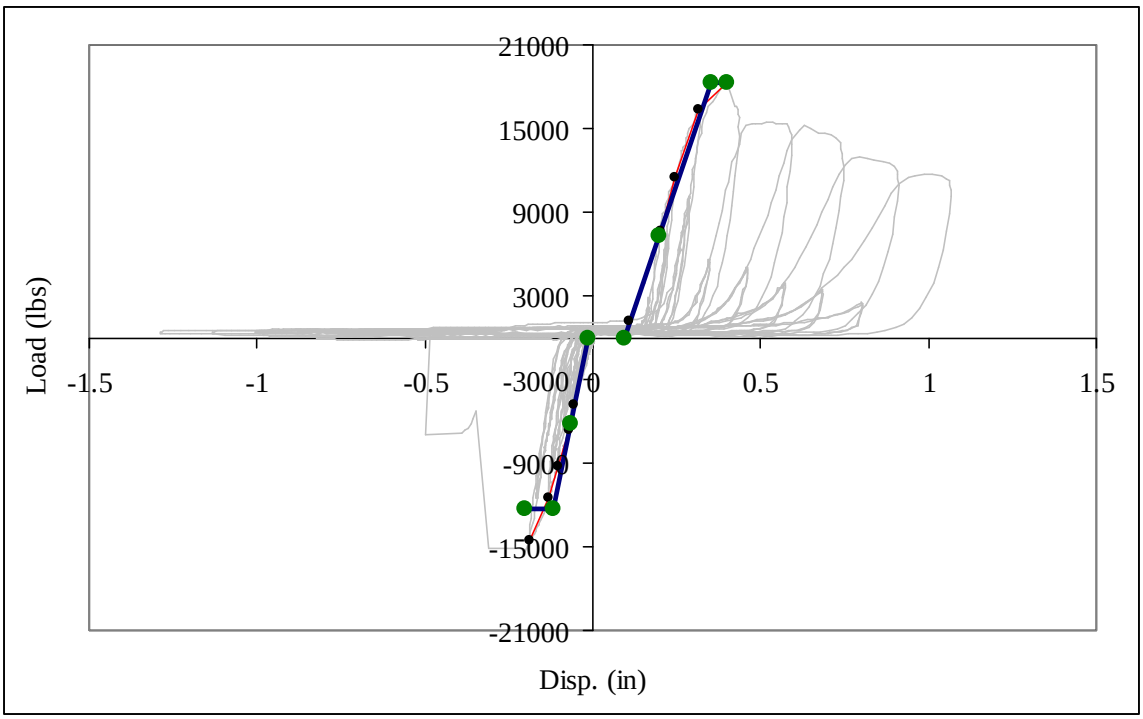

Figure A.132: Load-Deflection plot: C18-10.

Table A.37a: Connection performance properties (SI), Configuration 19.

Connection Performance Properties: Configuration 19

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	65.75	81.49	76.23	82.42	83.87	64.01	92.66	79.80		87.16	79.27	9.37	0.12
@Displacement (mm)	6.93	13.50	11.21	8.70	12.95	7.61	10.03	11.32		8.52	10.09	2.32	0.23
Failure Load (kN)	52.60	65.19	60.98	65.93	67.09	51.21	74.13	63.84		69.73	63.41	7.50	0.12
@Displacement (mm)	6.93	13.50	11.21	8.70	14.00	7.61	10.03	11.32		8.52	10.20	2.50	0.25
40% Max (kN)	26.30	32.60	30.49	32.97	33.55	25.60	37.07	31.92		34.87	31.71	3.75	0.12
@Displacement (mm)	3.59	3.96	4.26	3.86	3.52	3.06	3.98	4.91		3.49	3.85	0.53	0.14
Yield (kN)	59.20	72.52	64.94	73.82	79.69	58.14	88.80	68.96	Invalid	73.64	71.08	9.71	0.14
@Displacement (mm)	3.99	6.98	7.45	7.17	7.41	5.72	7.83	8.81	Data	5.85	6.80	1.42	0.21
5% Offset Yield (kN)	41.28	66.66	63.67	77.97	73.99	60.61	88.48	69.61		69.52	67.98	12.98	0.19
@Displacement (mm)	4.91	7.16	7.90	8.02	7.56	6.68	8.43	9.50		6.22	7.38	1.34	0.18
Elastic Stiff. (N/mm)	9401.13	13426.87	11190.53	12526.15	11887.61	11804.67	13513.29	9564.29		16537.35	12205.77	2185.24	0.18
E.E.P. Energy (N*m)	214.55	685.09	450.57	343.93	826.32	297.53	496.67	450.77		380.37	460.64	191.32	0.42
Ductility Ratio	1.39	1.92	1.54	1.21	1.84	1.48	1.27	1.27		1.43	1.48	0.25	0.17
Yield Mode	II-IIIs	II-IIIs	IIIs	IIIs	IIIs	IIIs	IIIs	IIIs		II-IIIs			
Failure Mode	Splitting	Splitting	Splitting	Ten Rup	Splitting	Splitting	Splitting	Splitting		Balk. Shr.			
Governing Member	Side	Side	Main	Side	Side	Side	Both	Both		Main			

Table A.37b: Connection performance properties (Std.), Configuration 19.

Connection Performance Properties: Configuration 19

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	14781.99	18319.85	17137.40	18527.64	18853.97	14390.47	20831.76	17939.85		19594.95	17819.76	2106.90	0.12
@ Displacement (in)	0.27	0.53	0.44	0.34	0.51	0.30	0.40	0.45		0.34	0.40	0.09	0.23
Failure Load (lbs)	11825.59	14655.88	13709.92	14822.11	15083.18	11512.38	16665.41	14351.88		15675.96	14255.81	1685.52	0.12
@ Displacement (in)	0.27	0.53	0.44	0.34	0.55	0.30	0.40	0.45		0.34	0.40	0.10	0.25
40% Max (lbs)	5912.80	7327.94	6854.96	7411.06	7541.59	5756.19	8332.71	7175.94		7837.98	7127.91	842.76	0.12
@ Displacement (in)	0.14	0.16	0.17	0.15	0.14	0.12	0.16	0.19		0.14	0.15	0.02	0.14
Yield (lbs)	13308.63	16304.04	14599.75	16595.34	17916.00	13069.89	19962.07	15502.47	Invalid	16555.05	15979.25	2183.96	0.14
@ Displacement (in)	0.16	0.27	0.29	0.28	0.29	0.23	0.31	0.35	Data	0.23	0.27	0.06	0.21
5% Offset Yield (lbs)	9280.84	14984.64	14312.48	17529.11	16632.92	13625.42	19891.53	15648.42		15628.54	15281.54	2918.97	0.19
@ Displacement (in)	0.19	0.28	0.31	0.32	0.30	0.26	0.33	0.37		0.24	0.29	0.05	0.18
Elastic Stiff. (lb/in)	53681.82	76669.42	63899.54	71526.15	67879.97	67406.41	77162.88	54613.50		94430.71	69696.71	12478.05	0.18
E.E.P. Energy (lb*in)	1898.88	6063.53	3987.86	3044.08	7313.53	2633.37	4395.89	3989.62		3366.54	4077.03	1693.32	0.42
Ductility Ratio	1.39	1.92	1.54	1.21	1.84	1.48	1.27	1.27		1.43	1.48	0.25	0.17
Yield Mode	II-IIIs	II-IIIs	IIIs	IIIs	IIIs	IIIs	IIIs	IIIs		II-IIIs			
Failure Mode	Splitting	Splitting	Splitting	Ten Rup	Splitting	Splitting	Splitting	Splitting		Balk. Shr.			
Governing Member	Side	Side	Main	Side	Side	Side	Both	Both		Main			

Table A.38a: Member properties (SI), Configuration 19.

Member Properties: Configuration 19

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.78	16.11	16.18	16.21	16.26	15.92	15.80	16.56	0.00	15.73	14.46	5.09	0.35
S.G.	0.49	0.52	0.42	0.43	0.49	0.51	0.49	0.46	0.00	0.52	0.43	0.16	0.36
D.E. 5% Offset Yield (kPa)	31165	30136	24610	22311	31914	31420	26103	25891	0	30011	25356	9496.47	0.37
D.E. Capacity (kPa)	31655	31129	27256	24706	32722	31608	28777	28754	0	31608	26821	9741.97	0.36
Side Member													
M.C. (%)	16.86	16.82	15.62	16.58	16.90	16.85	17.10	15.58	0.00	14.58	14.69	5.22	0.36
S.G.	0.45	0.45	0.43	0.47	0.55	0.55	0.49	0.42	0.00	0.54	0.43	0.16	0.37
D.E. 5% Offset Yield (kPa)	21508	21993	26565	24688	28810	30195	26345	22813	0	34083	23700	9204.34	0.39
D.E. Capacity (kPa)	23097	23602	28771	25824	30900	30195	26899	23733	0	34781	24780	9473.15	0.38

Table A.38b: Member properties (Std.), Configuration 19.

Member Properties: Configuration 19

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	15.78	16.11	16.18	16.21	16.26	15.92	15.80	16.56		15.73	16.06	0.27	0.02
S.G.	0.49	0.52	0.42	0.43	0.49	0.51	0.49	0.46		0.52	0.48	0.04	0.07
D.E. 5% Offset Yield (psi)	4520.09	4370.81	3569.33	3235.90	4628.73	4557.10	3785.90	3755.16		4352.68	4086.19	505.75	0.12
D.E. Capacity (psi)	4591.10	4514.78	3953.19	3583.30	4745.83	4584.31	4173.71	4170.34		4584.31	4322.32	379.72	0.09
Side Member													
M.C. (%)	16.86	16.82	15.62	16.58	16.90	16.85	17.10	15.58		14.58	16.32	0.86	0.05
S.G.	0.45	0.45	0.43	0.47	0.55	0.55	0.49	0.42		0.54	0.48	0.05	0.11
D.E. 5% Offset Yield (psi)	3119.41	3189.80	3852.93	3580.66	4178.49	4379.46	3821.02	3308.72		4943.23	3819.30	603.21	0.16
D.E. Capacity (psi)	3349.94	3423.13	4172.80	3745.49	4481.60	4379.46	3901.30	3442.19		5044.51	3993.38	574.18	0.14

Table A.39a: Hysteretic connection properties (SI), Configuration 19.

Hysteretic Connection Properties: Configuration 19

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.20	0.97	0.81	0.16	0.05	0.30	-1.18	1.08	0.92	-0.12	0.08	0.66
Primary2	1.60	1.04	0.65	0.36	0.09	0.24	-1.69	1.50	0.89	-0.27	0.12	0.44
Primary3	3.41	2.27	0.67	1.06	0.24	0.23	-4.95	4.38	0.88	-0.95	0.19	0.20
Primary4	8.24	4.73	0.57	1.99	0.29	0.14	-10.89	6.24	0.57	-1.69	0.30	0.18
Primary5	15.42	14.21	0.92	2.89	0.97	0.34	-16.33	8.77	0.54	-2.17	0.46	0.21
Primary6	35.18	18.12	0.52	4.69	1.11	0.24	-34.27	8.30	0.24	-3.56	0.65	0.18
Primary7	55.27	22.16	0.40	6.50	1.49	0.23	-46.80	6.03	0.13	-4.54	0.69	0.15
Primary8	73.23	26.54	0.36	8.62	2.09	0.24	-60.41	6.26	0.10	-6.06	1.15	0.19
Primary9	83.97	32.31	0.38	11.11	2.67	0.24	-63.33	19.24	0.30	-7.09	1.05	0.15
Primary10	74.86	44.49	0.59	12.94	2.33	0.18	-57.14	29.32	0.51	-9.62	3.46	0.36
Primary11	77.13	49.60	0.64	15.68	3.40	0.22	-54.31	35.49	0.65	-10.96	1.30	0.12

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.24	0.12	0.51	0.15	0.16	1.01	0.30	0.11	0.35	9896.92	7945.25	0.80
Primary2	0.66	0.34	0.51	0.46	0.30	0.65	0.24	0.06	0.25	5943.98	4606.24	0.77
Primary3	3.09	1.75	0.56	3.99	2.47	0.62	0.13	0.04	0.29	4145.96	2598.60	0.63
Primary4	8.37	2.38	0.28	16.65	3.64	0.22	0.08	0.03	0.32	5281.34	1554.65	0.29
Primary5	17.66	14.59	0.83	44.29	33.81	0.76	0.06	0.02	0.27	6085.36	1928.41	0.32
Primary6	51.25	20.18	0.39	148.24	61.92	0.42	0.06	0.01	0.19	8399.11	1355.97	0.16
Primary7	88.77	37.62	0.42	290.99	89.91	0.31	0.05	0.01	0.13	9359.22	1207.24	0.13
Primary8	204.77	96.00	0.47	505.38	125.38	0.25	0.06	0.03	0.41	9263.36	1307.55	0.14
Primary9	372.51	196.74	0.53	694.15	205.94	0.30	0.09	0.07	0.70	8288.19	2249.83	0.27
Primary10	488.15	207.14	0.42	695.53	253.75	0.36	0.12	0.05	0.42	6525.88	3171.17	0.49
Primary11	696.54	188.54	0.27	864.71	284.88	0.33	0.14	0.05	0.39	4997.51	2607.12	0.52

Table A.39b: Hysteretic connection properties (Std.), Configuration 19.

Hysteretic Connection Properties: Configuration 19

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	270.22	218.42	0.81	0.01	0.00	0.30	-265.92	243.71	0.92	0.00	0.00	0.66
Primary2	360.01	234.13	0.65	0.01	0.00	0.24	-380.21	337.10	0.89	-0.01	0.00	0.44
Primary3	765.64	509.44	0.67	0.04	0.01	0.23	-1113.03	984.72	0.88	-0.04	0.01	0.20
Primary4	1852.31	1063.35	0.57	0.08	0.01	0.14	-2448.40	1403.16	0.57	-0.07	0.01	0.18
Primary5	3467.36	3194.97	0.92	0.11	0.04	0.34	-3670.67	1971.77	0.54	-0.09	0.02	0.21
Primary6	7908.37	4073.52	0.52	0.18	0.04	0.24	-7703.08	1865.87	0.24	-0.14	0.03	0.18
Primary7	12424.89	4980.65	0.40	0.26	0.06	0.23	-10520.59	1355.05	0.13	-0.18	0.03	0.15
Primary8	16461.65	5965.46	0.36	0.34	0.08	0.24	-13581.32	1406.59	0.10	-0.24	0.05	0.19
Primary9	18877.48	7263.54	0.38	0.44	0.11	0.24	-14237.11	4326.40	0.30	-0.28	0.04	0.15
Primary10	16829.10	10001.63	0.59	0.51	0.09	0.18	-12845.19	6592.08	0.51	-0.38	0.14	0.36
Primary11	17339.53	11150.22	0.64	0.62	0.13	0.22	-12210.37	7978.35	0.65	-0.43	0.05	0.12

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	2.12	1.08	0.51	1.37	1.38	1.01	0.30	0.11	0.35	56512.86	45368.53	0.80
Primary2	5.85	2.97	0.51	4.10	2.67	0.65	0.24	0.06	0.25	33940.99	26302.32	0.77
Primary3	27.39	15.46	0.56	35.29	21.84	0.62	0.13	0.04	0.29	23674.06	14838.36	0.63
Primary4	74.06	21.09	0.28	147.39	32.25	0.22	0.08	0.03	0.32	30157.21	8877.29	0.29
Primary5	156.31	129.09	0.83	391.96	299.23	0.76	0.06	0.02	0.28	34748.29	11011.48	0.32
Primary6	453.59	178.58	0.39	1311.99	548.05	0.42	0.06	0.01	0.19	47960.15	7742.80	0.16
Primary7	785.70	332.98	0.42	2575.44	795.76	0.31	0.05	0.01	0.19	53442.52	6893.51	0.13
Primary8	1812.41	849.68	0.47	4473.03	1109.70	0.25	0.06	0.03	0.40	52895.14	7466.28	0.14
Primary9	3296.98	1741.32	0.53	6143.73	1822.76	0.30	0.10	0.07	0.68	47326.75	12846.84	0.27
Primary10	4320.53	1833.38	0.42	6155.97	2245.88	0.36	0.12	0.05	0.42	37263.72	18107.86	0.49
Primary11	6164.87	1668.73	0.27	7653.35	2521.39	0.33	0.14	0.05	0.39	28536.54	14887.03	0.52

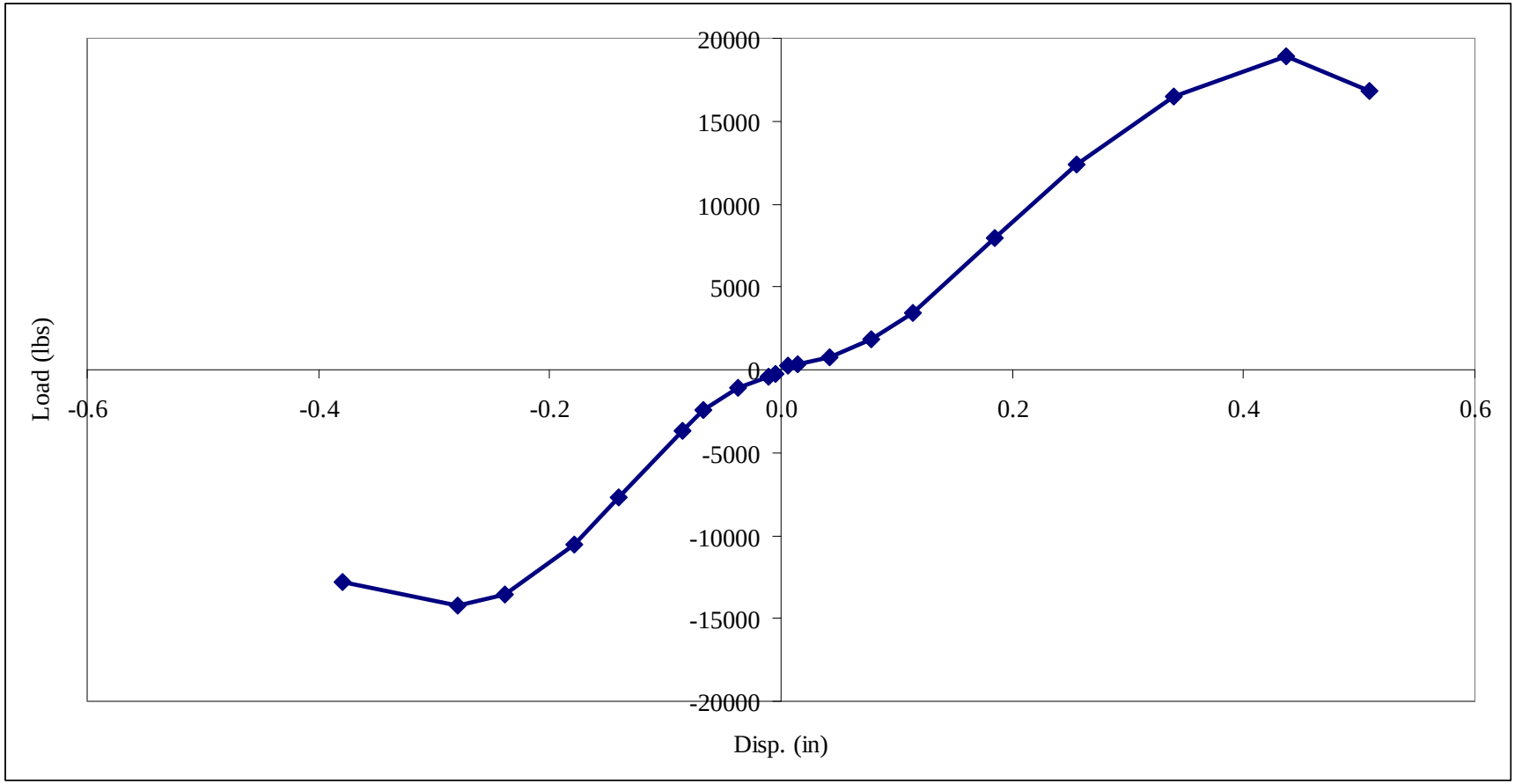

Figure A.133: Mean envelope curve: Configuration 19.

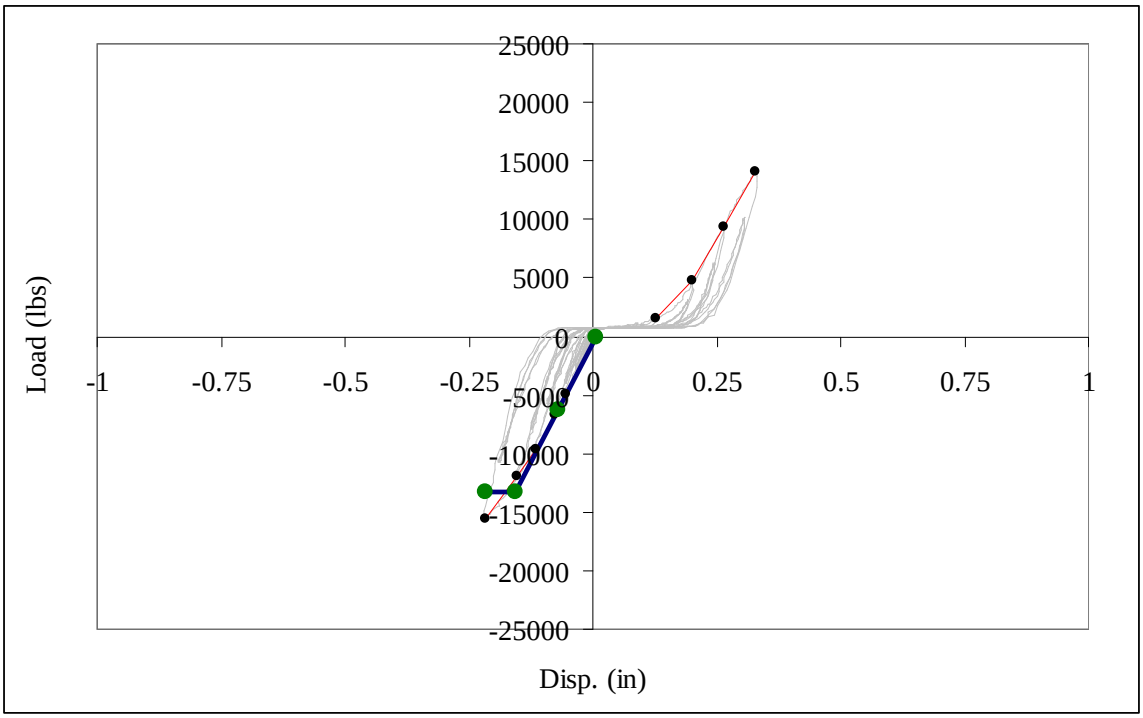

Figure A.134: Load-Deflection plot: C19-1.

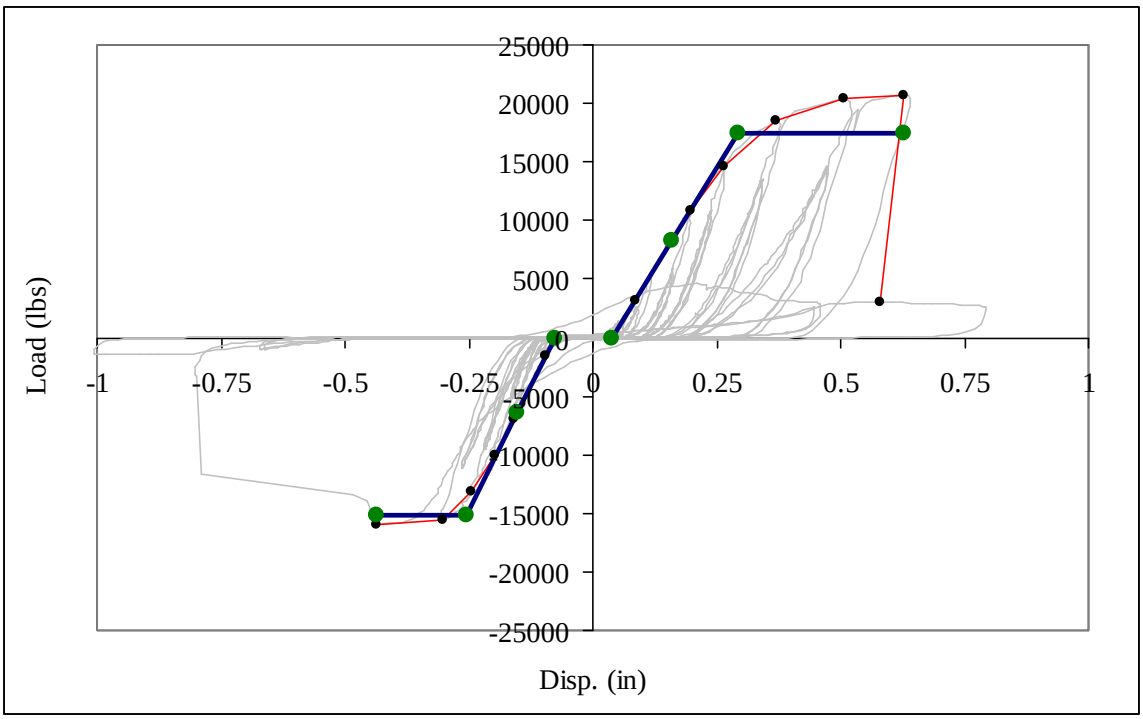

Figure A.135: Load-Deflection plot: C19-2.

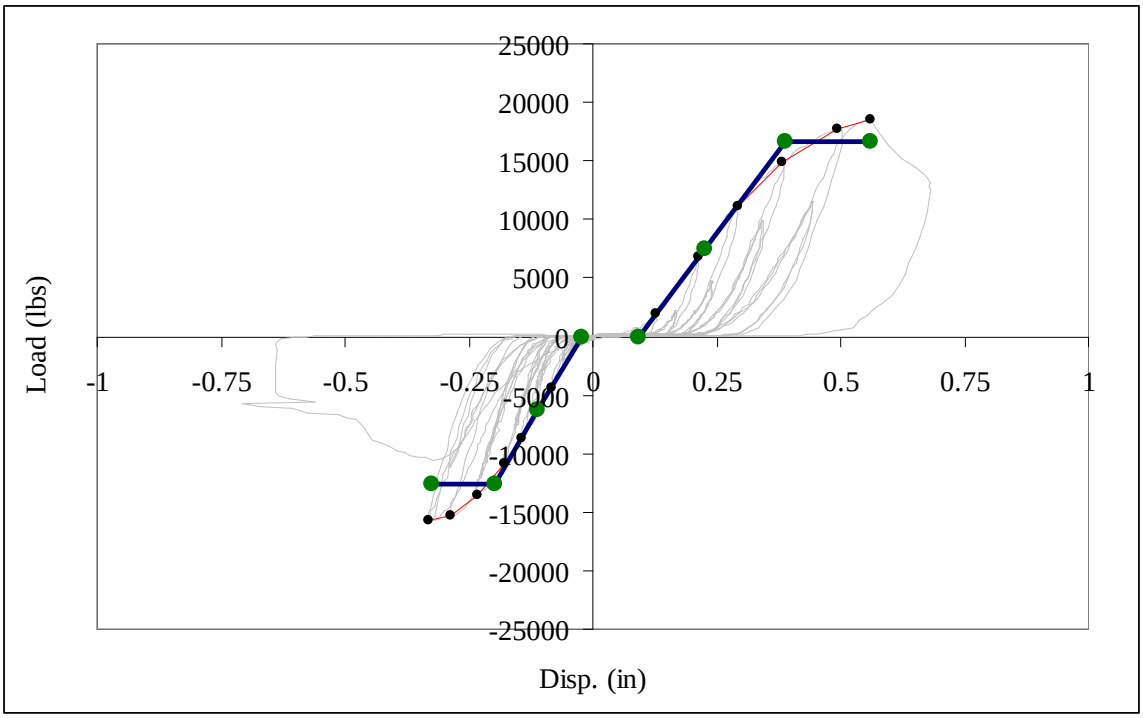

Figure A.136: Load-Deflection plot: C19-3.

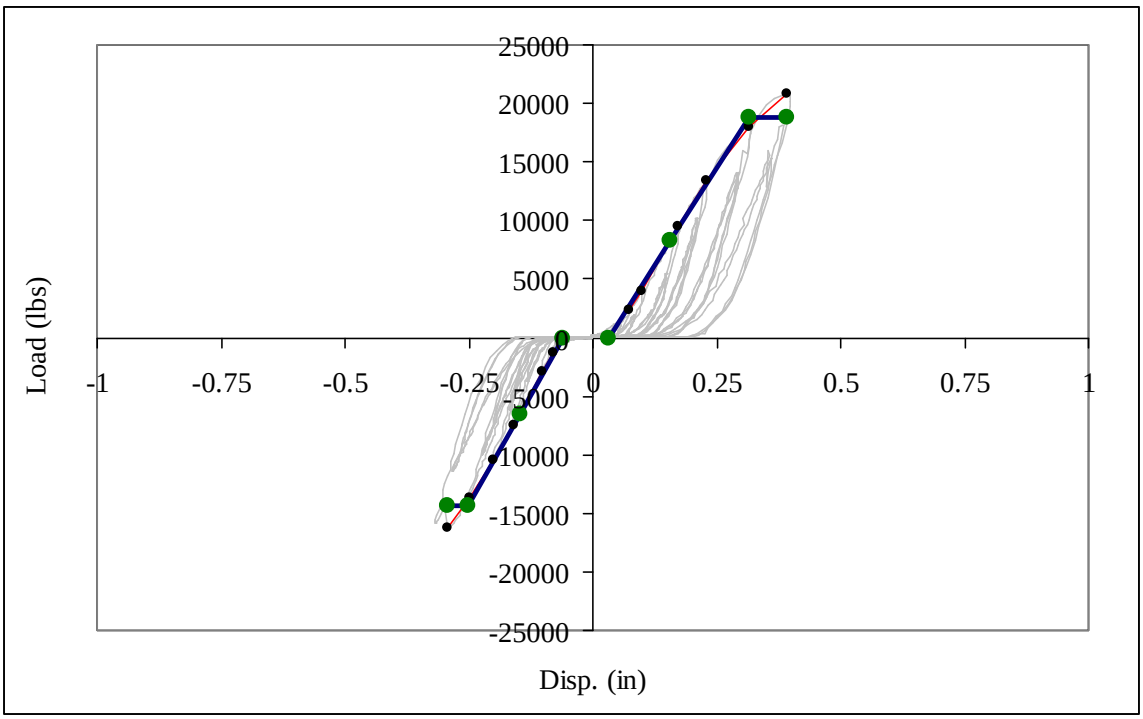

Figure A.137: Load-Deflection plot: C19-4.

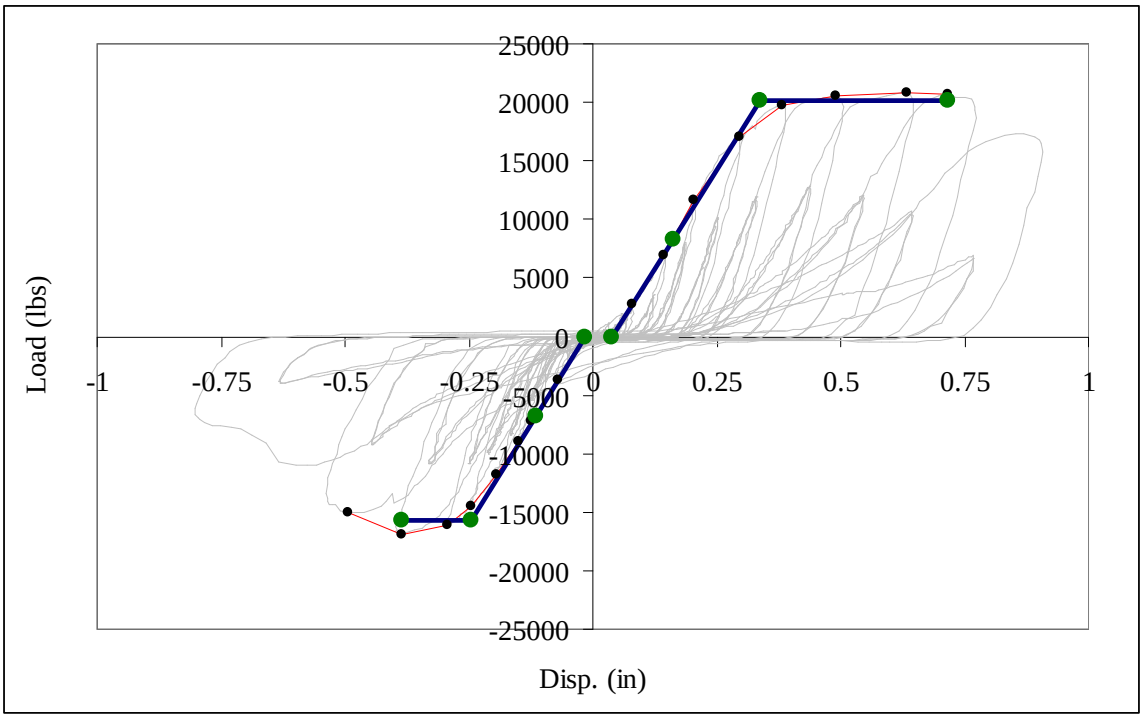

Figure A.138: Load-Deflection plot: C19-5.

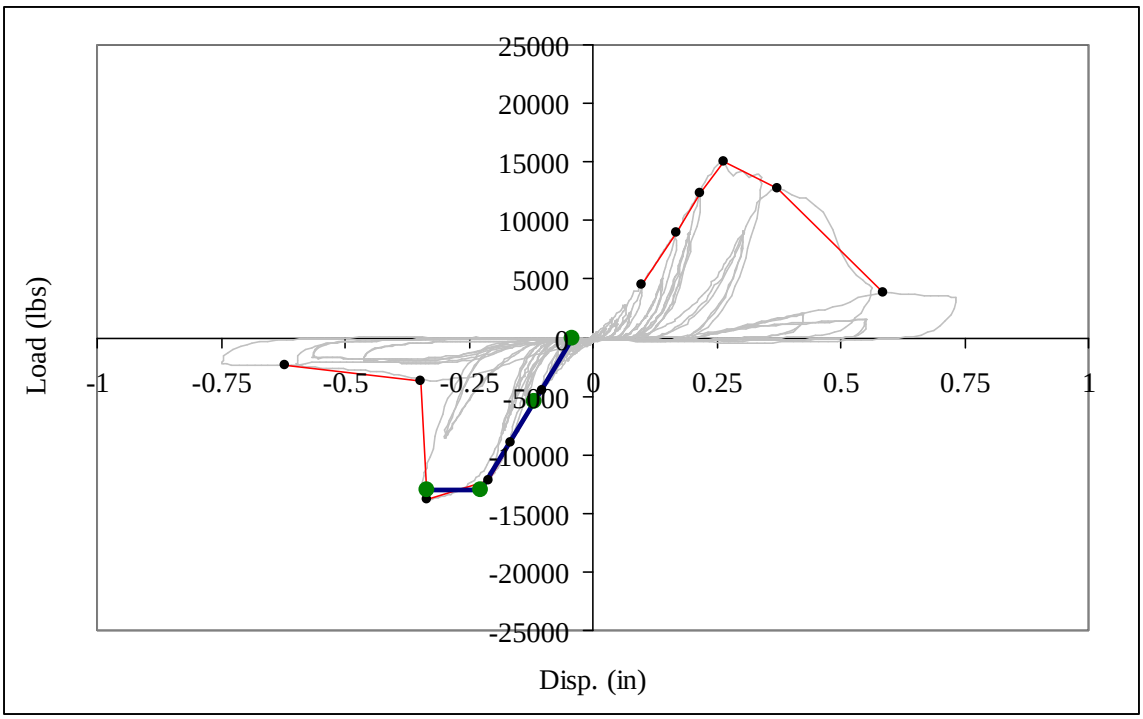

Figure A.139: Load-Deflection plot: C19-6.

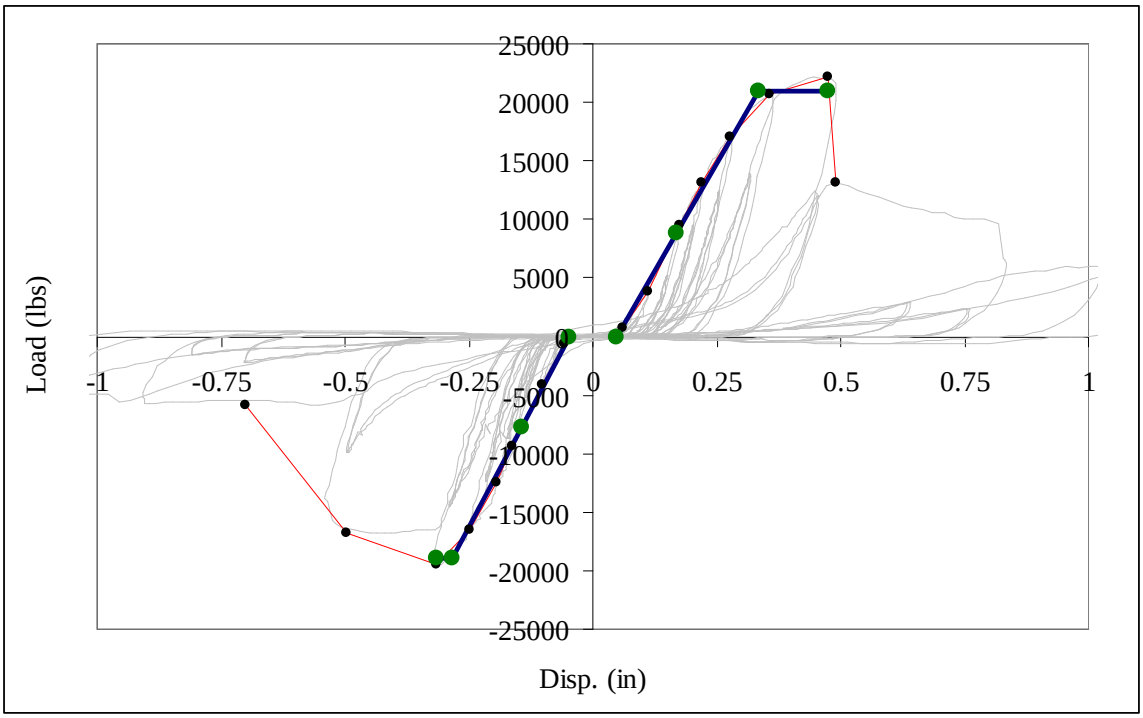

Figure A.140: Load-Deflection plot: C19-7.

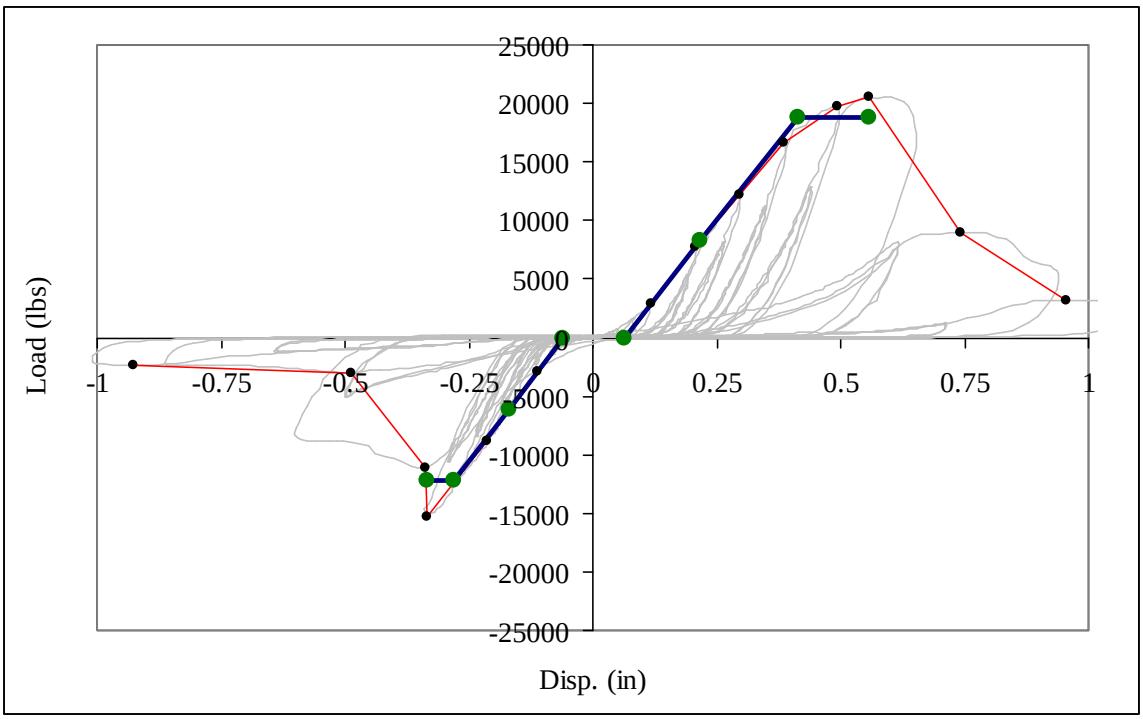

Figure A.141: Load-Deflection plot: C19-8.

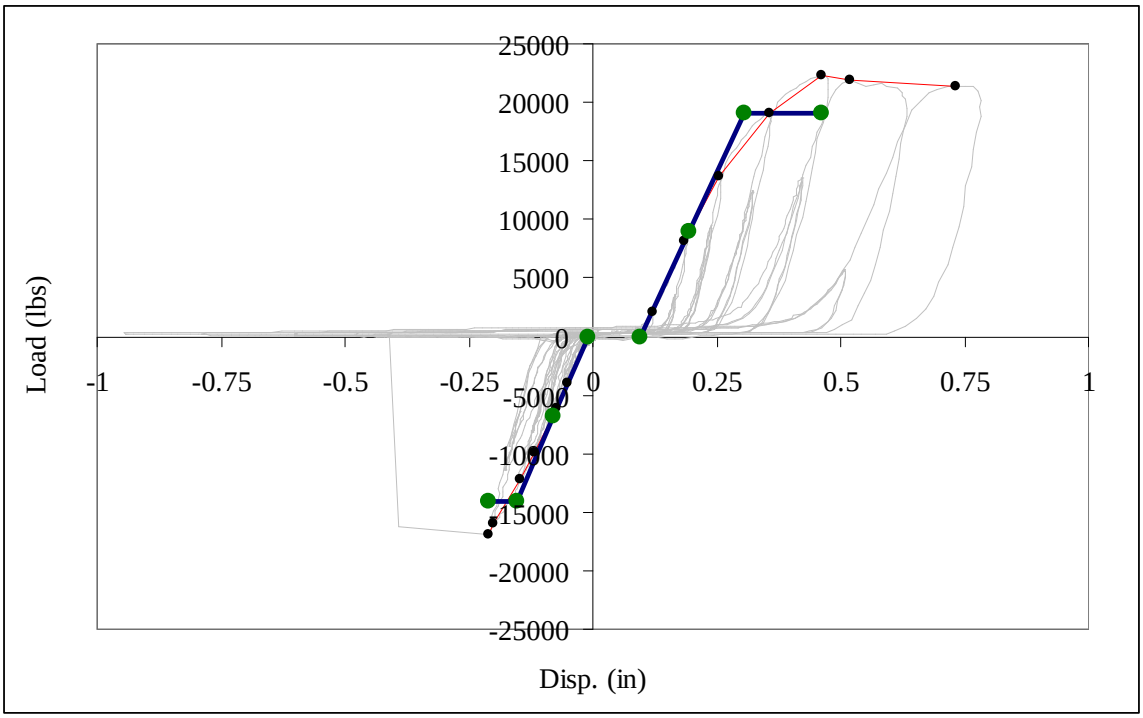

Figure A.142: Load-Deflection plot: C19-10.

