REINFORCER™
technologies
by Metwood

Reports

Legacy Report

ICC Evaluation Service, Inc.

In-situ Repair for Improperly cut I-Joists

Department of Wood Science and Forest Products
Virginia Polytechnic Institute and State University

LEGACY REPORT

97-73

Reissued April 1, 2005

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Legacy report on the BOCA® *National Building Code*/1999 and the 1998 *International One- and Two-Family Dwelling Code*®

DIVISION: 06—WOOD AND PLASTICS
Section: 06090—Wood and Plastic Fastenings

REPORT HOLDER:

METWOOD, INC.
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(540) 334-4294
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EVALUATION SUBJECT:

METWOOD 2×10 JOIST REINFORCER

EVALUATION SCOPE

Compliance with the following codes:

BOCA® *National Building Code*/1999

- Section 106.4 Alternative materials and equipment
- Section 2305.3 Cutting and notching
- Section 2305.3.1 Solid lumber joists

1998 *International One- and Two-Family Dwelling Code*®

- Section 108.1 Alternative materials, methods, and equipment
- Section 502.6 Drilling and notching
- Section 502.6.1 Sawn lumber

DESCRIPTION

The Metwood 2×10 Joist Reinforcer is a steel plate bracket with fasteners that allows for holes larger than those allowed by the applicable code to be used on nominal 2×10 solid sawn No. 2 Southern pine lumber joists. The Metwood 2×10 Joist Reinforcer is fabricated from 18 gauge steel with a yield strength (Fy) of 50 ksi conforming ASTM A 446, to allow for a 6-inch-diameter (51 mm) hole located in the center of the joist depth. See Figure 1 of this report for a diagram of, and installation requirements for, the Metwood 2×10 Joist Reinforcer.

CONDITIONS OF USE

This report is limited to the applications and products as stated in this report. The ICC-ES Subcommittee on National Codes intends that the report be used by the code official to determine that the report subject complies with the code requirements specifically addressed, provided that this product is installed in accordance with the following conditions:

- The Metwood 2×10 Joist Reinforcer shall be installed in accordance with this report.
- The Metwood 2×10 Joist Reinforcer shall be limited to use with nominal 2×10 solid sawn No. 2 Southern pine lumber joists with a maximum span of 15 feet (4570 mm).
- A maximum of one Metwood 2×10 Joist Reinforcer shall be used along the span of the joist.
- Holes in the joists, other than the Metwood 2×10 Joist Reinforcer, shall be limited to a maximum size of $1^1/_2$-inch-diameter (38 mm), and shall be no closer than 20 inches (508 mm) from either outside edge of the Metwood 2×10 Joist Reinforcer.
- The application of the Metwood 2×10 Joist Reinforcer is limited to covered, dry conditions of use. Dry conditions of use are those conditions at which the moisture content for solid-sawn lumber is less than 16 percent.
- Use of the Metwood 2×10 Joist Reinforcer with preservative treated lumber is outside the scope of this report.
- The Metwood 2×10 Joist Reinforcer shall not be located closer than 12 inches (305 mm) from the closest support.
- This report is subject to periodic re-examination. For information on the current status of this report, contact the ICC-ES.

APPLICATION FOR PERMIT

To aid in the determination of compliance with this report, the following represents the minimum level of information to accompany the application for permit:

- The language "See ICC-ES Legacy Report No. 97-73" or a copy of this report;
- Construction documents indicating compliance with this report. The following items shall be clearly shown on the construction documents:
  - Location and quantity of the Metwood 2×10 Joist Reinforcer, consistent with this report.
  - Species, Grade, nominal cross-sectional size, and span of the solid sawn lumber joists used with the Metwood 2×10 Joist Reinforcer, consistent with this report.
  - Design calculations and details verifying the ability of the building structure, in which the Metwood 2×10 Joist Reinforcer is used, to carry all superimposed loads as required by Chapter 16 of the BOCA® *National Building Code*/1999. These documents shall be prepared by an individual competent and qualified in the application of the structural design principles involved. The individual shall possess the registration or license in accordance with the professional registration laws of the state in which the project is constructed.

ITEMS REQUIRING VERIFICATION

The following items are related to the use of the report subject, but are not within the scope of this evaluation. However, these items are related to the determination of code compliance:

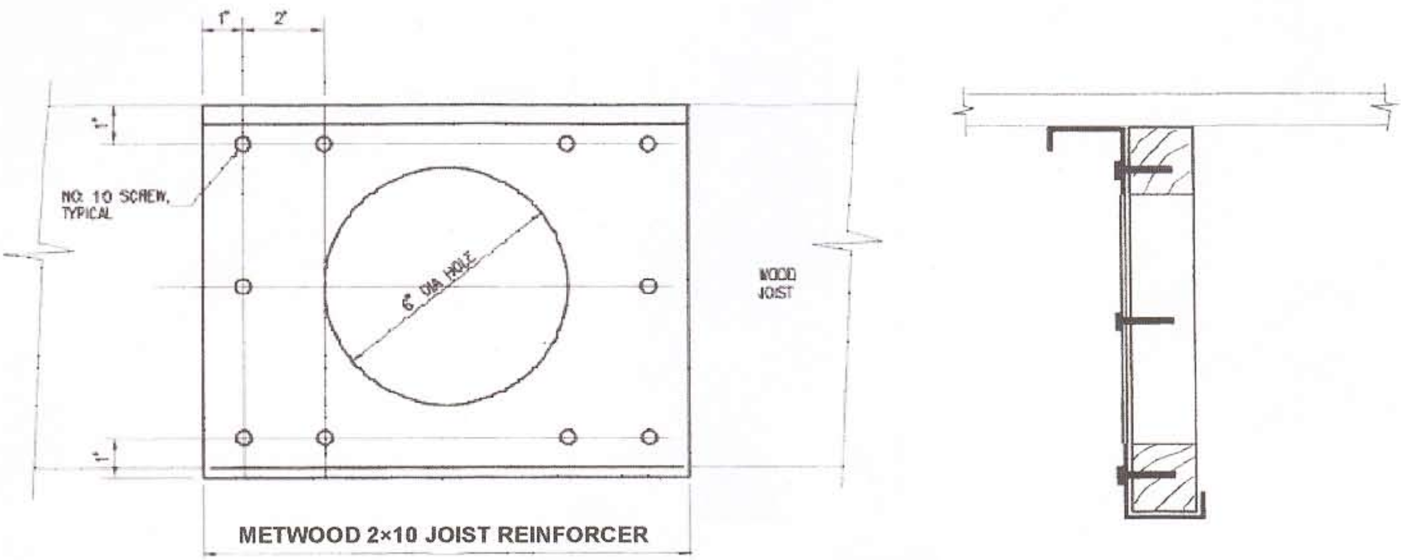
- • Details, notes and calculations for the design and construction of the building structure in which the Metwood 2×10 Joist Reinforcer is used, as required by the BOCA® *National Building Code*/1999, prepared by a qualified individual as indicated in this report.

INFORMATION SUBMITTED

- Report to Metwood Incorporated, prepared and signed by Dr. Joseph R. Loferski, dated July 20, 2000, containing physical testing and statistical analysis. The physical testing compared the maximum strengths and modulus of elasticity of nominal 2×10 solid sawn No. 2 Southern pine lumber joists, at a 15 foot span, with and without the Metwood 2×10 Joist Reinforcer installed. The joists without the Metwood 2×10 Joist Reinforcer installed were tested without holes or notches. The joists with the Metwood 2×10 Joist Reinforcer installed were tested with a 6-inch-diameter hole located at the Metwood 2×10 Joist Reinforcer in accordance with the manufacturer's instructions. Both bending and shear were investigated. The testing and analysis indicate no significant difference in maximum strength and modulus of elasticity of the joists tested.
- Standard specification for the sheet steel used for Metwood 2×10 Joist Reinforcer manufacture, by Metwood, Inc., containing minimum submittal, material and finish specifications for steel sheet to be used to manufacture the Metwood 2×10 Joist Reinforcer, consistent with this report.

PRODUCT IDENTIFICATION

- Metwood 2×10 Joist Reinforcer shall be marked at the plant with the identifying language "See ICC-ES Legacy Report No. 97-73."



ELEVATION **SECTION**

10 fasteners shall be used in the predrilled holes located as indicated above.
The fasteners shall be $1^1/_4$-inch-long (32 mm) No. 10 wood screws.

FIGURE 1*—METWOOD 2×10 JOIST REINFORCER

*THIS DRAWING IS FOR ILLUSTRATION PURPOSES ONLY. IT IS NOT INTENDED FOR USE AS A CONSTRUCTION DOCUMENT FOR THE PURPOSE OF DESIGN, FABRICATION OR ERECTION.

In-situ Repair for Improperly Cut I-joists

Final Report for Metwood, Inc.

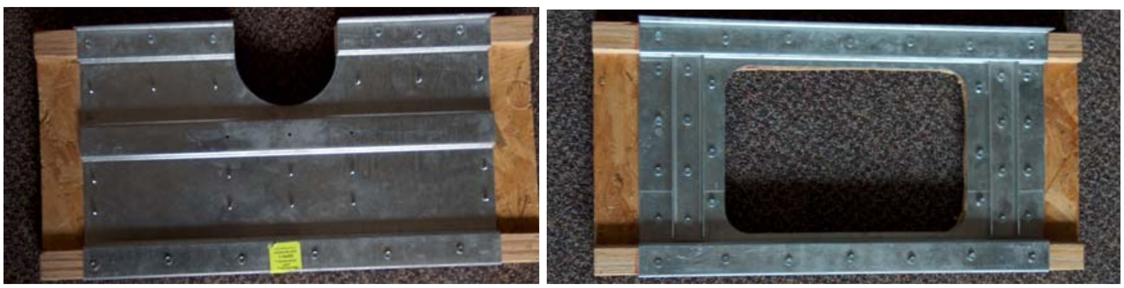
Department of Wood Science and Forest Products
Virginia Polytechnic Institute and State University

Prepared by Daniel P. Hindman and Joseph R. Loferski

May 1, 2006

Introduction and Purpose

Metwood, Inc. has invented two novel reinforcement products for in-situ repairs of improperly cut I-joists. These reinforcers are designed to increase the strength and stiffness of the improperly cut I-joists to appreciable levels. The two reinforcers address different repairs for the I-joist – one for flange repairs and one for web repairs. The "Metwood I-joist Flange Reinforcer" is a flange reinforcement that can accommodate a 5 inch diameter hole cut into the flange and part of the web with approximately 5 inches of the flange removed. The "Metwood I-joist Web Reinforcer" is a web reinforcement that can be used with a maximum hole size of 12 inches wide by 8 inches tall. For the I-joists tested, this maximum hole size of the web reinforcer leaves ½" of web connected to the top and bottom flange. Figure 1 shows the flange reinforcer (a) and web reinforcer (b).



(a) (b)

Figure 1: Metwood I-joist Reinforcers Tested, a) Metwood Ijoist Reinforcer MR100 Series, b) Metwood Web Reinforcer MR100 Series

The purpose of this testing was to determine the capacity of the I-joist Flange and I-joist Web Reinforcer products developed by Metwood, Inc. when subjected to bending loadings. All reinforcers were tested on 11-7/8" tall Boise BCI 600S I-joists. Table 1 lists the design properties of the I-joists from the Boise literature (www.bc.com/wood/ewp/east.jsp). The MR100 series Metwood I-joist Reinforcer and Metwood Web Reinforcer products were used with these I-joists.

Table 1: Mechanical Properties of 11-78" Boise BCI/60 2.0 I-joists

Property	Value
Weight	3 lbs per lineal foot
Moment	5307 ft-lbs
Bending Stiffness, EI	417 x 10^6 lb-in^2
Shear Deformation Coefficient, K	6.52 x 10^6 lbs
Maximum End Reaction on 3½" Bearing Support Without Web Stiffeners	1475 lbs

Test Methodology

Figure 2 shows the bending test configuration used for all specimens. A simply supported beam with a span of 15 feet was loaded at the third points (5 feet from each end). A series of lateral supports were positioned at approximately 32 inch intervals along the length of the beam to prevent lateral buckling of the specimen during the test.

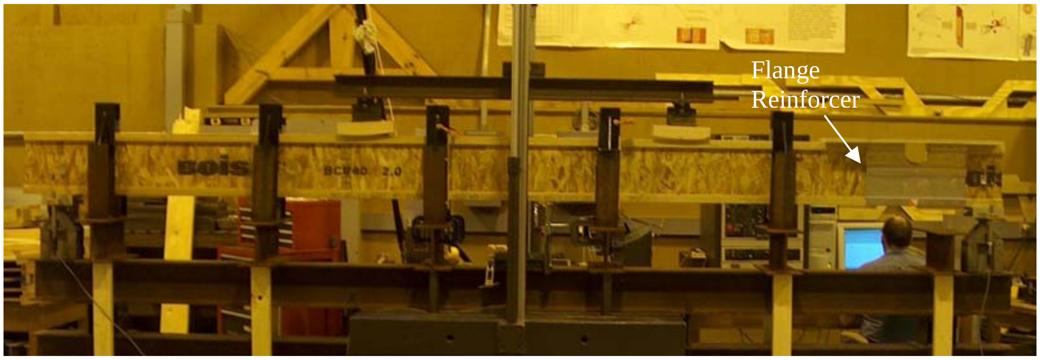


Figure 2: Simply Supported Beam with Load Applied at the Third Points, Specimen With Flange Reinforcer With Sheathing 11” From Support

An MTS universal test machine with a 50,000 lb maximum capacity was used for load application. Load was applied at 0.25 inches per minute until failure occurred. Deflection was measured by an integral LVDT in the MTS and also by an external LVDT attached to the specimen at the neutral axis at the center of the span. All data was collected and processed by HP Vee data acquisition software.

Test Plan

Table 2 shows the test plan used for this work. The variables studied included the type of reinforcement used, the location of the reinforcement, if a section of sheathing was used in the testing and if the reinforcer was glued to the I-joist. The Control group consisted of 5 uncut I-joists with no reinforcer used to provide a direct comparison for the other test results. The standard ‘Flange’ reinforcer used a U-channel reinforcement which was attached with self-tapping screws and used two reinforcers, one on either side of the I-joist. Variations of the flange reinforcer include ‘FlangeGW##’, which used two reinforcers with a welded rebar instead of the U-channel glued to the I-joist, ‘FlangeG##’ which used standard flange reinforcers glued to each side of the I-joist and single ‘FlangeSS##’, which was a single standard Flange reinforcer without glue. The standard ‘Web’ reinforcer was only applied to a single side. Variations of the web reinforcer included ‘WebG##’, which was a glued single web reinforcer and ‘WebDG##’ which was a glued double web reinforcer, one per side.

The location of the reinforcement (‘##’ portion of the sample nomenclature) was varied to study if the moment capacity of the I-joist changed as the position of the reinforcement changed. Eleven inches was the closest distance that the reinforcer could be placed to the end support. This condition represents the distance from the wall of a typical toilet drain pipe, which is one of the stated uses of the flange reinforcer. Other locations tested included 40 inches from the support, 60 inches from the support, which was directly under one of the load points, and 90 inches from the support, which was the midspan of the beam.