A1.3 - Predicted Yield Mode II Configurations

Table A.40a: Connection performance properties (SI), Configuration 21.

Connection Performance Properties: Configuration 21

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	15.89	15.69	12.40	13.60	14.44	15.07	12.56	14.31	11.76	16.10	14.18	1.55	0.11
@Displacement (mm)	16.00	15.43	16.23	12.20	11.99	22.15	20.62	10.53	18.07	16.00	15.92	3.72	0.23
Failure Load (kN)	12.71	12.55	9.92	10.88	11.55	12.05	10.04	11.45	9.40	12.88	11.34	1.24	0.11
@Displacement (mm)	16.00	15.43	16.23	12.20	11.99	22.15	20.62	10.53	18.07	16.00	15.92	3.72	0.23
40% Max (kN)	6.35	6.28	4.96	5.44	5.78	6.03	5.02	5.72	4.70	6.44	5.67	0.62	0.11
@Displacement (mm)	5.01	5.66	5.57	4.66	4.83	5.78	6.35	4.36	4.98	4.93	5.21	0.61	0.12
Yield (kN)	13.40	13.03	10.69	11.52	12.33	12.93	10.94	12.11	9.81	13.87	12.06	1.31	0.11
@Displacement (mm)	8.69	9.96	10.03	7.76	8.06	10.89	11.86	7.24	8.61	8.40	9.15	1.48	0.16
5% Offset Yield (kN)	10.94	12.06	9.05	10.52	11.18	9.56	8.67	11.38	7.26	10.70	10.13	1.47	0.14
@Displacement (mm)	8.37	10.29	9.75	8.18	8.44	9.36	10.77	7.86	7.78	7.88	8.87	1.09	0.12
Elastic Stiff. (N/mm)	1912.93	1588.24	1317.59	1973.47	2030.48	1352.57	1104.06	2220.40	1430.83	2178.33	1710.89	399.28	0.23
E.E.P. Energy (N*m)	145.31	125.39	110.75	85.81	86.18	207.24	151.40	72.93	127.18	151.31	126.35	40.15	0.32
Ductility Ratio	1.84	1.58	1.62	1.57	1.50	2.04	1.74	1.47	2.11	1.92	1.74	0.23	0.13
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Splitting	Plg. Shr.	Splitting	Splitting	Plg. Shr.	Splitting	Splitting	Splitting	Splitting			
Governing Member	Main	Main	Side	Side	Side	Main	Both	Main	Side	Main			

Table A.40b: Connection performance properties (Std.), Configuration 21.

Connection Performance Properties: Configuration 21

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	3571.52	3526.88	2788.33	3057.49	3246.52	3387.28	2822.74	3216.58	2642.82	3619.90	3188.01	349.58	0.11
@ Displacement (in)	0.63	0.61	0.64	0.48	0.47	0.87	0.81	0.41	0.71	0.63	0.63	0.15	0.23
Failure Load (lbs)	2857.21	2821.50	2230.66	2445.99	2597.22	2709.82	2258.19	2573.27	2114.25	2895.92	2550.40	279.66	0.11
@ Displacement (in)	0.63	0.61	0.64	0.48	0.47	0.87	0.81	0.41	0.71	0.63	0.63	0.15	0.23
40% Max (lbs)	1428.61	1410.75	1115.33	1222.99	1298.61	1354.91	1129.10	1286.63	1057.13	1447.96	1275.20	139.83	0.11
@ Displacement (in)	0.20	0.22	0.22	0.18	0.19	0.23	0.25	0.17	0.20	0.19	0.21	0.02	0.12
Yield (lbs)	3012.14	2929.22	2403.64	2588.90	2772.02	2906.68	2458.85	2722.36	2204.62	3118.57	2711.70	293.63	0.11
@ Displacement (in)	0.34	0.39	0.39	0.31	0.32	0.43	0.47	0.28	0.34	0.33	0.36	0.06	0.16
5% Offset Yield (lbs)	2458.82	2712.24	2033.73	2364.90	2514.37	2150.17	1949.51	2557.78	1632.11	2405.41	2277.90	330.03	0.14
@ Displacement (in)	0.33	0.41	0.38	0.32	0.33	0.37	0.42	0.31	0.31	0.31	0.35	0.04	0.12
Elastic Stiff. (lb/in)	10923.10	9069.06	7523.62	11268.81	11594.32	7723.38	6304.32	12678.80	8170.27	12438.60	9769.43	2279.94	0.23
E.E.P. Energy (lb*in)	1286.10	1109.83	980.24	759.45	762.74	1834.22	1340.01	645.47	1125.62	1339.19	1118.29	355.37	0.32
Ductility Ratio	1.84	1.58	1.62	1.57	1.50	2.04	1.74	1.47	2.11	1.92	1.74	0.23	0.13
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Splitting	Plg. Shr.	Splitting	Splitting	Plg. Shr.	Splitting	Splitting	Splitting	Splitting			
Governing Member	Main	Main	Side	Side	Side	Main	Both	Main	Side	Main			

Table A.41a: Member properties (SI), Configuration 21.

Member Properties: Configuration 21

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.69	14.76	14.12	15.55	14.46	14.83	14.17	15.34	15.60	15.10	14.86	0.53	0.04
S.G.	0.49	0.49	0.41	0.51	0.54	0.45	0.42	0.55	0.42	0.52	0.48	0.05	0.10
D.E. 5% Offset Yield (kPa)	30515	29759	23446	29085	35402	24915	24412	27808	21403	30998	27774	4223.63	0.15
D.E. Capacity (kPa)	30515	29975	23554	29085	35402	25523	24412	27808	21403	30998	27868	4181.13	0.15
Side Member													
M.C. (%)	14.29	15.05	15.35	15.12	15.67	15.11	14.89	15.35	15.89	14.62	15.13	0.47	0.03
S.G.	0.53	0.49	0.40	0.46	0.53	0.45	0.42	0.53	0.40	0.52	0.47	0.06	0.12
D.E. 5% Offset Yield (kPa)	31412	30271	23047	28482	28091	25422	23627	30639	20822	30674	27249	3761.42	0.14
D.E. Capacity (kPa)	31575	30271	23047	28482	28091	25482	23627	30639	20822	30782	27282	3789.56	0.14

Table A.41b: Member properties (Std.): Configuration 21.

Member Properties: Configuration 21

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.69	14.76	14.12	15.55	14.46	14.83	14.17	15.34	15.60	15.10	14.86	0.53	0.04
S.G.	0.49	0.49	0.41	0.51	0.54	0.45	0.42	0.55	0.42	0.52	0.48	0.05	0.10
D.E. 5% Offset Yield (psi)	4425.78	4316.19	3400.57	4218.44	5134.60	3613.54	3540.60	4033.15	3104.29	4495.89	4028.31	612.58	0.15
D.E. Capacity (psi)	4425.78	4347.46	3416.22	4218.44	5134.60	3701.74	3540.60	4033.15	3104.29	4495.89	4041.82	606.42	0.15
Side Member													
M.C. (%)	14.29	15.05	15.35	15.12	15.67	15.11	14.89	15.35	15.89	14.62	15.13	0.47	0.03
S.G.	0.53	0.49	0.40	0.46	0.53	0.45	0.42	0.53	0.40	0.52	0.47	0.06	0.12
D.E. 5% Offset Yield (psi)	4555.87	4390.40	3342.61	4131.01	4074.23	3687.19	3426.81	4443.72	3019.96	4448.93	3952.07	545.54	0.14
D.E. Capacity (psi)	4579.60	4390.40	3342.61	4131.01	4074.23	3695.82	3426.81	4443.72	3019.96	4464.52	3956.87	549.63	0.14

Table A.42a: Hysteretic connection properties (SI), Configuration 21.

Hysteretic Connection Properties: Configuration 21

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.19	0.16	0.89	0.38	0.14	0.37	-0.21	0.28	1.32	-0.48	0.16	0.34
Primary2	0.31	0.36	1.16	0.63	0.31	0.49	-0.29	0.40	1.37	-0.72	0.32	0.44
Primary3	1.13	1.10	0.98	2.07	0.15	0.07	-0.99	1.15	1.16	-1.97	0.50	0.25
Primary4	2.89	2.00	0.69	3.35	0.16	0.05	-2.81	1.66	0.59	-3.45	0.09	0.03
Primary5	4.90	2.62	0.54	4.59	0.18	0.04	-4.92	1.91	0.39	-4.68	0.07	0.02
Primary6	8.40	3.69	0.44	7.61	1.49	0.20	-9.42	2.17	0.23	-8.03	0.25	0.03
Primary7	12.25	4.28	0.35	11.23	0.67	0.06	-12.27	2.32	0.19	-11.41	0.36	0.03
Primary8	13.19	5.17	0.39	15.95	1.85	0.12	-12.33	2.86	0.23	-14.64	1.97	0.13
Primary9	9.26	4.60	0.50	18.22	1.63	0.09	-6.44	5.63	0.87	-17.49	3.76	0.22
Primary10	6.05	4.90	0.81	21.57	3.39	0.16	-6.59	6.38	0.97	-23.39	1.13	0.05

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.16	0.09	0.55	0.10	0.09	0.93	0.33	0.11	0.32	475.67	345.19	0.73
Primary2	0.33	0.20	0.61	0.25	0.23	0.91	0.27	0.14	0.51	437.03	327.80	0.75
Primary3	1.72	0.82	0.48	2.29	1.02	0.44	0.12	0.03	0.21	549.73	315.32	0.57
Primary4	5.09	1.08	0.21	9.72	1.49	0.15	0.08	0.02	0.23	840.73	145.81	0.17
Primary5	10.90	1.93	0.18	22.77	5.20	0.23	0.08	0.01	0.10	1058.84	242.33	0.23
Primary6	46.56	11.21	0.24	71.29	16.35	0.23	0.10	0.00	0.04	1136.78	201.34	0.18
Primary7	82.72	16.01	0.19	138.73	23.76	0.17	0.09	0.01	0.06	1084.18	192.77	0.18
Primary8	138.69	35.13	0.25	197.77	53.87	0.27	0.11	0.01	0.11	834.91	152.73	0.18
Primary9	92.21	55.19	0.60	152.28	101.50	0.67	0.10	0.02	0.15	418.86	181.25	0.43
Primary10	69.42	46.41	0.67	149.08	136.92	0.92	0.11	0.06	0.58	267.97	232.16	0.87

Table A.42b: Hysteretic connection properties (Std.), Configuration 21.

Hysteretic Connection Properties: Configuration 21

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	41.62	36.92	0.89	0.01	0.01	0.37	-47.56	62.57	1.32	-0.02	0.01	0.34
Primary2	68.72	79.89	1.16	0.02	0.01	0.49	-65.45	89.71	1.37	-0.03	0.01	0.44
Primary3	253.36	247.72	0.98	0.08	0.01	0.07	-223.51	258.80	1.16	-0.08	0.02	0.25
Primary4	649.79	449.43	0.69	0.13	0.01	0.05	-632.37	372.98	0.59	-0.14	0.00	0.03
Primary5	1100.57	590.12	0.54	0.18	0.01	0.04	-1105.53	428.31	0.39	-0.18	0.00	0.02
Primary6	1887.32	830.21	0.44	0.30	0.06	0.20	-2117.24	486.86	0.23	-0.32	0.01	0.03
Primary7	2753.18	963.04	0.35	0.44	0.03	0.06	-2758.14	521.14	0.19	-0.45	0.01	0.03
Primary8	2965.83	1163.03	0.39	0.63	0.07	0.12	-2772.85	643.19	0.23	-0.58	0.08	0.13
Primary9	2080.89	1033.35	0.50	0.72	0.06	0.09	-1448.77	1266.71	0.87	-0.69	0.15	0.22
Primary10	1359.70	1102.02	0.81	0.85	0.13	0.16	-1481.90	1435.02	0.97	-0.92	0.04	0.05

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.44	0.80	0.55	0.84	0.79	0.93	0.33	0.11	0.32	2716.15	1971.06	0.73
Primary2	2.93	1.79	0.61	2.21	2.02	0.91	0.25	0.17	0.66	2495.51	1871.77	0.75
Primary3	15.18	7.24	0.48	20.25	8.99	0.44	0.14	0.04	0.29	3139.05	1800.52	0.57
Primary4	45.09	9.52	0.21	86.02	13.16	0.15	0.09	0.02	0.27	4800.67	832.57	0.17
Primary5	96.46	17.09	0.18	201.53	46.01	0.23	0.09	0.02	0.23	6046.12	1383.76	0.23
Primary6	412.08	99.21	0.24	630.96	144.74	0.23	0.10	0.00	0.04	6491.19	1149.67	0.18
Primary7	732.13	141.72	0.19	1227.86	210.28	0.17	0.09	0.01	0.06	6190.85	1100.75	0.18
Primary8	1227.49	310.92	0.25	1750.42	476.77	0.27	0.11	0.01	0.11	4767.47	872.10	0.18
Primary9	816.13	488.47	0.60	1347.79	898.39	0.67	0.10	0.02	0.15	2391.75	1034.95	0.43
Primary10	614.43	410.79	0.67	1319.46	1211.86	0.92	0.13	0.05	0.39	1530.13	1325.64	0.87

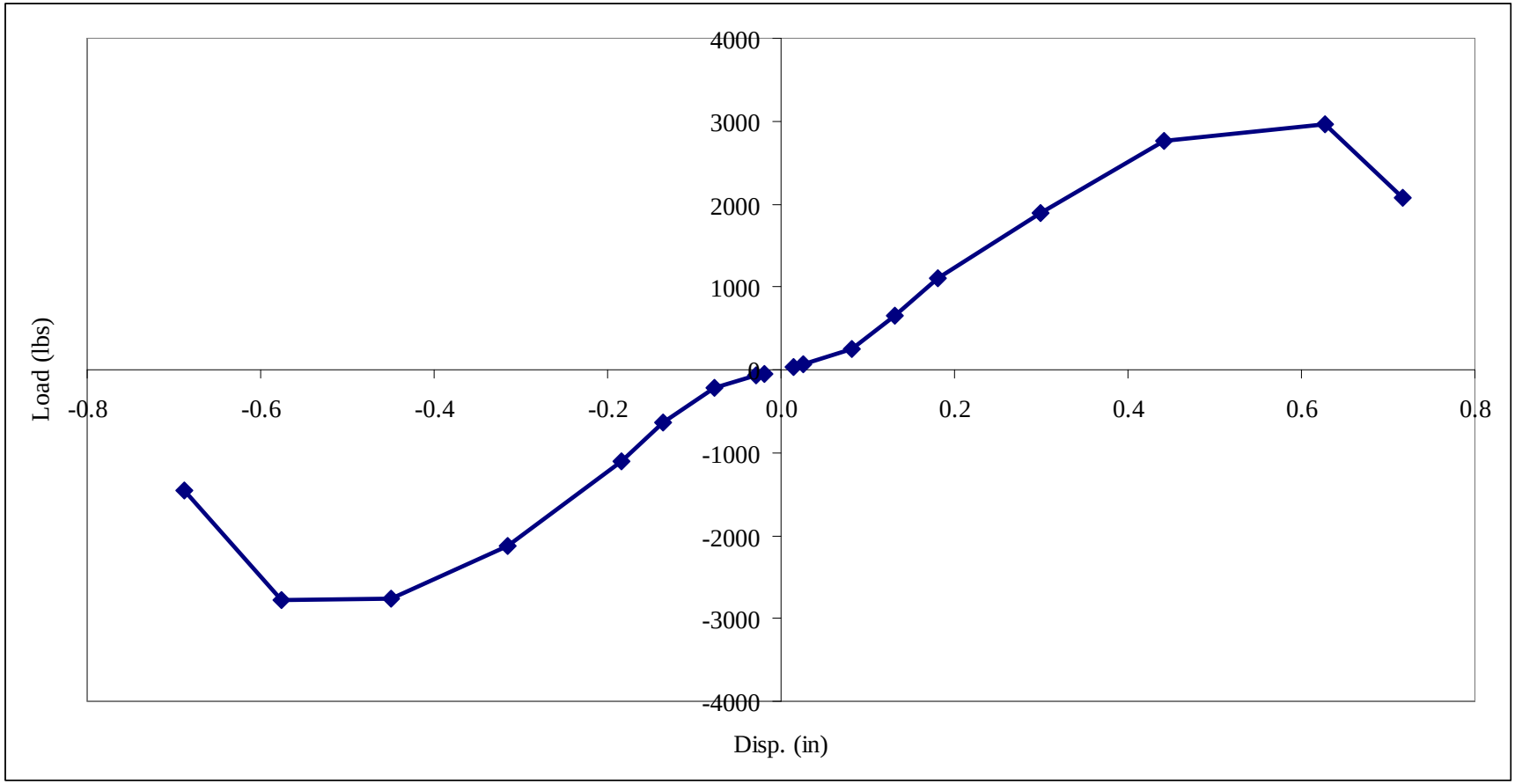

Figure A.143: Mean envelope curve: Configuration 21.

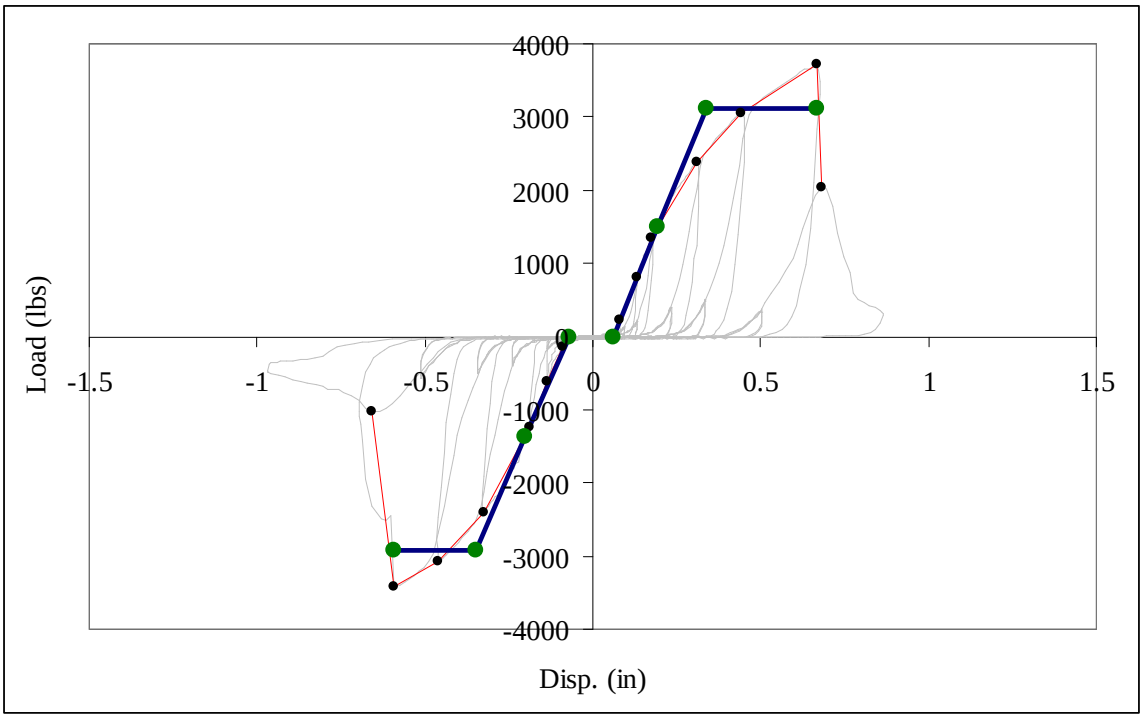

Figure A.144: Load-Deflection plot: C21-1.

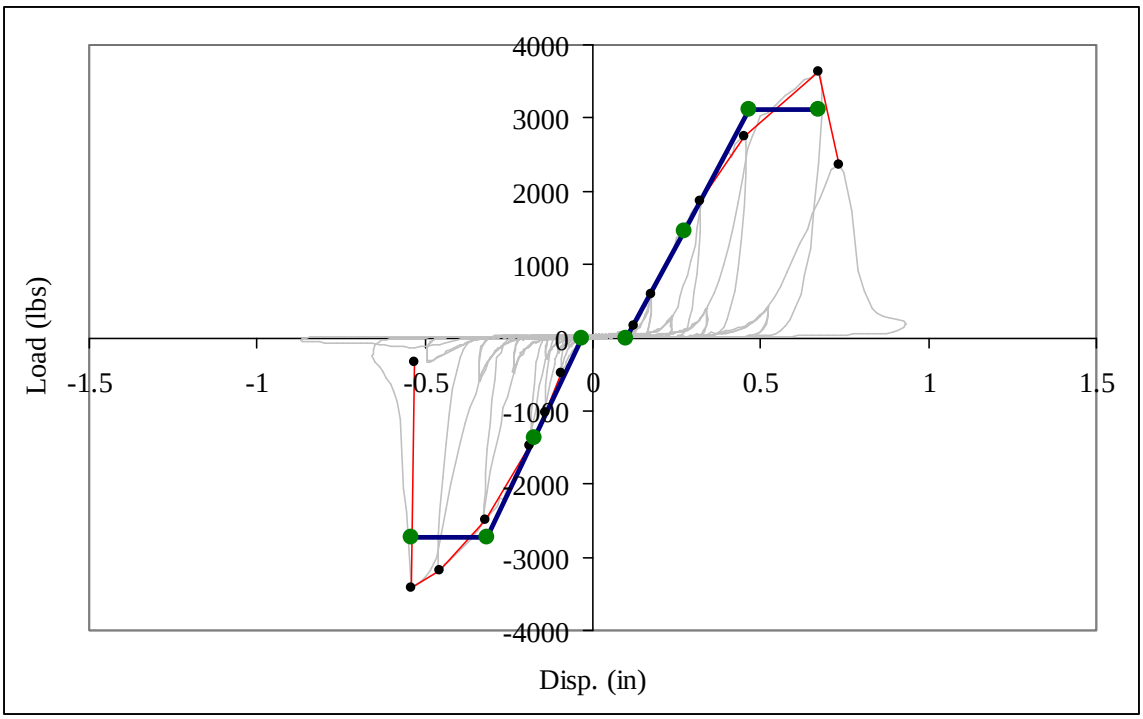

Figure A.145: Load-Deflection plot: C21-2.

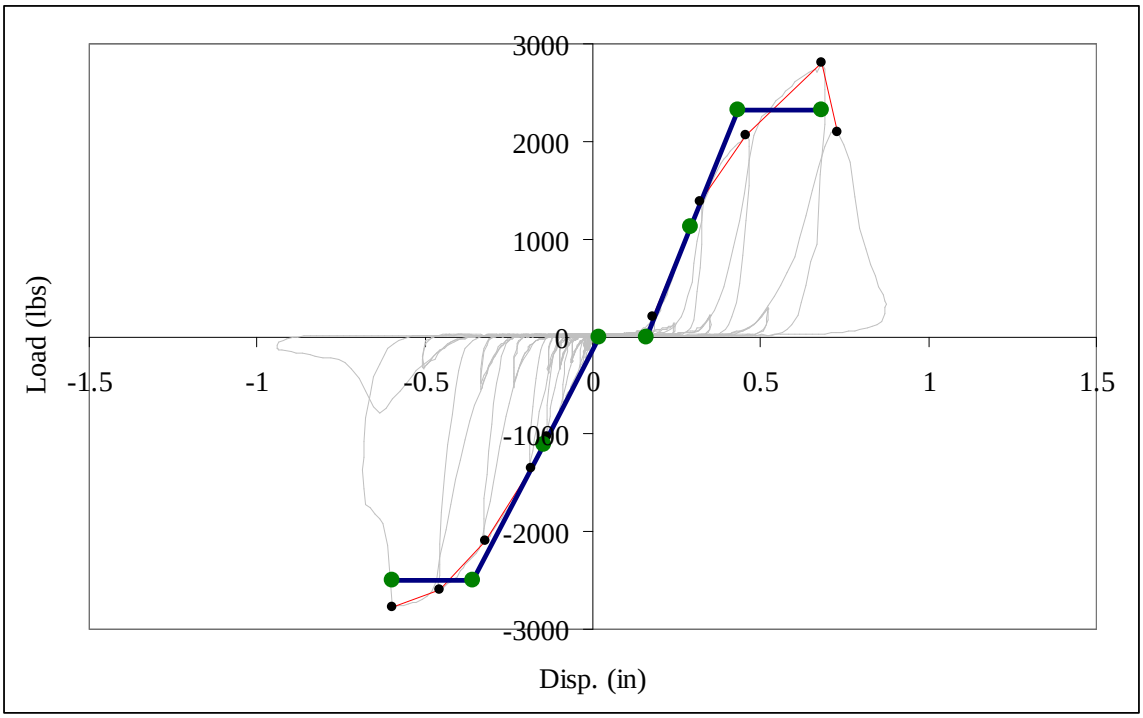

Figure A.146: Load-Deflection plot: C21-3.

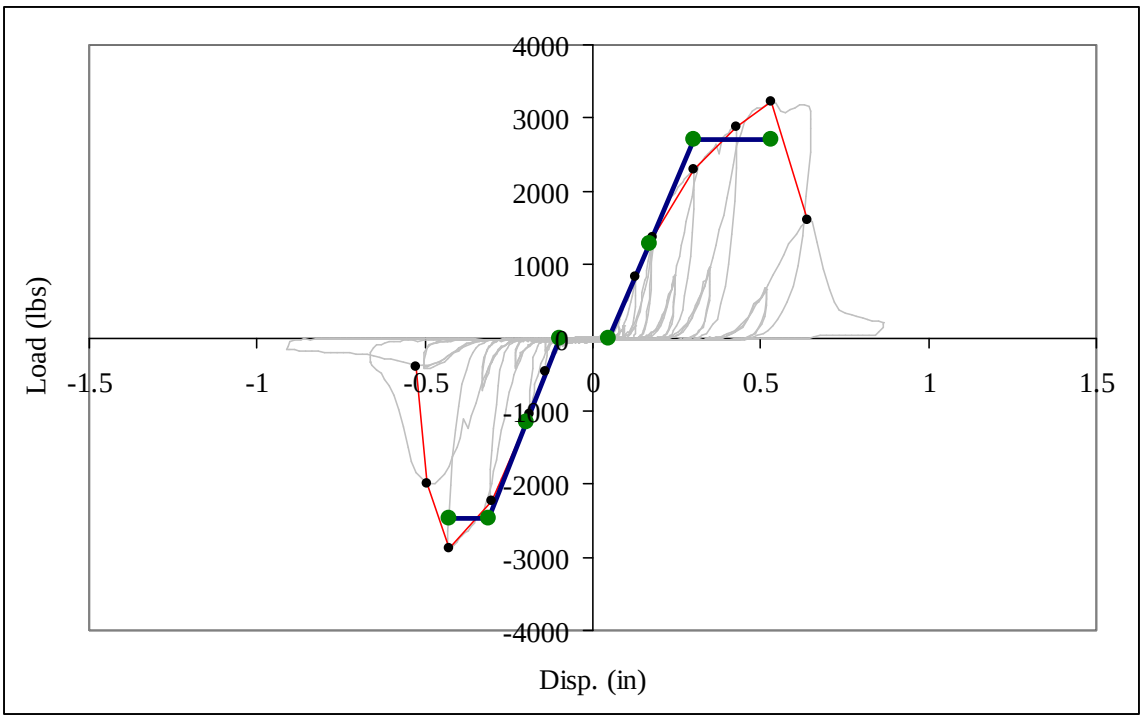

Figure A.147: Load-Deflection plot: C21-4.

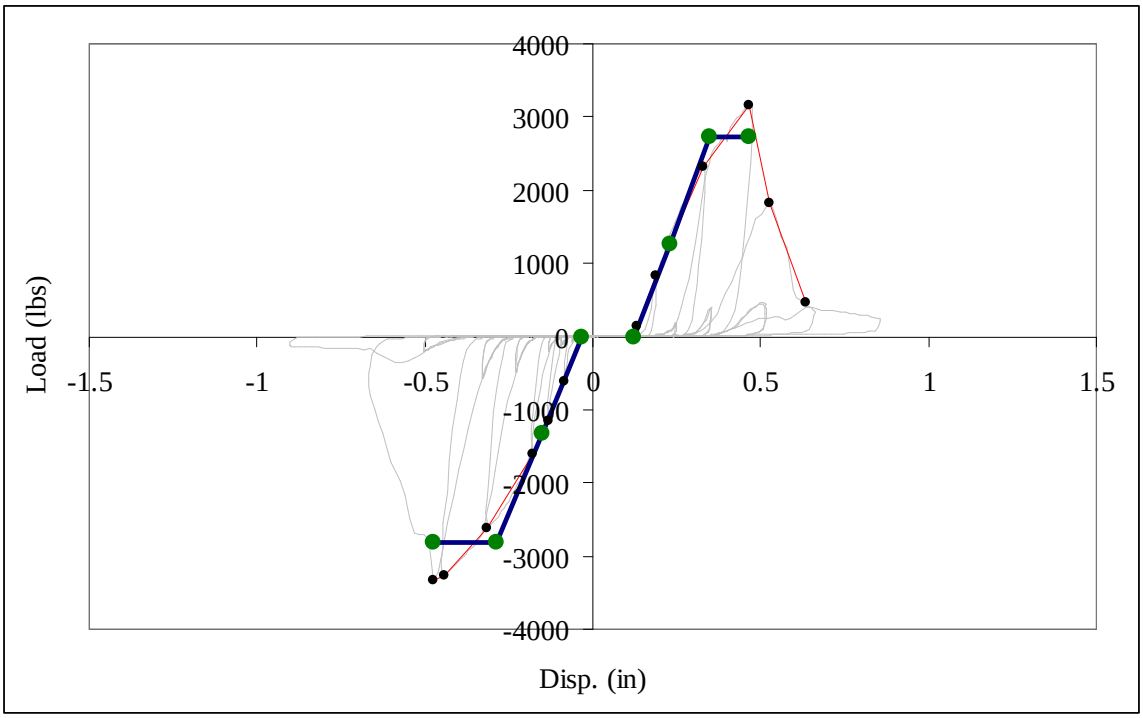

Figure A.148: Load-Deflection plot: C21-5.

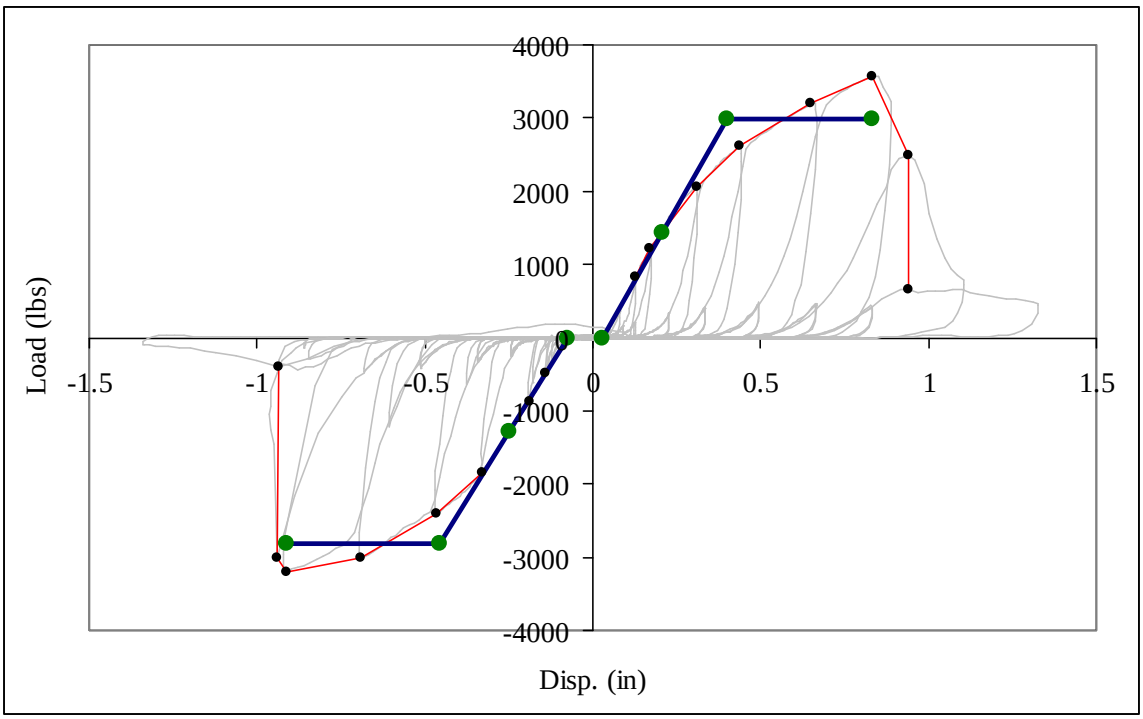

Figure A.149: Load-Deflection plot: C21-6.

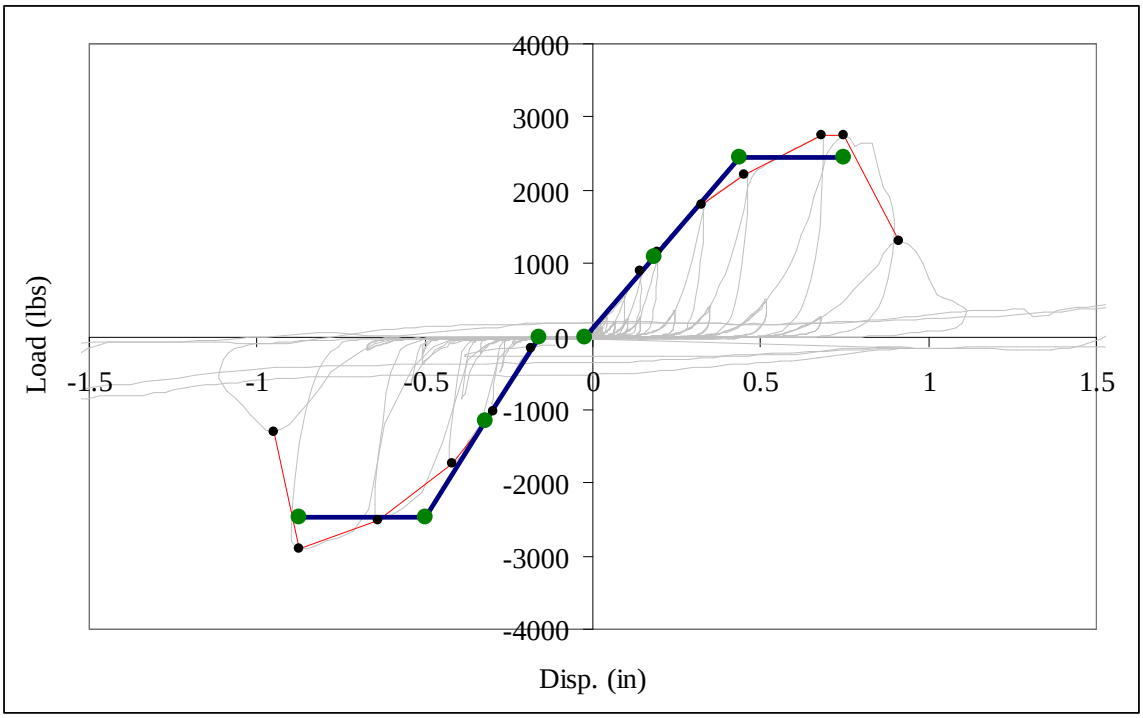

Figure A.150: Load-Deflection plot: C21-7.

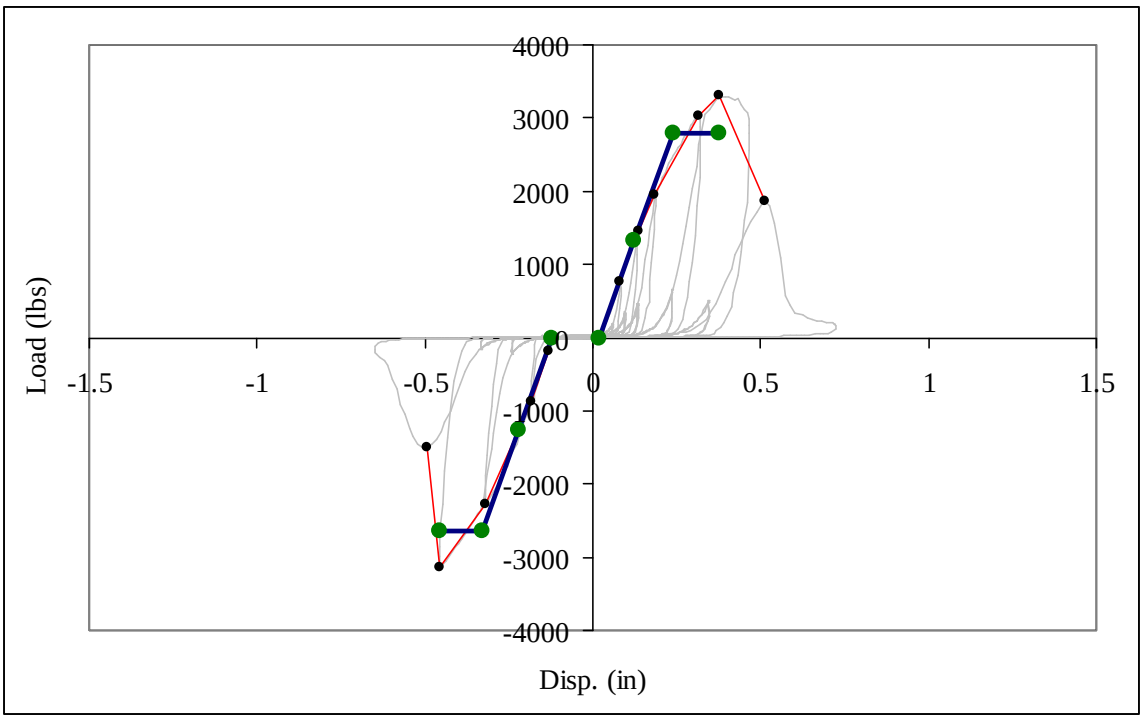

Figure A.151: Load-Deflection plot: C21-8.

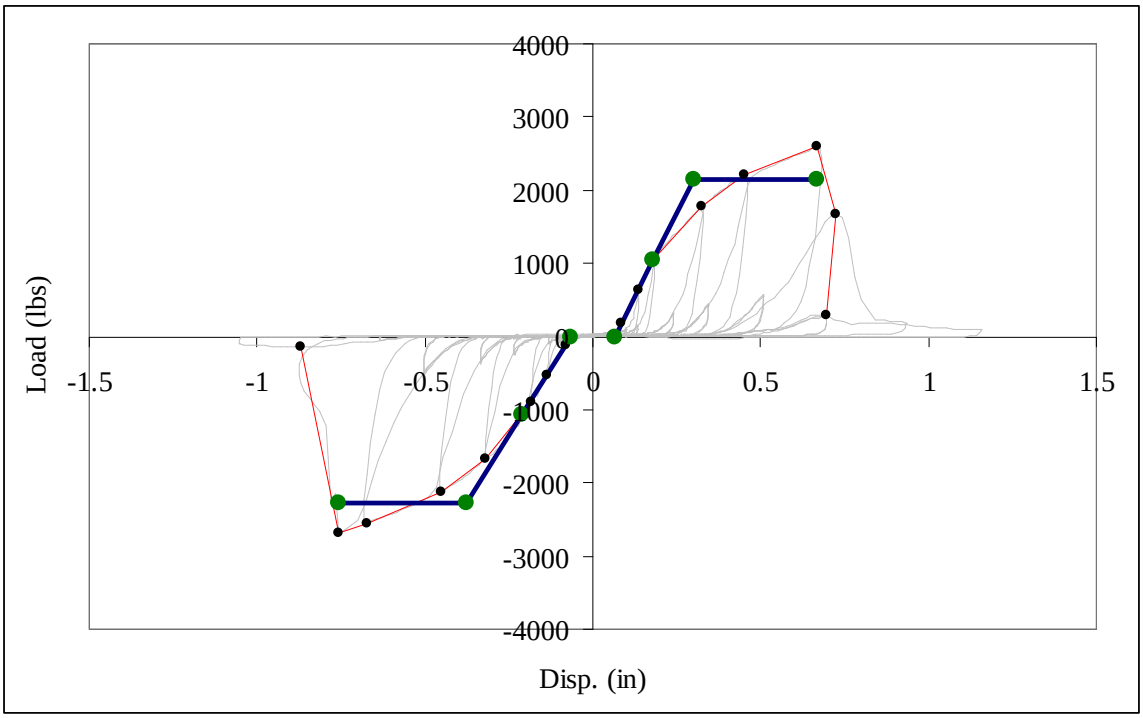

Figure A.152: Load-Deflection plot: C21-9.

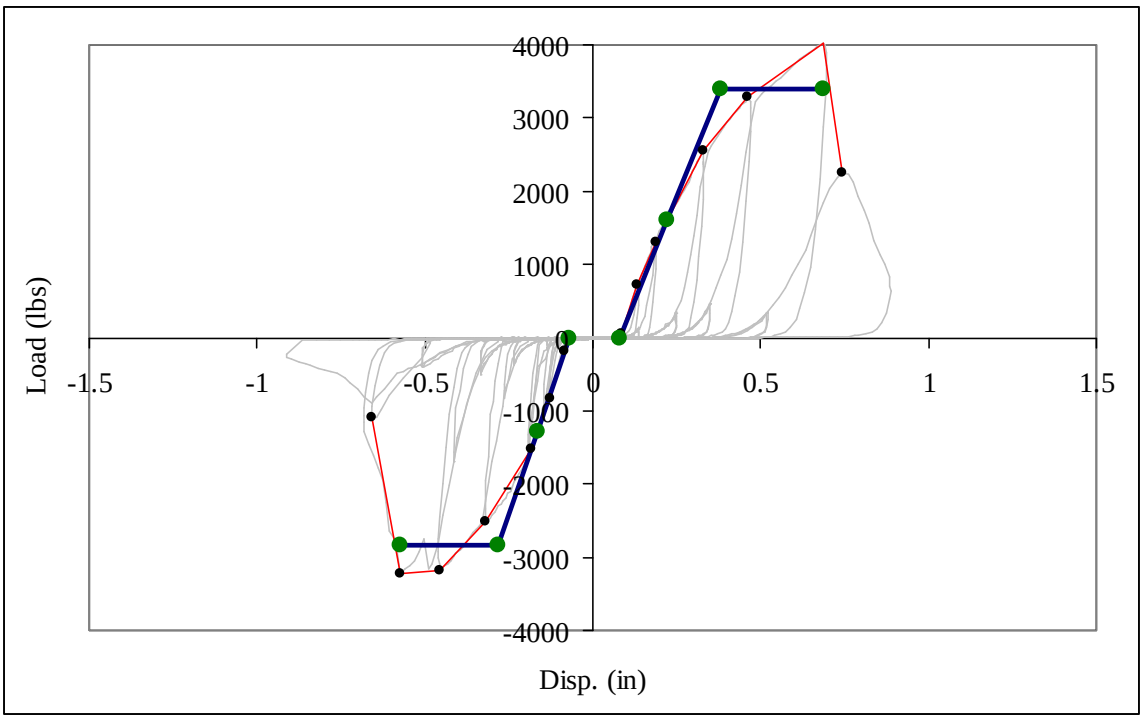

Figure A.153: Load-Deflection plot: C21-10.

Table A.43a: Connection performance properties (SI), Configuration 22.