After some initial testing with bare I-joists (no sheathing), some of the flange reinforcers failed due to buckling of the top flange out of plane. Since the reinforcers are intended to be installed in-situ with sheathing already covering the I-joists, a 4 foot section of sheathing was centered over the reinforcer to simulate expected conditions for all other testing. A 5 inch diameter hole was also placed in the sheathing for the flange reinforcer and centered over the 5 inch hole in the reinforcer. The sheathing was attached to both the I-joist and reinforcer using a construction adhesive if noted and also self-tapping screws were placed in all pre-punched holes on the reinforcer (approximately 3 inches on center). Also note that all control samples were tested without sheathing. An ‘S; was added to the end of the sample nomenclature t indicate that sheathing was applied during testing.

Table 2: Test Plan For Evaluation of Flange and Web Reinforcers

Name	Type of Reinforcement	Location of Reinforcement (from support)	Include Sheathing?	Glue?	Number of Samples
Control	No Reinforcement	N/A	No	No	5
FlangeGW90	Flange, welded rebar	90 inches	No	Yes	5
FlangeG90	Flange	90 inches	No	Yes	5
FlangeGS90	Flange	90 inches	Yes	Yes	1
FlangeSS90	Flange on one side only	90 inches	Yes	No	1
FlangeS90	Flange	90 inches	Yes	No	4
FlangeS60	Flange	60 inches	Yes	No	4
FlangeS40	Flange	40 inches	Yes	No	5
FlangeS11	Flange	11 inches	Yes	No	2
WebG11	Web	11 inches	No	Yes	2
WebDG11	Web Reinforcer on both sides of I-joist	11 inches	No	Yes	5
Web90	Web	90 inches	No	No	2
WebS90	Web	90 inches	Yes	No	5
WebS60	Web	60 inches	Yes	No	2
WebS40	Web	40 inches	Yes	No	6
WebS11	Web	11 inches	Yes	No	3

The standard installation instructions provided by Metwood include the use of construction adhesive to attach the reinforcers to the I-joists. However, the IBC only allows for the structural attachment using adhesive if an independent certified third party inspects the joints. Since this procedure was felt to be too tedious, the majority of the reinforcers were tested without construction adhesive. This lack of adhesive should provide a worst case scenario for the reinforcers.

Criteria to compare the performance of the I-joist reinforcers need to be created. The following criteria were used, as well as analysis and description of the failures of each test group.

a) Maximum load at failure – the maximum load that the I-joist held

b) Load-deflection slope – this slope is used for stiffness comparisons due to the difficulty of determining EI for the reinforced sections

c) Load at a deflection of L/240 (or 15 ft *12 in/ft / 240 = 0.75 in) – this is the standard deflection limit criteria for dead loads used for residential applications

Results and Discussion

Table 3 shows the average and coefficient of variance (COV) results of the three criteria described above (maximum load, load-deflection slope and load at 0.75 in.) for all cases tested.

The COV is calculated as the standard deviation divided by the average expressed as a percentage. No COV values are given for the FlangeG90 and FlangeGS90 since these treatments had only one specimen each. The greatest COV value was 12.6% for the maximum load of the 'WebS60' samples, where only 2 samples were observed. The COV values demonstrate little variation in the strength and stiffness of the I-joists tested. The maximum load values for the Control specimens were greater than the maximum load for the flange reinforcers, but were less than the maximum load for the glued web reinforcers (WebDG11, WebS90 and WebS60). The 'FlangeS11' and 'WebS60' reinforcers were the only reinforcers with load-deflection slopes greater than the average 'Control' value. The 'Web90' reinforcer was the only reinforcer with a load at 0.75 inches of deflection greater than the average 'Control' value.

Table 3: Maximum Load Results from I-joist Reinforcer Testing

Name	**Maximum Load, lbs (COV)**	**Load-Deflection Slope, lb/in (COV)**	**Load at Δ=0.75 in, lbs (COV)**
Control	6339 (9.6%)	3437 (1.5%)	2559 (5.5%)
FlangeGW90	4345 (8.8%)	2295 (5.2%)	2133 (3.0%)
FlangeG90	4073 (3.2%)	2265 (3.8%)	2129 (2.8%)
FlangeGS90	3683[1]	2750[1]	2024[1]
FlangeSS90	2066[1]	1986[1]	1702[1]
FlangeS90	3483 (7.7%)	2240 (6.0%)	1725 (7.7%)
FlangeS60	3267 (5.7%)	2164 (0.7%)	1725 (4.9%)
FlangeS40	4865 (6.2%)	3065 (6.3%)	2175 (4.3%)
FlangeS11	4901 (66.5%)	3454 (7.1%)	2500 (1.8%)
WebG11	5120 (5.3%)	2835 (0.3%)	2409 (0.2%)
WebDG11	7157 (5.4%)	3074 (1.9%)	2503 (4.4%)
Web90	5354 (3.5%)	3251 (1.9%)	2614 (3.7%)
WebS90	7435 (1.3%)	3357 (4.0%)	2185 (7.5%)
WebS60	7742 (12.6%)	3459 (2.2%)	2262 (2.0%)
WebS40	4656 (5.8%)	3093 (2.6%)	2279 (4.9%)
WebS11	4835 (7.5%)	3165 (2.9%)	2271 (2.3%)

[1] These values represent singles samples and no COV can be determined.

Comparison of Flange and Web Reinforcer Results to Control Results

Table 4 shows the percentage difference of the control values with the flange and web reinforcer cases studied. A negative percent difference value indicates that the reinforcer value was less than the 'Control' value. Table 4 is useful to observe the differences between the flange and web reinforcers to the 'Control' samples.

The average maximum load of the flange reinforcers varies from 22.7% less to 67.4% less than the maximum load of the average 'Control' value. The lowest average maximum load was for the 'FlangeSS90', which was markedly less than all other flange reinforcers located at midspan. There is a large difference between the maximum load of the single-sided flange reinforcer and the double sided reinforcers. There is littlechange in the percent difference between the flange reinforcers that were glued and the non-glued flange reinforcers. As the flange reinforcer is moved towards the end support, the maximum load increases as noted in the results for the 40 inch and 11 inch reinforcer locations.

The average load-defection slope of the flange reinforcers varies from 42.2% less than to 0.5% greater than the average 'Control' value. The lowest average load-deflection slope was from the 'FlangeSS90 ', which is the single-sided flange reinforcer. There is little difference in the slope of the glued flange reinforcers compared to the non-glued flange reinforcers. As in the maximum load, there is a dramatic change in the percent difference of the load-deflection slope for the reinforcers placed 40 inches and 11 inches from the support. The flange reinforcer at 11 inches from the support actually has a slightly higher average load-deflection slope than the average 'Control' value.

Table 4: Percent Difference Values Comparing Control to Reinforcers[1,2]

Name	% Difference Maximum Load	% Difference Load-Deflection Slope	% Difference Load at 0.75 in Deflection
FlangeGW90	-31.5%	-33.2%	-16.7%
FlangeG90	-35.8%	-34.1%	-16.8%
FlangeGS90	-41.9%	-20.0%	-20.9%
FlangeSS90	-67.4%	-42.2%	-33.5%
FlangeS90	-45.1%	-34.8%	-32.6%
FlangeS60	-48.5%	-37.0%	-32.6%
FlangeS40	-23.3%	-10.8%	-15.0%
FlangeS11	-22.7%	+0.5%	-2.3%
WebG11	-19.2%	-17.5%	-5.9%
WebDG11	+12.9%	-10.6%	-2.2%
Web90	-15.5%	-5.4%	+2.2%
WebS90	+17.3%	-2.3%	-14.6%
WebS60	+22.1%	+0.6%	-11.6%
WebS40	-26.6%	-10.0%	-10.9%
WebS11	-23.7%	-7.9%	-11.3%

[1] % Difference = (Test Value – Control)/Control * 100%.

[2] A negative percent difference indicates the value was less than the control.

The average load at 0.75 inches deflection for the flange reinforcers varied from 33.5% to 2.3% less than the load at 0.75 inches of the average 'Control' value. The 'FlangeSS90' had a similar percent difference to the 'FlangeS90' and 'FlangeS60' samples. The g1ued reinforcers have greater loads at 0.75 inch deflection (approximately 19% less than the average 'Control' value) compared to the non-glued reinforcers (approximately 33% less than the average 'Control' value). As in the maximum load and load-deflection slope values, the flange reinforcer loads at 11 inches and 40 inches from the support had greater loads than the reinforcers at 60 inches and 90 inches from the support.

The average maximum load of the web reinforcers varied from 26.6% less than to 22.1% more than the average 'Control' maximum load value. The web reinforcers located in the middle third of the beam had higher maximum load values compared to the reinforcers located in the outer third of the beam. The 'WebS90' and 'WebS60' samples had greater average maximum load values than the average 'Control' value. The double web reinforcer 'WebDG11' had a maximum load 12.9% greater than the average 'Control' value, while the single web reinforcer 'WebG11' had a maximum load 19.2% less.

The average load-deflection slope of the web reinforcers varied from 17.5% less than to 0.6% greater than the average 'Control' value. As in the maximum load values, the 'WebS90' and

‘WebS60’ load-deflection slopes were very similar to the average ‘Control’ value, while the other web reinforcers had average values less than the average ‘Control’ value. The double web reinforcer ‘WebDG11’ had an average load-deflection slope 10.6% less than the average ‘Control’ value, while the single web reinforcer ‘WebG11’ had an average load-deflection slope 17.5% less.

The average load at 0.75 inches of the web reinforcers varied from 14.6% less than to 2.2% greater than the average ‘Control’ value. The load at 0.75 inches follows a different trend than the maximum load and load-deflection slopes for the web reinforcers. All of the web reinforcers with sheathing, regardless of location, had very similar load values (all approximately 11% less than the average ‘Control’ value) . The web reinforcer with the highest average load at 0.75 inches is the web reinforcer in the center of the beam with no sheathing. The double web reinforcer ‘WebDG11’ had an average load at 0.75 inches of 2.2% less than the average ‘Control’ value, while the single web reinforcer ‘WebG11’ had an average load at 0.75 inches of 5.9% less than the average ‘Control’ value. The double web reinforcer increased the maximum load value more than the load at 0.75 inches of the I-joist.

Effect of Glue on Reinforcer Properties

Table 5 shows the comparison between the glued and non-glued flange and web reinforcers. For the flange reinforcers, the most direct comparison is between ‘FlangeG90’ and ‘FlangeS90’. A comparison could be made with the ‘FlangeGS90’ but only a single specimen was tested, so this comparison was not considered valid. There is a definite difference between the glued and non-glued reinforcer in terms of the maximum load and load at 0.75 inches, while the load-deflection slope had little change for the flange reinforcer. For the web reinforcers, the most direction comparison is between the ‘WebG11’ and ‘WebS11’. This comparison is confounded with the sheathing variable. The non-glued reinforcer load values were approximately 5% less than the glued reinforcer values, while the load-deflection slope of the non-glued reinforcer was almost 9% greater than the glued reinforcer. This change in stiffness of the web reinforcer may be due to the addition of the sheathing rather than the glue.

Table 5: Percent Difference Values Comparing Glued and Non-glued Reinforcers[1]

Test Name or Comparison	% Difference Maximum Load	% Difference Load-Deflection Slope	% Difference Load at 0.75 in Deflection
FlangeG90 vs. FlangeS90	+14.5%	+1.1%	+19.0%
WebG11 vs. WebS11	+5.6%	-8.6%	+5.7%

[1] % Difference = (Glued – Non-glued)/Glued * 100%

Effect of Location on Reinforcer Properties

The ‘FlangeS90’, ‘FlangeS60’, ‘FlangeS40’ and ‘FlangeS11’ as well as the ‘WebS90’, ‘WebS60’, ‘WebS40’ and ‘WebS11’ test values can be displayed as functions of the distance from the support for comparison.

Figure 3 shows the maximum load values for the flange and web reinforcers as a function of the position from the end support. The flange and web reinforcers at the 11 inch and 40 inch positions show almost identical maximum load values. These average maximum loads were approximately 23% less than the average maximum load of the 'Control' samples. As the flange reinforcers move to the middle third of the beam, the average maximum load decreases to approximately 45% less than the average maximum load of the 'Control' samples. As the moment reaches the maximum value in the center third of the beam, the maximum load carried by the flange reinforcer decreases. The web reinforcers show the reverse trend compared to the flange reinforcers. As the location of the web reinforcer moves to the middle third of the beam, the average maximum load increases to approximately 20% greater than the average maximum load of the 'Control' samples , shown by the thick solid line.

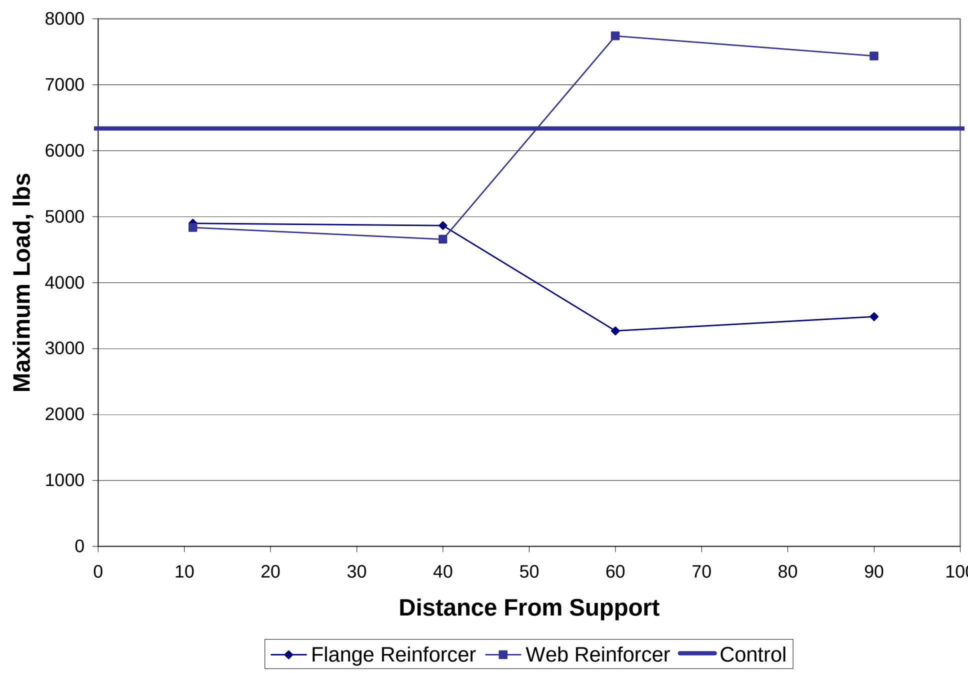


Figure 3. Graph of Maximum Load vs. Position of Reinforcer

Figure 4 shows the average load-deflection slope compared to the position of the reinforcer. The flange and web reinforcers in the 11 inch and 40 inch positions showed similar magnitudes for the average load-deflection slope, approximately 7% less than the average load-deflection slope of the 'Control' samples , shown by the thick solid line. The flange reinforcer shows a similar trend to the maximum load shown in Figure 3 with the load-deflection slope of the 11 inch and 40 inch flange reinforcer positions being greater than the load-deflection slopes of the 60 inch and 90 inch positions. The web reinforcer shows a similar trend to the maximum load shown in Figure 3. The change in the load-deflection slope between the 11 inch and 40 inch samples and the 40 inch and 60 inch samples is not as dramatic as the maximum load, but a better performance of the web reinforcer for the load-deflection slope is achieved by location in the middle third of the beam.