Connection Performance Properties: Configuration 22

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	29.47	34.90	37.50	35.65	34.48	27.19	38.98	37.50	34.24	38.99	34.89	3.90	0.11
@Displacement (mm)	8.06	11.60	11.32	11.15	9.39	7.34	8.62	16.29	9.83	10.43	10.40	2.51	0.24
Failure Load (kN)	23.57	27.92	30.00	28.52	27.58	21.75	31.19	30.00	27.39	31.19	27.91	3.12	0.11
@Displacement (mm)	8.06	11.60	11.32	11.15	9.39	7.34	8.62	16.29	9.83	10.43	10.40	2.51	0.24
40% Max (kN)	11.79	13.96	15.00	14.26	13.79	10.88	15.59	15.00	13.69	15.59	13.96	1.56	0.11
@Displacement (mm)	4.20	4.72	5.17	4.87	3.96	3.95	4.17	6.58	4.42	4.46	4.65	0.78	0.17
Yield (kN)	26.16	30.91	33.26	31.73	28.84	25.76	34.84	33.14	29.57	34.67	30.89	3.26	0.11
@Displacement (mm)	6.86	8.13	9.04	8.46	6.11	6.76	6.87	12.18	7.37	7.60	7.94	1.73	0.22
5% Offset Yield (kN)	29.07	28.45	34.63	30.89	27.47	29.18	37.58	29.15	31.22	30.18	30.78	3.09	0.10
@Displacement (mm)	7.97	8.63	10.27	9.25	6.87	8.06	8.21	12.04	8.65	10.35	9.03	1.50	0.17
Elastic Stiff. (N/mm)	5464.33	5013.29	4798.60	4858.29	7063.14	5274.13	7145.28	3259.60	5384.51	6076.37	5433.75	1138.44	0.21
E.E.P. Energy (N*m)	94.94	199.58	197.29	190.92	153.89	78.19	145.68	315.37	155.95	202.97	173.48	66.05	0.38
Ductility Ratio	1.22	1.47	1.26	1.33	1.54	1.09	1.27	1.34	1.35	1.42	1.33	0.13	0.10
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Row TO	Splitting	Splitting	Plg. Shr.	Splitting	Splitting	Splitting	Splitting	Row TO	Splitting			
Governing Member	Side	Main	Main	Side	Side	Main	Main	Side	Main	Side			

Table A.43b: Connection performance properties (Std.), Configuration 22.

Connection Performance Properties: Configuration 22

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	6624.17	7845.83	8429.60	8013.75	7750.77	6113.38	8763.92	8429.31	7696.61	8764.32	7843.17	876.93	0.11
@ Displacement (in)	0.32	0.46	0.45	0.44	0.37	0.29	0.34	0.64	0.39	0.41	0.41	0.10	0.24
Failure Load (lbs)	5299.33	6276.67	6743.68	6411.00	6200.62	4890.70	7011.14	6743.45	6157.29	7011.46	6274.53	701.54	0.11
@ Displacement (in)	0.32	0.46	0.45	0.44	0.37	0.29	0.34	0.64	0.39	0.41	0.41	0.10	0.24
40% Max (lbs)	2649.67	3138.33	3371.84	3205.50	3100.31	2445.35	3505.57	3371.73	3078.64	3505.73	3137.27	350.77	0.11
@ Displacement (in)	0.17	0.19	0.20	0.19	0.16	0.16	0.16	0.26	0.17	0.18	0.18	0.03	0.17
Yield (lbs)	5880.92	6948.69	7476.96	7132.61	6482.62	5790.82	7832.07	7450.40	6648.53	7793.29	6943.69	733.80	0.11
@ Displacement (in)	0.27	0.32	0.36	0.33	0.24	0.27	0.27	0.48	0.29	0.30	0.31	0.07	0.22
5% Offset Yield (lbs)	6535.16	6395.06	7785.79	6944.45	6175.66	6560.06	8448.40	6553.40	7017.78	6785.59	6920.13	695.66	0.10
@ Displacement (in)	0.31	0.34	0.40	0.36	0.27	0.32	0.32	0.47	0.34	0.41	0.36	0.06	0.17
Elastic Stiff. (lb/in)	31202.15	28626.65	27400.70	27741.56	40331.56	30116.06	40800.60	18612.80	30746.31	34696.97	31027.54	6500.64	0.21
E.E.P. Energy (lb*in)	840.27	1766.42	1746.18	1689.76	1362.01	692.04	1289.41	2791.27	1380.31	1796.45	1535.41	584.62	0.38
Ductility Ratio	1.22	1.47	1.26	1.33	1.54	1.09	1.27	1.34	1.35	1.42	1.33	0.13	0.10
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Row TO	Splitting	Splitting	Plg. Shr.	Splitting	Splitting	Splitting	Splitting	Row TO	Splitting			
Governing Member	Side	Main	Main	Side	Side	Main	Main	Side	Main	Side			

Table A.44a: Member properties (SI), Configuration 22.

Member Properties: Configuration 22

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.58	14.43	13.95	14.01	14.64	13.96	15.04	14.85	16.15	14.19	14.58	0.67	0.05
S.G.	0.52	0.45	0.45	0.48	0.52	0.50	0.54	0.45	0.50	0.46	0.49	0.03	0.07
D.E. 5% Offset Yield (kPa)	31882	25054	29702	26803	28794	28564	32212	27137	26962	30788	28790	2359.95	0.08
D.E. Capacity (kPa)	31882	25570	29702	28004	28794	28564	32212	27395	28024	30788	29094	2074.70	0.07
Side Member													
M.C. (%)	16.06	14.64	13.89	15.79	15.49	13.90	15.50	15.96	15.39	15.17	15.18	0.79	0.05
S.G.	0.51	0.44	0.50	0.48	0.53	0.51	0.57	0.51	0.49	0.48	0.50	0.04	0.07
D.E. 5% Offset Yield (kPa)	33582	25894	29653	25374	29704	25494	32506	24552	26879	26005	27964	3194.15	0.11
D.E. Capacity (kPa)	34615	25894	29653	25787	29704	26370	32506	24650	27052	29499	28573	3210.60	0.11

Table A.44b: Member properties (Std.), Configuration 22.

Member Properties: Configuration 22

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.58	14.43	13.95	14.01	14.64	13.96	15.04	14.85	16.15	14.19	14.58	0.67	0.05
S.G.	0.52	0.45	0.45	0.48	0.52	0.50	0.54	0.45	0.50	0.46	0.49	0.03	0.07
D.E. 5% Offset Yield (psi)	4624.03	3633.80	4307.86	3887.46	4176.17	4142.87	4671.95	3935.85	3910.43	4465.46	4175.59	342.28	0.08
D.E. Capacity (psi)	4624.03	3708.64	4307.86	4061.60	4176.17	4142.87	4671.95	3973.36	4064.55	4465.46	4219.65	300.91	0.07
Side Member													
M.C. (%)	16.06	14.64	13.89	15.79	15.49	13.90	15.50	15.96	15.39	15.17	15.18	0.79	0.05
S.G.	0.51	0.44	0.50	0.48	0.53	0.51	0.57	0.51	0.49	0.48	0.50	0.04	0.07
D.E. 5% Offset Yield (psi)	4870.64	3755.52	4300.80	3680.17	4308.19	3697.55	4714.53	3560.94	3898.51	3771.69	4055.85	463.27	0.11
D.E. Capacity (psi)	5020.47	3755.52	4300.80	3740.12	4308.19	3824.65	4714.53	3575.15	3923.56	4278.38	4144.14	465.65	0.11

Table A.45a: Hysteretic connection properties (SI), Configuration 22.

Hysteretic Connection Properties: Configuration 22

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.36	0.57	1.58	0.34	0.17	0.48	-0.25	0.10	0.42	-0.47	0.15	0.32
Primary2	0.58	0.89	1.53	0.69	0.13	0.19	-0.33	0.19	0.56	-0.78	0.13	0.17
Primary3	2.81	3.25	1.15	1.91	0.13	0.07	-2.29	2.35	1.03	-2.05	0.16	0.08
Primary4	7.28	5.35	0.73	3.07	0.16	0.05	-6.40	4.63	0.72	-3.18	0.16	0.05
Primary5	13.26	6.56	0.50	4.25	0.27	0.06	-11.66	5.20	0.45	-4.22	0.22	0.05
Primary6	26.76	9.66	0.36	7.14	0.54	0.08	-24.12	4.60	0.19	-6.90	0.35	0.05
Primary7	31.43	13.69	0.44	9.05	1.58	0.17	-29.39	7.25	0.25	-9.03	0.80	0.09
Primary8	25.62	15.13	0.59	10.98	1.76	0.16	-20.32	15.53	0.76	-9.77	4.10	0.42
Primary9	10.19	9.21	0.90	14.66	1.98	0.14	-13.34	20.28	1.52	-14.01	4.28	0.31

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.25	0.11	0.44	0.13	0.11	0.88	0.41	0.24	0.58	770.39	518.98	0.67
Primary2	0.48	0.22	0.47	0.33	0.25	0.76	0.27	0.08	0.29	625.56	532.89	0.85
Primary3	3.02	1.41	0.47	5.07	2.27	0.45	0.10	0.02	0.21	1290.97	586.08	0.45
Primary4	9.15	2.29	0.25	21.14	5.13	0.24	0.07	0.01	0.18	2190.79	497.49	0.23
Primary5	19.58	3.04	0.16	52.20	10.30	0.20	0.06	0.01	0.14	2945.28	592.63	0.20
Primary6	85.62	13.92	0.16	177.71	23.56	0.13	0.08	0.01	0.12	3635.07	618.37	0.17
Primary7	137.01	38.31	0.28	281.17	71.92	0.26	0.08	0.02	0.31	3344.95	681.12	0.20
Primary8	198.71	78.01	0.39	265.26	132.43	0.50	0.12	0.04	0.32	2084.42	808.96	0.39
Primary9	136.64	187.79	1.37	191.22	258.16	1.35	0.12	0.06	0.48	780.24	824.91	1.06

Table A.45b: Hysteretic connection properties (Std.), Configuration 22.

Hysteretic Connection Properties: Configuration 22

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	80.82	127.69	1.58	0.01	0.01	0.48	-55.99	23.55	0.42	-0.02	0.01	0.32
Primary2	131.11	200.47	1.53	0.03	0.01	0.19	-74.71	41.89	0.56	-0.03	0.01	0.17
Primary3	632.50	729.91	1.15	0.08	0.01	0.07	-514.44	527.59	1.03	-0.08	0.01	0.08
Primary4	1637.13	1202.68	0.73	0.12	0.01	0.05	-1438.33	1041.05	0.72	-0.13	0.01	0.05
Primary5	2979.91	1475.81	0.50	0.17	0.01	0.06	-2622.04	1168.77	0.45	-0.17	0.01	0.05
Primary6	6014.79	2172.60	0.36	0.28	0.02	0.08	-5421.41	1034.22	0.19	-0.27	0.01	0.05
Primary7	7065.91	3077.33	0.44	0.36	0.06	0.17	-6607.91	1629.55	0.25	-0.36	0.03	0.09
Primary8	5760.12	3400.31	0.59	0.43	0.07	0.16	-4568.04	3492.12	0.76	-0.38	0.16	0.42
Primary9	2290.71	2069.97	0.90	0.58	0.08	0.14	-2999.35	4559.77	1.52	-0.55	0.17	0.31

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	2.19	0.96	0.44	1.15	1.01	0.88	0.41	0.24	0.58	4399.03	2963.44	0.67
Primary2	4.21	1.97	0.47	2.91	2.23	0.76	0.28	0.09	0.33	3572.04	3042.87	0.85
Primary3	26.77	12.51	0.47	44.90	20.13	0.45	0.14	0.11	0.80	7371.61	3346.58	0.45
Primary4	80.98	20.26	0.25	187.08	45.40	0.24	0.07	0.02	0.27	12509.74	2840.74	0.23
Primary5	173.27	26.93	0.16	462.01	91.21	0.20	0.06	0.01	0.14	16818.00	3384.02	0.20
Primary6	757.77	123.18	0.16	1572.91	208.56	0.13	0.08	0.01	0.09	20756.79	3531.01	0.17
Primary7	1212.60	339.07	0.28	2488.55	636.58	0.26	0.08	0.02	0.27	19100.14	3889.28	0.20
Primary8	1758.75	690.49	0.39	2347.74	1172.10	0.50	0.13	0.04	0.28	11902.36	4619.30	0.39
Primary9	1209.38	1662.04	1.37	1692.42	2284.91	1.35	0.12	0.06	0.48	4455.26	4710.34	1.06

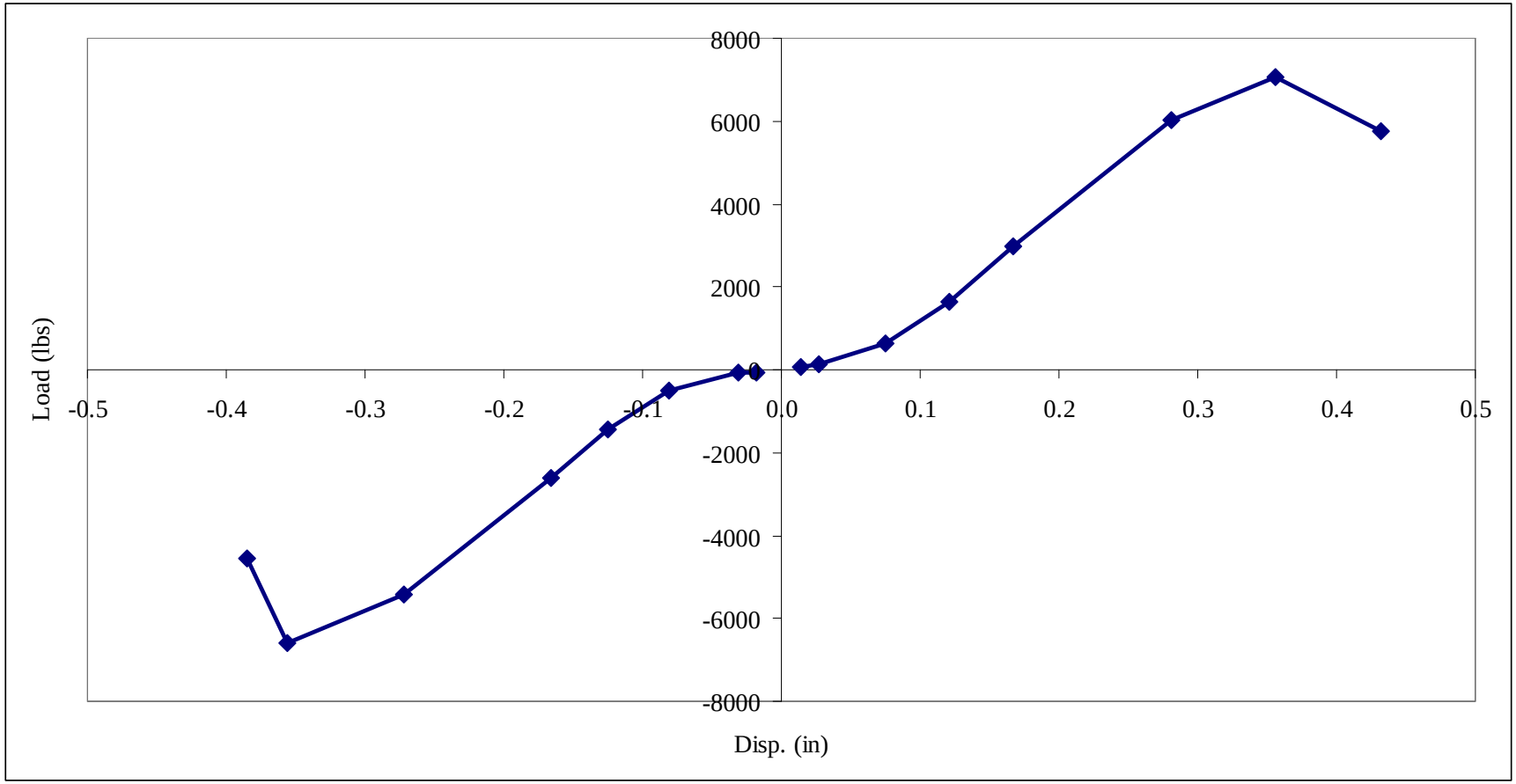

Figure A.154: Mean envelope curve: Configuration 22.

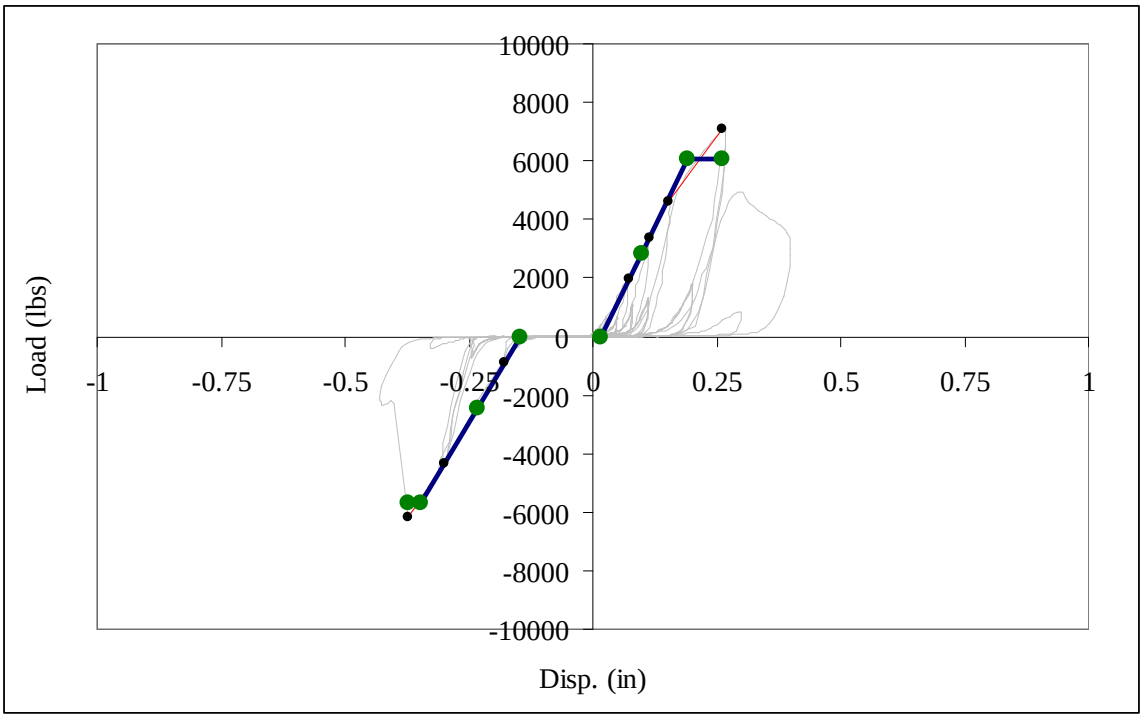

Figure A.155: Load-Deflection plot: C22-1.

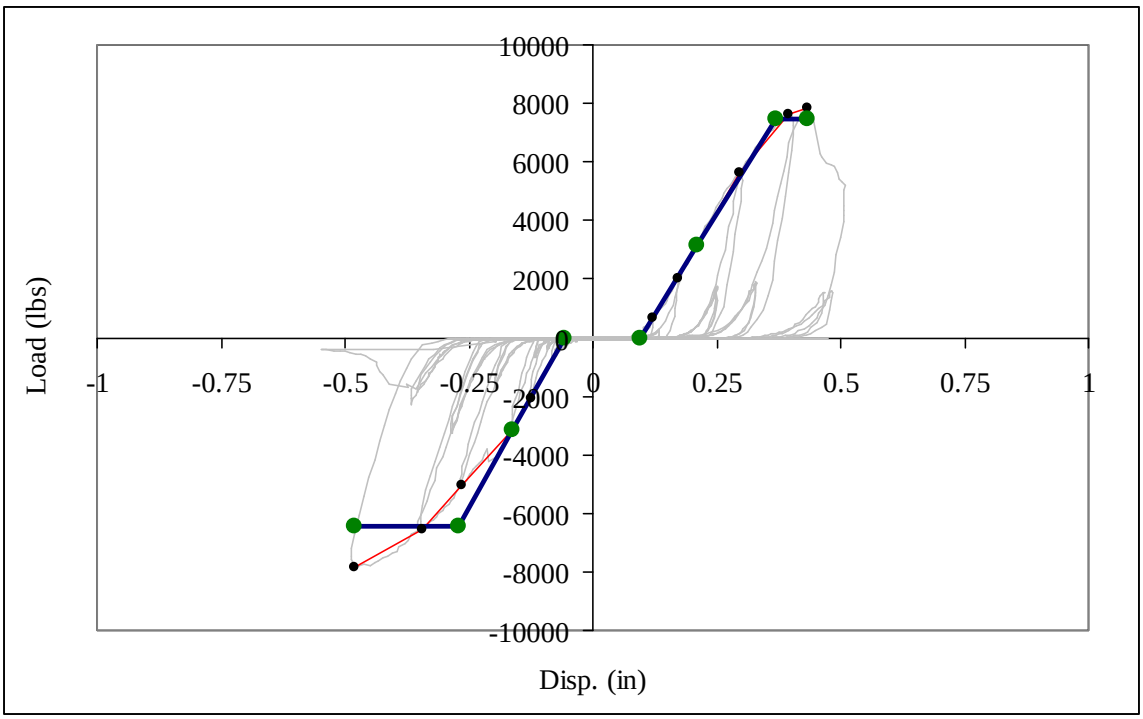

Figure A.156: Load-Deflection plot: C22-2.

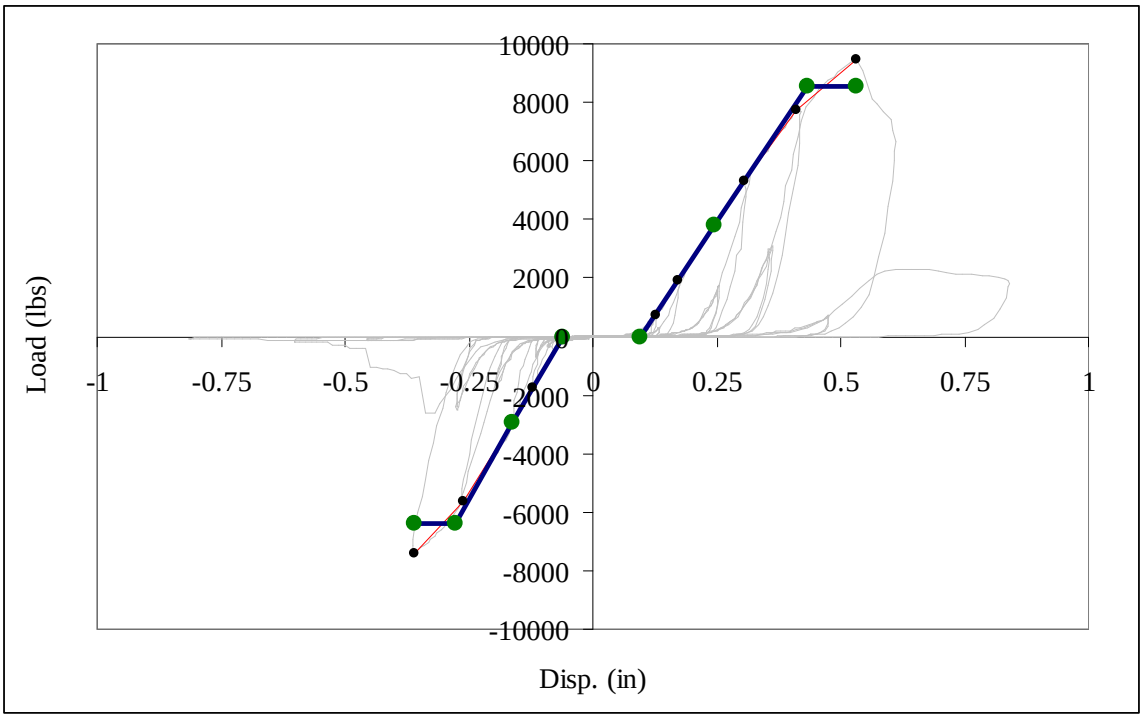

Figure A.157: Load-Deflection plot: C22-3.

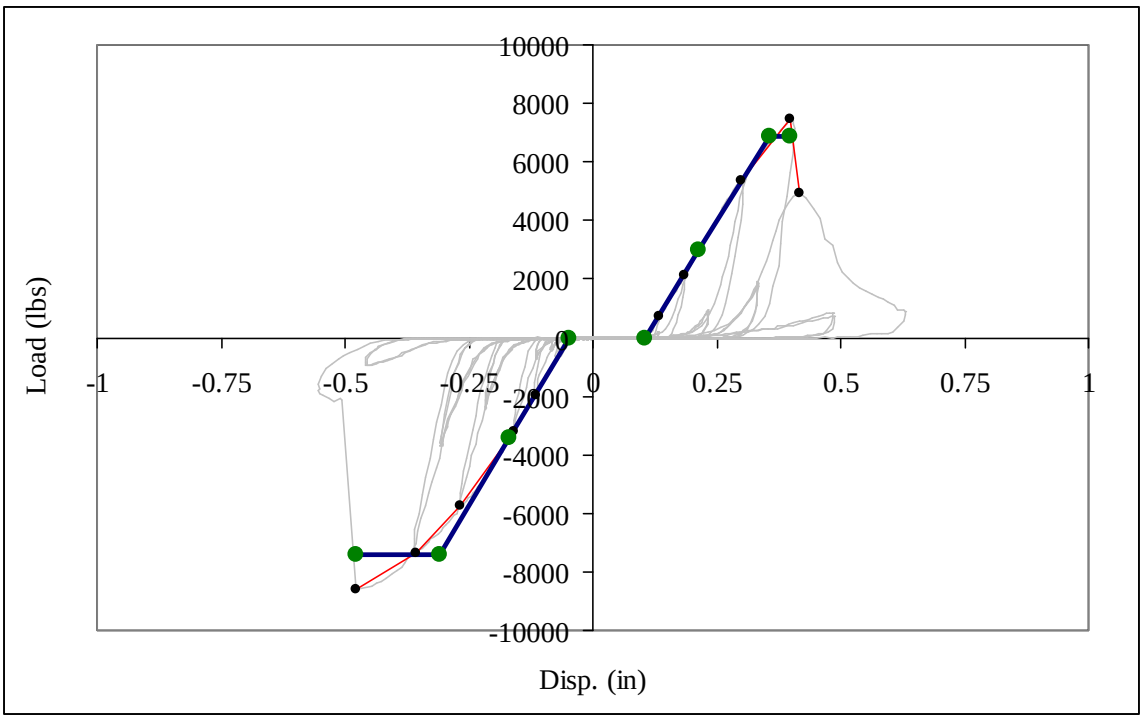

Figure A.158: Load-Deflection plot: C22-4.

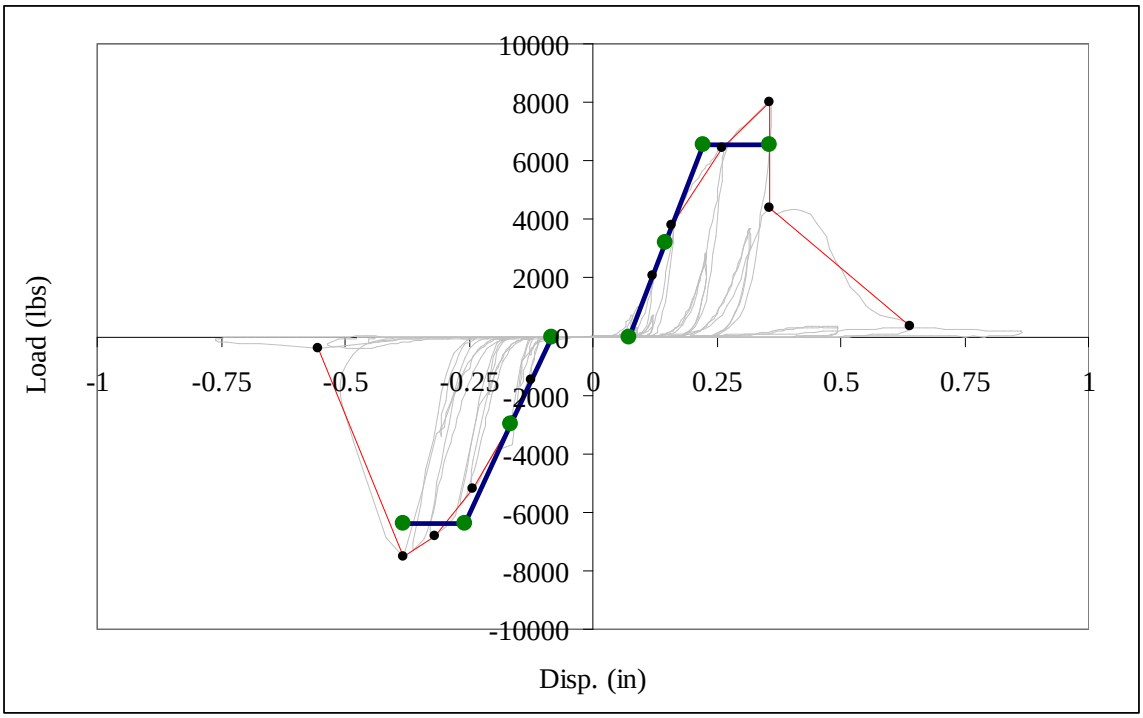

Figure A.159: Load-Deflection plot: C22-5.

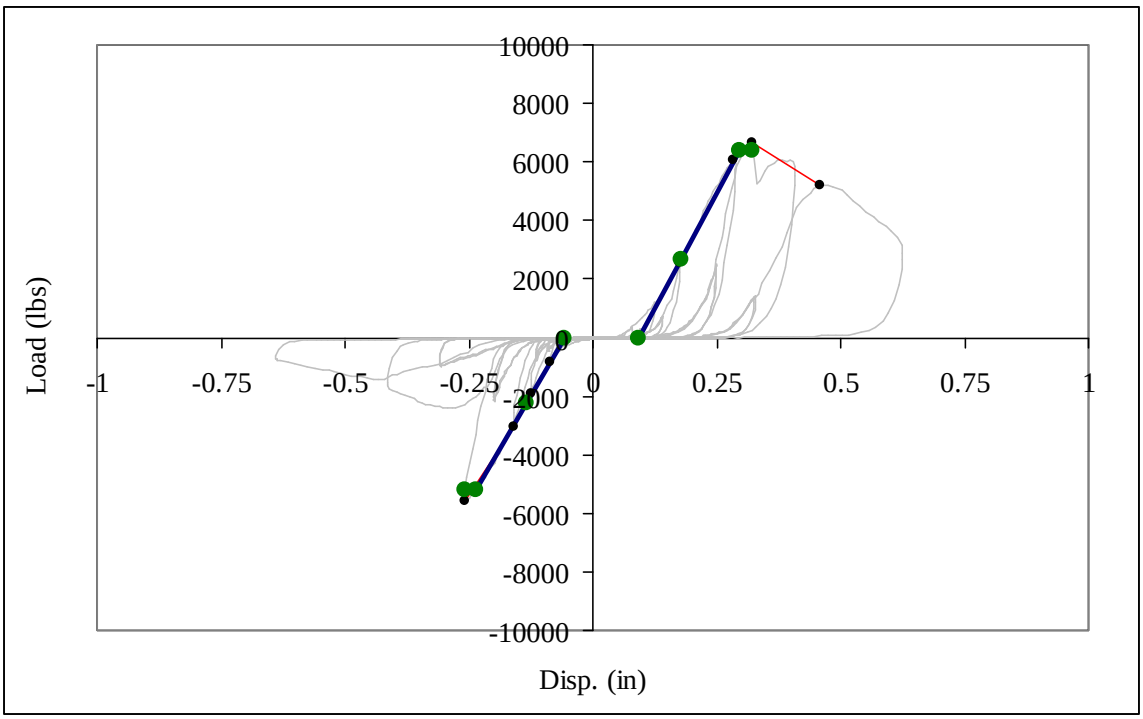

Figure A.160: Load-Deflection plot: C22-6.

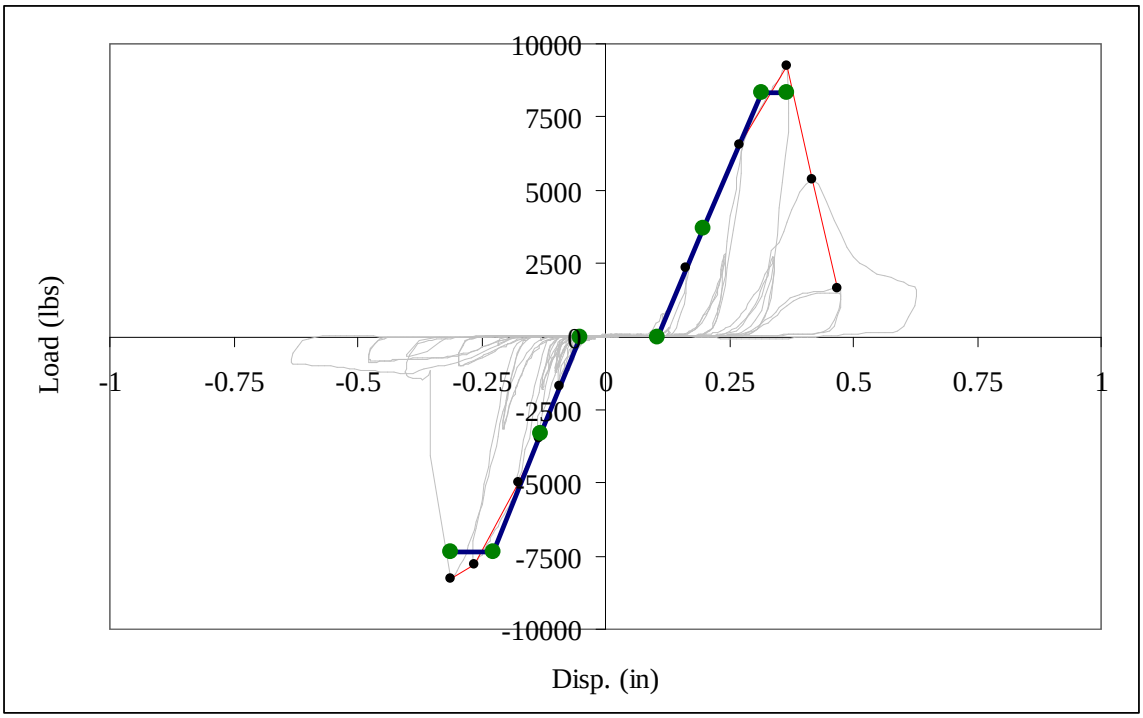

Figure A.161: Load-Deflection plot: C22-7.

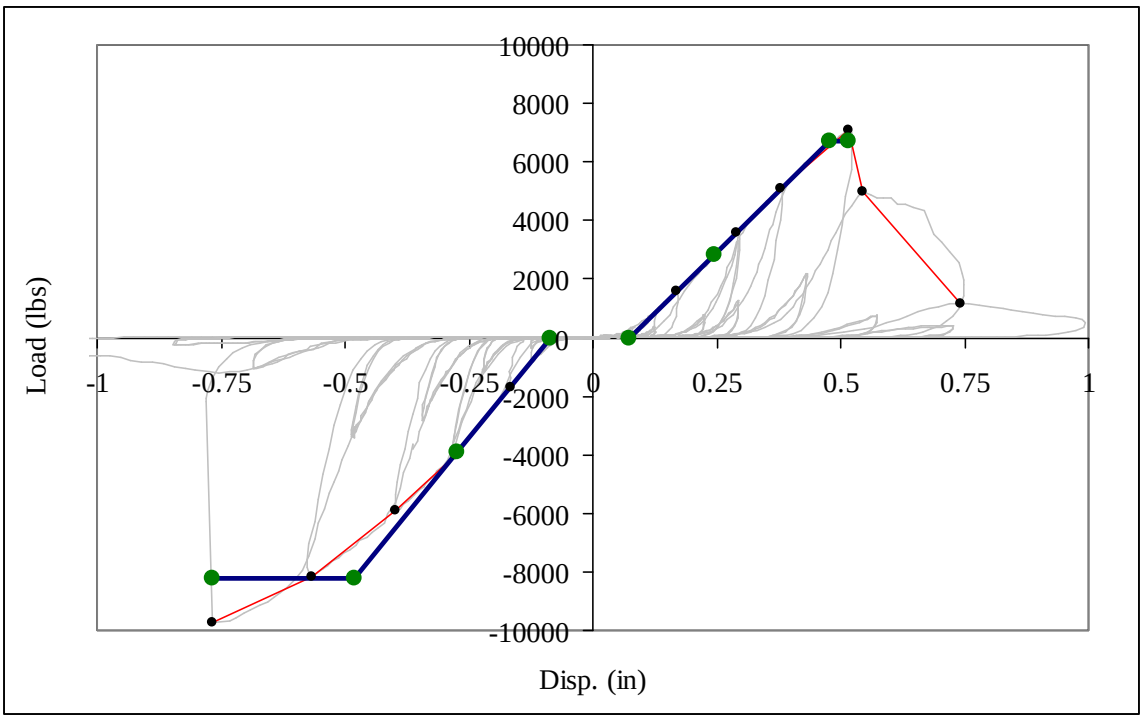

Figure A.162: Load-Deflection plot: C22-8.

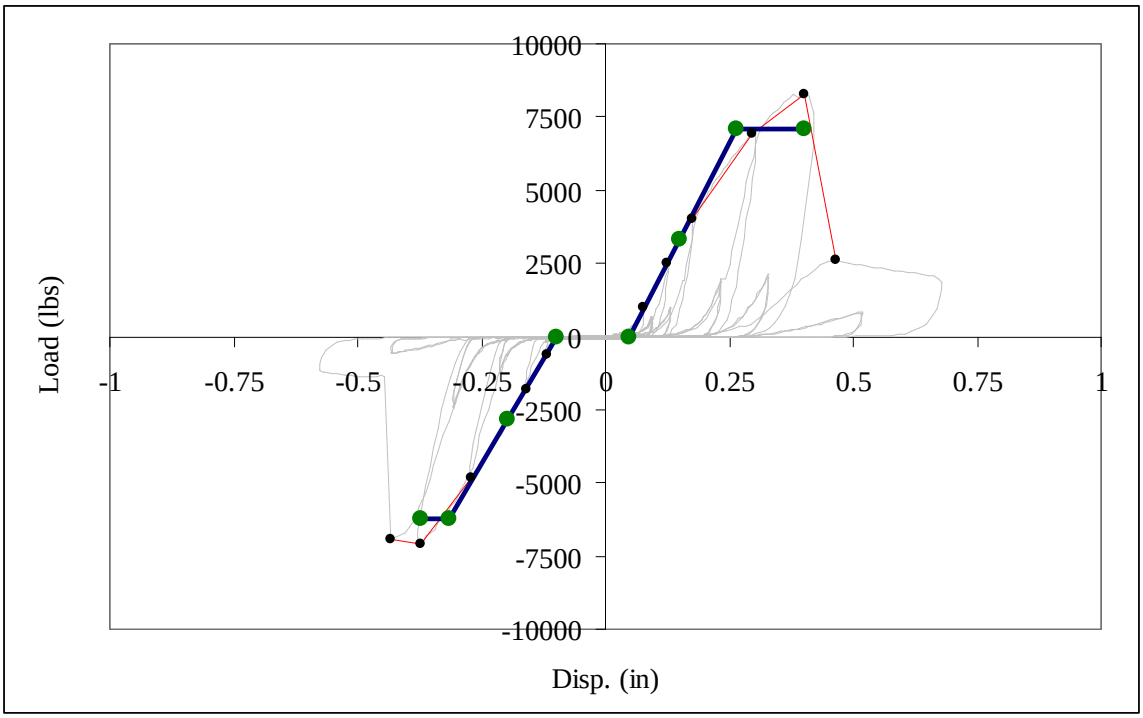

Figure A.163: Load-Deflection plot: C22-9.

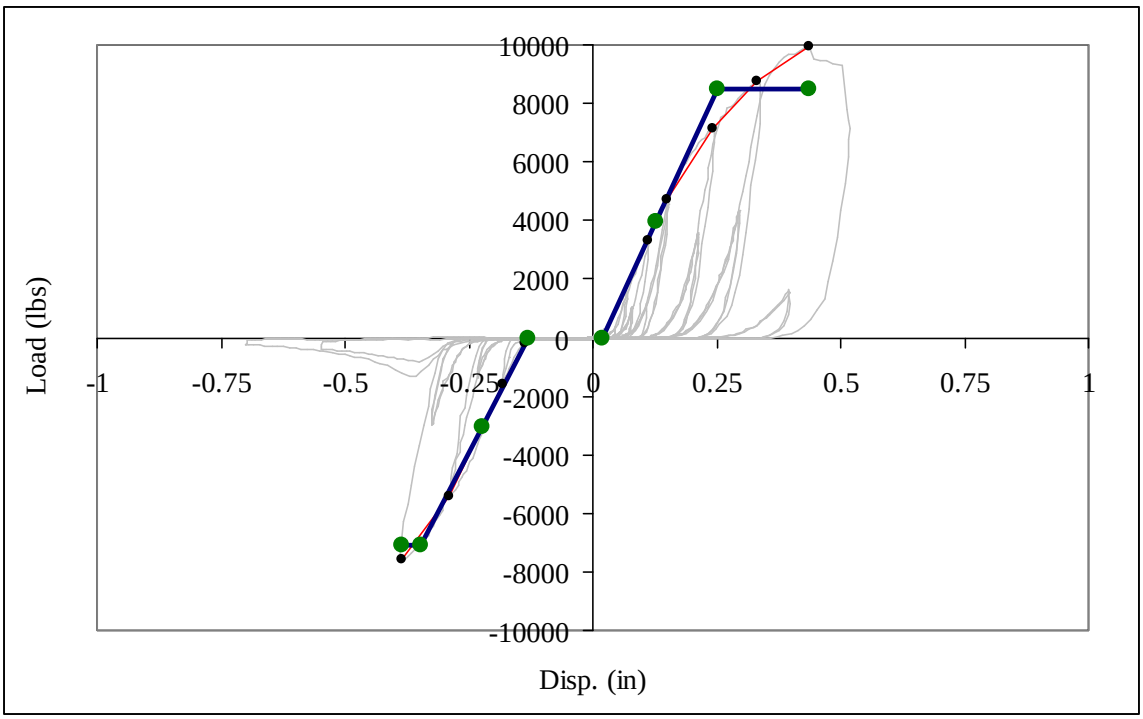

Figure A.164: Load-Deflection plot: C22-10.

Table A.46a: Connection performance properties (SI), Configuration 24.

Connection Performance Properties: Configuration 24

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	40.64	42.07	35.40	33.62	31.80	40.02	40.95	41.47	54.40	35.84	39.62	6.32	0.16
@Displacement (mm)	23.60	20.92	19.47	15.24	19.77	18.72	18.97	21.81	28.17	16.15	20.28	3.70	0.18
Failure Load (kN)	32.51	33.65	28.32	26.90	25.44	32.02	32.76	33.17	43.52	28.67	31.70	5.06	0.16
@Displacement (mm)	23.60	20.92	19.47	15.24	19.77	18.72	18.97	21.81	28.17	16.15	20.28	3.70	0.18
40% Max (kN)	16.25	16.83	14.16	13.45	12.72	16.01	16.38	16.59	21.76	14.34	15.85	2.53	0.16
@Displacement (mm)	8.98	6.37	6.43	6.03	5.84	6.07	5.78	7.14	7.64	6.31	6.66	1.00	0.15
Yield (kN)	37.04	36.57	31.57	28.31	28.40	37.18	36.92	36.83	48.50	31.66	35.30	5.88	0.17
@Displacement (mm)	12.91	12.15	11.85	10.66	10.82	12.64	10.86	14.31	15.15	11.49	12.28	1.51	0.12
5% Offset Yield (kN)	28.93	28.45	26.74	26.49	23.13	33.83	31.55	31.82	35.50	28.88	29.53	3.70	0.13
@Displacement (mm)	12.33	10.72	11.29	11.04	10.30	12.56	10.50	13.50	12.46	11.68	11.64	1.05	0.09
Elastic Stiff. (N/mm)	Censored	3469.01	3213.77	3212.92	3108.31	3220.89	4042.60	2818.39	3566.25	3320.38	3330.28	341.51	0.10
E.E.P. Energy (N*m)	525.36	520.29	396.37	272.78	430.34	456.04	471.41	523.01	962.54	311.24	486.94	188.39	0.39
Ductility Ratio	1.84	1.75	1.64	1.40	1.77	1.46	1.73	1.52	1.88	1.41	1.64	0.18	0.11
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Balk. Shr.	Balk. Shr.	Splitting	Balk. Shr.			
Governing Member	Main	Main	Side	Main	Side	Side	Side	Side	Side	Side			

Table A.46b: Connection performance properties (Std.), Configuration 24.