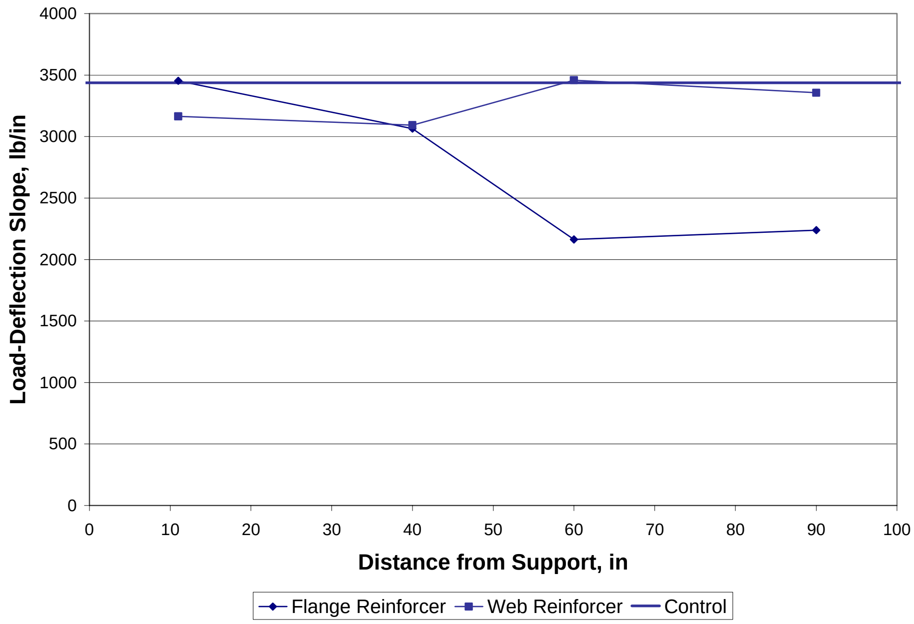


Figure 4. Graph of Load-Deflection Slope vs. Position of Reinforcer

Figure 5 shows the load at 0.75 inch deflection as a function of the position of the flange and web reinforcer. For the flange reinforcer, the load at 0.75 in decreases as the distance from support increases, where the flange reinforcer is only 2.3% less than the average load at 0.75 in of the 'Control' samples at 11 inches from the support but decreases to 32.6% less at 90 inches from the support. This trend is consistent with the maximum load and load-deflection slope. The web reinforcer load at 0.75 in is similar for the different positions of the reinforcer along the beam and is approximately 12% less than the average load at 0.75 in of the 'Control' samples over the distances measured..

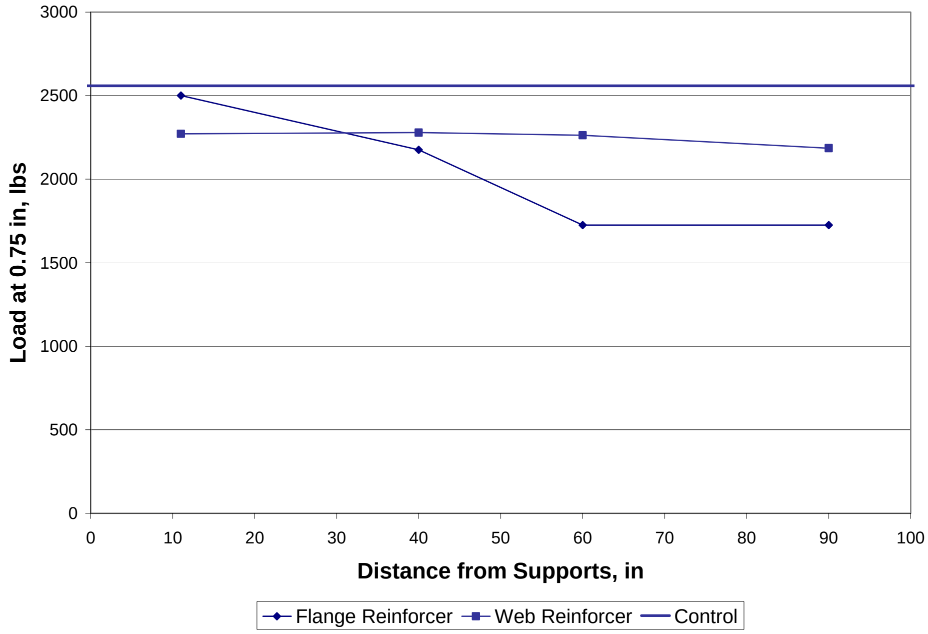


Figure 5. Graph of Load at 0.75 in Deflection vs. Position of Reinforcer

Reinforcer Failure Analysis

The following section describes the typical failures observed for each group of samples tested. The appendix contains a list of failure descriptions for each individual sample tested. There was some variation in failures observed, but as evidenced by the low COV values in Table 3, most of the failures for each group had the same root causes.

Figure 6 shows the failure of a Control sample. All of the 'Control' beams failed in pure bending towards the center of the span. Figure 6 shows fracture in the bottom flange, delamination of the lower veneers in the top flange and a crack running through the web (white arrows).

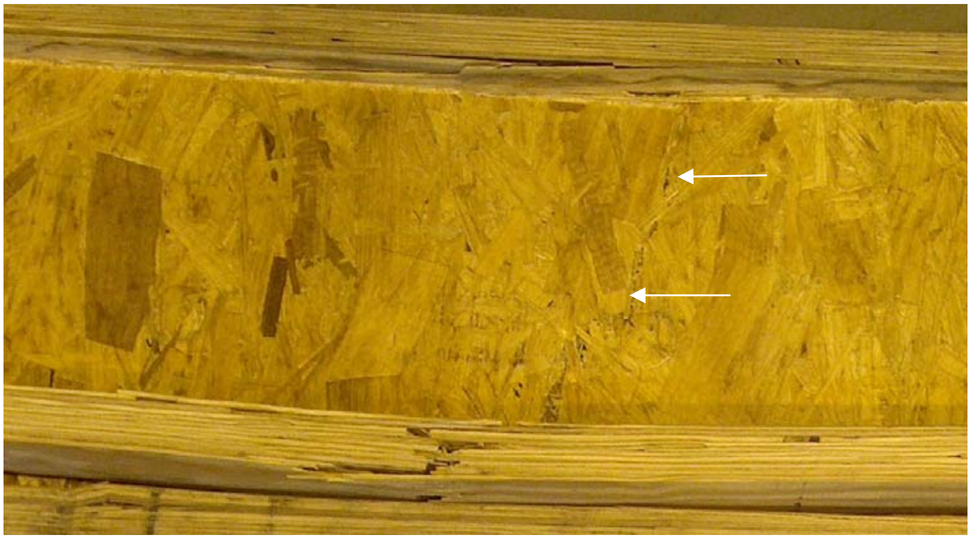


Figure 6: Failure of Control

Figure 7 shows the failure of the FlangGW90 samples. Failure was initiated by buckling of the top flange at the hole in the flange reinforcer. The second image in Figure 7 is a top view showing the permanent deflection of the flanges and the wrinkling of the web and reinforcer below. As stated earlier, this failure mode was considered unrealistic for the situation where the I-joist reinforcers are installed in a sheathed floor, where buckling of the top flange would be prevented by the sheathing material.

Figure 7: Failure of FlangeGW90 Showing Close-Up of Flange Buckling

Figure 8 shows the failure of the FlangeG90 samples. This failure was consistent with the FlangeGW90 samples discussed in Figure 7. Buckling of the top flange at the point of the cut caused the failure. Note the resulting failure of plies in the top flange to the left of the reinforcer.

Figure 8: Failure of FlangeG90

Figure 9 shows the failure of the FlangeGS90 sample. This sample failed by fracture in the bottom flange and the screws attaching the reinforcer to the sheathing pulling out. The bending deformation of the I-joist became so great as to pull out the screws attaching the sheathing to the reinforcer. The fracture of the bottom flange indicates that the failure was caused by bending in the I-joist but not the reinforcer, which is similar to the failures in the Control samples.

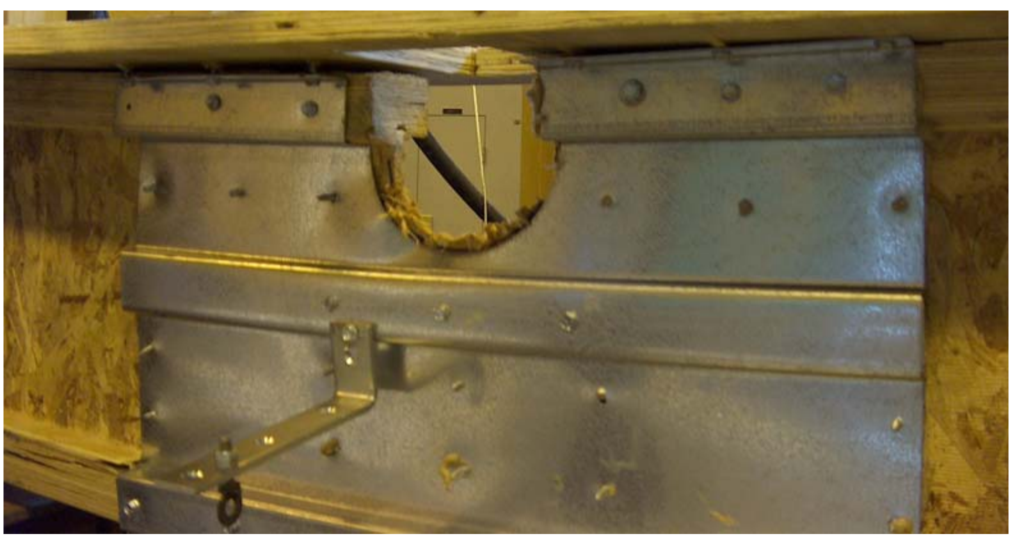


Figure 9: Failure of FlangeGS90

Figure 10 shows the failure of the FlangeSS90 sample. This reinforcer experienced web buckling (white arrows in Figure 10) underneath the hole that was made in the flange. As was noted in the discussion of Tables 3 and 4, using a single flange reinforcer does not produce adequate loads compared to using two flange reinforcers.

Figure 10: Failure of FlangeSS90

Figure 11 shows the failure of the FlangeS90 samples. The reinforcer broke at the bottom flange and also split the top flange along the line of fasteners connecting the reinforcer to the top flange. Also, the excessive deflection of the I-joist caused the screws attaching the reinforcer to the sheathing to pull out.

Figure 11: Failure of FlangeS90

Figure 12 shows the failure of the FlangeS60 samples. The failure was a break in the bottom flange caused by horizontal shear in the outer third of the beam. Figure 12 also shows the change in angle of the beam at the outer corner of the reinforcer. In the higher shear area underneath the load head (the reinforcer was initially centered on the load head), the reinforcer acted to strengthen the I-joist, causing a failure in shear at the outer side. Figure 12 also shows the uplift of the top sheathing as the deflection became excessive and the I-joist curvature became large.

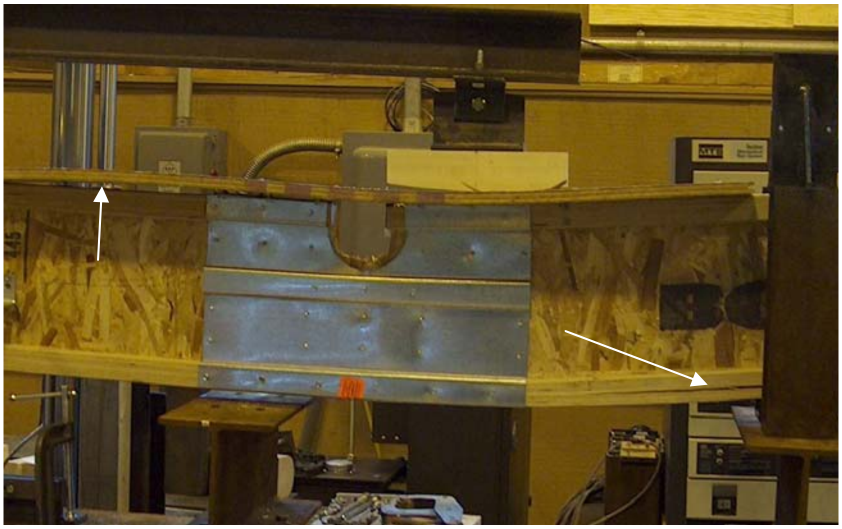


Figure 12: Failure of FlangeS60

Figure 13 shows the failure of the FlangeS40 samples. These samples failed due to web buckling between the reinforcer and the load head. The white arrows point to the buckled material. The buckling initiated with a peeling of the lowest veneer of the top flange. Again, this failure seems to be caused by high shear in the I-joist itself.

Figure 13: Failure of FlangeS40

Figure 14 shows the failure of the FlangeS11 samples. The failure was due to bending in the flanges and shear in the web of the I-joist itself. The bottom flange is broken at a location away from the reinforcer, the web experienced a shear failure progressing at 45 degrees from the top corner of the reinforcer, while the top flange was broken at the line of screws connecting the flange to the reinforcer.

Figure 14: Failure of FlangeS11

Figure 15 shows the failure of the WebG11 samples. The failure was caused by horizontal shear in the section which caused the reinforcer to become a parallelogram.

Figure 15: Failure of WebG11

Figure 16 shows the failure of the WEBDG11 samples. The I-joist failed due to crushing in the web and failure of the top flange. This failure occurred approximately 2 feet away from the reinforcer underneath the load point.

Figure 16: Failure of WebDG11

Figure 17 shows the failure of the Web90 samples. The failure was caused by buckling of the cross-section, which caused the failure of the top flange, noted by the veneer fibers upraised and broken on the side without the reinforcer. This reinforcer was tested without sheathing and this failure mode was felt to be unrealistic for the situation where the reinforcer is used in an already constructed floor system. The inclusion of sheathing may have prevented this failure from occurring.

Figure 17: Failure of Web90

Figure 18 shows the failure of the WebS90 samples. This failure was caused by brash tension in the top flange due to bending stresses with buckling in the web (series of white arrows). This failure occurred approximately 24 inches from the center of the reinforcer at the edge of the sheathing section. In Figure 18, the web reinforcer itself is not visible.