Connection Performance Properties: Configuration 24

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	9135.25	9456.96	7957.53	7558.56	7149.96	8997.66	9206.56	9322.34	12229.55	8057.85	8907.22	1421.75	0.16
@ Displacement (in)	0.93	0.82	0.77	0.60	0.78	0.74	0.75	0.86	1.11	0.64	0.80	0.15	0.18
Failure Load (lbs)	7308.20	7565.57	6366.02	6046.84	5719.97	7198.13	7365.25	7457.87	9783.64	6446.28	7125.78	1137.40	0.16
@ Displacement (in)	0.93	0.82	0.77	0.60	0.78	0.74	0.75	0.86	1.11	0.64	0.80	0.15	0.18
40% Max (lbs)	3654.10	3782.79	3183.01	3023.42	2859.99	3599.06	3682.62	3728.94	4891.82	3223.14	3562.89	568.70	0.16
@ Displacement (in)	0.35	0.25	0.25	0.24	0.23	0.24	0.23	0.28	0.30	0.25	0.26	0.04	0.15
Yield (lbs)	8326.22	8221.38	7096.34	6364.36	6384.03	8358.01	8300.89	8279.30	10902.17	7116.83	7934.95	1321.43	0.17
@ Displacement (in)	0.51	0.48	0.47	0.42	0.43	0.50	0.43	0.56	0.60	0.45	0.48	0.06	0.12
5% Offset Yield (lbs)	6503.44	6396.67	6012.44	5954.46	5198.85	7604.28	7092.69	7152.43	7981.19	6491.69	6638.81	832.44	0.13
@ Displacement (in)	0.49	0.42	0.44	0.43	0.41	0.49	0.41	0.53	0.49	0.46	0.46	0.04	0.09
Elastic Stiff. (lb/in)	Censored	19808.54	18351.07	18346.23	17748.91	18391.78	23083.83	16093.40	20363.83	18959.84	19016.38	1950.08	0.10
E.E.P. Energy (lb*in)	4649.85	4604.98	3508.16	2414.34	3808.84	4036.28	4172.29	4629.03	8519.20	2754.73	4309.77	1667.40	0.39
Ductility Ratio	1.84	1.75	1.64	1.40	1.77	1.46	1.73	1.52	1.88	1.41	1.64	0.18	0.11
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Balk. Shr.	Balk. Shr.	Splitting	Balk. Shr.			
Governing Member	Main	Main	Side	Main	Side	Side	Side	Side	Side	Side			

Table A.47a: Member properties (SI), Configuration 24.

Member Properties: Configuration 24

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.38	14.10	14.09	14.61	13.86	13.99	14.18	14.03	14.18	14.12	14.15	0.21	0.01
S.G.	0.43	0.44	0.46	0.46	0.42	0.39	0.44	0.46	0.42	0.44	0.44	0.02	0.06
D.E. 5% Offset Yield (kPa)	26010	23963	27193	26336	22988	20747	24734	27171	25243	25214	24960	1991.58	0.08
D.E. Capacity (kPa)	26010	24237	27193	27160	23009	20747	24837	27495	26121	25214	25202	2115.38	0.08
Side Member													
M.C. (%)	13.99	13.84	13.97	13.63	13.41	12.76	13.27	14.15	13.84	14.18	13.70	0.45	0.03
S.G.	0.43	0.43	0.47	0.43	0.38	0.50	0.44	0.38	0.43	0.44	0.43	0.04	0.08
D.E. 5% Offset Yield (kPa)	25873	26356	26713	27172	23104	25383	27516	25101	22445	23364	25303	1783.34	0.07
D.E. Capacity (kPa)	26068	26645	28475	27324	23197	26722	27800	25223	22445	23364	25726	2091.01	0.08

Table A.47b: Member properties (Std.), Configuration 24.

Member Properties: Configuration 24

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.38	14.10	14.09	14.61	13.86	13.99	14.18	14.03	14.18	14.12	14.15	0.21	0.01
S.G.	0.43	0.44	0.46	0.46	0.42	0.39	0.44	0.46	0.42	0.44	0.44	0.02	0.06
D.E. 5% Offset Yield (psi)	3772.48	3475.55	3943.98	3819.63	3334.17	3009.06	3587.40	3940.82	3661.21	3656.95	3620.13	288.85	0.08
D.E. Capacity (psi)	3772.48	3515.32	3943.98	3939.23	3337.14	3009.06	3602.25	3987.72	3788.46	3656.95	3655.26	306.81	0.08
Side Member													
M.C. (%)	13.99	13.84	13.97	13.63	13.41	12.76	13.27	14.15	13.84	14.18	13.70	0.45	0.03
S.G.	0.43	0.43	0.47	0.43	0.38	0.50	0.44	0.38	0.43	0.44	0.43	0.04	0.08
D.E. 5% Offset Yield (psi)	3752.54	3822.63	3874.37	3940.93	3350.91	3681.52	3990.86	3640.51	3255.37	3388.71	3669.84	258.65	0.07
D.E. Capacity (psi)	3780.75	3864.58	4129.86	3962.93	3364.47	3875.62	4032.07	3658.29	3255.37	3388.71	3731.26	303.27	0.08

Table A.48a: Hysteretic connection properties (SI), Configuration 24.

Hysteretic Connection Properties: Configuration 24

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.25	0.16	0.66	0.37	0.10	0.26	-0.30	0.41	1.36	-0.41	0.08	0.18
Primary2	0.32	0.23	0.71	0.66	0.09	0.14	-0.49	0.58	1.20	-0.73	0.09	0.13
Primary3	1.16	1.07	0.92	1.84	0.09	0.05	-1.80	1.67	0.93	-1.78	0.13	0.08
Primary4	3.23	2.14	0.66	2.81	0.39	0.14	-4.25	2.99	0.70	-2.91	0.12	0.04
Primary5	6.46	3.57	0.55	4.01	0.41	0.10	-7.46	4.03	0.54	-3.94	0.10	0.03
Primary6	17.28	7.66	0.44	7.45	0.16	0.02	-16.97	4.55	0.27	-6.85	0.30	0.04
Primary7	26.59	8.75	0.33	10.37	0.38	0.04	-24.62	3.76	0.15	-9.42	0.58	0.06
Primary8	36.19	11.70	0.32	14.84	0.92	0.06	-31.81	5.22	0.16	-12.90	1.07	0.08
Primary9	41.56	13.63	0.33	19.15	0.85	0.04	-32.02	10.66	0.33	-15.66	3.42	0.22
Primary10	43.27	16.72	0.39	23.68	0.93	0.04	-28.15	15.51	0.55	-20.36	2.80	0.14
Primary11	42.21	20.09	0.48	28.77	2.40	0.08	-26.49	16.29	0.62	-23.72	7.84	0.33

	Hysteretic Energy (lb*in)			Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.26	0.12	0.48	0.12	0.11	0.91	0.42	0.13	0.30	707.31	424.58	0.60
Primary2	0.53	0.26	0.49	0.30	0.22	0.75	0.33	0.12	0.35	560.81	328.90	0.59
Primary3	2.48	1.11	0.45	2.75	1.52	0.55	0.17	0.09	0.52	808.04	419.00	0.52
Primary4	6.52	2.48	0.38	10.92	4.33	0.40	0.12	0.09	0.71	1284.63	493.69	0.38
Primary5	13.96	4.75	0.34	28.07	9.93	0.35	0.09	0.04	0.40	1725.47	604.27	0.35
Primary6	66.28	20.25	0.31	122.55	31.07	0.25	0.08	0.02	0.19	2394.56	595.58	0.25
Primary7	122.55	23.34	0.19	253.69	24.00	0.09	0.08	0.01	0.16	2591.13	285.00	0.11
Primary8	261.05	41.49	0.16	475.04	51.41	0.11	0.09	0.01	0.15	2450.74	234.54	0.10
Primary9	349.90	73.96	0.21	659.99	108.09	0.16	0.08	0.01	0.14	2112.12	287.48	0.14
Primary10	369.93	128.87	0.35	805.26	196.14	0.24	0.08	0.02	0.32	1618.64	399.63	0.25
Primary11	467.58	139.08	0.30	947.53	273.83	0.29	0.08	0.01	0.15	1309.94	420.28	0.32

Table A.48b: Hysteretic connection properties (Std.), Configuration 24.

Hysteretic Connection Properties: Configuration 24

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	55.90	37.04	0.66	0.01	0.00	0.26	-68.19	92.43	1.36	-0.02	0.00	0.18
Primary2	72.24	51.01	0.71	0.03	0.00	0.14	-109.28	130.78	1.20	-0.03	0.00	0.13
Primary3	261.47	241.16	0.92	0.07	0.00	0.05	-405.29	374.96	0.93	-0.07	0.01	0.08
Primary4	725.82	480.63	0.66	0.11	0.02	0.14	-955.66	671.09	0.70	-0.11	0.00	0.04
Primary5	1452.25	803.58	0.55	0.16	0.02	0.10	-1676.40	906.38	0.54	-0.16	0.00	0.03
Primary6	3884.51	1721.65	0.44	0.29	0.01	0.02	-3815.85	1021.97	0.27	-0.27	0.01	0.04
Primary7	5978.37	1968.16	0.33	0.41	0.01	0.04	-5534.68	844.49	0.15	-0.37	0.02	0.06
Primary8	8136.51	2630.87	0.32	0.58	0.04	0.06	-7150.46	1172.73	0.16	-0.51	0.04	0.08
Primary9	9342.93	3064.31	0.33	0.75	0.03	0.04	-7198.76	2395.40	0.33	-0.62	0.13	0.22
Primary10	9726.55	3759.79	0.39	0.93	0.04	0.04	-6328.01	3487.55	0.55	-0.80	0.11	0.14
Primary11	9489.52	4515.53	0.48	1.13	0.09	0.08	-5954.32	3663.22	0.62	-0.93	0.31	0.33

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	2.30	1.10	0.48	1.04	0.95	0.91	0.42	0.13	0.30	4038.85	2424.44	0.60
Primary2	4.67	2.30	0.49	2.63	1.98	0.75	0.37	0.14	0.39	3202.30	1878.07	0.59
Primary3	21.92	9.81	0.45	24.36	13.49	0.55	0.21	0.12	0.57	4614.02	2392.57	0.52
Primary4	57.69	21.94	0.38	96.61	38.34	0.40	0.14	0.09	0.64	7335.40	2819.04	0.38
Primary5	123.57	42.05	0.34	248.42	87.88	0.35	0.10	0.04	0.40	9852.69	3450.46	0.35
Primary6	586.66	179.27	0.31	1084.63	275.03	0.25	0.08	0.02	0.19	13673.32	3400.85	0.25
Primary7	1084.70	206.54	0.19	2245.35	212.41	0.09	0.08	0.01	0.16	14795.71	1627.39	0.11
Primary8	2310.49	367.25	0.16	4204.50	455.03	0.11	0.09	0.01	0.15	13994.08	1339.23	0.10
Primary9	3096.86	654.57	0.21	5841.43	956.67	0.16	0.08	0.01	0.14	12060.53	1641.54	0.14
Primary10	3274.18	1140.60	0.35	7127.12	1735.99	0.24	0.08	0.02	0.32	9242.66	2281.93	0.25
Primary11	4138.45	1230.92	0.30	8386.36	2423.56	0.29	0.08	0.01	0.15	7479.97	2399.88	0.32

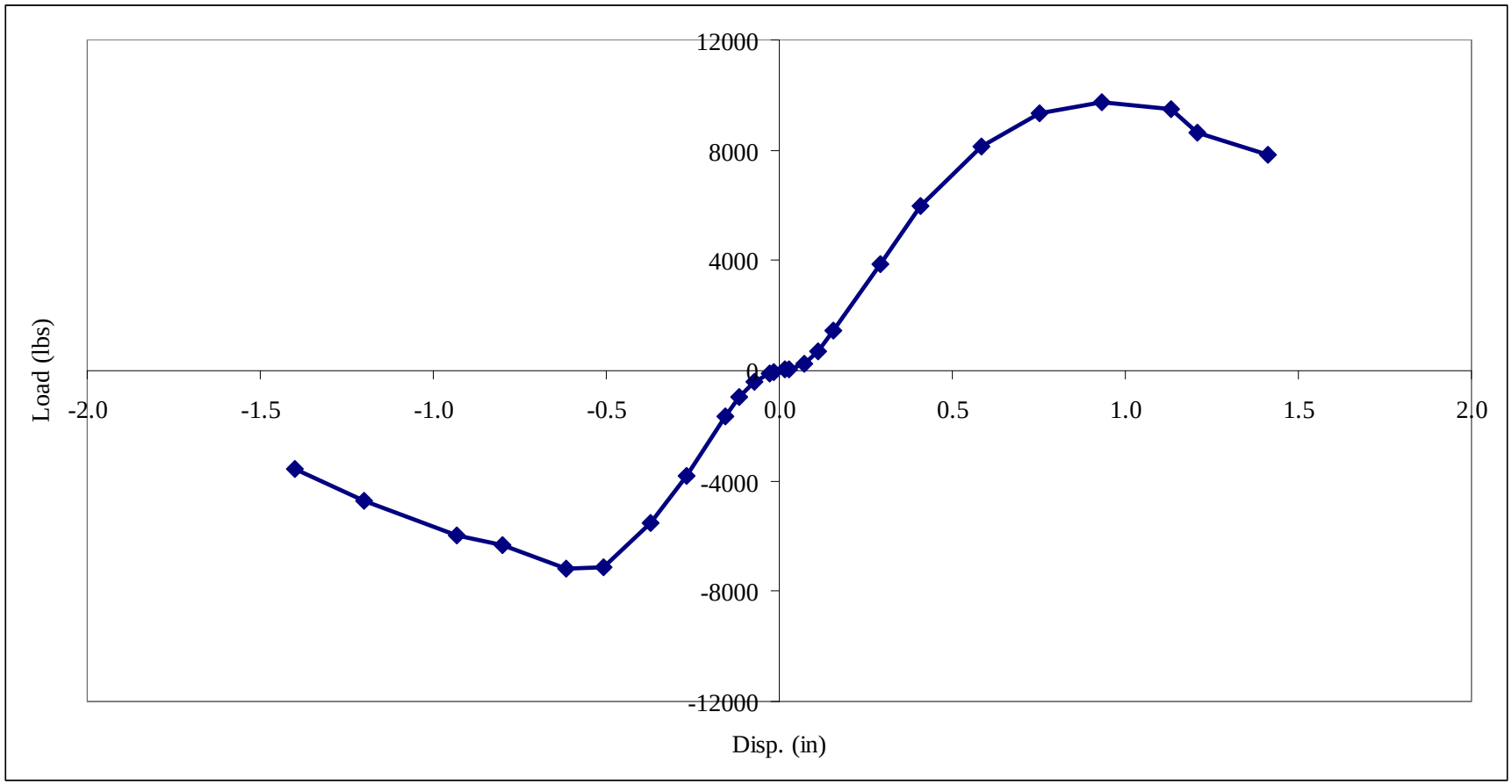

Figure A.165: Mean envelope curve: Configuration 24.

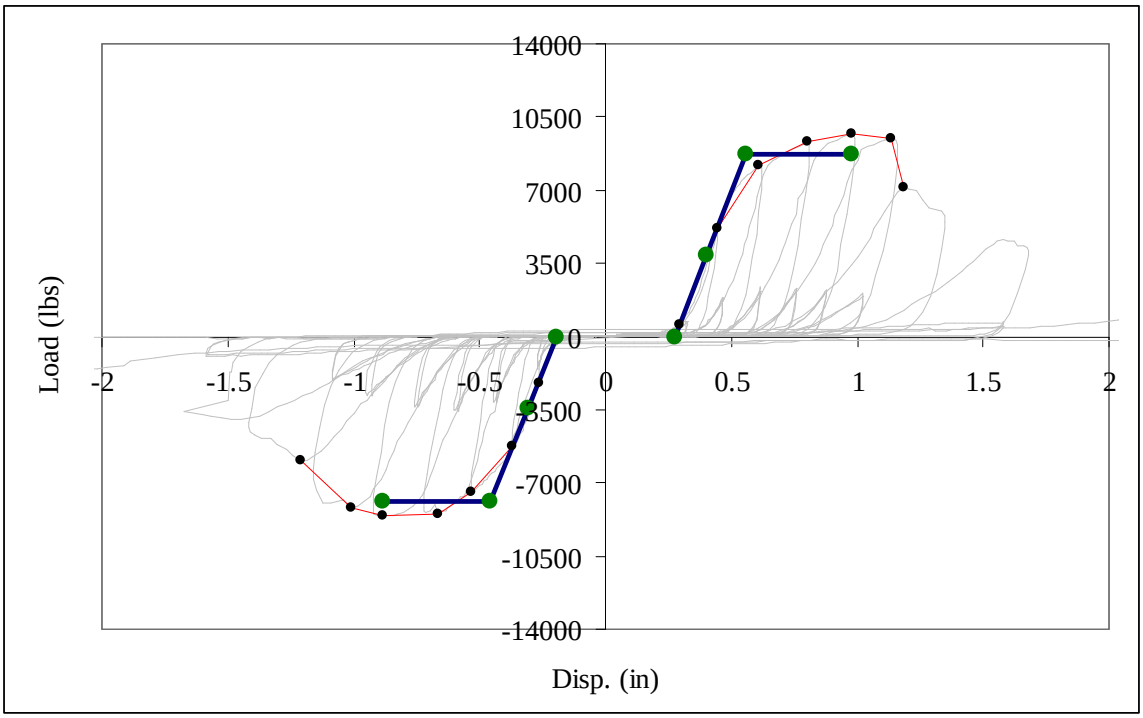

Figure A.166: Load-Deflection plot: C24-1.

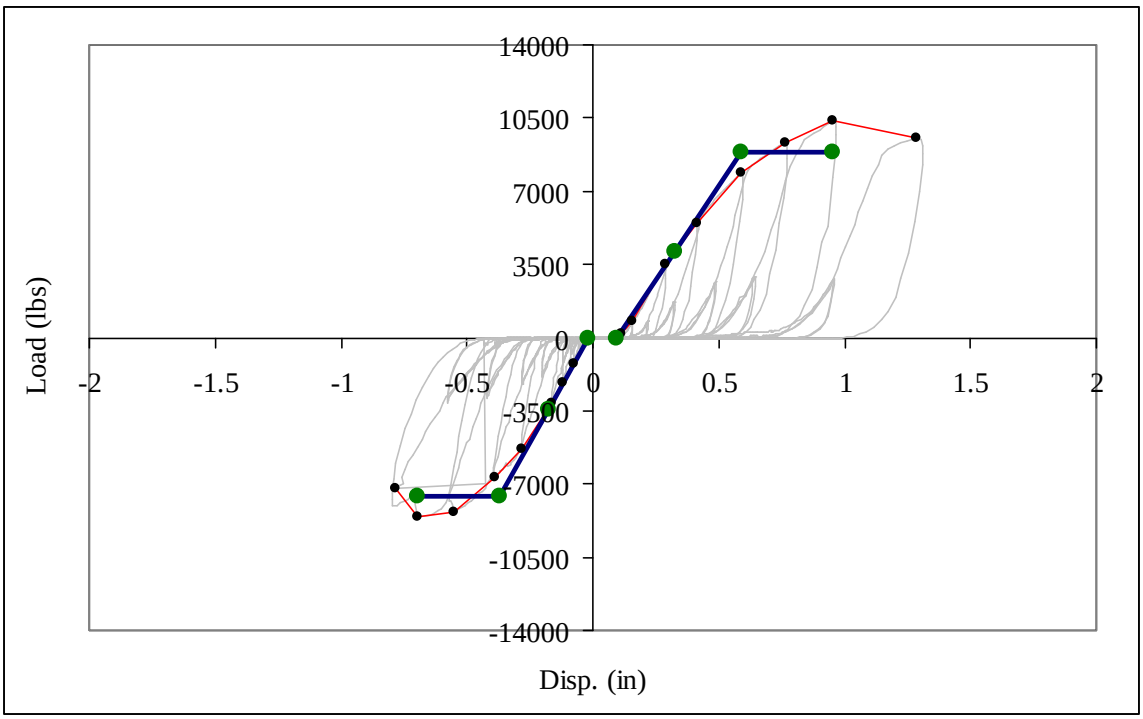

Figure A.167: Load-Deflection plot: C24-2.

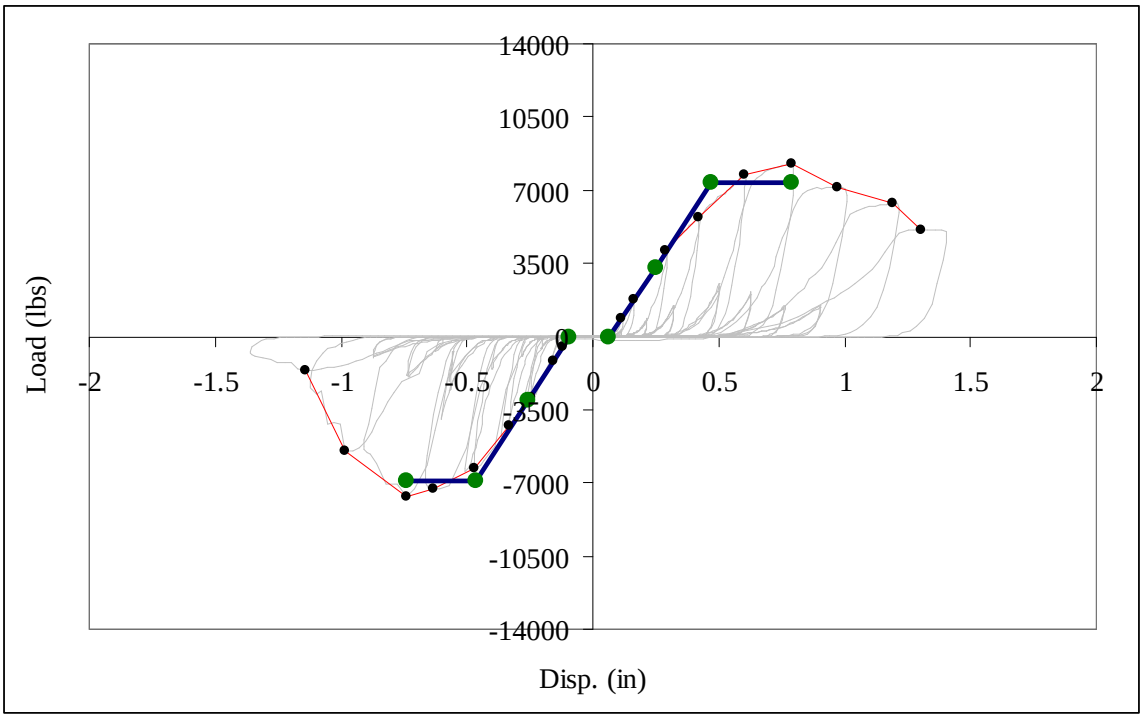

Figure A.168: Load-Deflection plot: C24-3.

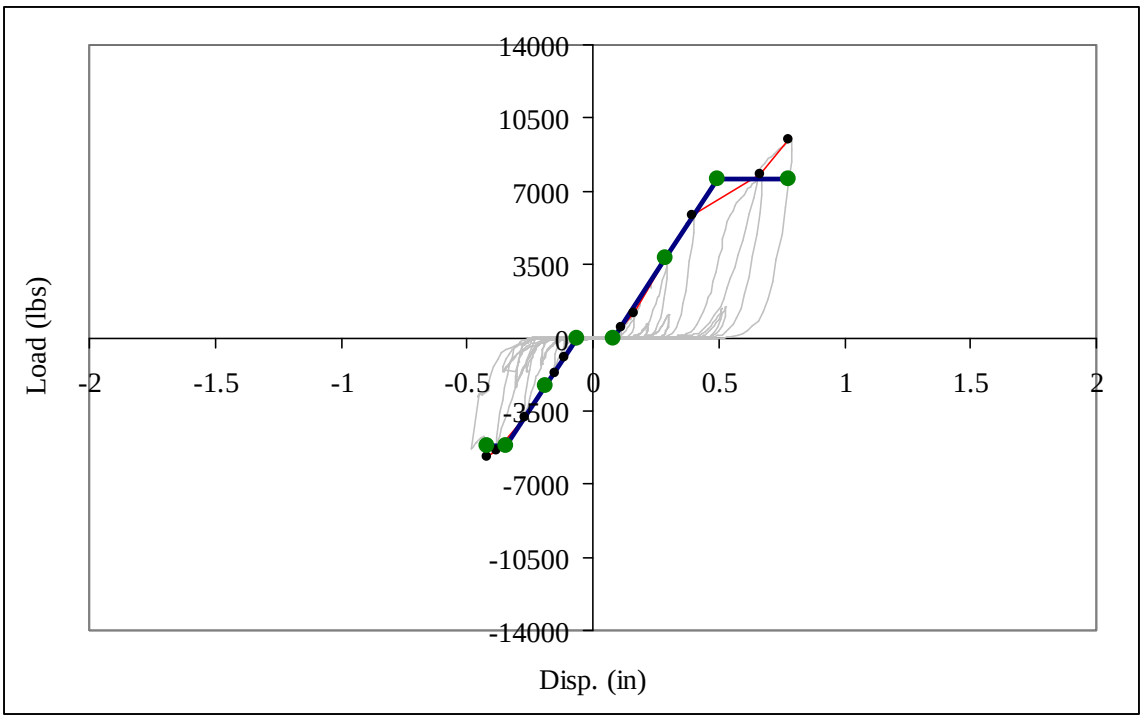

Figure A.169: Load-Deflection plot: C24-4.

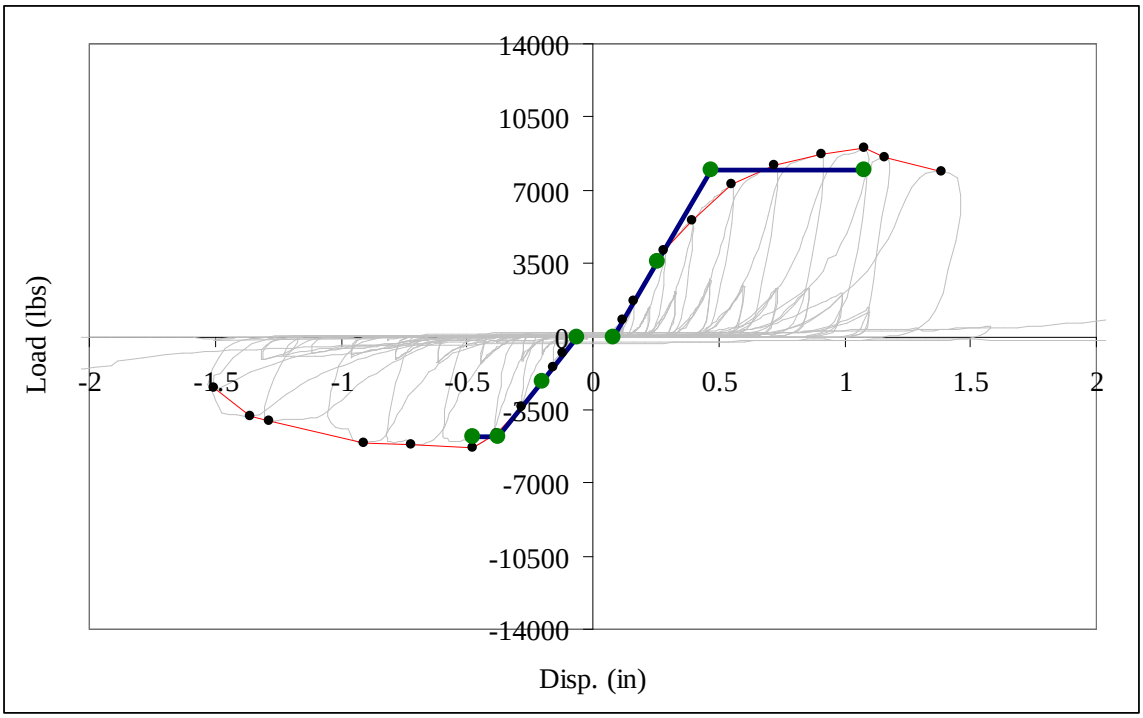

Figure A.170: Load-Deflection plot: C24-5.

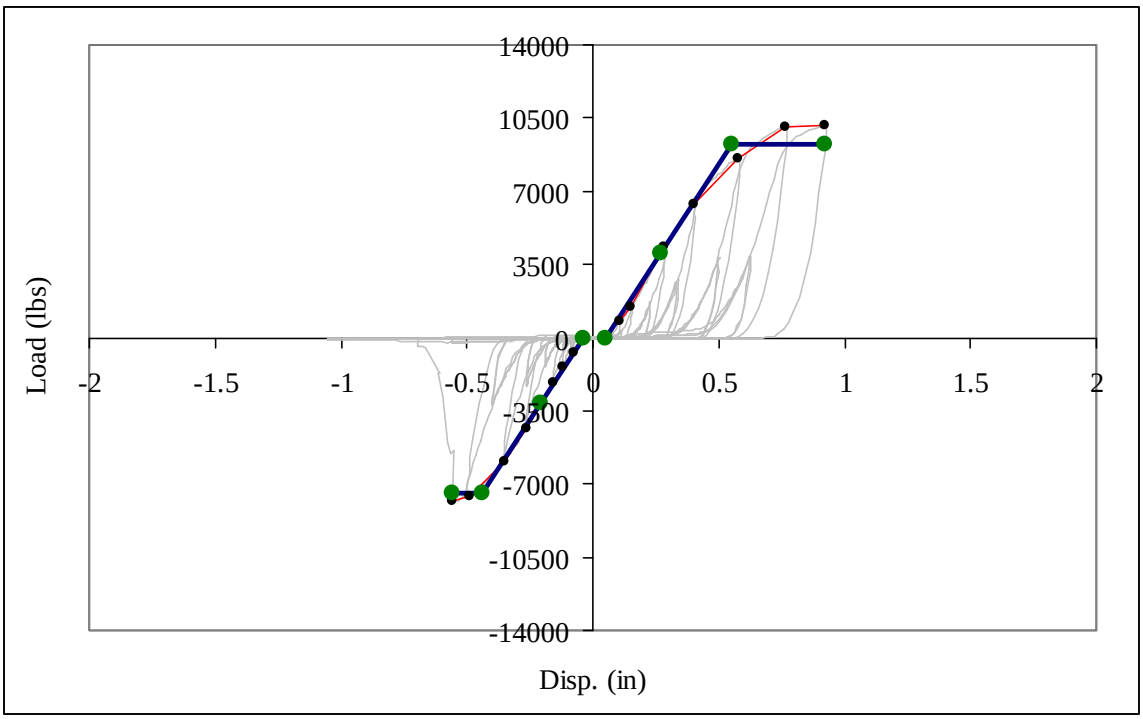

Figure A.171: Load-Deflection plot: C24-6.

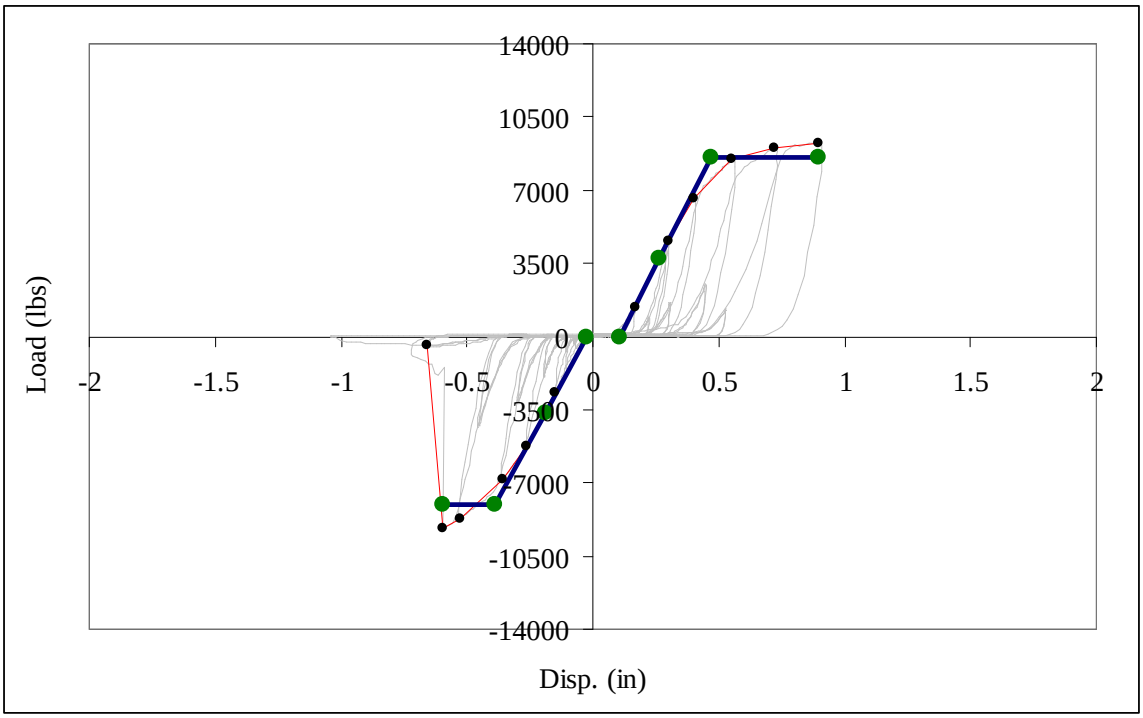

Figure A.172: Load-Deflection plot: C24-7.

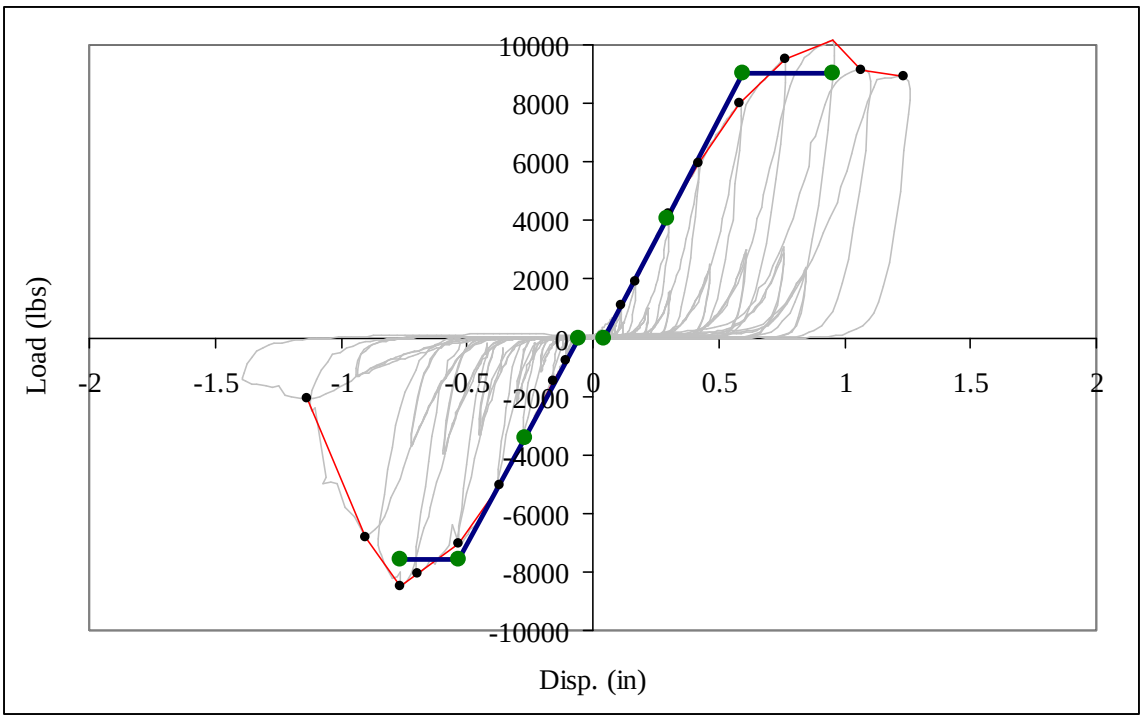

Figure A.173: Load-Deflection plot: C24-8.

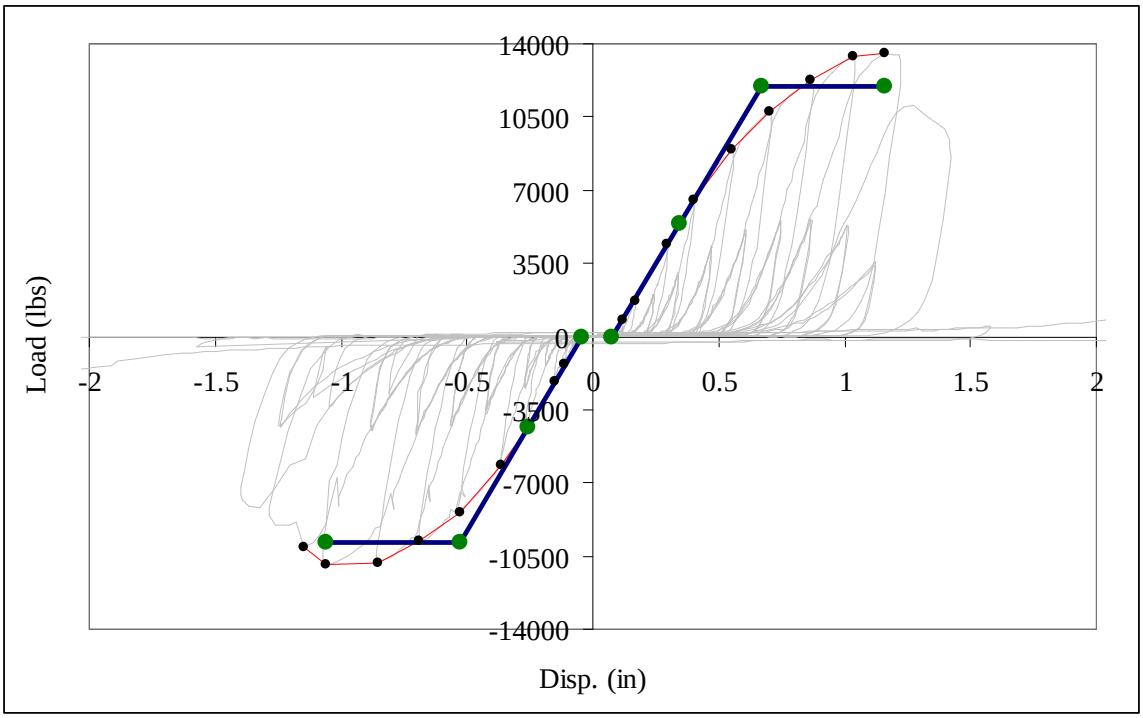

Figure A.174: Load-Deflection plot: C24-9.

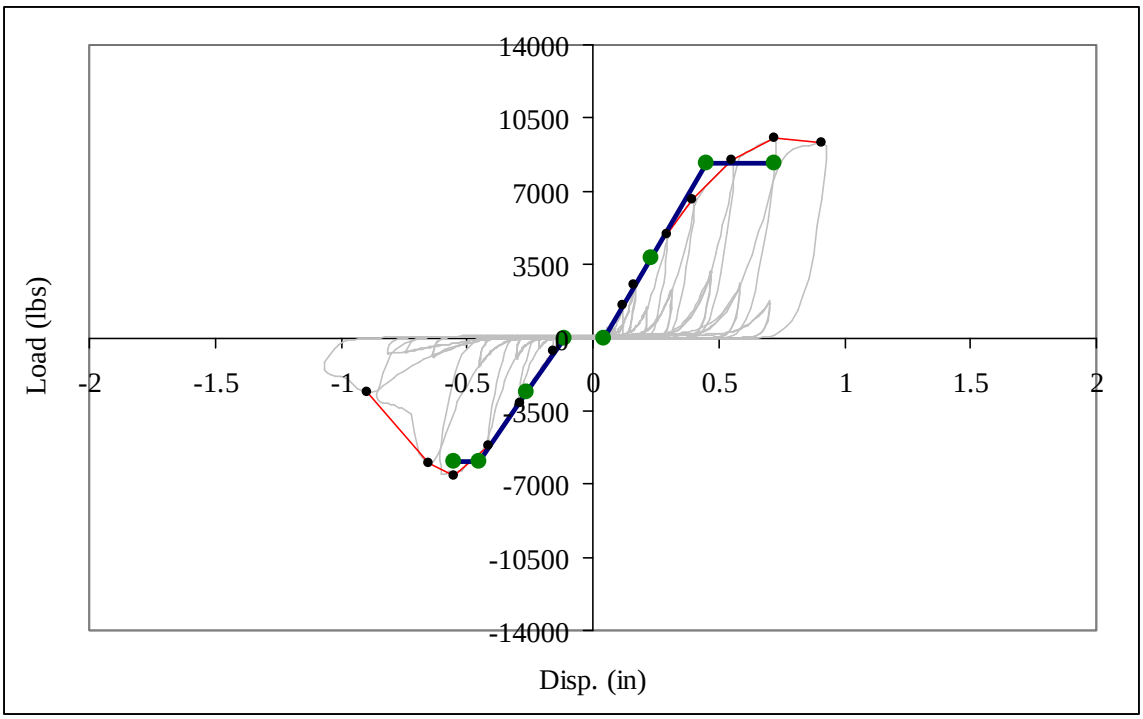

Figure A.175: Load-Deflection plot: C24-10.

Table A.49a: Connection performance properties (SI), Configuration 25.

Connection Performance Properties: Configuration 25

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	44.00	51.41	48.69	43.65	39.22	43.59	42.34	43.53	40.27	47.77	44.45	3.79	0.09
@Displacement (mm)	17.45	20.94	23.91	23.27	22.39	25.68	20.99	16.26	15.77	15.21	20.19	3.75	0.19
Failure Load (lbs)	35.20	41.12	38.95	34.92	31.37	34.87	33.87	34.82	32.22	38.22	35.56	3.03	0.09
@ Displacement (in)	17.45	20.94	23.91	21.56	22.39	25.68	20.99	16.26	15.77	15.21	20.02	3.63	0.18
40% Max (kN)	17.60	20.56	19.48	17.46	15.69	17.44	16.94	17.41	16.11	19.11	17.78	1.52	0.09
@Displacement (mm)	5.56	6.38	7.68	7.82	6.35	7.07	6.55	5.86	5.97	5.62	6.48	0.80	0.12
Yield (kN)	39.87	43.92	43.07	36.90	34.75	37.47	38.77	37.68	33.57	42.75	38.87	3.52	0.09
@Displacement (mm)	11.48	12.01	14.88	14.95	11.35	12.97	12.98	10.78	10.37	10.71	12.25	1.66	0.14
5% Offset Yield (kN)	35.35	36.22	34.79	32.45	26.18	26.24	33.54	33.00	29.64	39.57	32.70	4.29	0.13
@Displacement (mm)	11.24	11.18	13.30	14.27	10.06	10.61	12.40	10.62	10.35	11.03	11.51	1.38	0.12
Elastic Stiff. (N/mm)	3756.02	4208.44	3276.84	2732.47	3828.44	3393.92	3390.13	4120.76	3952.97	4654.86	3731.49	550.34	0.15
E.E.P. Energy (N*m)	461.77	624.42	672.37	494.89	542.07	683.24	534.16	381.04	326.03	395.44	511.54	123.47	0.24
Ductility Ratio	1.54	1.77	1.61	1.45	1.98	1.98	1.62	1.51	1.52	1.42	1.64	0.20	0.12
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Splitting	Splitting	Balk. Shr.	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Side	Both	Both	Side	Both	Both	Both	Both	Both	Both			

Table A.49b: Connection performance properties (Std.), Configuration 25.

Connection Performance Properties: Configuration 25

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	9891.64	11556.43	10945.66	9812.45	8816.48	9800.08	9518.10	9785.24	9052.85	10739.98	9991.89	851.58	0.09
@ Displacement (in)	0.69	0.82	0.94	0.92	0.88	1.01	0.83	0.64	0.62	0.60	0.79	0.15	0.19
Failure Load (lbs)	7913.31	9245.15	8756.52	7849.96	7053.19	7840.06	7614.48	7828.19	7242.28	8591.99	7993.51	681.26	0.09
@ Displacement (in)	0.69	0.82	0.94	0.85	0.88	1.01	0.83	0.64	0.62	0.60	0.79	0.14	0.18
40% Max (lbs)	3956.66	4622.57	4378.26	3924.98	3526.59	3920.03	3807.24	3914.10	3621.14	4295.99	3996.76	340.63	0.09
@ Displacement (in)	0.22	0.25	0.30	0.31	0.25	0.28	0.26	0.23	0.24	0.22	0.26	0.03	0.12
Yield (lbs)	8962.30	9874.32	9682.18	8296.54	7812.49	8423.14	8714.89	8470.11	7546.51	9611.14	8739.36	791.48	0.09
@ Displacement (in)	0.45	0.47	0.59	0.59	0.45	0.51	0.51	0.42	0.41	0.42	0.48	0.07	0.14
5% Offset Yield (lbs)	7947.12	8143.44	7820.22	7294.84	5884.67	5899.23	7540.67	7419.69	6664.08	8896.35	7351.03	964.08	0.13
@ Displacement (in)	0.44	0.44	0.52	0.56	0.40	0.42	0.49	0.42	0.41	0.43	0.45	0.05	0.12
Elastic Stiff. (lb/in)	21447.44	24030.82	18711.24	15602.81	21860.97	19379.79	19358.15	23530.16	22572.05	26579.92	21307.34	3142.54	0.15
E.E.P. Energy (lb*in)	4087.00	5526.56	5950.95	4380.11	4797.72	6047.19	4727.73	3372.52	2885.62	3499.97	4527.54	1092.82	0.24
Ductility Ratio	1.54	1.77	1.61	1.45	1.98	1.98	1.62	1.51	1.52	1.42	1.64	0.20	0.12
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Splitting	Splitting	Balk. Shr.	Splitting	Splitting	Splitting	Splitting	Splitting	Splitting			
Governing Member	Side	Both	Both	Side	Both	Both	Both	Both	Both	Both			

Table A.50a: Member properties (SI), Configuration 25.

Member Properties: Configuration 25

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.18	13.78	13.87	14.99	14.85	14.59	14.77	14.87	13.26	13.30	14.24	0.66	0.05
S.G.	0.50	0.49	0.45	0.40	0.45	0.46	0.49	0.49	0.46	0.49	0.47	0.03	0.07
D.E. 5% Offset Yield (kPa)	31580	28498	27198	24748	23468	26575	26993	29015	28725	29892	27669	2401.59	0.09
D.E. Capacity (kPa)	31580	29001	27198	24748	23468	26711	27037	30225	28725	29892	27858	2517.16	0.09
Side Member													
M.C. (%)	14.01	13.71	13.96	13.66	15.35	15.17	13.96	13.58	13.34	13.32	14.01	0.70	0.05
S.G.	0.48	0.48	0.43	0.42	0.44	0.47	0.48	0.50	0.47	0.49	0.47	0.03	0.06
D.E. 5% Offset Yield (kPa)	28982	31285	27431	25222	23911	24647	27959	32185	26488	30198	27831	2830.38	0.10
D.E. Capacity (kPa)	29407	31562	27818	25708	24236	24647	28331	32185	26488	30198	28058	2790.18	0.10

Table A.50b: Member properties (Std.), Configuration 25.

Member Properties: Configuration 25

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.18	13.78	13.87	14.99	14.85	14.59	14.77	14.87	13.26	13.30	14.24	0.66	0.05
S.G.	0.50	0.49	0.45	0.40	0.45	0.46	0.49	0.49	0.46	0.49	0.47	0.03	0.07
D.E. 5% Offset Yield (psi)	4580.26	4133.21	3944.78	3589.35	3403.69	3854.36	3915.03	4208.19	4166.17	4335.48	4013.05	348.32	0.09
D.E. Capacity (psi)	4580.26	4206.15	3944.78	3589.35	3403.69	3874.03	3921.30	4383.77	4166.17	4335.48	4040.50	365.08	0.09
Side Member													
M.C. (%)	14.01	13.71	13.96	13.66	15.35	15.17	13.96	13.58	13.34	13.32	14.01	0.70	0.05
S.G.	0.48	0.48	0.43	0.42	0.44	0.47	0.48	0.50	0.47	0.49	0.47	0.03	0.06
D.E. 5% Offset Yield (psi)	4203.41	4537.49	3978.53	3658.11	3467.99	3574.72	4055.14	4667.94	3841.75	4379.77	4036.48	410.51	0.10
D.E. Capacity (psi)	4265.15	4577.60	4034.68	3728.54	3515.13	3574.72	4109.06	4667.94	3841.75	4379.77	4069.43	404.68	0.10

Table A.51a: Hysteretic connection properties (SI), Configuration 25.

Hysteretic Connection Properties: Configuration 25

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.52	0.48	0.92	0.35	0.11	0.31	-0.46	0.36	0.78	-0.41	0.13	0.32
Primary2	0.74	0.63	0.85	0.60	0.22	0.37	-0.68	0.53	0.78	-0.63	0.24	0.37
Primary3	2.74	3.04	1.11	1.81	0.19	0.10	-2.42	1.14	0.47	-1.61	0.53	0.33
Primary4	5.31	4.18	0.79	2.98	0.31	0.11	-5.03	1.34	0.27	-2.83	0.13	0.05
Primary5	9.72	5.12	0.53	4.33	0.22	0.05	-8.03	1.87	0.23	-3.74	0.20	0.05
Primary6	21.30	8.17	0.38	7.48	0.28	0.04	-17.03	3.89	0.23	-6.00	0.64	0.11
Primary7	29.14	10.38	0.36	9.92	0.51	0.05	-24.42	5.34	0.22	-8.18	0.88	0.11
Primary8	38.12	12.99	0.34	13.99	0.83	0.06	-34.07	5.41	0.16	-11.98	1.32	0.11
Primary9	43.91	14.77	0.34	18.37	1.00	0.05	-39.16	3.59	0.09	-15.62	1.41	0.09
Primary10	44.79	14.77	0.33	22.31	1.37	0.06	-39.62	5.67	0.14	-19.45	1.72	0.09
Primary11	38.25	14.93	0.39	25.58	1.92	0.08	-34.35	11.03	0.32	-23.62	1.21	0.05

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.26	0.09	0.35	0.18	0.09	0.54	0.26	0.06	0.23	1438.73	1155.94	0.80
Primary2	0.49	0.19	0.39	0.45	0.22	0.48	0.19	0.04	0.21	1392.09	1196.06	0.86
Primary3	3.61	1.69	0.47	4.69	2.15	0.46	0.12	0.01	0.11	1678.59	1345.96	0.80
Primary4	8.32	4.04	0.48	14.20	6.48	0.46	0.09	0.01	0.08	1771.67	515.73	0.29
Primary5	15.42	6.05	0.39	33.89	12.86	0.38	0.07	0.01	0.11	2193.83	450.68	0.21
Primary6	65.22	13.16	0.20	131.05	25.73	0.20	0.08	0.01	0.13	2837.87	487.48	0.17
Primary7	102.54	18.89	0.18	245.50	40.26	0.16	0.07	0.01	0.13	2959.73	460.30	0.16
Primary8	238.37	37.80	0.16	472.74	63.00	0.13	0.08	0.01	0.12	2781.95	343.13	0.12
Primary9	344.62	54.28	0.16	709.38	53.22	0.08	0.08	0.01	0.13	2453.74	295.94	0.12
Primary10	446.34	39.82	0.09	886.95	110.84	0.12	0.08	0.01	0.14	2023.13	187.37	0.09
Primary11	516.49	99.37	0.19	903.45	236.48	0.26	0.09	0.01	0.15	1468.10	299.76	0.20

Table A.51b: Hysteretic connection properties (Std.), Configuration 25.

Hysteretic Connection Properties: Configuration 25

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	116.35	107.61	0.92	0.01	0.00	0.31	-102.80	80.70	0.78	-0.02	0.01	0.32
Primary2	166.30	142.18	0.85	0.02	0.01	0.37	-152.01	118.41	0.78	-0.02	0.01	0.37
Primary3	614.95	683.98	1.11	0.07	0.01	0.10	-543.95	257.02	0.47	-0.06	0.02	0.33
Primary4	1193.75	938.68	0.79	0.12	0.01	0.11	-1131.74	300.81	0.27	-0.11	0.01	0.05
Primary5	2184.43	1150.58	0.53	0.17	0.01	0.05	-1805.34	420.42	0.23	-0.15	0.01	0.05
Primary6	4787.32	1836.64	0.38	0.29	0.01	0.04	-3827.70	874.32	0.23	-0.24	0.03	0.11
Primary7	6550.32	2333.32	0.36	0.39	0.02	0.05	-5488.98	1201.60	0.22	-0.32	0.03	0.11
Primary8	8569.98	2920.99	0.34	0.55	0.03	0.06	-7658.19	1217.16	0.16	-0.47	0.05	0.11
Primary9	9872.43	3320.93	0.34	0.72	0.04	0.05	-8804.63	806.02	0.09	-0.62	0.06	0.09
Primary10	10069.55	3319.90	0.33	0.88	0.05	0.06	-8907.73	1274.04	0.14	-0.77	0.07	0.09
Primary11	8599.49	3356.01	0.39	1.01	0.08	0.08	-7722.44	2478.66	0.32	-0.93	0.05	0.05

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	2.29	0.79	0.35	1.56	0.84	0.54	0.27	0.08	0.31	8215.35	6600.60	0.80
Primary2	4.37	1.68	0.39	3.98	1.91	0.48	0.20	0.07	0.34	7949.05	6829.69	0.86
Primary3	31.97	14.97	0.47	41.54	19.06	0.46	0.13	0.04	0.29	9584.99	7685.63	0.80
Primary4	73.65	35.72	0.48	125.66	57.33	0.46	0.10	0.02	0.21	10116.49	2944.89	0.29
Primary5	136.48	53.51	0.39	299.91	113.86	0.38	0.08	0.01	0.15	12527.08	2573.47	0.21
Primary6	577.23	116.47	0.20	1159.86	227.76	0.20	0.09	0.01	0.17	16204.68	2783.58	0.17
Primary7	907.57	167.22	0.18	2172.90	356.30	0.16	0.07	0.02	0.21	16900.50	2628.40	0.16
Primary8	2109.71	334.57	0.16	4184.09	557.59	0.13	0.08	0.01	0.08	15885.32	1959.30	0.12
Primary9	3050.18	480.39	0.16	6278.52	471.08	0.08	0.08	0.01	0.12	14011.22	1689.88	0.12
Primary10	3950.48	352.43	0.09	7850.17	981.03	0.12	0.08	0.01	0.14	11552.38	1069.92	0.09
Primary11	4571.37	879.47	0.19	7996.17	2093.04	0.26	0.09	0.01	0.15	8383.06	1711.67	0.20

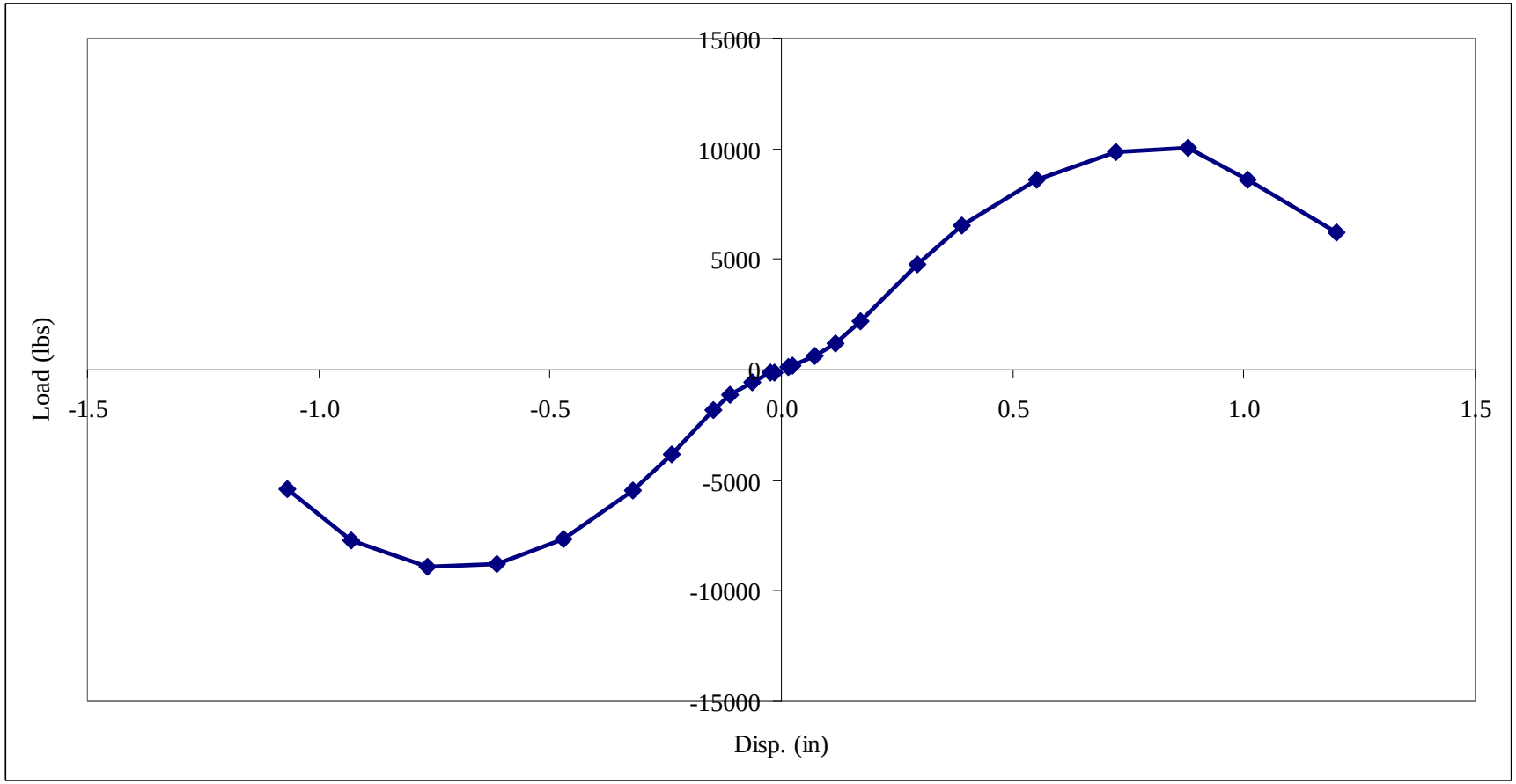

Figure A.176: Mean envelope curve: Configuration 25.

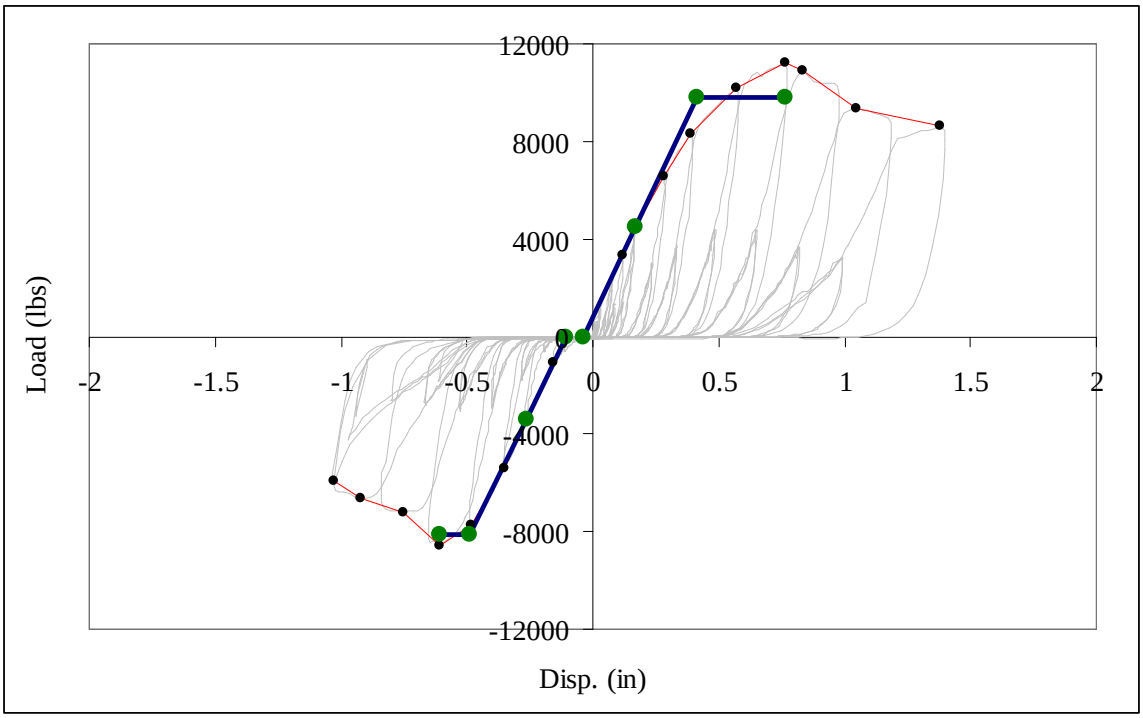

Figure A.177: Load-Deflection plot: C25-1.

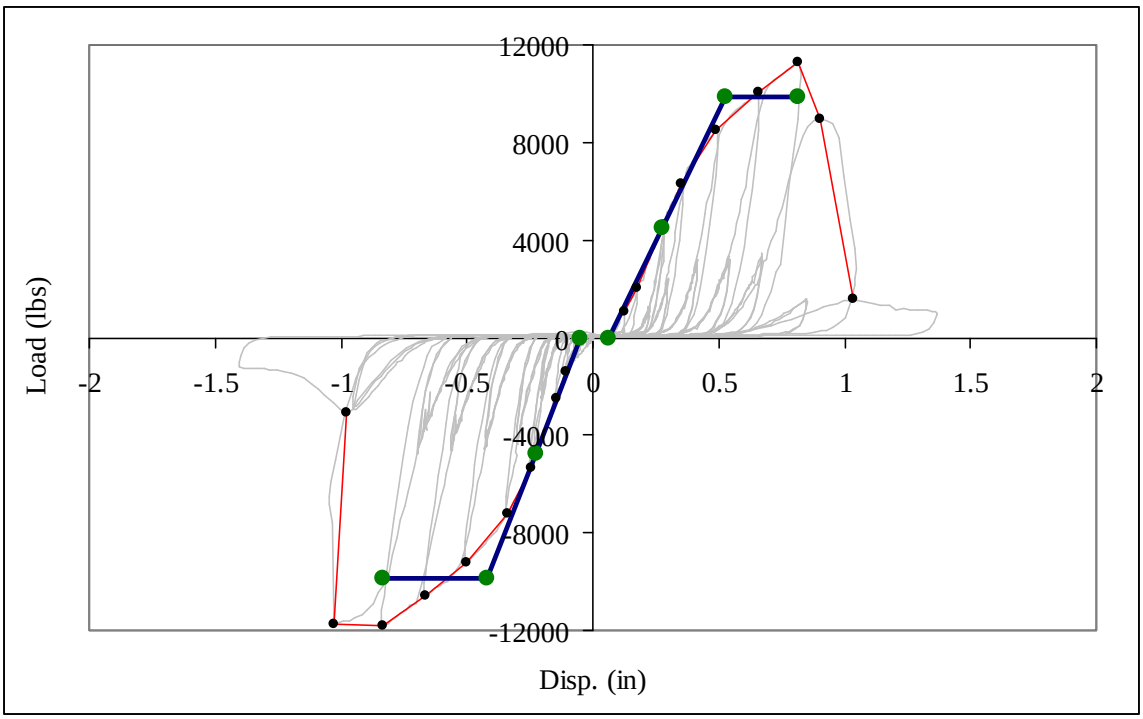

Figure A.178: Load-Deflection plot: C25-2.

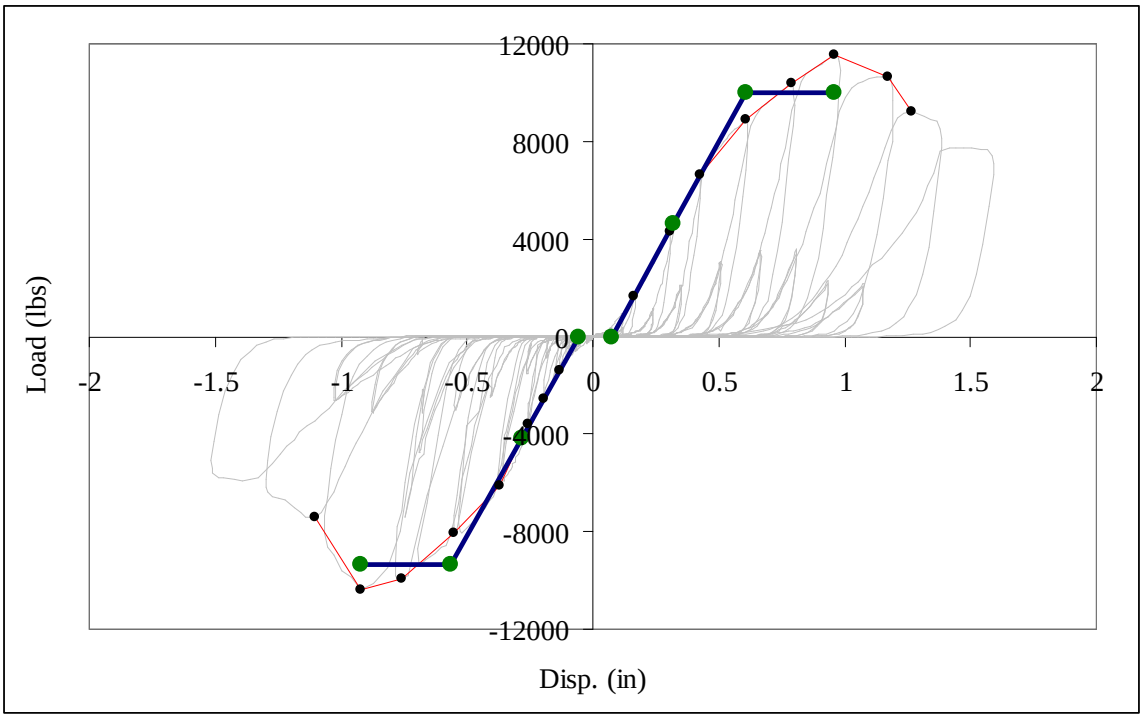

Figure A.179: Load-Deflection plot: C25-3.

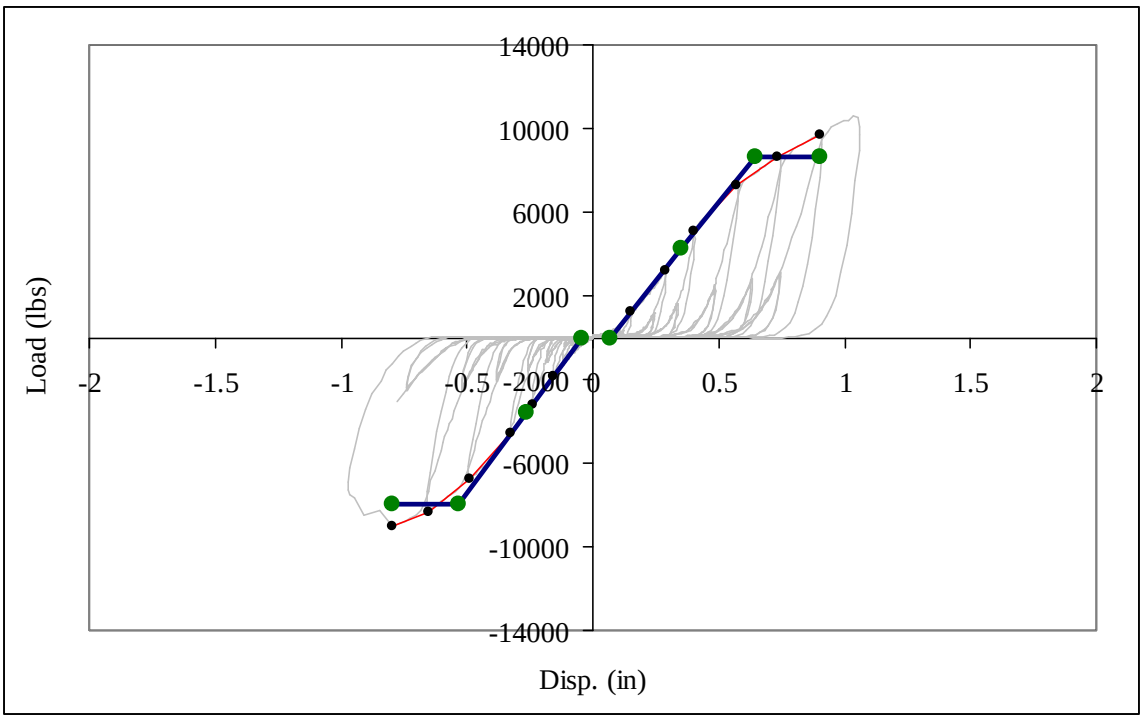

Figure A.180: Load-Deflection plot: C25-4.

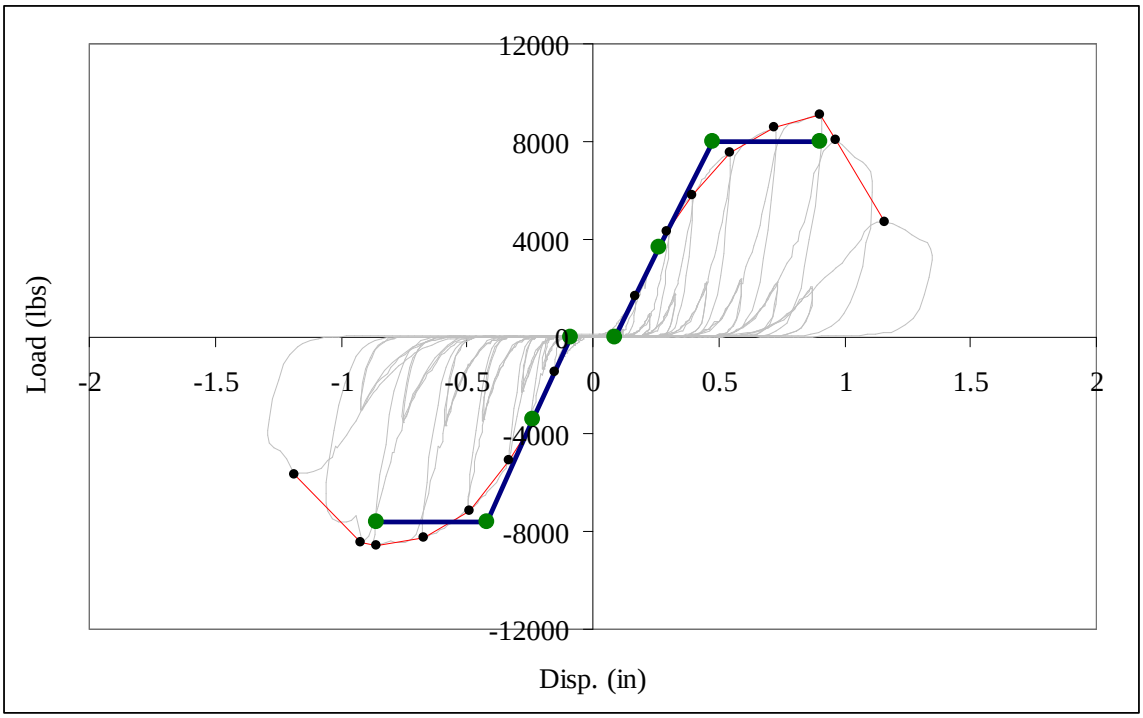

Figure A.181: Load-Deflection plot: C25-5.

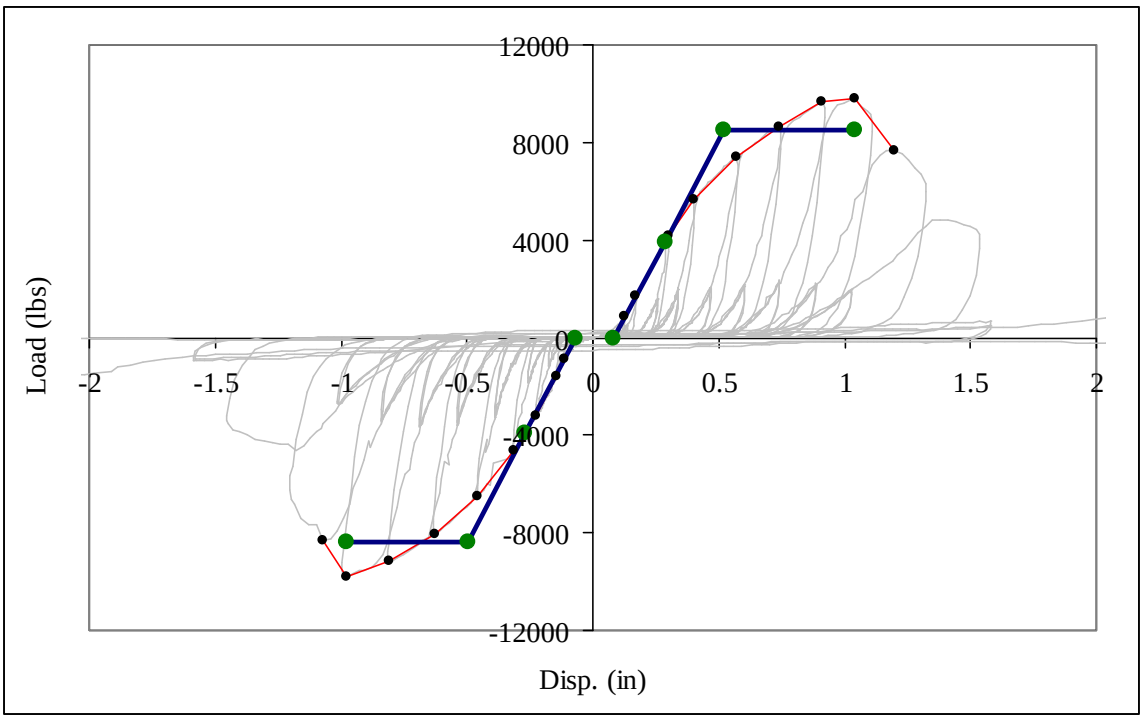

Figure A.182: Load-Deflection plot: C25-6.

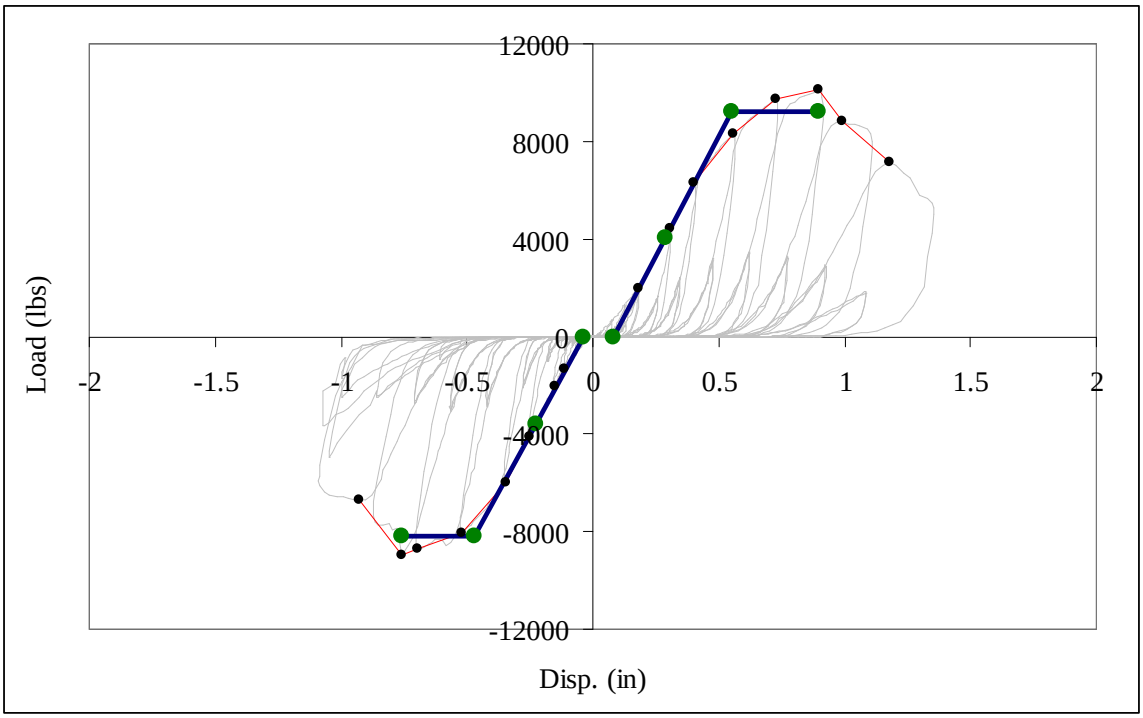

Figure A.183: Load-Deflection plot: C25-7.

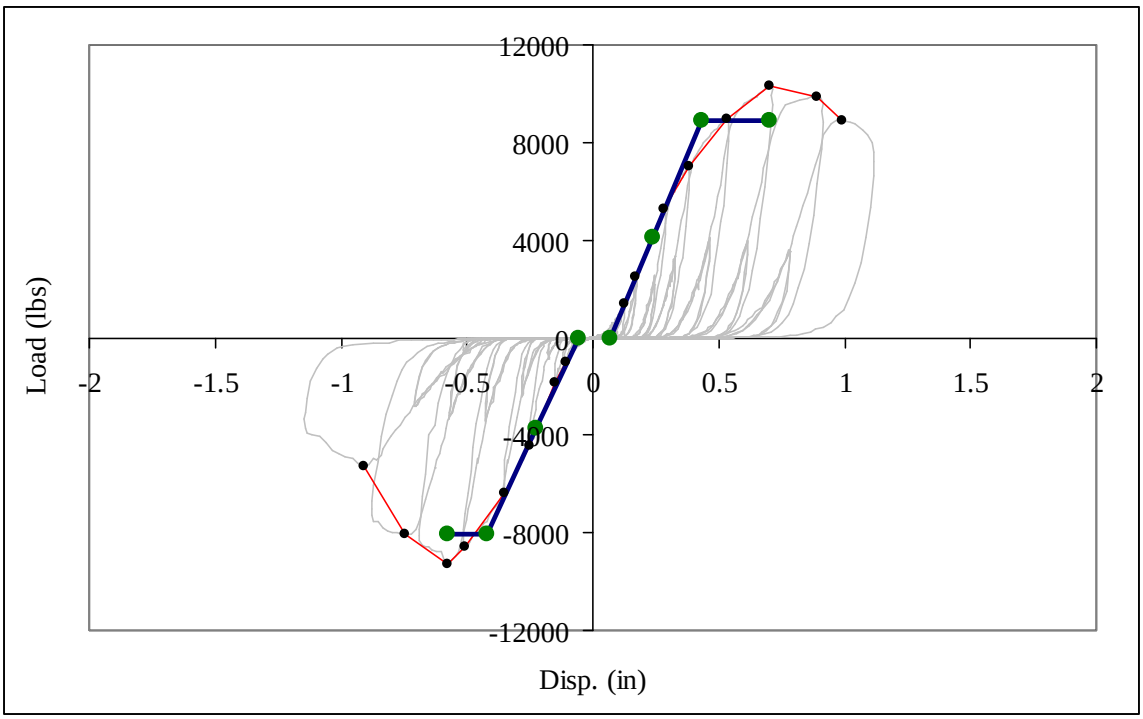

Figure A.184: Load-Deflection plot: C25-8.

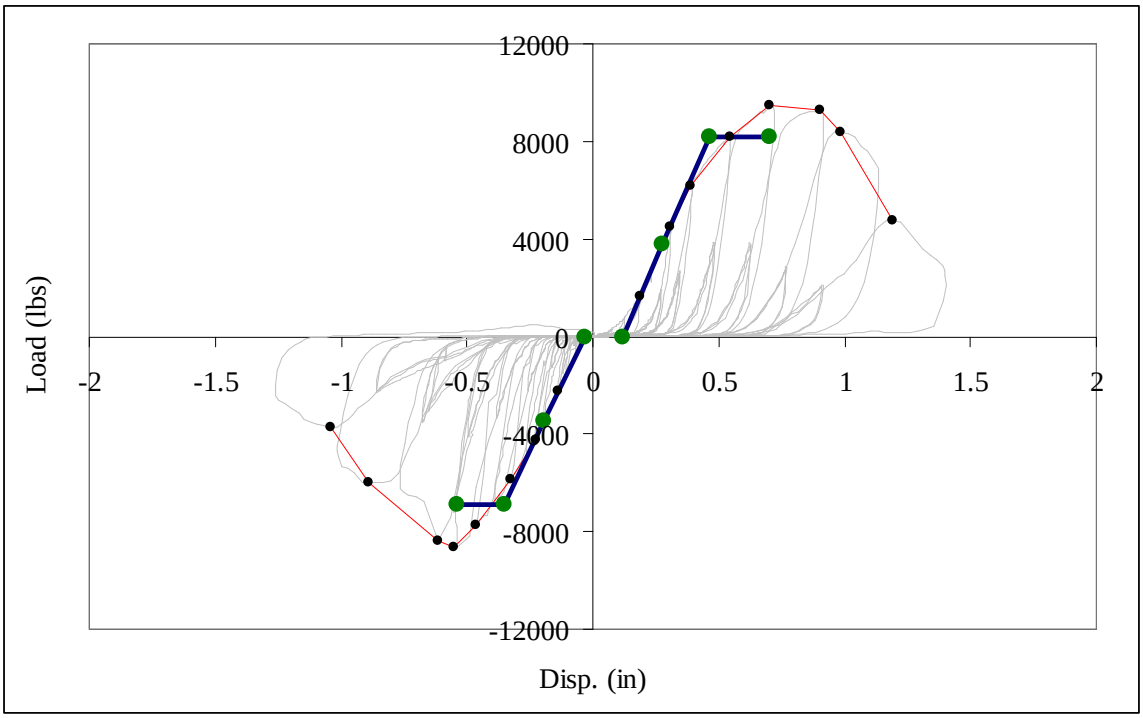

Figure A.185: Load-Deflection plot: C25-9.

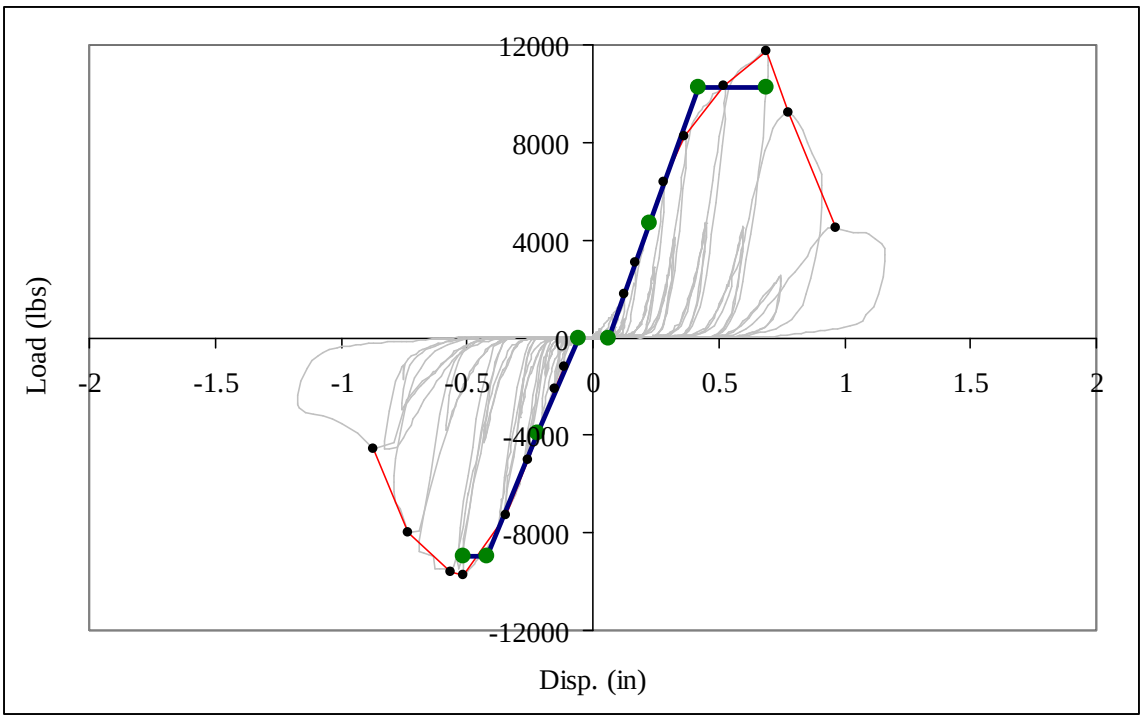

Figure A.186: Load-Deflection plot: C25-10.

Table A.52a: Connection performance properties (SI), Configuration 28.

Connection Performance Properties: Configuration 28

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	73.02	75.75	88.28	93.96	96.55	57.27	71.78	93.83	105.96	76.70	83.31	14.74	0.18
@Displacement (mm)	11.49	9.09	13.82	11.63	11.47	6.64	8.67	14.26	16.54	13.80	11.74	2.99	0.25
Failure Load (kN)	58.42	60.60	70.63	75.17	77.24	45.82	57.43	75.06	84.77	61.36	66.65	11.79	0.18
@Displacement (mm)	11.49	9.09	13.82	11.63	11.47	6.64	8.67	14.49	16.54	13.80	11.77	3.01	0.26
40% Max (kN)	29.21	30.30	35.31	37.59	38.62	22.91	28.71	37.53	42.38	30.68	33.32	5.89	0.18
@Displacement (mm)	5.26	4.54	5.03	4.63	4.80	3.64	4.20	5.12	6.20	4.61	4.80	0.68	0.14
Yield (kN)	74.65	66.02	80.01	81.03	84.61	52.20	64.31	81.36	88.95	70.18	74.33	11.17	0.15
@Displacement (mm)	8.96	7.67	9.02	7.86	8.43	6.01	7.61	8.80	10.53	8.72	8.36	1.18	0.14
5% Offset Yield (kN)	63.69	75.75	77.10	78.12	83.25	57.27	71.78	74.75	72.02	65.62	71.93	7.73	0.11
@Displacement (mm)	9.76	9.09	9.73	8.59	9.28	6.64	8.67	9.16	9.89	9.20	9.00	0.94	0.10
Elastic Stiff. (N/mm)	9889.50	11470.87	11369.90	13484.70	12637.86	12392.98	10448.61	12222.62	10955.53	10294.98	11516.76	1155.47	0.10
E.E.P. Energy (N*m)	444.24	300.99	656.65	599.02	586.25	143.13	269.21	768.79	921.19	642.66	533.21	241.31	0.45
Ductility Ratio	1.31	1.17	1.58	1.44	1.34	1.10	1.14	1.68	1.57	1.63	1.40	0.21	0.15
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Balk. Shr.	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Balk. Shr.	Balk. Shr.	Splitting	Splitting	Splitting			
Governing Member	Main	Main	Main	Main	Main	Main	Side	Side	Main	Side			

Table A.52b: Connection performance properties (Std.), Configuration 28.