Figure 18: Failure of WebS90

Figure 19 shows the failure of the WebS60 samples. These reinforcers were positioned directly underneath the support points. Failure occurred through brash tension in the flange due to bending stresses approximately 6 inches from the edge of the reinforcer. Also, note the failure of the web section underneath the flange failure (white arrow).

Figure 19: Failure of WebS60

Figure 20 shows the failure of the WebS40 samples. The samples failed in horizontal shear, which caused failure of the web-flange joint in the top flange (note the peeling of the top flange veneers in the upper right corner) and failure of the web (white arrow in lower left hand corner). The outer third of the beam tested is where the highest shear force , which led to failure, was present.

Figure 20: Failure of WebS40

Figure 21 shows the failure of the WebS11 samples. The web reinforcer failed in horizontal shear which caused breakage web-flange interface in the top flange along with distortion of the web reinforcer into a parallelogram shape. In this position, which was in the high shear zone, the fai1ure was due to shear stress.

Figure 21: Failure of WebS11

Conclusions of Reinforcer Failure Analysis

Table 6 shows the summary of the types of reinforcers and the elements involved in the failure. The reinforcers were involved in the failures of the FlangeGW90, FlangeG90, FlangeS90, WebG11, Web90, and WebS40. There are no clear trends of the elements involved in the failures for certain types of reinforcers used. However, some trends can be observed. For the single unglued flange reinforcers, the failures away from the center of the beam did not involve the reinforcers. Note that the typical toilet is placed 11 inches from a wall. For the single unglued web reinforcers, the reinforcers in the center third of the beam (90 and 60 inch positions) did not involve the reinforcers.

Table 6: Summary of Elements involved in Reinforcer Failures

Reinforcer	Elements Involved in Failure
FlangeGW90	Reinforcer
FlangeG90	Reinforcer
FlangeGS90	Screws in Reinforcer / Flange
FlangeSS90	Web
FlangeS90	Flange / Reinforcer
FlangeS60	Flange
FlangeS40	Web
FlangeS11	Web
WebG11	Reinforcer
WebDG11	Flange / Web
Web90	Flange / Reinforcer
WebS90	Flange / Web
WebS60	Flange / Web
WebS40	Reinforcer
WebS11	Flange

Conclusions

This research documents the strength and stiffness of the Metwood I-joist flange and web reinforcers. The test method produced low COVs for all strength and stiffness assessments, demonstrating a uniformity in the types of failures between the different kinds of reinforcer arrangements. For the set of Metwood I-joist flange reinforcers using the two-sided reinforcer with sheathing, the lowest maximum load was 48.5% less than the average ‘Control’ value, the lowest load-deflection slope was 37.0% less and the lowest load at 0.75 inches was 32.6% less. For the set of Metwood I-joist web reinforcers using a single-sided reinforcer with sheathing, the lowest maximum load was 26.6% less than the average ‘Control’ value, the lowest load-deflection slope was 10.0% less than the average ‘Control’ value, and the lowest load at 0.75 inches was 14.6% less than the average ‘Control’ value.

The types of failures observed from the two-sided unglued flange reinforcers and single-sided unglued web reinforcer do not show a trend in the failures observed. The two-sided unglued flange reinforcers had failures which did not involve the reinforcer when placed in the outer third of the beam (areas of low moment). The single-sided unglued web reinforcers had failures which did not involve the reinforcer when placed in the center third of the beam (area of zero shear).

Several other combinations of reinforcers were tested with different results. The use of a single-sided flange reinforcer produced the greatest percent difference values compared to the ‘Control’ samples. This was the reinforcer which had the lowest strength and stiffness. The use of a single flange reinforcer is not recommended. The double-sided web reinforcer increases the strength and stiffness of the I-joist more than the single-sided web reinforcer, but this increase in strength and stiffness was small. The double-sided web reinforcer was effective in separating the failure of the I-joist from the area immediately surrounding the reinforcer, indicating that the section of the I-joist with the reinforcer had equivalent or greater stiffness to the uncut I-joist. The use of construction adhesive to secure the reinforcer to the I-joist increased the loads that the reinforcers can carry, but did not increase the stiffness of the I-joist.