Connection Performance Properties: Configuration 28

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	16416.60	17029.42	19846.44	21123.63	21705.00	12875.60	16137.16	21092.85	23821.06	17243.07	18729.08	3312.94	0.18
@ Displacement (in)	0.45	0.36	0.54	0.46	0.45	0.26	0.34	0.56	0.65	0.54	0.46	0.12	0.25
Failure Load (lbs)	13133.28	13623.54	15877.15	16898.90	17364.00	10300.48	12909.73	16874.28	19056.85	13794.46	14983.27	2650.35	0.18
@ Displacement (in)	0.45	0.36	0.54	0.46	0.45	0.26	0.34	0.57	0.65	0.54	0.46	0.12	0.26
40% Max (lbs)	6566.64	6811.77	7938.57	8449.45	8682.00	5150.24	6454.86	8437.14	9528.42	6897.23	7491.63	1325.18	0.18
@ Displacement (in)	0.21	0.18	0.20	0.18	0.19	0.14	0.17	0.20	0.24	0.18	0.19	0.03	0.14
Yield (lbs)	16781.96	14841.03	17986.14	18215.28	19021.25	11734.19	14457.35	18289.83	19995.83	15776.46	16709.93	2510.68	0.15
@ Displacement (in)	0.35	0.30	0.36	0.31	0.33	0.24	0.30	0.35	0.41	0.34	0.33	0.05	0.14
5% Offset Yield (lbs)	14317.61	17029.42	17332.54	17561.62	18714.33	12875.60	16137.16	16804.69	16190.43	14751.01	16171.44	1738.54	0.11
@ Displacement (in)	0.38	0.36	0.38	0.34	0.37	0.26	0.34	0.36	0.39	0.36	0.35	0.04	0.10
Elastic Stiff. (lb/in)	56470.48	65500.35	64923.82	76999.63	72164.02	70765.75	59663.07	69792.97	62557.71	58785.85	65762.37	6597.90	0.10
E.E.P. Energy (lb*in)	3931.82	2664.01	5811.87	5301.77	5188.74	1266.79	2382.73	6804.38	8153.17	5688.04	4719.33	2135.80	0.45
Ductility Ratio	1.31	1.17	1.58	1.44	1.34	1.10	1.14	1.68	1.57	1.63	1.40	0.21	0.15
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Balk. Shr.	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Balk. Shr.	Balk. Shr.	Splitting	Splitting	Splitting			
Governing Member	Main	Main	Main	Main	Main	Main	Side	Side	Main	Side			

Table A.53a: Member properties (SI), Configuration 28.

Member Properties: Configuration 28

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.42	14.22	14.74	14.62	14.78	14.26	15.24	15.42	15.48	14.74	14.79	0.45	0.03
S.G.	0.37	0.36	0.44	0.43	0.46	0.52	0.54	0.50	0.50	0.44	0.45	0.06	0.13
D.E. 5% Offset Yield (kPa)	20764	20468	23943	26075	25580	26377	28865	25844	27011	23024	24795	2711.44	0.11
D.E. Capacity (kPa)	20764	20593	24602	26654	25910	26377	28978	26115	27011	23286	25029	2728.87	0.11
Side Member													
M.C. (%)	14.00	14.36	14.91	14.64	14.36	14.47	14.48	15.08	15.03	14.93	14.63	0.35	0.02
S.G.	0.43	0.39	0.43	0.40	0.46	0.50	0.52	0.54	0.52	0.45	0.46	0.05	0.11
D.E. 5% Offset Yield (kPa)	23206	26645	27102	24289	25702	25904	29197	28261	26085	24962	26135	1785.62	0.07
D.E. Capacity (kPa)	23206	26864	27406	24534	27527	26727	29536	28540	26085	26381	26681	1826.19	0.07

Table A.53b: Member properties (Std.), Configuration 28.

Member Properties: Configuration 28

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.42	14.22	14.74	14.62	14.78	14.26	15.24	15.42	15.48	14.74	14.79	0.45	0.03
S.G.	0.37	0.36	0.44	0.43	0.46	0.52	0.54	0.50	0.50	0.44	0.45	0.06	0.13
D.E. 5% Offset Yield (psi)	3011.60	2968.57	3472.674	3781.80	3709.98	3825.60	4186.52	3748.35	3917.60	3339.33	3596.20	393.26	0.11
D.E. Capacity (psi)	3011.60	2986.75	3568.25	3865.78	3757.89	3825.60	4202.89	3787.67	3917.60	3377.35	3630.14	395.79	0.11
Side Member													
M.C. (%)	14.00	14.36	14.91	14.64	14.36	14.47	14.48	15.08	15.03	14.93	14.63	0.35	0.02
S.G.	0.43	0.39	0.43	0.40	0.46	0.50	0.52	0.54	0.52	0.45	0.46	0.05	0.11
D.E. 5% Offset Yield (psi)	3365.79	3864.44	3930.84	3522.74	3727.69	3757.09	4234.70	4098.84	3783.23	3620.47	3790.58	258.98	0.07
D.E. Capacity (psi)	3365.79	3896.24	3974.83	3558.29	3992.43	3876.47	4283.87	4139.33	3783.23	3826.24	3869.67	264.86	0.07

Table A.54a: Hysteretic connection properties (SI), Configuration 28.

Hysteretic Connection Properties: Configuration 28

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.38	0.76	0.55	0.25	0.10	0.39	-1.39	0.86	0.62	-0.26	0.09	0.34
Primary2	1.63	0.90	0.55	0.45	0.15	0.35	-1.86	1.29	0.69	-0.42	0.13	0.30
Primary3	3.30	1.59	0.48	1.43	0.28	0.19	-4.82	3.35	0.69	-1.33	0.25	0.19
Primary4	7.74	4.21	0.54	2.51	0.19	0.08	-9.46	5.53	0.58	-2.20	0.34	0.16
Primary5	13.85	6.79	0.49	3.40	0.23	0.07	-16.69	6.02	0.36	-2.99	0.42	0.14
Primary6	39.05	13.38	0.34	5.66	0.21	0.04	-37.00	4.78	0.13	-4.74	0.74	0.16
Primary7	61.78	19.97	0.32	7.88	0.25	0.03	-52.27	4.28	0.08	-6.28	1.04	0.17
Primary8	87.61	30.02	0.34	11.25	0.88	0.08	-67.06	8.16	0.12	-8.55	1.38	0.16
Primary9	103.55	39.21	0.38	14.51	1.80	0.12	-62.41	28.09	0.45	-10.80	2.83	0.26
Primary10	100.83	52.40	0.52	16.80	3.52	0.21	-47.92	49.15	1.03	-10.54	3.97	0.38

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.72	0.29	0.41	0.37	0.19	0.51	0.33	0.08	0.23	5617.86	2996.91	0.53
Primary2	1.48	0.82	0.55	0.82	0.49	0.59	0.30	0.07	0.24	4091.00	1928.01	0.47
Primary3	6.87	3.84	0.56	5.66	2.52	0.44	0.20	0.08	0.39	2970.85	1082.96	0.36
Primary4	15.47	6.92	0.45	19.85	4.20	0.21	0.12	0.04	0.36	3675.22	785.59	0.21
Primary5	25.25	10.33	0.41	47.61	7.66	0.16	0.08	0.02	0.26	4805.57	751.80	0.16
Primary6	93.97	28.51	0.30	197.24	24.84	0.13	0.08	0.02	0.23	7347.86	781.11	0.11
Primary7	188.72	45.55	0.24	406.50	43.26	0.11	0.07	0.01	0.19	8098.77	814.50	0.10
Primary8	472.44	148.00	0.31	779.25	85.22	0.11	0.10	0.03	0.31	7869.74	984.64	0.13
Primary9	752.94	390.57	0.52	1114.29	295.99	0.27	0.10	0.04	0.41	6500.83	904.56	0.14
Primary10	637.86	342.13	0.54	1148.22	552.93	0.48	0.09	0.05	0.58	5422.42	1394.51	0.26

Table A.54b: Hysteretic connection properties (Std.), Configuration 28.

Hysteretic Connection Properties: Configuration 28

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	310.19	170.98	0.55	0.01	0.00	0.39	-312.75	192.55	0.62	-0.01	0.00	0.34
Primary2	365.83	201.83	0.55	0.02	0.01	0.35	-418.85	289.16	0.69	-0.02	0.01	0.30
Primary3	741.18	358.55	0.48	0.06	0.01	0.19	-1083.75	752.27	0.69	-0.05	0.01	0.19
Primary4	1739.00	947.47	0.54	0.10	0.01	0.08	-2126.69	1243.50	0.58	-0.09	0.01	0.16
Primary5	3113.64	1526.55	0.49	0.13	0.01	0.07	-3751.82	1352.52	0.36	-0.12	0.02	0.14
Primary6	8778.30	3008.71	0.34	0.22	0.01	0.04	-8317.96	1075.41	0.13	-0.19	0.03	0.16
Primary7	13888.22	4488.37	0.32	0.31	0.01	0.03	-11751.09	962.22	0.08	-0.25	0.04	0.17
Primary8	19694.46	6749.68	0.34	0.44	0.03	0.08	-15076.76	1835.53	0.12	-0.34	0.05	0.16
Primary9	23279.17	8815.31	0.38	0.57	0.07	0.12	-14029.83	6313.96	0.45	-0.43	0.11	0.26
Primary10	22666.54	11779.00	0.52	0.66	0.14	0.21	-10773.58	11050.23	1.03	-0.42	0.16	0.38

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	6.34	2.60	0.41	3.28	1.66	0.51	0.33	0.08	0.23	32078.83	17112.79	0.53
Primary2	13.13	7.27	0.55	7.25	4.31	0.59	0.30	0.07	0.24	23360.20	11009.19	0.47
Primary3	60.78	34.00	0.56	50.07	22.27	0.44	0.21	0.08	0.36	16964.01	6183.87	0.36
Primary4	136.93	61.23	0.45	175.67	37.16	0.21	0.12	0.04	0.36	20986.04	4485.81	0.21
Primary5	223.50	91.46	0.41	421.40	67.77	0.16	0.08	0.02	0.26	27440.49	4292.86	0.16
Primary6	831.72	252.33	0.30	1745.75	219.90	0.13	0.08	0.02	0.23	41957.37	4460.27	0.11
Primary7	1670.33	403.19	0.24	3597.85	382.87	0.11	0.07	0.01	0.19	46245.18	4650.92	0.10
Primary8	4181.47	1309.95	0.31	6896.94	754.29	0.11	0.10	0.03	0.31	44937.35	5622.43	0.13
Primary9	6664.11	3456.81	0.52	9862.28	2619.77	0.27	0.10	0.04	0.41	37120.67	5165.15	0.14
Primary10	5645.57	3028.14	0.54	10162.63	4893.85	0.48	0.09	0.05	0.58	30962.81	7962.83	0.26

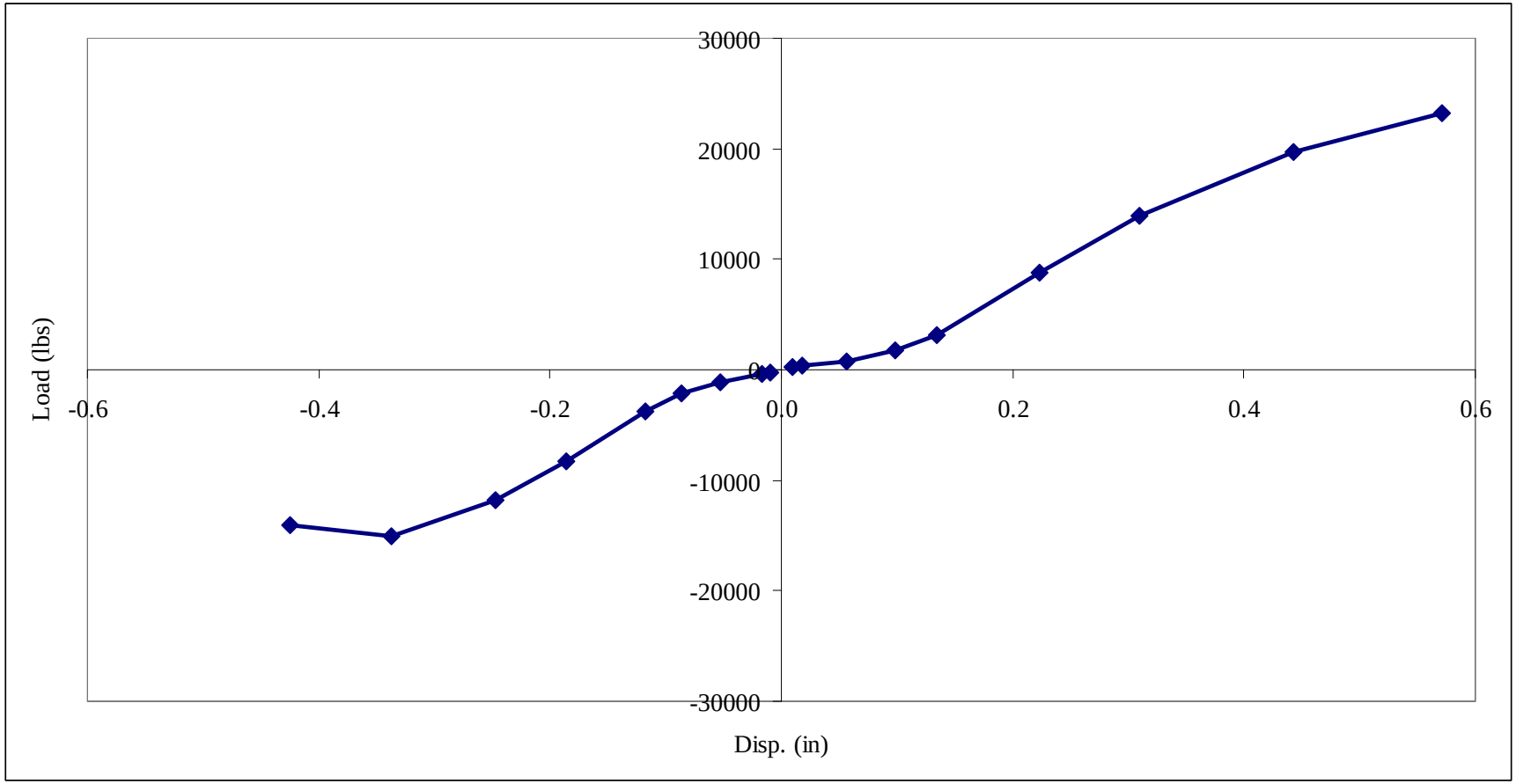

Figure A.187: Mean envelope curve: Configuration 28.

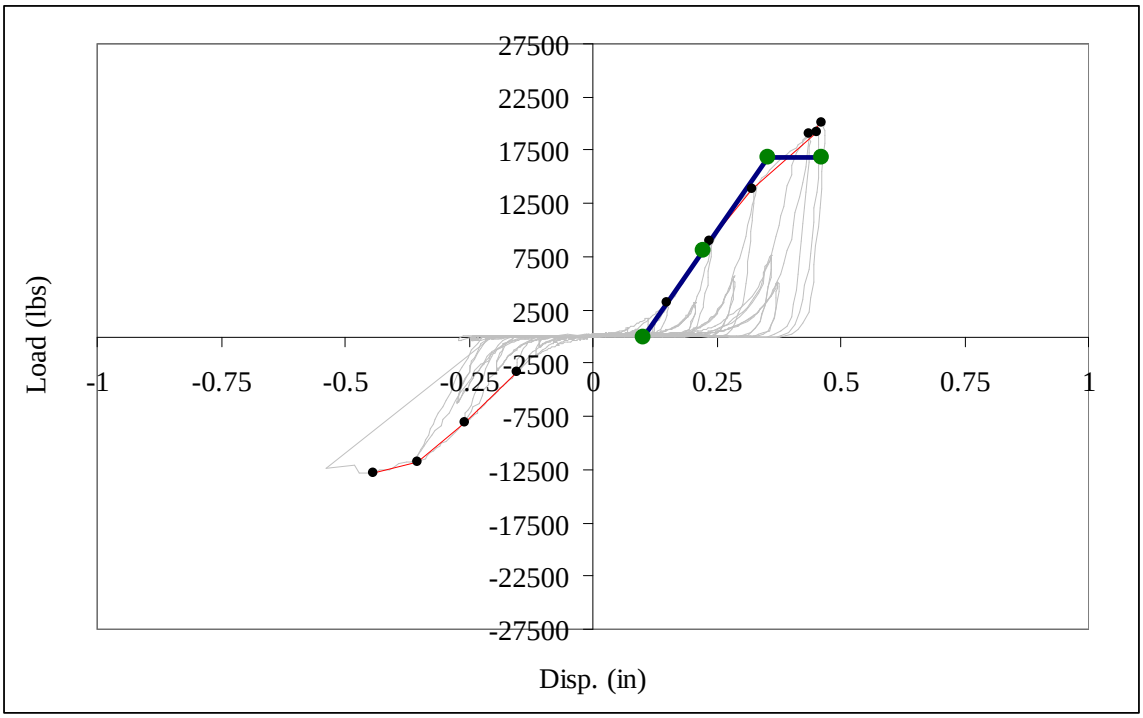

Figure A.188: Load-Deflection plot: C28-1.

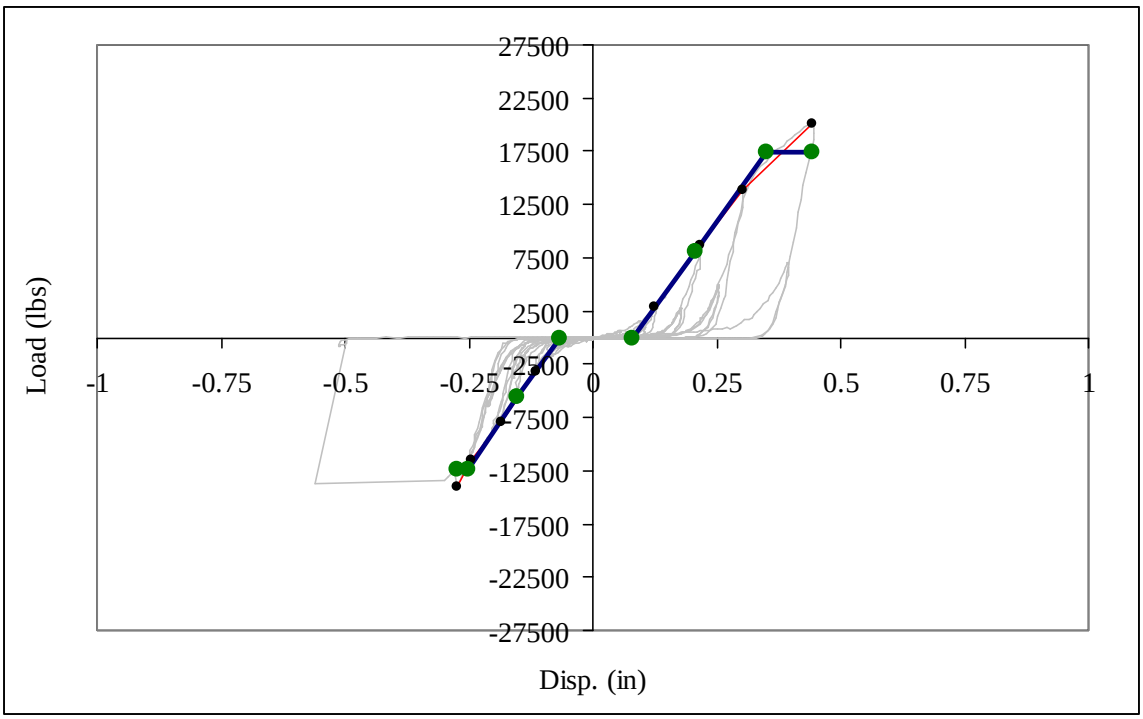

Figure A.189: Load-Deflection plot: C28-2.

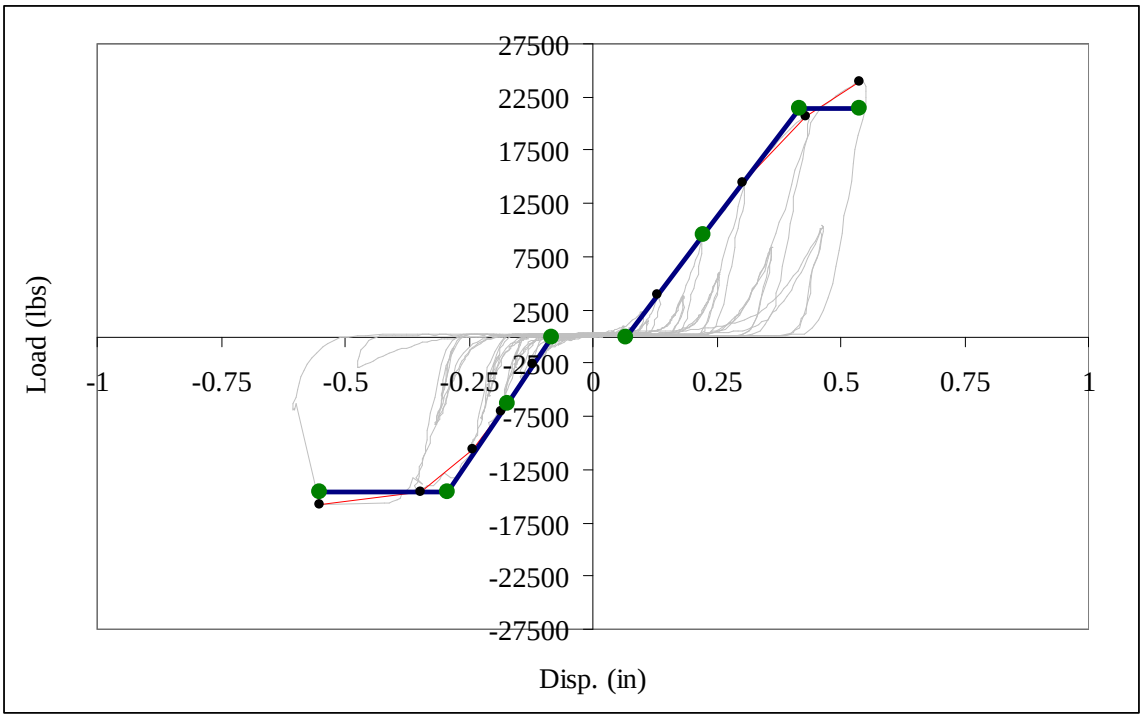

Figure A.190: Load-Deflection plot: C28-3.

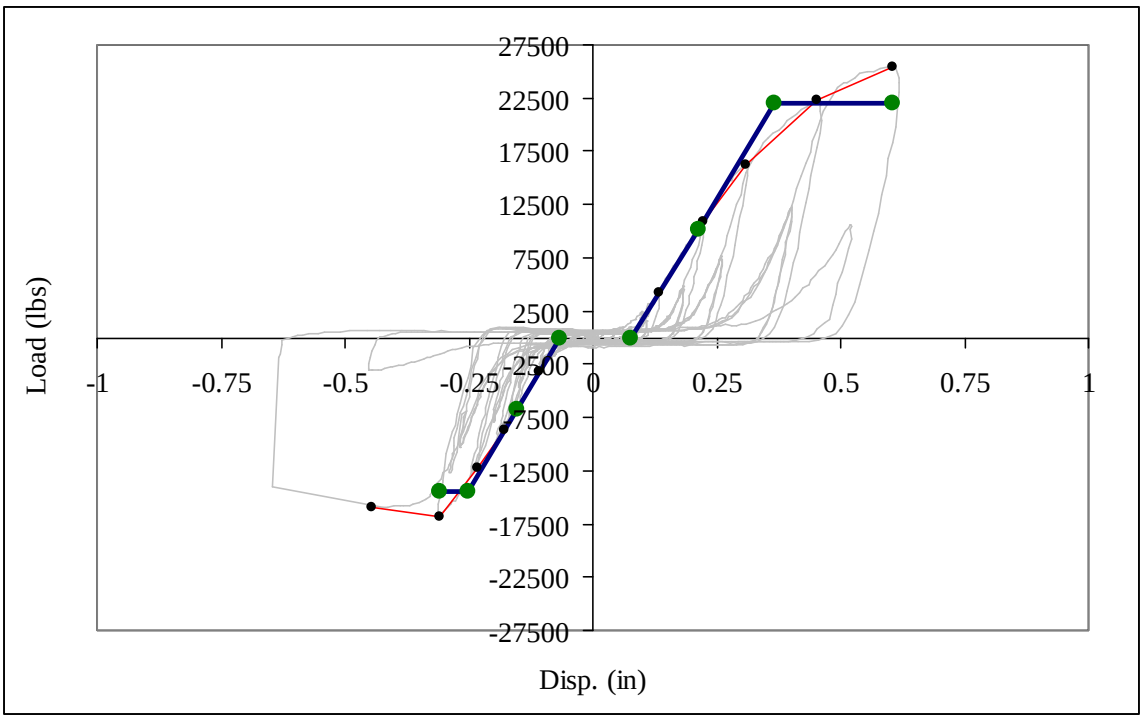

Figure A.191: Load-Deflection plot: C28-4.

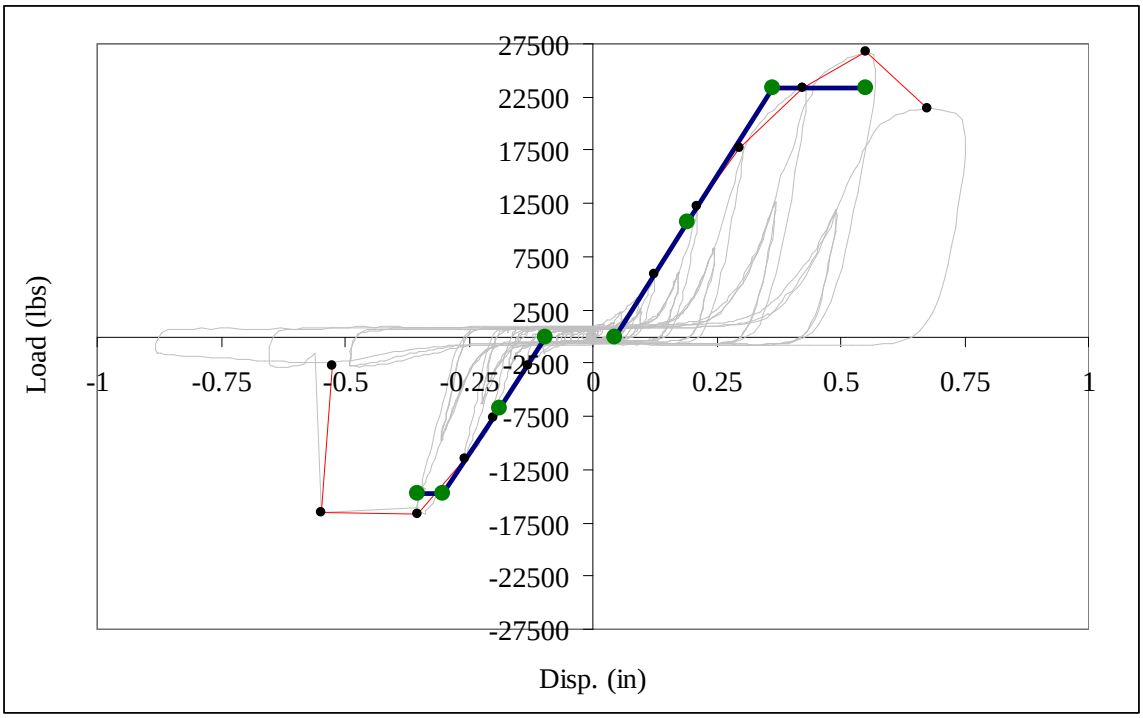

Figure A.192: Load-Deflection plot: C28-5.

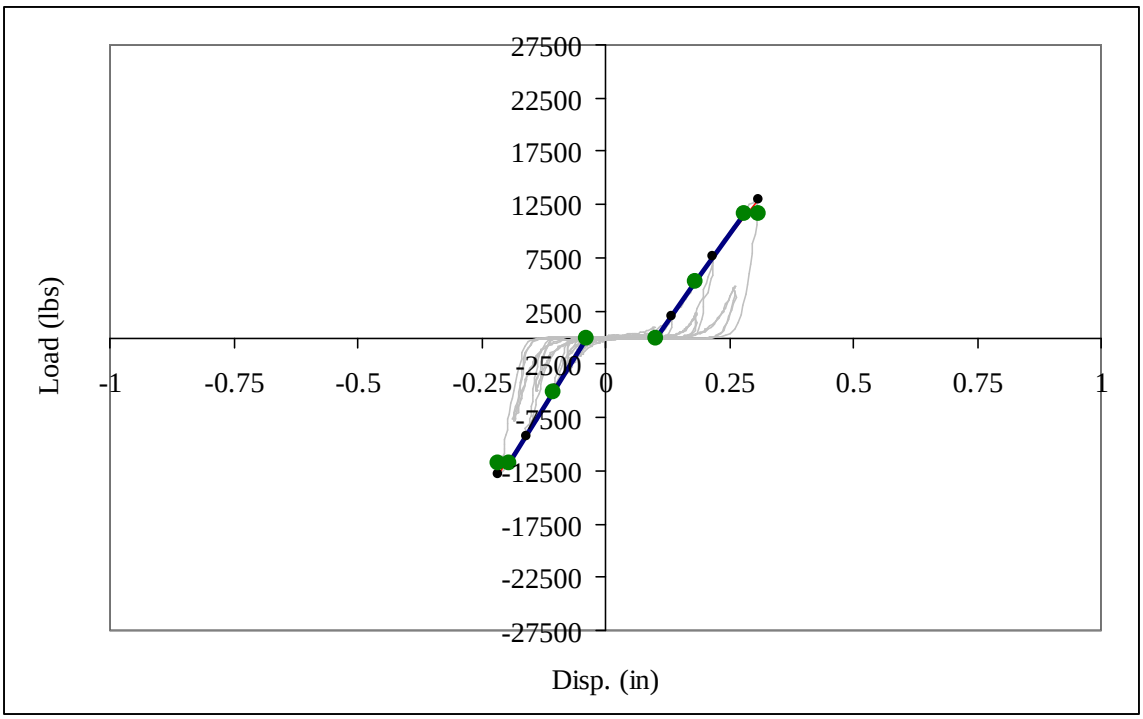

Figure A.193: Load-Deflection plot: C28-6.

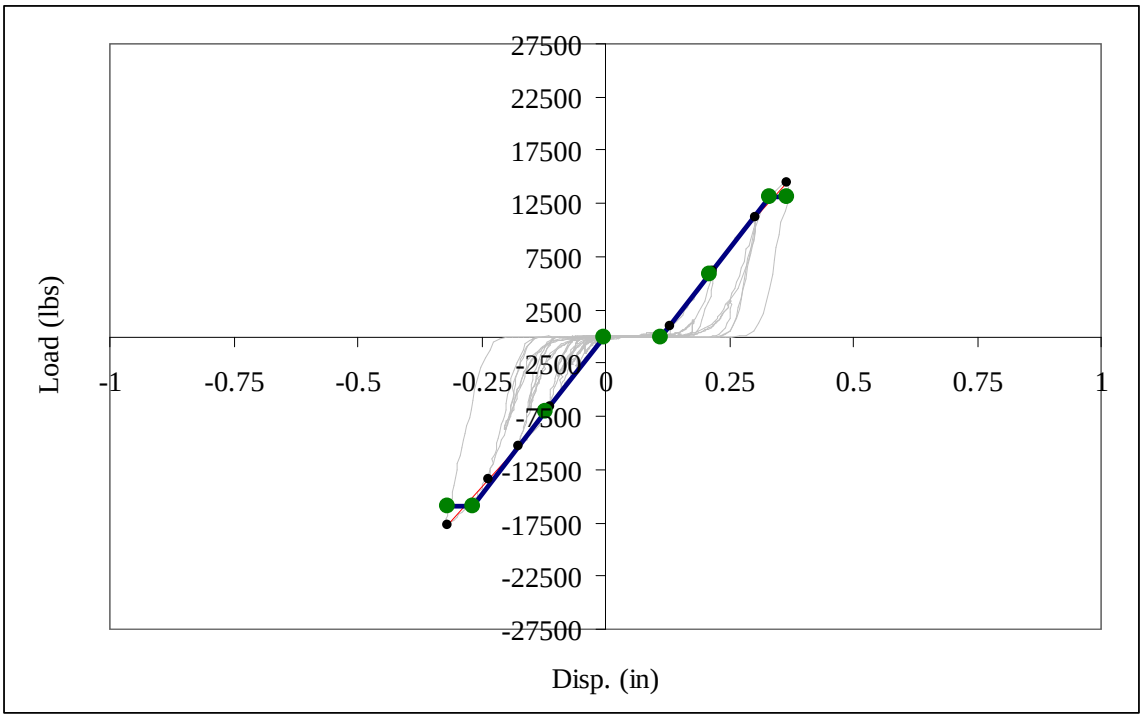

Figure A.194: Load-Deflection plot: C28-7.

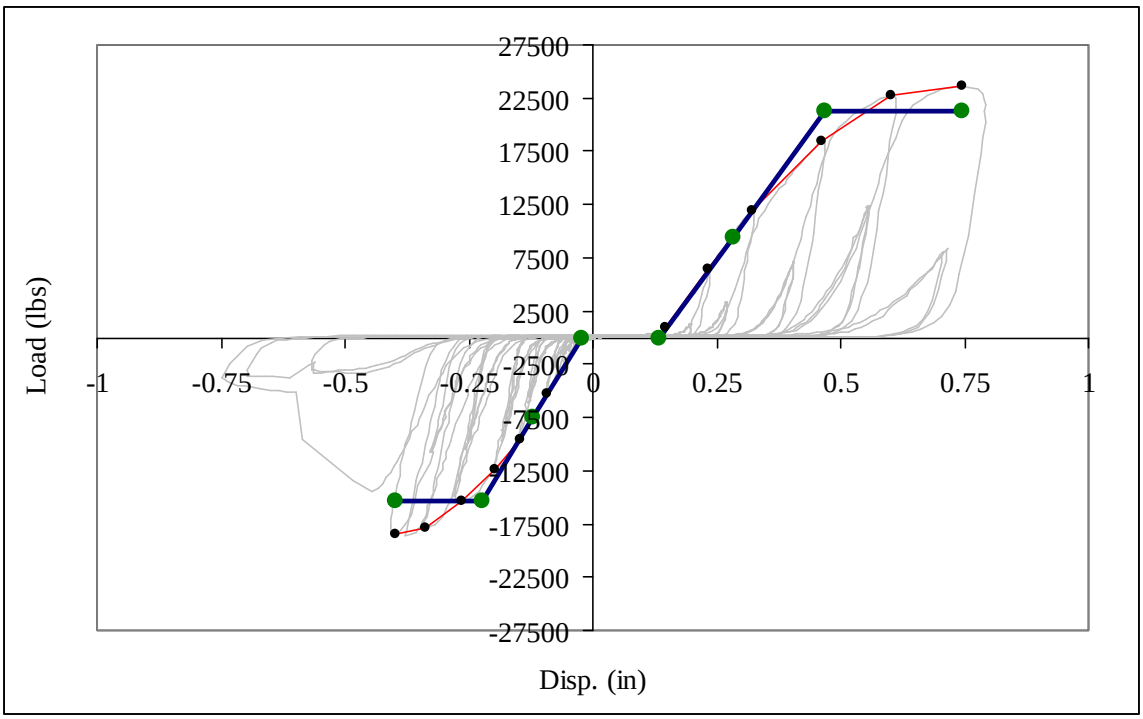

Figure A.195: Load-Deflection plot: C28-8.

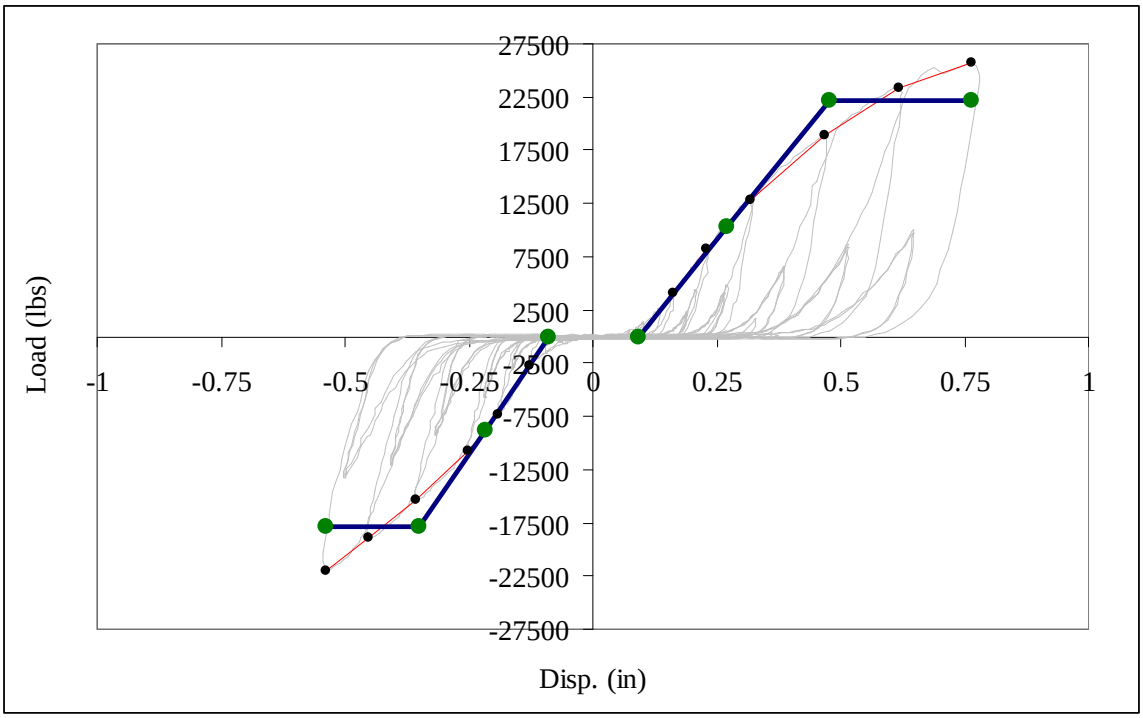

Figure A.196: Load-Deflection plot: C28-9.

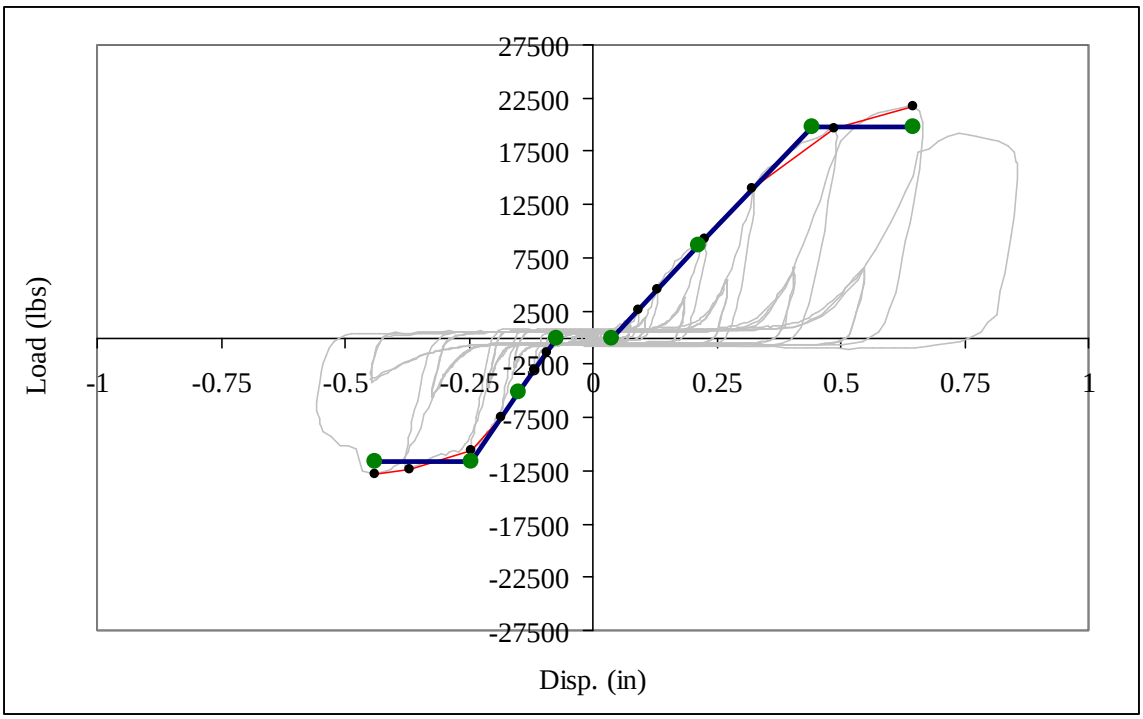

Figure A.197: Load-Deflection plot: C28-10.

Table A.55a: Connection performance properties (SI), Configuration 29.

Connection Performance Properties: Configuration 29

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	94.67	102.98	90.92	87.15	106.63	109.49	103.69	115.33	108.97	105.38	102.52	8.90	0.09
@Displacement (mm)	11.20	11.48	14.36	12.79	9.19	12.28	12.81	11.72	14.16	12.52	12.25	1.49	0.12
Failure Load (kN)	75.73	82.39	72.74	69.72	85.30	87.59	82.95	92.27	87.18	84.31	82.02	7.12	0.09
@Displacement (mm)	11.20	11.48	14.36	12.79	9.19	12.28	12.81	11.72	14.16	12.52	12.25	1.49	0.12
40% Max (kN)	37.87	41.19	36.37	34.86	42.65	43.80	41.47	46.13	43.59	42.15	41.01	3.56	0.09
@Displacement (mm)	4.06	4.35	4.62	4.06	4.10	4.37	4.50	4.72	4.83	4.75	4.44	0.30	0.07
Yield (kN)	82.14	85.34	81.33	77.67	88.47	92.47	90.92	101.12	88.20	93.90	88.16	6.90	0.08
@Displacement (mm)	7.11	7.58	8.35	7.19	6.53	7.52	8.28	8.56	8.37	8.26	7.77	0.69	0.09
5% Offset Yield (kN)	74.98	77.00	77.58	69.40	93.63	81.63	83.71	99.67	77.53	87.68	82.28	9.16	0.11
@Displacement (mm)	7.55	7.90	9.00	7.53	7.76	7.77	8.68	9.52	8.46	8.81	8.30	0.69	0.08
Elastic Stiff. (N/mm)	15027.02	14027.38	12058.95	13702.12	18822.06	15527.04	13071.16	14483.49	12786.39	14742.02	14424.76	1880.06	0.13
E.E.P. Energy (N*m)	591.13	623.59	752.45	682.51	466.48	727.67	743.44	687.29	852.41	708.52	683.55	104.72	0.15
Ductility Ratio	1.57	1.50	1.71	1.80	1.42	1.62	1.55	1.40	1.66	1.52	1.58	0.12	0.08
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Balk. Shr.	Balk. Shr.	Tension	Balk. Shr.	Splitting	Splitting	Balk. Shr.	Splitting	Splitting			
Governing Member	Side	Side	Main	Main	Side	Main	Main	Main	Main	Side			

Table A.55b: Connection performance properties (Std.), Configuration 29.

Connection Performance Properties: Configuration 29

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	21282.20	23151.54	20440.12	19591.63	23970.73	24613.91	23309.78	25927.96	24498.38	23691.33	23047.76	2001.67	0.09
@ Displacement (in)	0.44	0.45	0.57	0.50	0.36	0.48	0.50	0.46	0.56	0.49	0.48	0.06	0.12
Failure Load (lbs)	17025.76	18521.23	16352.10	15673.30	19176.59	19691.13	18647.83	20742.37	19598.71	18953.06	18438.21	1601.33	0.09
@ Displacement (in)	0.44	0.45	0.57	0.50	0.36	0.48	0.50	0.46	0.56	0.49	0.48	0.06	0.12
40% Max (lbs)	8512.88	9260.61	8176.05	7836.65	9588.29	9845.56	9323.91	10371.19	9799.35	9476.53	9219.10	800.67	0.09
@ Displacement (in)	0.16	0.17	0.18	0.16	0.16	0.17	0.18	0.19	0.19	0.19	0.17	0.01	0.07
Yield (lbs)	18465.72	19185.42	18284.01	17460.91	19889.86	20788.77	20439.33	22731.95	19828.80	21109.06	19818.38	1550.25	0.08
@ Displacement (in)	0.28	0.30	0.33	0.28	0.26	0.30	0.33	0.34	0.33	0.33	0.31	0.03	0.09
5% Offset Yield (lbs)	16855.07	17309.60	17440.61	15601.56	21048.07	18352.24	18818.52	22407.29	17428.52	19712.03	18497.35	2058.75	0.11
@ Displacement (in)	0.30	0.31	0.35	0.30	0.31	0.31	0.34	0.37	0.33	0.35	0.33	0.03	0.08
Elastic Stiff. (lb/in)	85806.48	80098.41	68858.38	78241.11	107476.71	88661.68	74638.22	82702.84	73012.14	84179.08	82367.50	10735.44	0.13
E.E.P. Energy (lb*in)	5231.91	5519.23	6659.76	6040.74	4128.70	6440.41	6579.98	6083.02	7544.48	6270.95	6049.92	926.82	0.15
Ductility Ratio	1.57	1.50	1.71	1.80	1.42	1.62	1.55	1.40	1.66	1.52	1.58	0.12	0.08
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Balk. Shr.	Balk. Shr.	Tension	Balk. Shr.	Splitting	Splitting	Balk. Shr.	Splitting	Splitting			
Governing Member	Side	Side	Main	Main	Side	Main	Main	Main	Main	Side			

Table A.56a: Member properties (SI), Configuration 29.

Member Properties: Configuration 29

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.49	15.42	14.69	13.64	14.77	13.48	15.64	14.96	14.01	14.95	14.61	0.71	0.05
S.G.	0.43	0.44	0.43	0.41	0.57	0.49	0.51	0.55	0.50	0.45	0.48	0.06	0.12
D.E. 5% Offset Yield (kPa)	26269	25430	25287	24971	33038	28990	28313	28064	24981	26915	27226	2514.38	0.09
D.E. Capacity (kPa)	26663	25716	25630	24971	33038	28990	28313	28136	25364	28081	27490	2418.16	0.09
Side Member													
M.C. (%)	14.21	15.42	13.29	14.09	15.01	15.45	14.52	14.48	13.97	13.90	14.43	0.69	0.05
S.G.	0.46	0.45	0.43	0.43	0.54	0.50	0.54	0.50	0.50	0.48	0.48	0.04	0.08
D.E. 5% Offset Yield (kPa)	25036	25545	23999	26273	36760	27443	31269	29704	23948	27851	27783	3949.99	0.14
D.E. Capacity (kPa)	25582	25646	24079	26338	36760	27570	31269	29704	24351	27851	27915	3848.74	0.14

Table A.56b: Member properties (Std.), Configuration 29.

Member Properties: Configuration 29

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.49	15.42	14.69	13.64	14.77	13.48	15.64	14.96	14.01	14.95	14.61	0.71	0.05
S.G.	0.43	0.44	0.43	0.41	0.57	0.49	0.51	0.55	0.50	0.45	0.48	0.06	0.12
D.E. 5% Offset Yield (psi)	3809.90	3688.22	3667.52	3621.74	4791.76	4204.59	4106.36	4070.29	3623.24	3903.73	3948.74	364.68	0.09
D.E. Capacity (psi)	3867.15	3729.80	3717.32	3621.74	4791.76	4204.59	4106.36	4080.71	3678.75	4072.77	3987.09	350.72	0.09
Side Member													
M.C. (%)	14.21	15.42	13.29	14.09	15.01	15.45	14.52	14.48	13.97	13.90	14.43	0.69	0.05
S.G.	0.46	0.45	0.43	0.43	0.54	0.50	0.54	0.50	0.50	0.48	0.48	0.04	0.08
D.E. 5% Offset Yield (psi)	3631.19	3704.95	3480.69	3810.52	5331.61	3980.26	4535.18	4308.25	3473.34	4039.47	4029.55	572.89	0.14
D.E. Capacity (psi)	3710.31	3719.63	3492.27	3820.02	5331.61	3998.65	4535.18	4308.25	3531.80	4039.47	4048.72	558.21	0.14

Table A.57a: Hysteretic connection properties (SI), Configuration 29.

Hysteretic Connection Properties: Configuration 29

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.20	1.01	0.84	0.19	0.09	0.49	-1.24	0.96	0.77	-0.21	0.10	0.45
Primary2	1.78	1.47	0.82	0.36	0.16	0.46	-1.40	1.01	0.72	-0.44	0.13	0.30
Primary3	8.07	7.59	0.94	1.34	0.43	0.32	-3.09	2.17	0.70	-1.47	0.53	0.36
Primary4	15.76	11.12	0.71	2.18	0.48	0.22	-7.42	4.09	0.55	-2.25	0.61	0.27
Primary5	27.92	19.12	0.68	3.14	0.70	0.22	-16.50	8.42	0.51	-3.04	0.93	0.31
Primary6	55.61	25.32	0.46	5.13	0.85	0.17	-39.09	8.03	0.21	-4.62	1.07	0.23
Primary7	79.07	30.26	0.38	7.27	1.20	0.17	-59.07	9.37	0.16	-6.27	1.22	0.19
Primary8	102.01	34.90	0.34	10.25	1.34	0.13	-79.08	11.90	0.15	-8.82	1.58	0.18
Primary9	107.84	37.22	0.35	13.28	1.54	0.12	-78.74	26.67	0.34	-12.46	2.97	0.24
Primary10	93.51	31.09	0.33	17.30	2.82	0.16	-54.57	38.95	0.71	-13.32	7.89	0.59
Primary11	72.87	31.99	0.44	22.73	2.37	0.10	-27.79	30.10	1.08	-14.09	5.43	0.39

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.48	0.22	0.45	0.23	0.13	0.57	0.37	0.13	0.35	9435.08	10615.65	1.13
Primary2	1.04	0.68	0.66	0.61	0.41	0.67	0.27	0.05	0.17	5603.19	6247.58	1.12
Primary3	7.16	5.03	0.70	8.43	7.49	0.89	0.15	0.05	0.35	4277.79	2280.91	0.53
Primary4	15.62	9.08	0.58	26.75	15.25	0.57	0.11	0.09	0.78	5127.72	1161.44	0.23
Primary5	34.04	31.73	0.93	75.69	65.03	0.86	0.09	0.07	0.77	6836.11	1648.43	0.24
Primary6	108.33	44.61	0.41	241.36	104.86	0.43	0.07	0.02	0.22	9590.58	1226.94	0.13
Primary7	220.27	98.46	0.45	483.99	183.83	0.38	0.07	0.01	0.16	10209.90	926.91	0.09
Primary8	508.67	168.68	0.33	878.48	212.97	0.24	0.09	0.02	0.21	9577.06	1264.93	0.13
Primary9	895.59	321.19	0.36	1176.02	209.43	0.18	0.12	0.05	0.38	7423.16	1756.03	0.24
Primary10	877.69	407.18	0.46	1109.03	369.40	0.33	0.13	0.05	0.37	5643.23	2386.59	0.42
Primary11	768.18	320.66	0.42	1061.10	693.63	0.65	0.13	0.04	0.28	2659.42	1380.87	0.52

Table A.57b: Hysteretic connection properties (Std.), Configuration 29.

Hysteretic Connection Properties: Configuration 29

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	270.50	228.01	0.84	0.01	0.00	0.49	-279.33	216.12	0.77	-0.01	0.00	0.45
Primary2	401.04	329.64	0.82	0.01	0.01	0.46	-314.32	226.58	0.72	-0.02	0.01	0.30
Primary3	1813.17	1706.67	0.94	0.05	0.02	0.32	-694.45	487.86	0.70	-0.06	0.02	0.36
Primary4	3542.86	2498.98	0.71	0.09	0.02	0.22	-1668.46	919.08	0.55	-0.09	0.02	0.27
Primary5	6277.58	4299.46	0.68	0.12	0.03	0.22	-3709.95	1892.11	0.51	-0.12	0.04	0.31
Primary6	12502.40	5691.74	0.46	0.20	0.03	0.17	-8788.40	1804.36	0.21	-0.18	0.04	0.23
Primary7	17776.12	6803.12	0.38	0.29	0.05	0.17	-13278.45	2106.04	0.16	-0.25	0.05	0.19
Primary8	22932.51	7846.13	0.34	0.40	0.05	0.13	-17777.11	2675.34	0.15	-0.35	0.06	0.18
Primary9	24243.85	8366.73	0.35	0.52	0.06	0.12	-17701.54	5996.27	0.34	-0.49	0.12	0.24
Primary10	21022.14	6988.41	0.33	0.68	0.11	0.16	-12268.48	8755.82	0.71	-0.52	0.31	0.59
Primary11	16382.80	7190.75	0.44	0.90	0.09	0.10	-6247.68	6766.76	1.08	-0.55	0.21	0.39

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	4.28	1.91	0.45	2.00	1.15	0.57	0.37	0.13	0.35	53875.67	60616.90	1.13
Primary2	9.21	6.03	0.66	5.43	3.63	0.67	0.28	0.05	0.17	31995.05	35674.58	1.12
Primary3	63.35	44.54	0.70	74.58	66.29	0.89	0.16	0.05	0.33	24426.78	13024.35	0.53
Primary4	138.28	80.39	0.58	236.80	135.00	0.57	0.12	0.09	0.75	29280.05	6631.98	0.23
Primary5	301.24	280.82	0.93	669.91	575.60	0.86	0.09	0.07	0.74	39035.18	9412.76	0.24
Primary6	958.83	394.82	0.41	2136.24	928.08	0.43	0.07	0.02	0.22	54763.60	7006.00	0.13
Primary7	1949.58	871.45	0.45	4283.67	1627.06	0.38	0.07	0.01	0.16	58300.04	5292.79	0.09
Primary8	4502.07	1492.99	0.33	7775.18	1884.97	0.24	0.09	0.02	0.21	54686.41	7222.94	0.13
Primary9	7926.66	2842.77	0.36	10408.62	1853.65	0.18	0.12	0.05	0.38	42387.32	10027.16	0.24
Primary10	7768.21	3603.83	0.46	9815.76	3269.48	0.33	0.13	0.05	0.37	32223.68	13627.77	0.42
Primary11	6798.93	2838.08	0.42	9391.53	6139.19	0.65	0.13	0.04	0.28	15185.66	7884.97	0.52

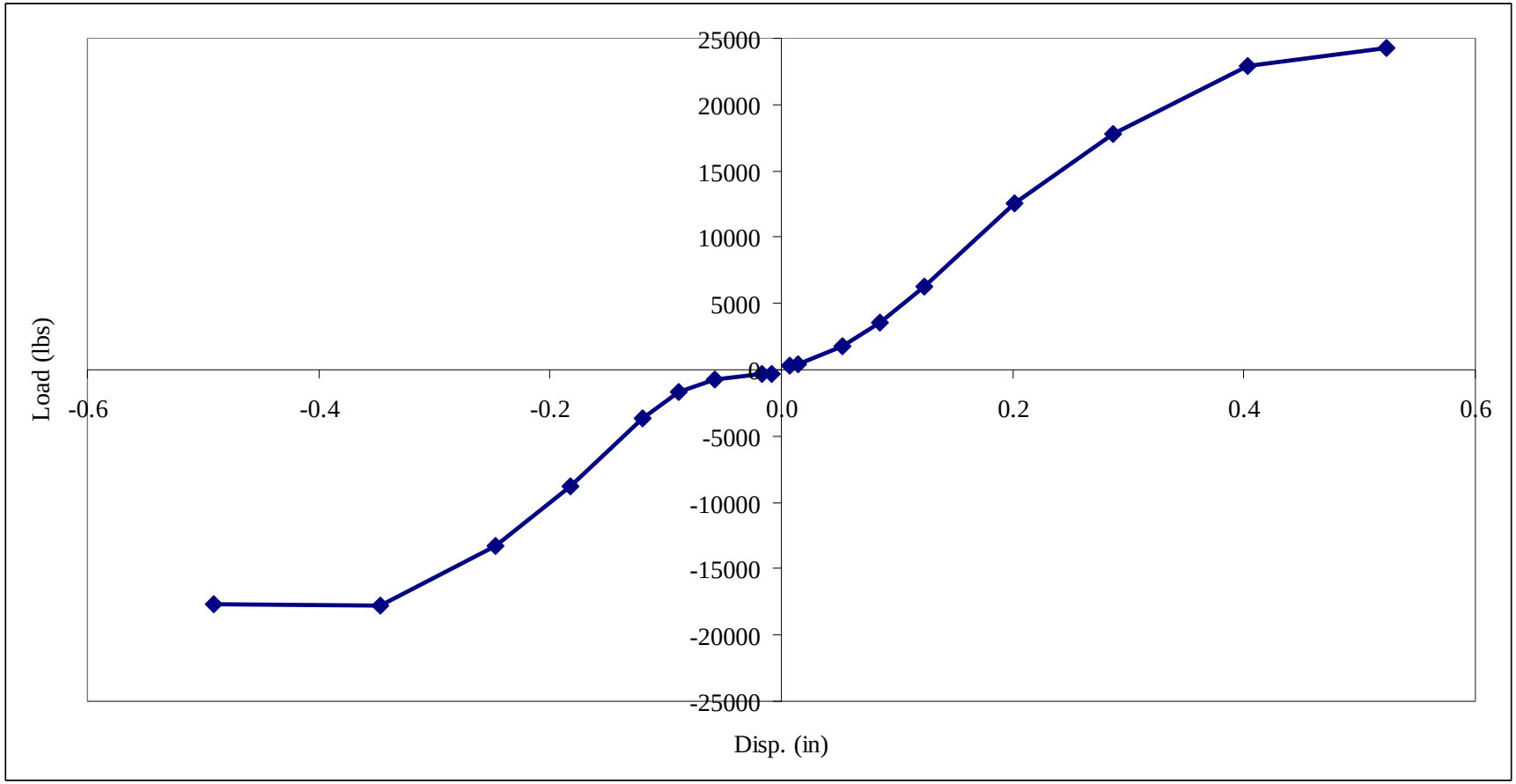

Figure A.198: Mean envelope curve: Configuration 29.

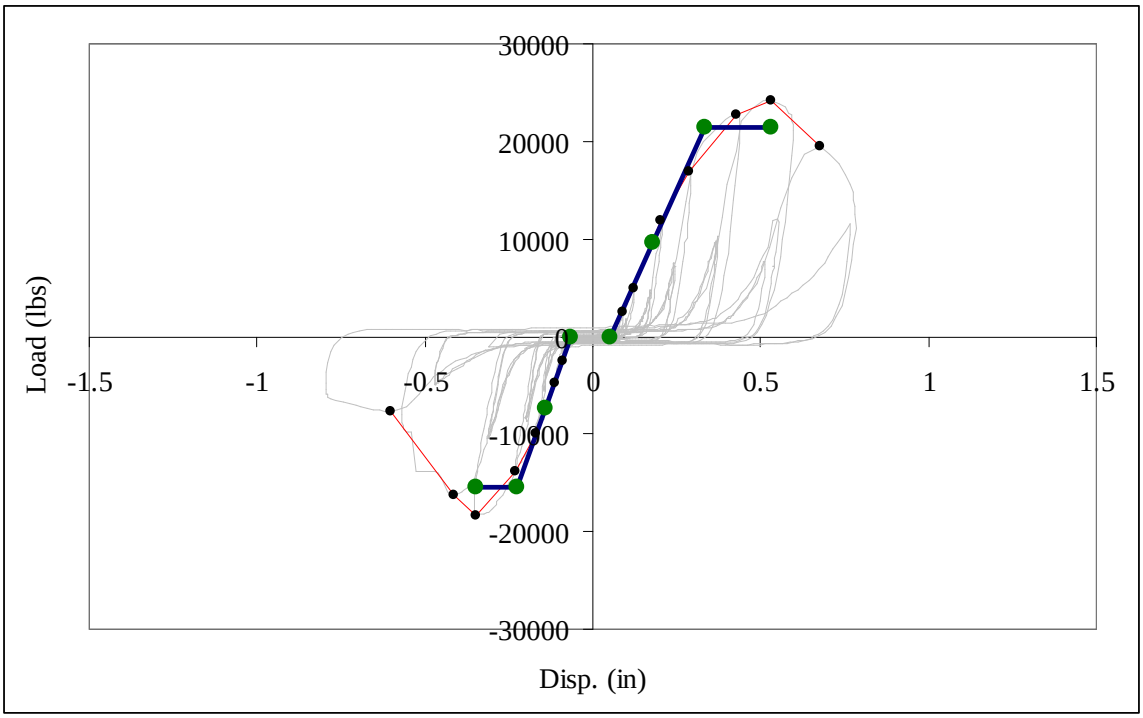

Figure A.199: Load-Deflection plot: C29-1.

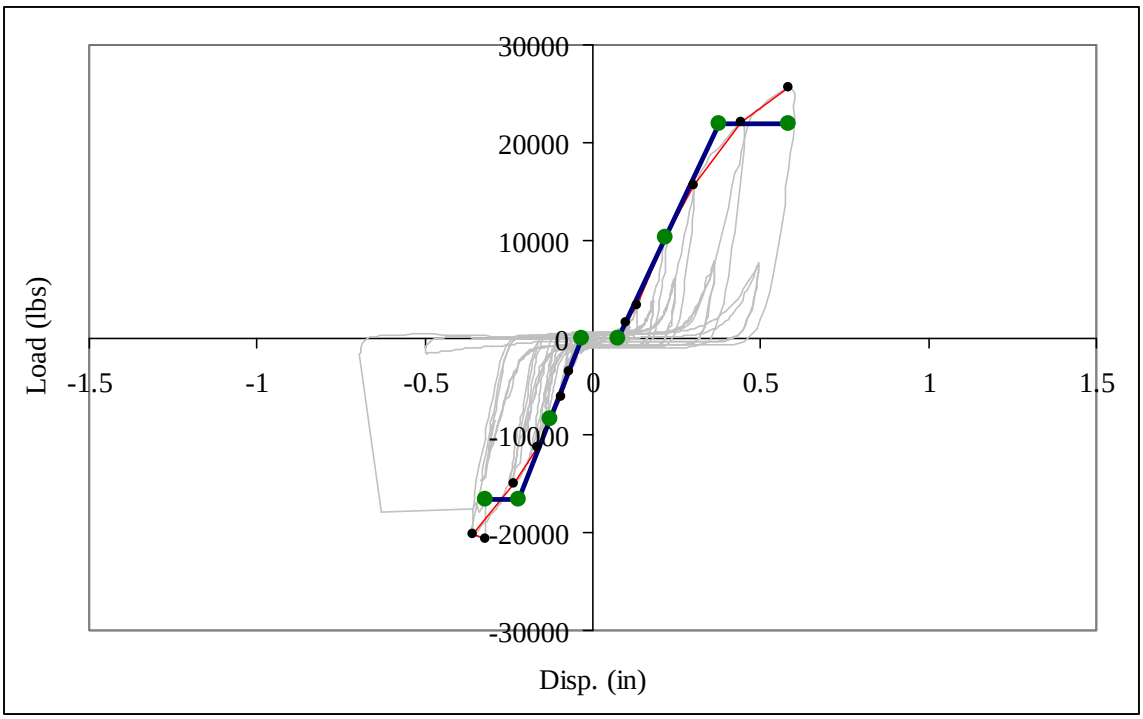

Figure A.200: Load-Deflection plot: C29-2.

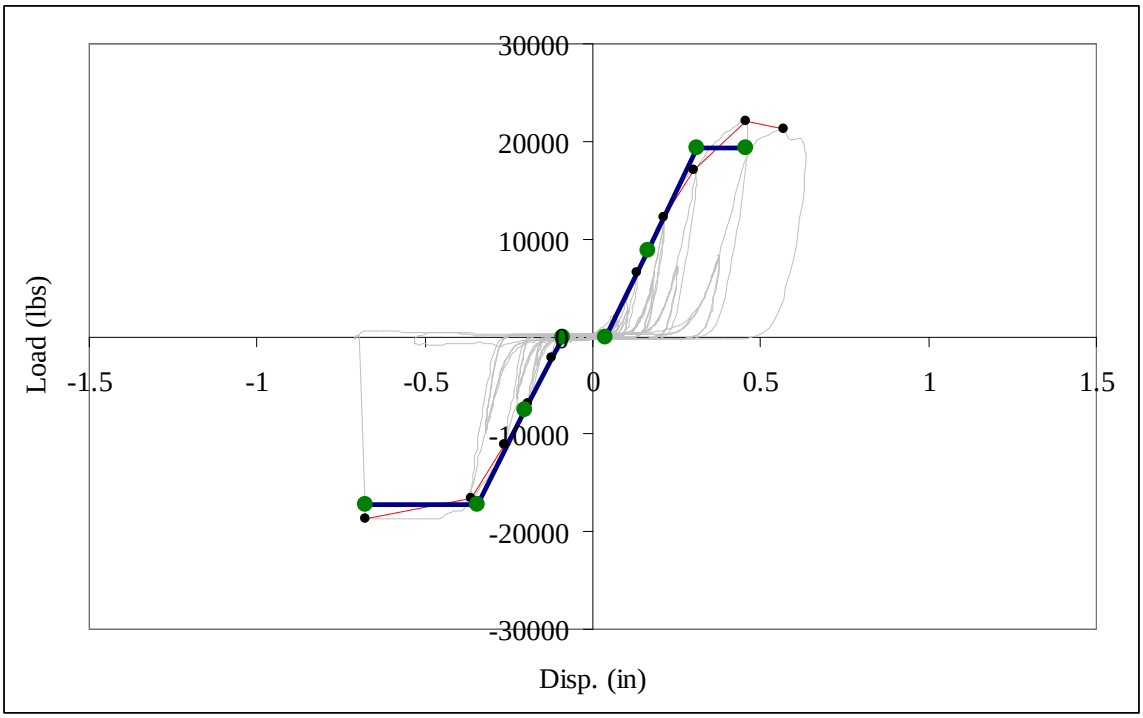

Figure A.201: Load-Deflection plot: C29-3.

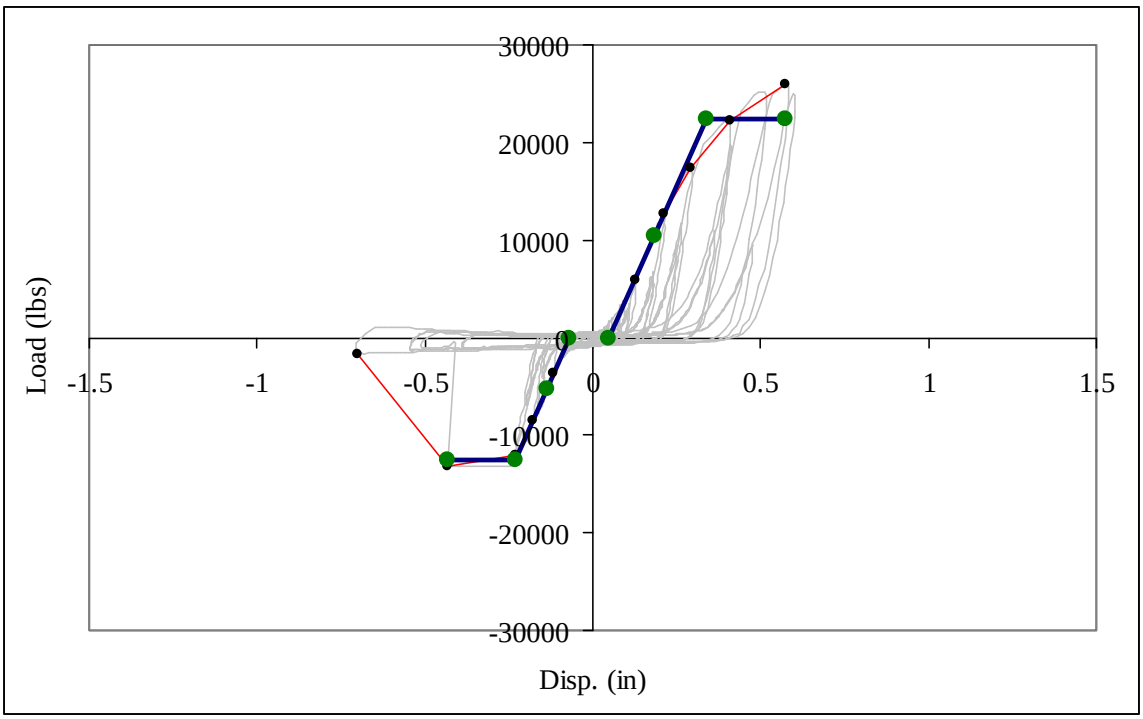

Figure A.202: Load-Deflection plot: C29-4.

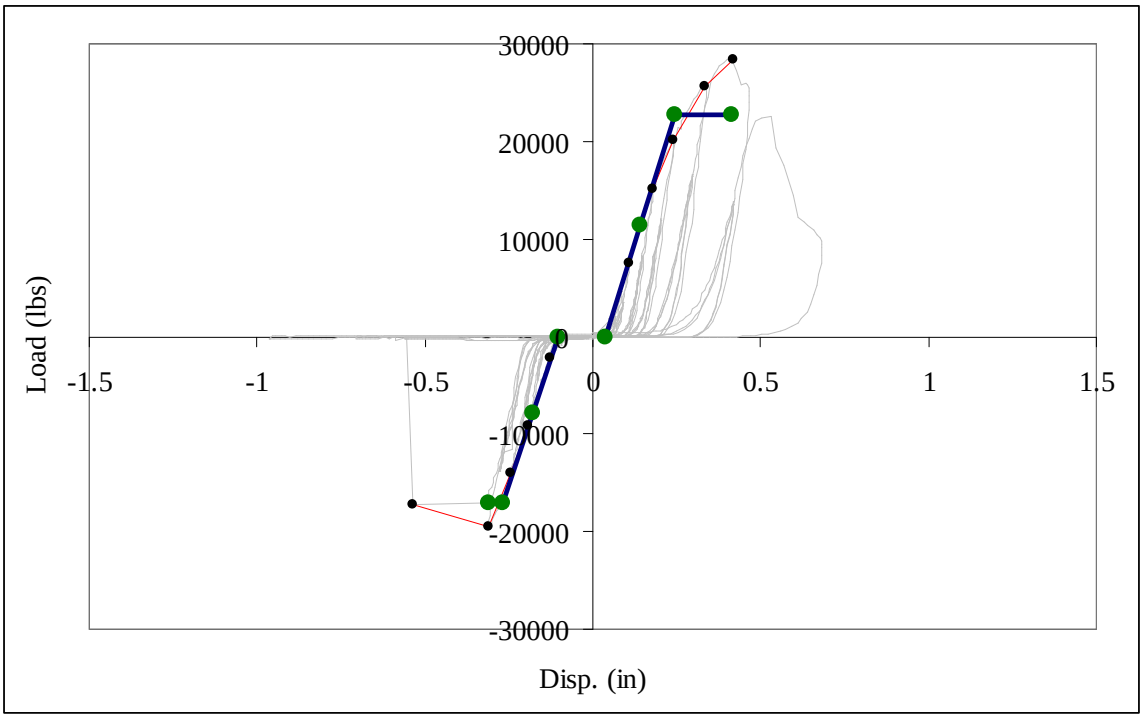

Figure A.203: Load-Deflection plot: C29-5.

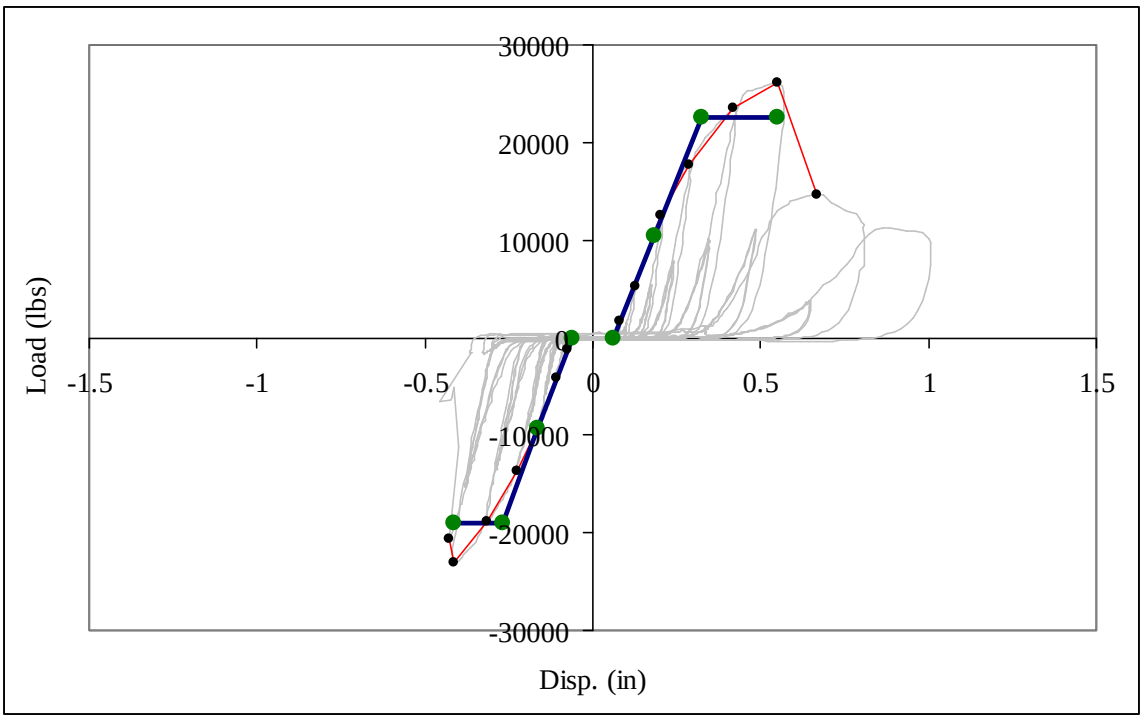

Figure A.204: Load-Deflection plot: C29-6.

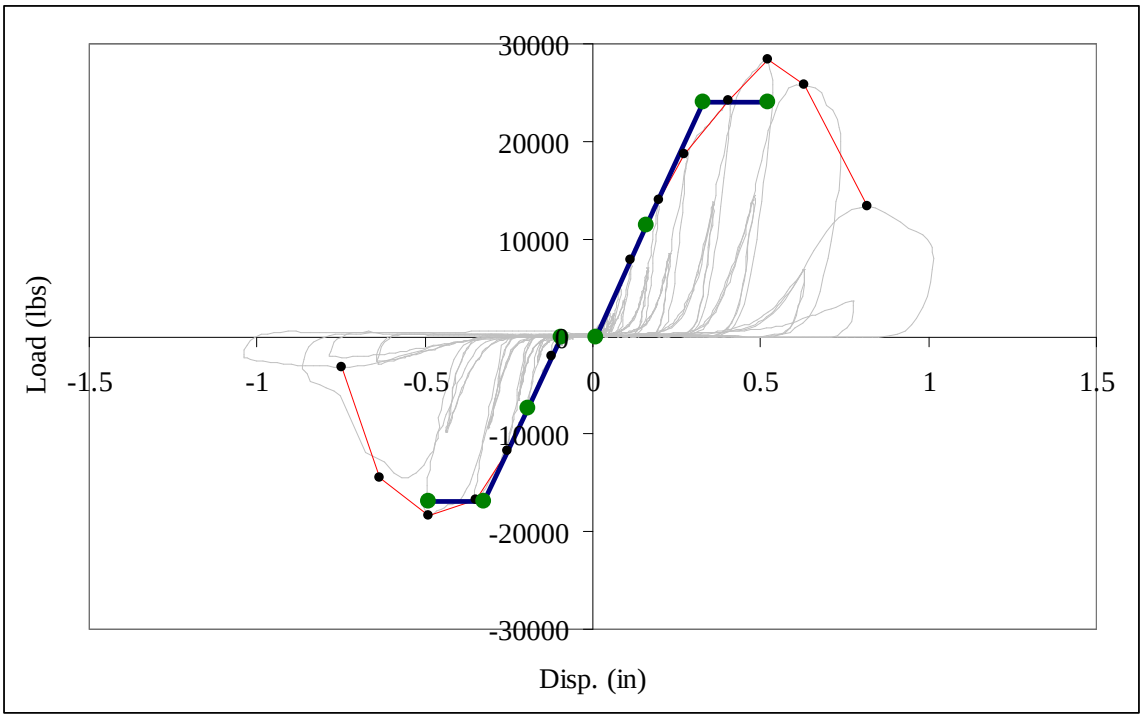

Figure A.205: Load-Deflection plot: C29-7.

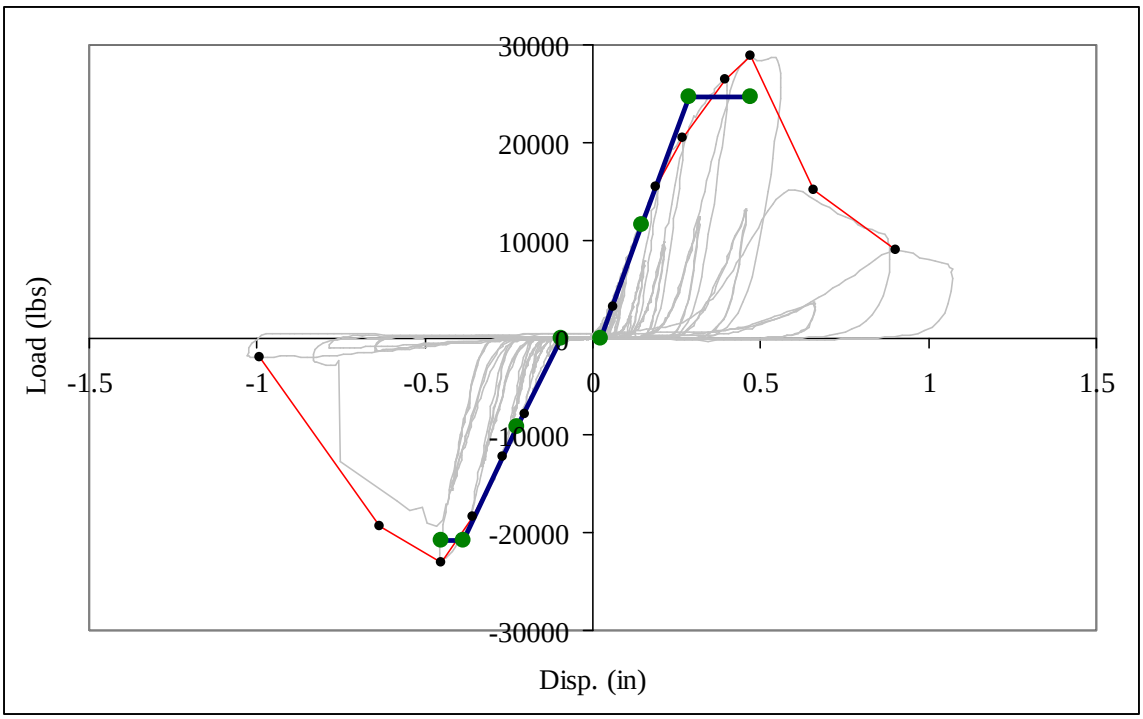

Figure A.206: Load-Deflection plot: C29-8.

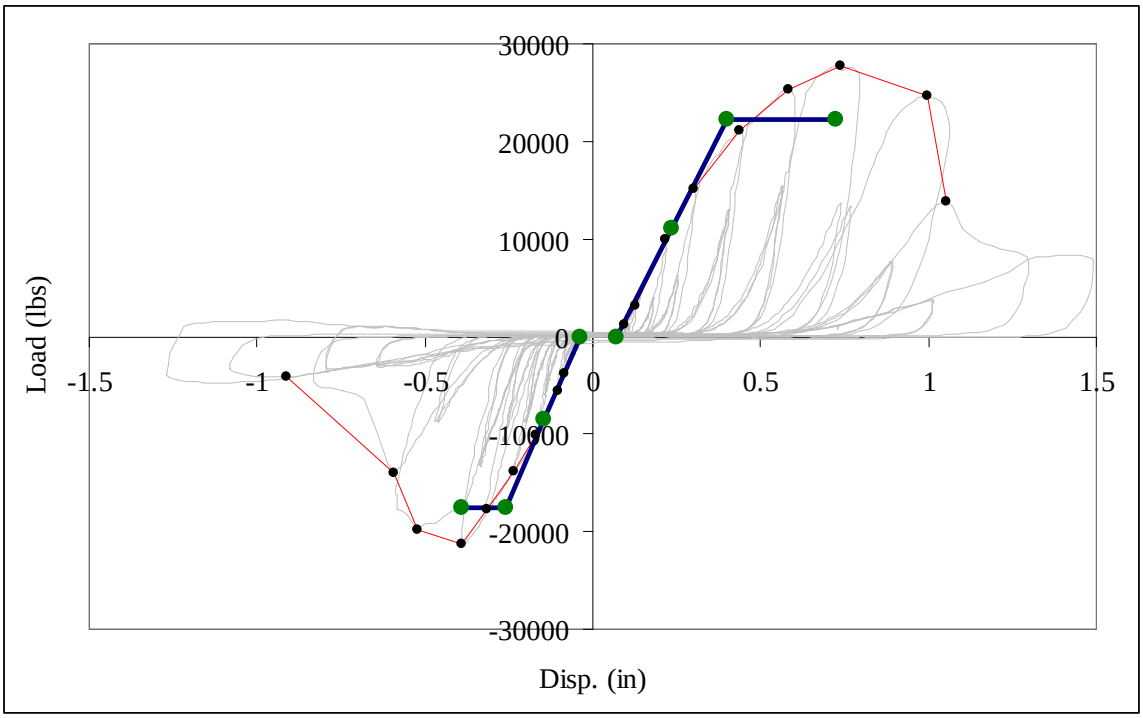

Figure A.207: Load-Deflection plot: C29-9.

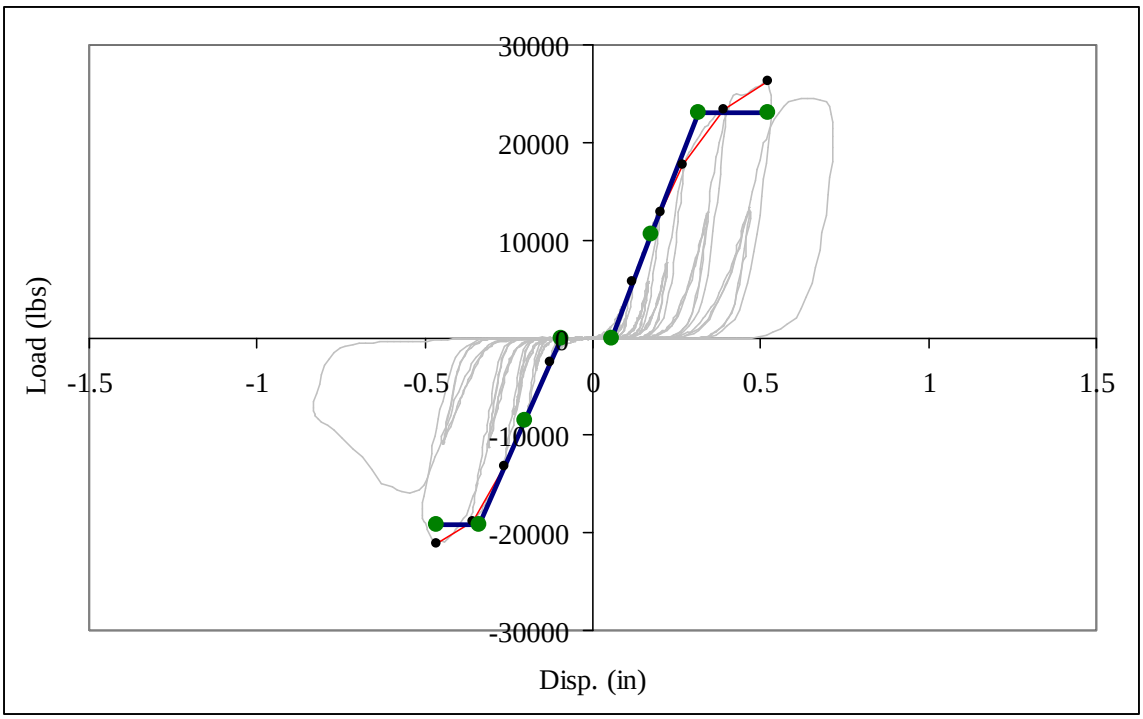

Figure A.208: Load-Deflection plot: C29-10.

Table A.58a: Connection performance properties (SI), Configuration 30.

Connection Performance Properties: Configuration 30

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (kN)	101.67	79.62	102.48	108.74	91.42	105.42	102.21	107.48	102.28	115.52	101.68	9.90	0.10
@Displacement (mm)	17.67	14.53	25.41	18.77	19.32	20.79	12.00	11.44	13.41	13.79	16.71	4.45	0.27
Failure Load (kN)	81.34	63.70	81.98	86.99	73.13	84.33	81.77	85.99	81.83	92.42	81.35	7.92	0.10
@Displacement (mm)	17.67	14.53	25.41	18.77	19.32	20.79	12.00	11.44	13.41	13.79	16.71	4.45	0.27
40% Max (kN)	40.67	31.85	40.99	43.50	36.57	42.17	40.88	42.99	40.91	46.21	40.67	3.96	0.10
@Displacement (mm)	6.84	5.43	7.25	7.35	5.88	6.90	5.44	5.28	5.57	5.81	6.17	0.82	0.13
Yield (kN)	93.68	65.50	86.42	99.97	76.82	84.40	108.94	83.99	89.17	104.21	89.31	13.01	0.15
@Displacement (mm)	13.04	9.54	13.77	11.94	10.88	12.57	13.83	7.21	9.78	11.11	11.37	2.10	0.19
5% Offset Yield (kN)	91.15	55.95	54.75	90.07	53.70	57.83	96.65	77.24	87.60	104.08	76.90	19.58	0.25
@Displacement (mm)	13.76	9.29	10.19	15.31	8.99	9.96	11.32	10.64	10.69	12.13	11.23	2.00	0.18
Elastic Stiff. (N/mm)	8495.47	8232.12	6974.12	7613.17	7988.86	7460.60	10718.34	12518.74	11393.98	10983.58	9237.90	1963.50	0.21
E.E.P. Energy (N*m)	968.11	590.35	1544.08	1141.58	1036.84	1172.23	637.53	494.96	694.76	795.00	907.54	325.25	0.36
Ductility Ratio	1.38	1.52	1.85	1.50	1.77	1.66	1.05	1.40	1.39	1.27	1.48	0.24	0.16
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Ten. Rup.	N.A.	Ten Rup	N.A.	Splitting	Splitting			
Governing Member	Both	Side	Side	Side	Main	N.A.	Main	N.A.	Both	Both			

Table A.58b: Connection performance properties (Std.), Configuration 30.

Connection Performance Properties: Configuration 30

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
Max Load (lbs)	22856.80	17899.81	23037.44	24445.28	20551.03	23698.59	22977.95	24163.02	22993.84	25970.87	22859.46	2225.85	0.10
@ Displacement (in)	0.70	0.57	1.00	0.74	0.76	0.82	0.47	0.45	0.53	0.54	0.66	0.18	0.27
Failure Load (lbs)	18285.44	14319.85	18429.95	19556.23	16440.83	18958.87	18382.36	19330.41	18395.07	20776.70	18287.57	1780.68	0.10
@ Displacement (in)	0.70	0.57	1.00	0.74	0.76	0.82	0.47	0.45	0.53	0.54	0.66	0.18	0.27
40% Max (lbs)	9142.72	7159.92	9214.98	9778.11	8220.41	9479.43	9191.18	9665.21	9197.53	10388.35	9143.78	890.34	0.10
@ Displacement (in)	0.27	0.21	0.29	0.29	0.23	0.27	0.21	0.21	0.22	0.23	0.24	0.03	0.13
Yield (lbs)	21059.13	14724.87	19428.61	22474.16	17270.58	18974.15	24491.62	18882.80	20045.71	23426.41	20077.80	2925.05	0.15
@ Displacement (in)	0.51	0.38	0.54	0.47	0.43	0.50	0.54	0.28	0.39	0.44	0.45	0.08	0.19
5% Offset Yield (lbs)	20491.65	12578.11	12307.62	20248.51	12071.14	13000.05	21727.58	17363.82	19692.43	23398.74	17287.97	4402.72	0.25
@ Displacement (in)	0.54	0.37	0.40	0.60	0.35	0.39	0.45	0.42	0.42	0.48	0.44	0.08	0.18
Elastic Stiff. (lb/in)	48510.38	47006.62	39823.23	43472.33	45617.56	42601.12	61203.29	71483.85	65061.31	62717.86	52749.75	11211.85	0.21
E.E.P. Energy (lb*in)	8568.47	5225.06	13666.24	10103.82	9176.84	10375.13	5642.61	4380.80	6149.11	7036.32	8032.44	2878.69	0.36
Ductility Ratio	1.38	1.52	1.85	1.50	1.77	1.66	1.05	1.40	1.39	1.27	1.48	0.24	0.16
Yield Mode	II	II	II	II	II	II	II	II	II	II			
Failure Mode	Splitting	Balk. Shr.	Splitting	Balk. Shr.	Ten. Rup.	N.A.	Ten Rup	N.A.	Splitting	Splitting			
Governing Member	Both	Side	Side	Side	Main	N.A.	Main	N.A.	Both	Both			

Table A.59a: Member properties (SI), Configuration 30.

Member Properties: Configuration 30

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.49	14.84	14.50	13.70	15.37	13.14	14.30	13.68	13.61	14.50	14.21	0.67	0.05
S.G.	0.50	0.58	0.48	0.46	0.50	0.46	0.56	0.56	0.48	0.57	0.52	0.05	0.09
D.E. 5% Offset Yield (kPa)	29645	32827	26791	27842	31180	25618	37824	36508	32178	34418	31483	4075.65	0.13
D.E. Capacity (kPa)	30634	34004	28387	29338	31180	25880	38072	36801	32432	36286	32301	3968.22	0.12
Side Member													
M.C. (%)	14.27	15.82	14.53	13.72	15.30	13.39	14.53	12.72	12.91	14.70	14.19	1.00	0.07
S.G.	0.51	0.51	0.49	0.49	0.49	0.52	0.53	0.61	0.50	0.58	0.52	0.04	0.08
D.E. 5% Offset Yield (kPa)	32125	29489	31123	26288	30373	31580	35499	38887	34731	36561	32666	3742.43	0.11
D.E. Capacity (kPa)	33397	31005	32956	27907	32262	34392	38223	39827	36003	39542	34551	3861.30	0.11

Table A.59b: Member properties (Std.), Configuration 30.

Member Properties: Configuration 30

Main Member	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Mean	Standard Deviation	COV
M.C. (%)	14.49	14.84	14.50	13.70	15.37	13.14	14.30	13.68	13.61	14.50	14.21	0.67	0.05
S.G.	0.50	0.58	0.48	0.46	0.50	0.46	0.56	0.56	0.48	0.57	0.52	0.05	0.09
D.E. 5% Offset Yield (psi)	4299.55	4761.14	3885.68	4038.17	4522.18	3715.58	5485.84	5295.05	4666.92	4991.84	4566.20	591.12	0.13
D.E. Capacity (psi)	4443.08	4931.78	4117.15	4255.03	4522.18	3753.52	5521.84	5337.47	4703.81	5262.85	4684.87	575.54	0.12
Side Member													
M.C. (%)	14.27	15.82	14.53	13.72	15.30	13.39	14.53	12.72	12.91	14.70	14.19	1.00	0.07
S.G.	0.51	0.51	0.49	0.49	0.49	0.52	0.53	0.61	0.50	0.58	0.52	0.04	0.08
D.E. 5% Offset Yield (psi)	4659.28	4276.99	4513.97	3812.68	4405.26	4580.31	5148.69	5640.09	5037.29	5302.69	4737.73	542.79	0.11
D.E. Capacity (psi)	4843.76	4496.92	4779.86	4047.61	4679.13	4988.10	5543.71	5776.41	5221.75	5735.02	5011.23	560.03	0.11

Table A.60a: Hysteretic connection properties (SI), Configuration 30.

Hysteretic Connection Properties: Configuration 30

	Pull Stroke						Push Stroke					
	Max Load (kN)			Displacement (mm)			Max Load (kN)			Displacement (mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	1.65	1.37	0.83	0.22	0.10	0.48	-1.06	0.64	0.60	-0.19	0.09	0.48
Primary2	2.71	2.41	0.89	0.46	0.11	0.24	-1.63	1.17	0.72	-0.44	0.11	0.25
Primary3	7.28	5.71	0.78	1.39	0.14	0.10	-4.33	3.70	0.85	-1.35	0.22	0.16
Primary4	12.95	8.87	0.69	2.30	0.22	0.10	-8.02	6.28	0.78	-2.35	0.29	0.12
Primary5	19.40	11.15	0.58	3.29	0.38	0.12	-13.19	7.89	0.60	-3.29	0.52	0.16
Primary6	39.64	15.63	0.39	5.44	0.80	0.15	-30.24	9.42	0.31	-5.50	0.93	0.17
Primary7	56.01	19.87	0.35	7.36	1.38	0.19	-43.83	10.12	0.23	-7.43	1.43	0.19
Primary8	78.77	26.88	0.34	10.47	2.34	0.22	-63.00	11.03	0.18	-10.51	2.36	0.22
Primary9	96.10	32.78	0.34	13.69	3.10	0.23	-80.54	12.10	0.15	-13.48	3.16	0.23
Primary10	110.57	44.14	0.40	16.99	3.83	0.23	-89.29	9.19	0.10	-16.76	3.23	0.19
Primary11	99.61	18.66	0.19	18.86	3.92	0.21	-89.48	12.86	0.14	-19.04	3.58	0.19

	Hysteretic Energy (N*m)			Strain Energy (N*m)			E.V.D.			Cyclic Stiffness (N/mm)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	0.40	0.23	0.58	0.25	0.16	0.65	0.27	0.11	0.42	7979.55	6076.49	0.76
Primary2	1.09	0.57	0.52	0.97	0.64	0.66	0.20	0.04	0.20	5124.94	3461.78	0.68
Primary3	5.78	2.12	0.37	7.98	2.72	0.34	0.12	0.02	0.18	4331.36	1777.50	0.41
Primary4	13.31	3.07	0.23	23.38	4.15	0.18	0.09	0.01	0.15	4585.99	1187.78	0.26
Primary5	21.71	3.10	0.14	50.58	6.07	0.12	0.07	0.01	0.14	4960.60	593.45	0.12
Primary6	81.57	32.78	0.40	186.72	32.57	0.17	0.07	0.02	0.27	6434.10	869.74	0.14
Primary7	158.79	83.80	0.53	365.58	76.50	0.21	0.07	0.02	0.34	6889.41	1255.74	0.18
Primary8	368.19	194.97	0.53	740.06	177.65	0.24	0.07	0.02	0.31	7029.18	1632.21	0.23
Primary9	586.96	462.83	0.79	1192.05	271.31	0.23	0.07	0.05	0.71	6818.32	1766.77	0.26
Primary10	932.54	444.46	0.48	1679.61	333.15	0.20	0.09	0.03	0.35	6153.45	1475.13	0.24
Primary11	1063.09	355.42	0.33	1813.06	525.55	0.29	0.10	0.04	0.39	5064.55	798.06	0.16

Table A.60b: Hysteretic connection properties (Std.), Configuration 30.

Hysteretic Connection Properties: Configuration 30

	Pull Stroke						Push Stroke					
	Max Load (pounds)			Displacement (inches)			Max Load (pounds)			Displacement (inches)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	369.90	308.59	0.83	0.01	0.00	0.48	-239.00	142.86	0.60	-0.01	0.00	0.48
Primary2	609.12	540.72	0.89	0.02	0.00	0.24	-366.70	262.99	0.72	-0.02	0.00	0.25
Primary3	1636.69	1283.47	0.78	0.05	0.01	0.10	-973.54	831.86	0.85	-0.05	0.01	0.16
Primary4	2910.54	1995.13	0.69	0.09	0.01	0.10	-1804.00	1411.67	0.78	-0.09	0.01	0.12
Primary5	4360.71	2507.68	0.58	0.13	0.01	0.12	-2965.70	1773.90	0.60	-0.13	0.02	0.16
Primary6	8911.13	3514.33	0.39	0.21	0.03	0.15	-6797.42	2117.39	0.31	-0.22	0.04	0.17
Primary7	12590.73	4466.74	0.35	0.29	0.05	0.19	-9854.13	2274.54	0.23	-0.29	0.06	0.19
Primary8	17707.17	6041.94	0.34	0.41	0.09	0.22	-14162.66	2479.94	0.18	-0.41	0.09	0.22
Primary9	21604.46	7369.55	0.34	0.54	0.12	0.23	-18106.72	2719.87	0.15	-0.53	0.12	0.23
Primary10	24857.79	9923.91	0.40	0.67	0.15	0.23	-20072.40	2065.37	0.10	-0.66	0.13	0.19
Primary11	22393.13	4194.88	0.19	0.74	0.15	0.21	-20115.57	2891.14	0.14	-0.75	0.14	0.19

	Hysteretic Energy (lb*in)			Strain Energy (lb*in)			E.V.D.			Cyclic Stiffness (lb/in)		
Cycle I.D.	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV	Mean	StDev	COV
Primary1	3.55	2.06	0.58	2.25	1.46	0.65	0.28	0.12	0.44	45564.41	34697.63	0.76
Primary2	9.67	5.02	0.52	8.59	5.69	0.66	0.22	0.07	0.32	29264.19	19767.27	0.68
Primary3	51.16	18.80	0.37	70.60	24.08	0.34	0.13	0.03	0.26	24732.70	10149.77	0.41
Primary4	117.77	27.14	0.23	206.89	36.71	0.18	0.10	0.02	0.23	26186.69	6782.38	0.26
Primary5	192.14	27.40	0.14	447.70	53.71	0.12	0.08	0.02	0.27	28325.75	3388.67	0.12
Primary6	721.98	290.16	0.40	1652.59	288.29	0.17	0.08	0.02	0.30	36739.67	4966.35	0.14
Primary7	1405.37	741.72	0.53	3235.62	677.08	0.21	0.07	0.02	0.29	39339.56	7170.48	0.18
Primary8	3258.78	1725.64	0.53	6550.08	1572.36	0.24	0.08	0.02	0.25	40137.62	9320.16	0.23
Primary9	5195.05	4096.39	0.79	10550.57	2401.26	0.23	0.08	0.04	0.58	38933.61	10088.50	0.26
Primary10	8253.69	3933.78	0.48	14865.76	2948.62	0.20	0.09	0.03	0.31	35137.12	8423.23	0.24
Primary11	9409.13	3145.77	0.33	16046.95	4651.52	0.29	0.10	0.04	0.37	28919.30	4557.03	0.16

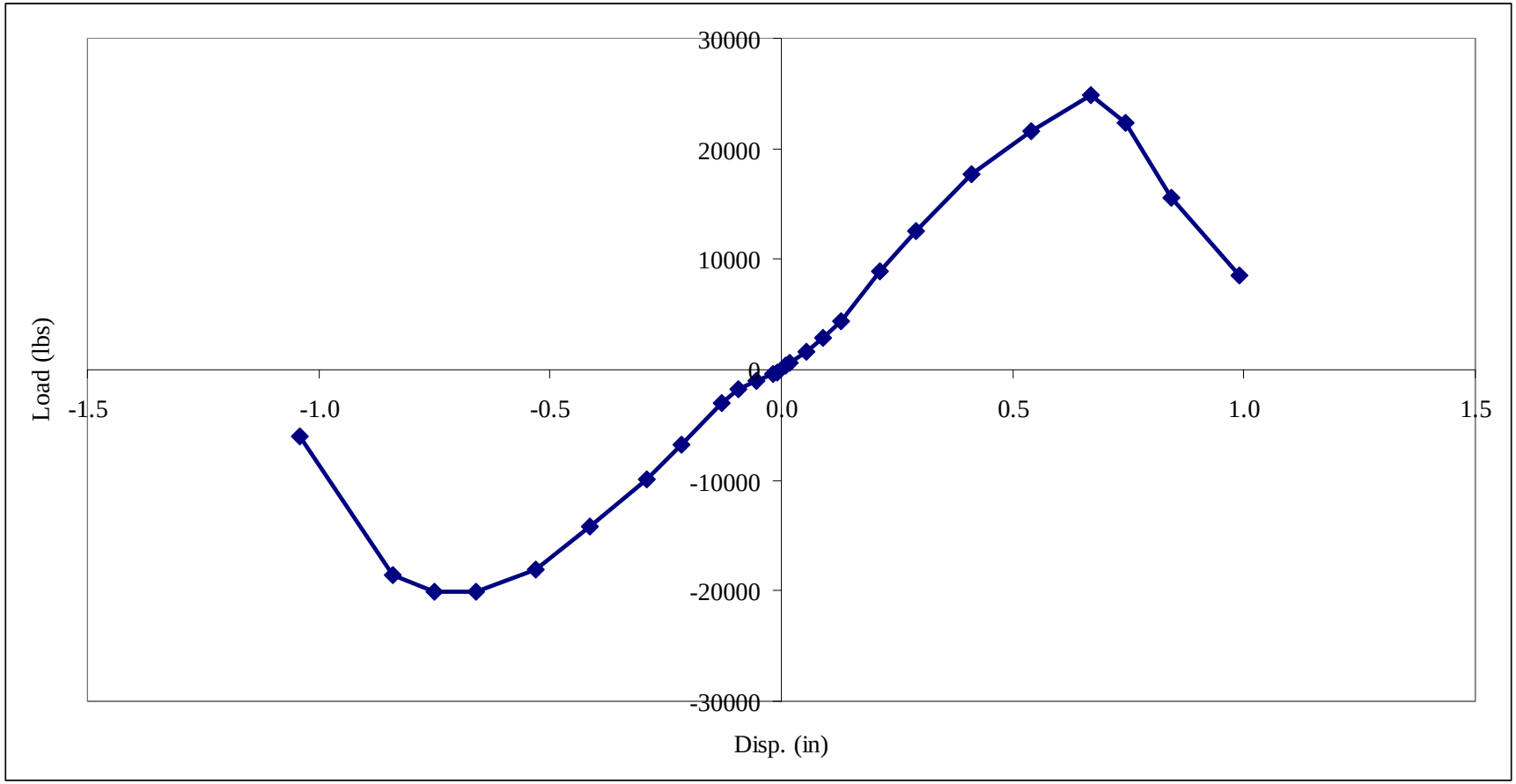

Figure A.209: Mean envelope curve: Configuration 30.

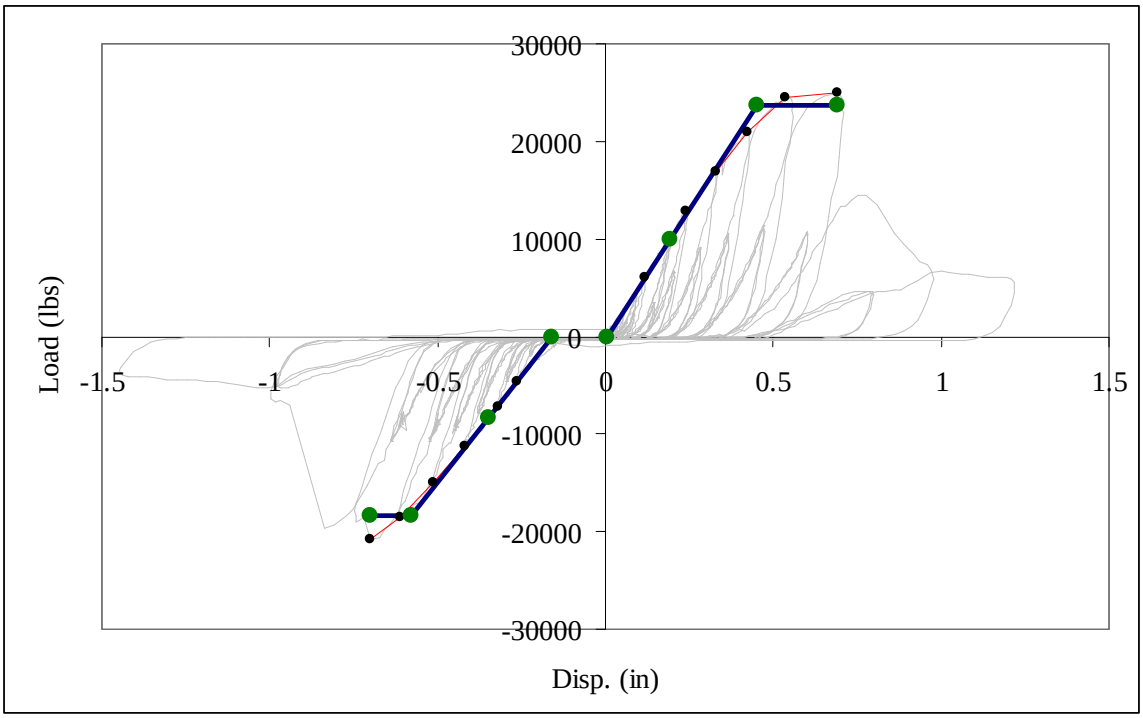

Figure A.210: Load-Deflection plot: C30-1.

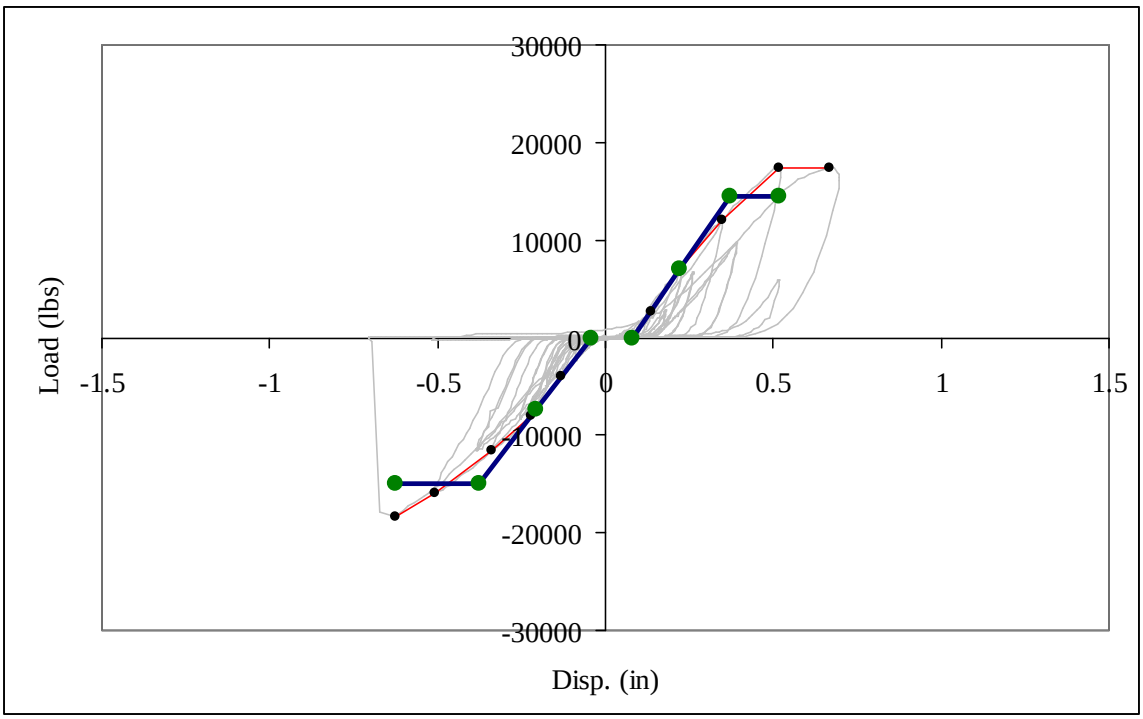

Figure A.211: Load-Deflection plot: C30-2.

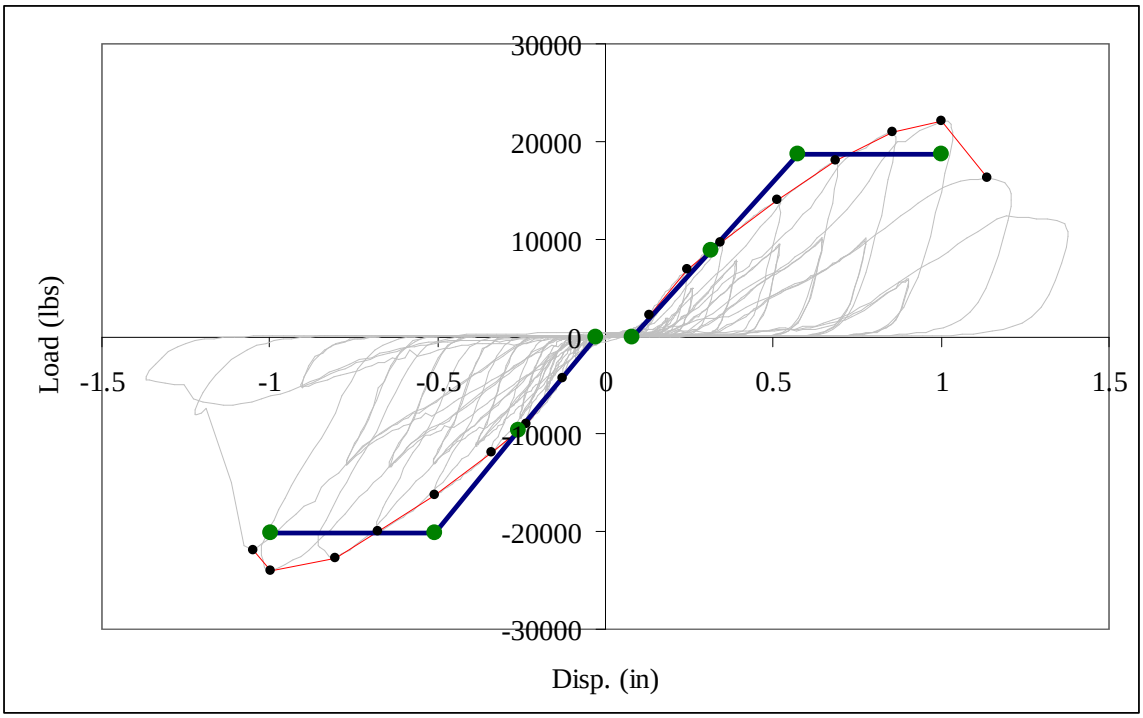

Figure A.212: Load-Deflection plot: C30-3.

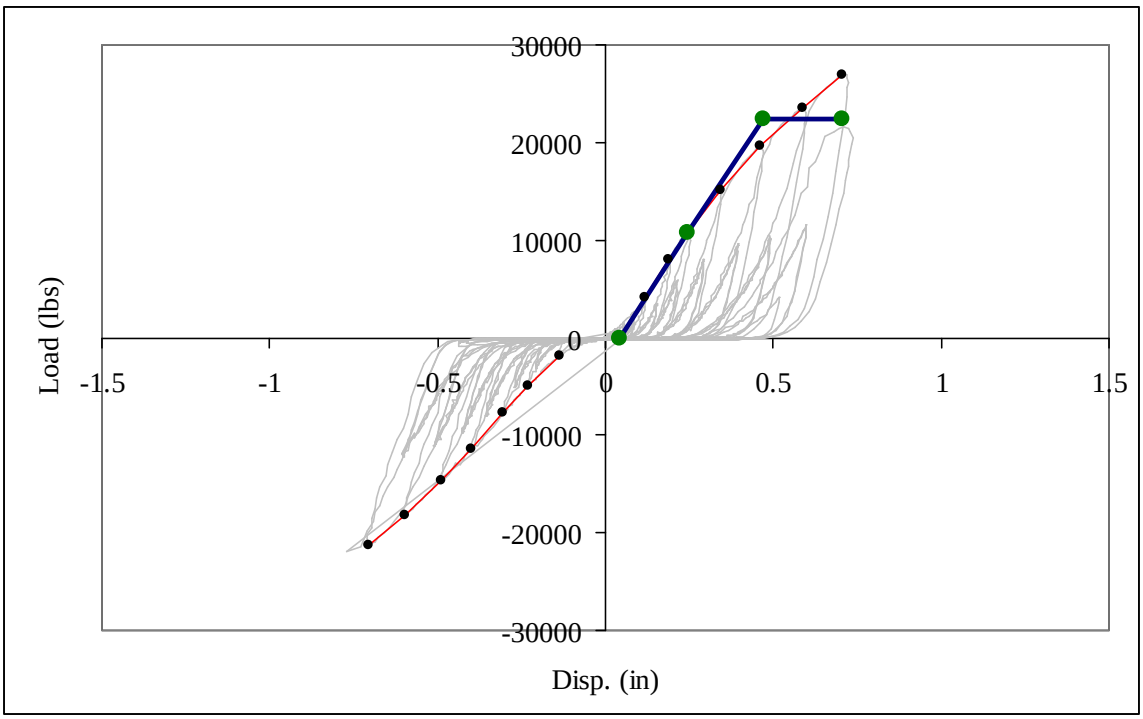

Figure A.213: Load-Deflection plot: C30-4.

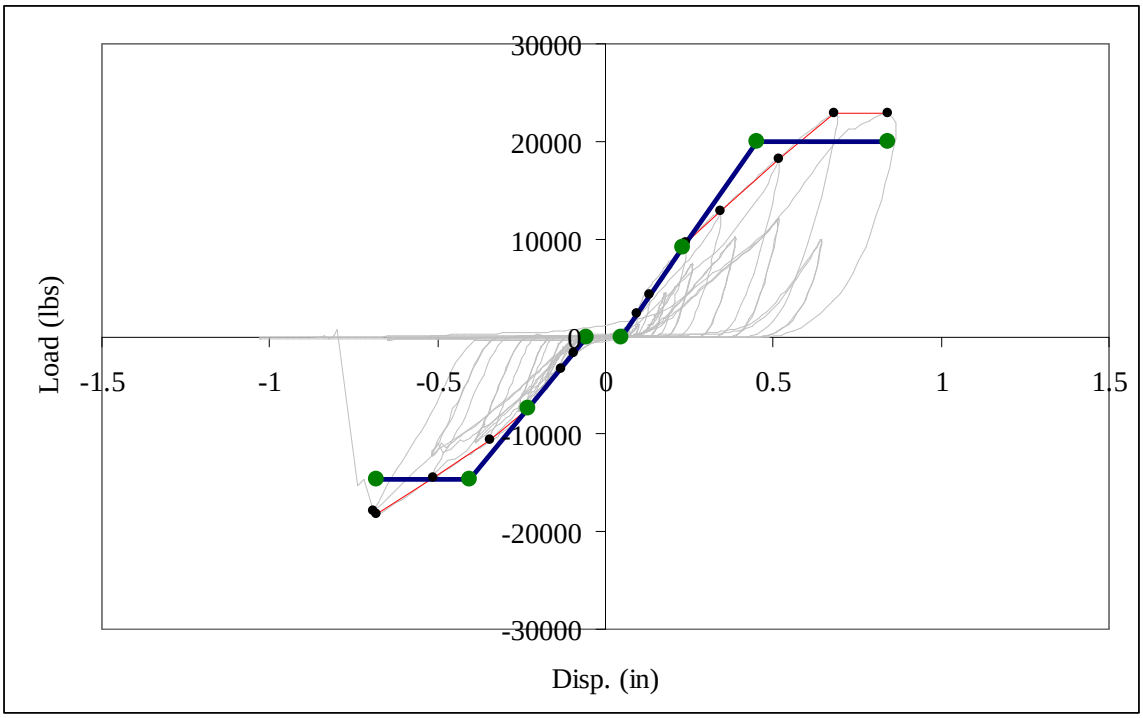

Figure A.214: Load-Deflection plot: C30-5.

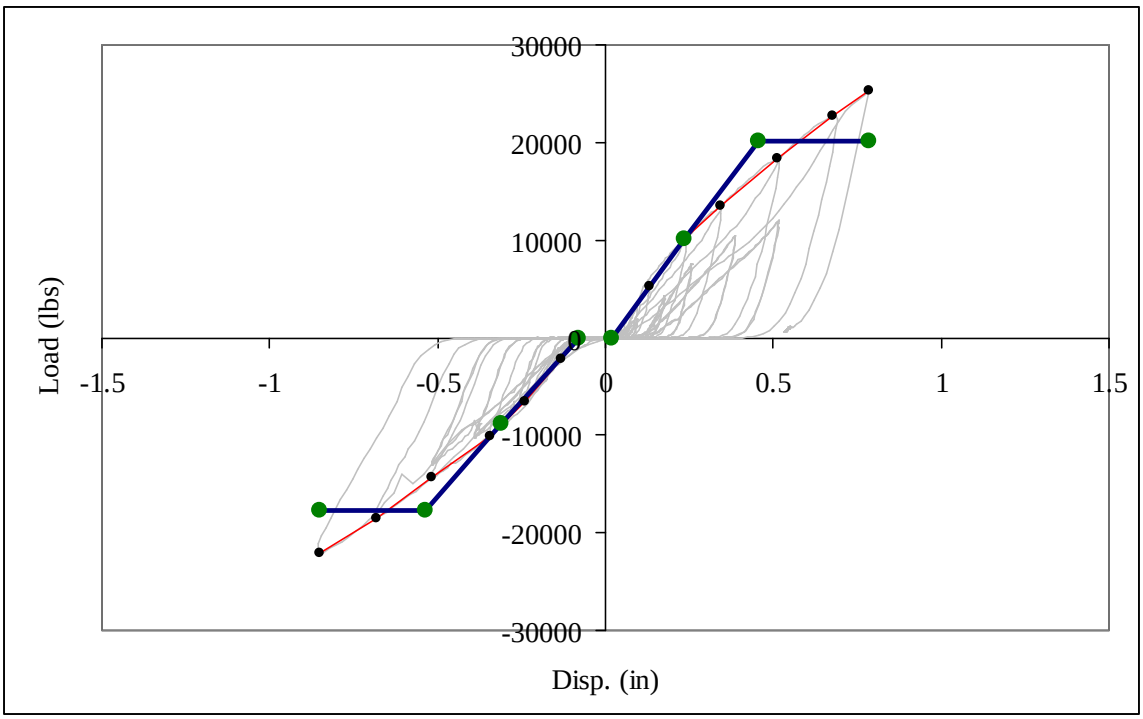

Figure A.215: Load-Deflection plot: C30-6.

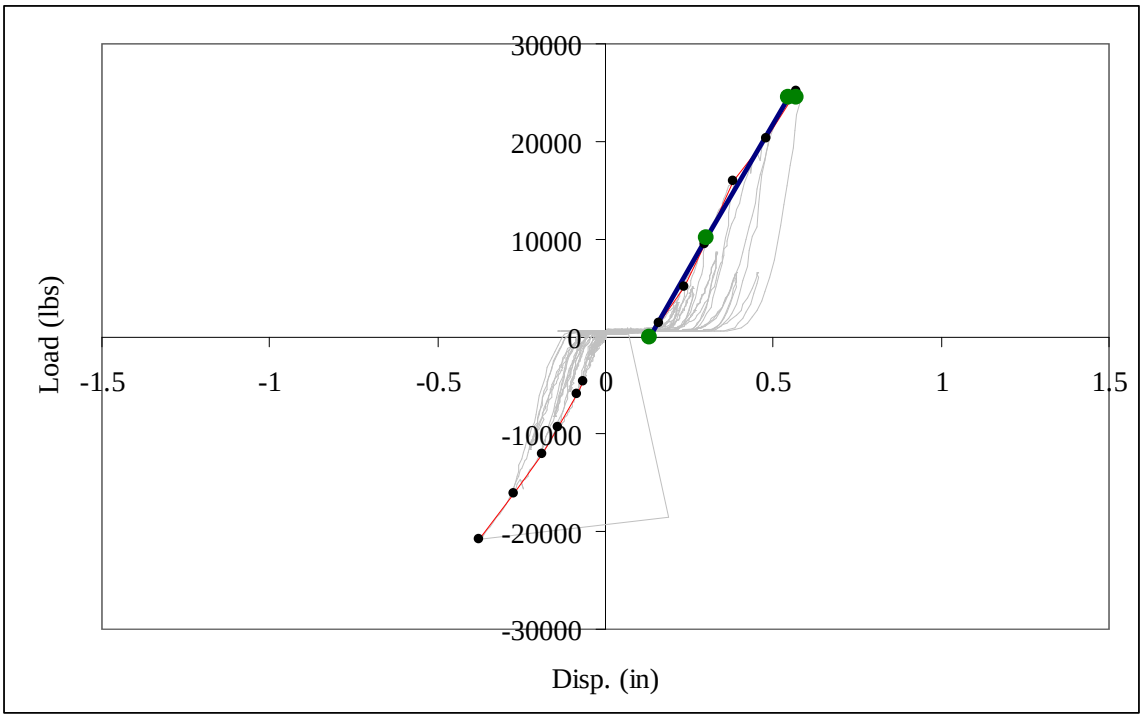

Figure A.216: Load-Deflection plot: C30-7.

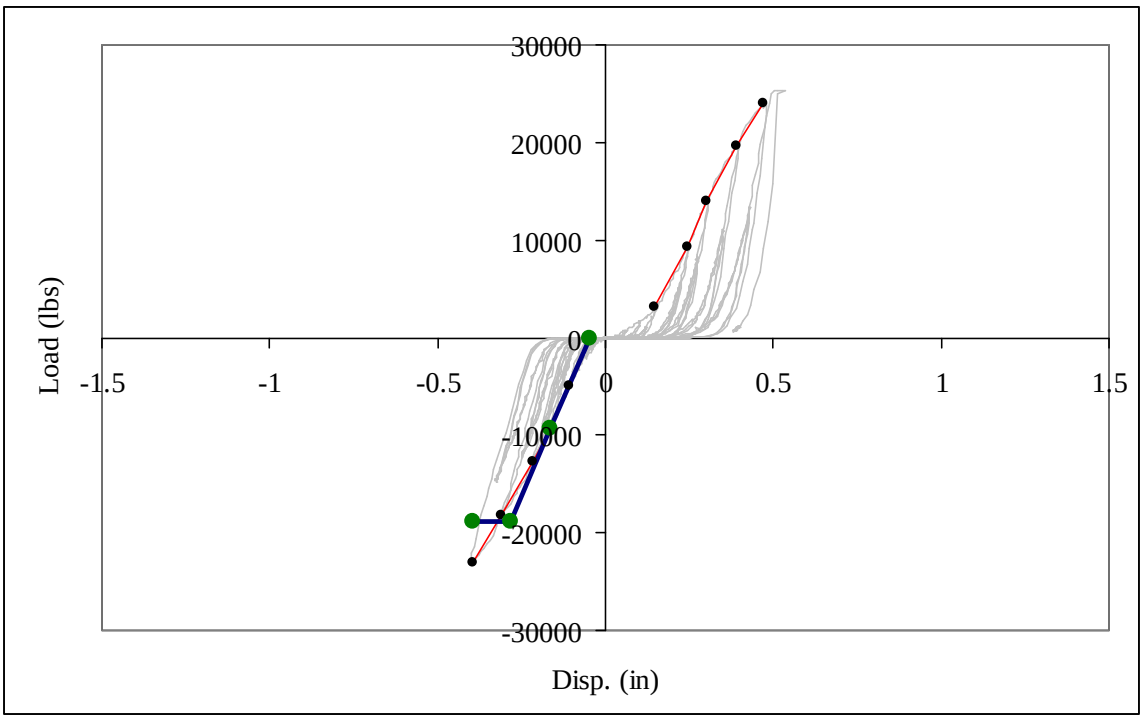

Figure A.217: Load-Deflection plot: C30-8.

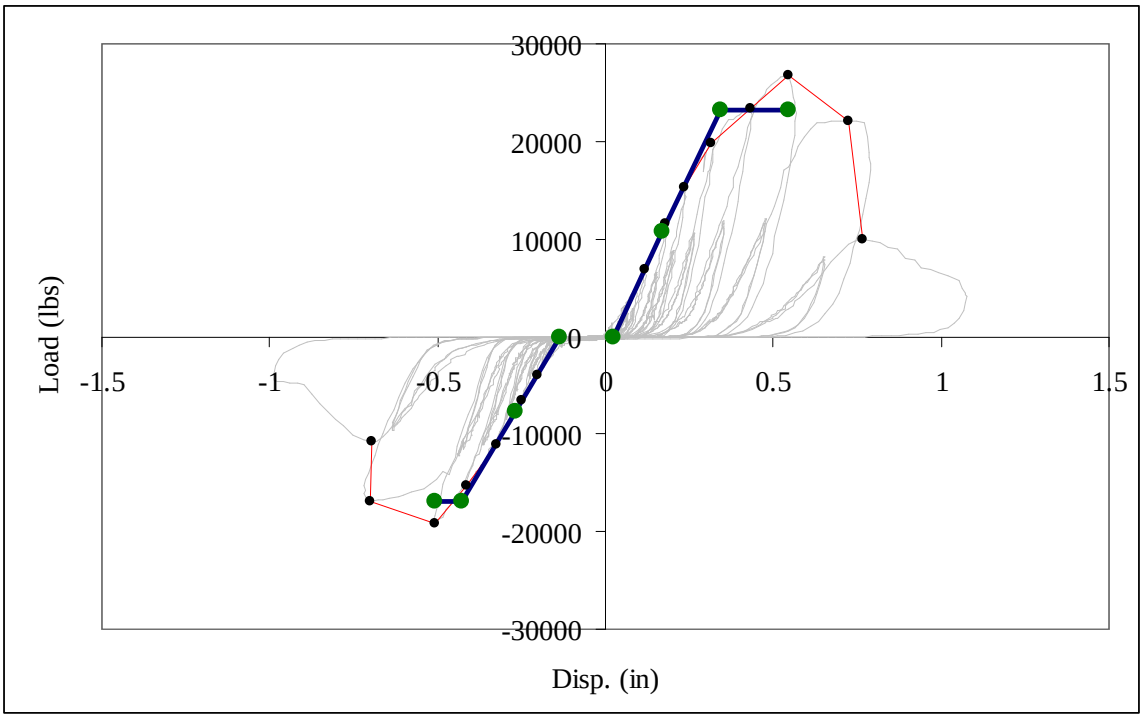

Figure A.218: Load-Deflection plot: C30-9.

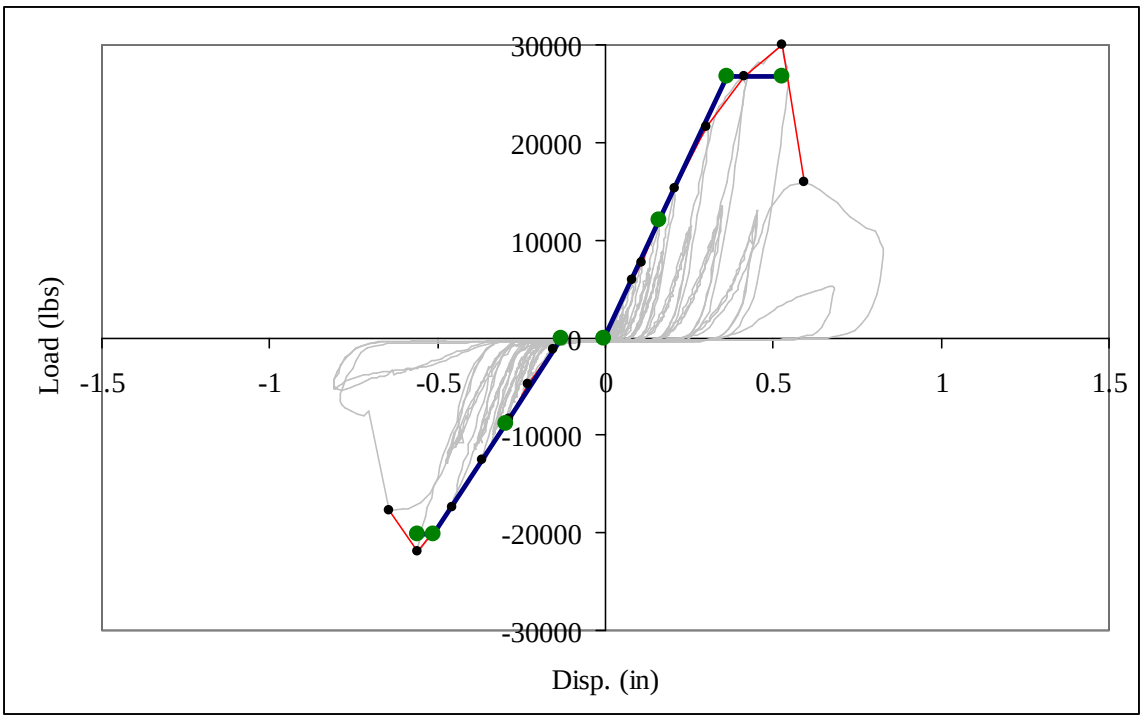

Figure A.219: Load-Deflection plot: C30-10

Vita

(December, 2006)

Caleb J. Knudson was born on August 30, 1980 in Walla Walla, Washington. He received a Bachelor of Science degree in Civil Engineering with an emphasis in structures from Washington State University in May, 2004. Caleb continued at Washington State University to pursue graduate studies in Structural Engineering. In July of 2005 Caleb began employment as a Research and Development Engineer at The Simpson Strong-Tie Co., Inc. while completing his graduate degree from Washington State University.