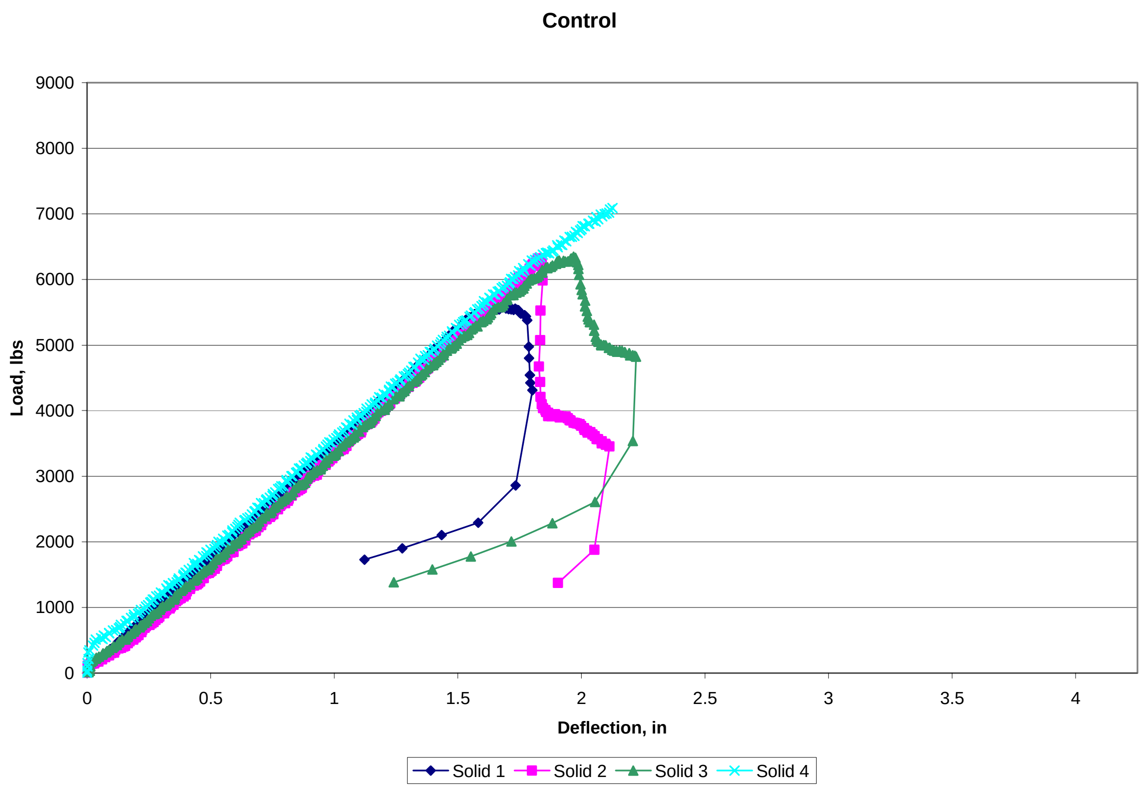
Appendix

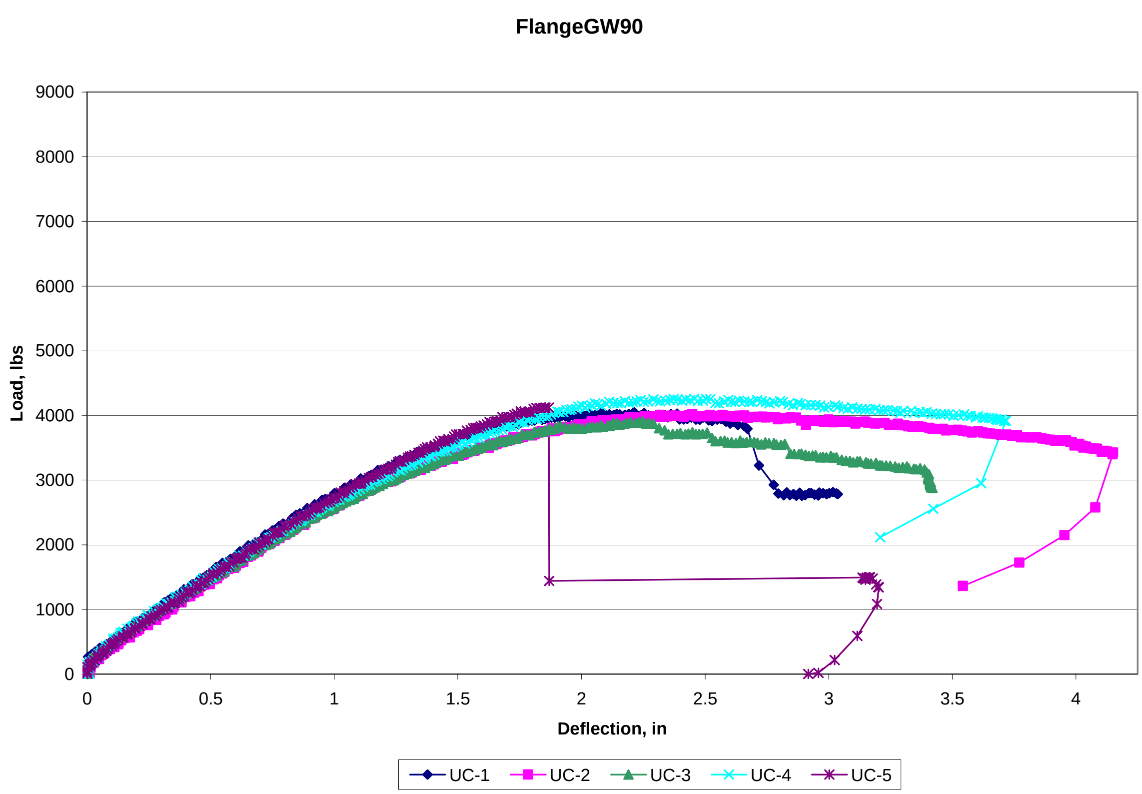
Appendix A: Failure Analysis of Individual Specimens

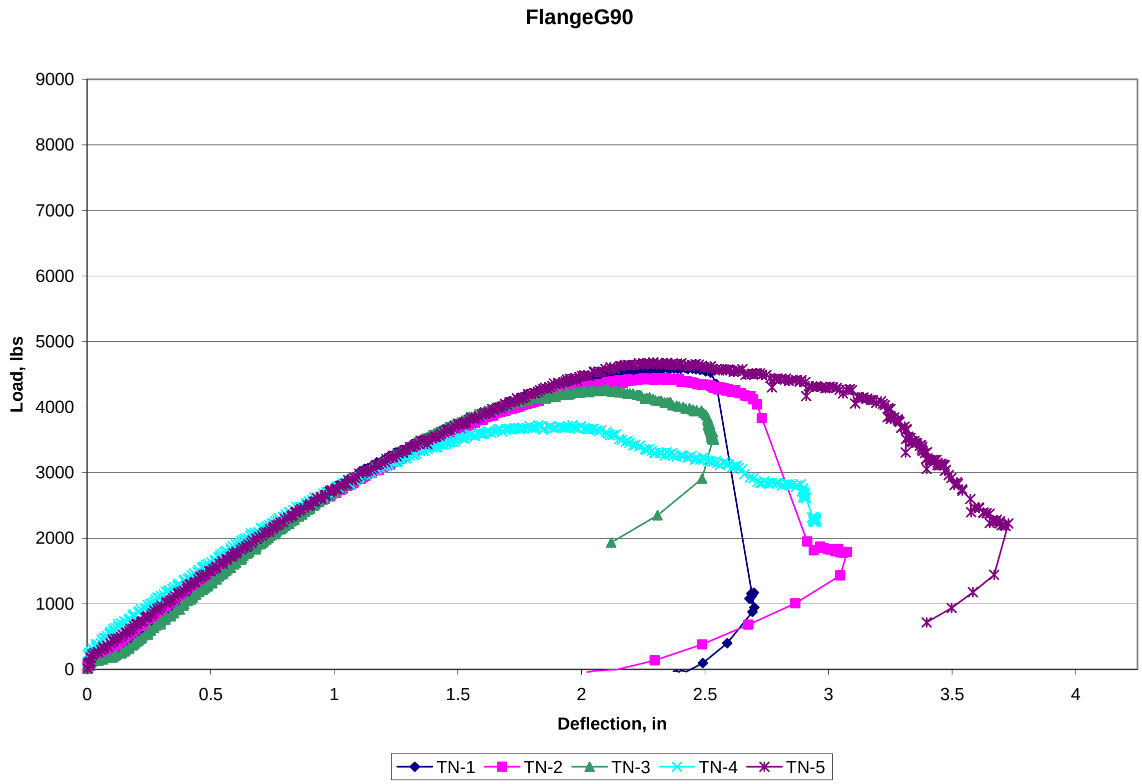
Name	Failure Description
FlangeGW90-1	Web buckling under hole. Left hand side flange deflected downward and outward. Patch has cut into web. Cracks in wood flange to the left of patch.
FlangeGW90-2	Downward movement of both flanges. No web buckling. Crinkle at bottom of cutout.
FlangeGW90-3	Downward movement of both flanges. No web buckling. Crinkle at bottom of cutout. Web buckling on left hand side involving knockout hole. Flange split on left hand side.
FlangeGW90-4	Crinkle in bottom of patch cutout.
FlangeGW90-5	Little damage to the patch itself. Web buckling on left hand side of patch. Left flange is displaced to the right compared to the patch. Left flange is split from the screws.
FlangeG90-1	Web buckling on left hand side. Splitting of flange from screws on left hand side. Flange is almost split in half.
FlangeG90-2	Web buckling on right hand side of patch. Crinkle in the sheet metal at the bottom of patch cutout.
FlangeG90-3	Crinkle in bottom of patch cutout.
FlangeG90-4	Web buckling under hole. Left hand side flange deflected downward and outward. Patch has cut into web. Cracks in wood flange to the left of patch.
FlangeG90-5	Same as FlangeG90-4. Separation of laminations in top flange LVL on left hand side of patch.
FlangeGS90	Break in bottom flange. Screws pulled from sheathing at top.
FlangeSS90	Web buckling from flange notch on side where reinforcer was not attached
FlangeS90-1	Break in bottom flange.
FlangeS90-2	Break in bottom flange. Break in top flange at screws
FlangeS90-3	Kink in reinforcer at the center of beam. Bending in reinforcer and flange. Screws pulled from sheathing at top.
FlangeS90-4	Break in bottom flange. Screws pulled from sheathing at top.
FlangeS60-1	Break in bottom flange.
FlangeS60-2	Break in bottom flange.
FlangeS60-3	Break in bottom flange. Break in top flange at screws
FlangeS60-4	Break in bottom flange. Sheathing pulled up, looks cupped
FlangeS40-1	Web butt joint separation approximately 6" from edge of reinforcers. Break in bottom flange.
FlangeS40-2	Web buckling at load point. Break in top flange at screws.
FlangeS40-3	Break in top flange at screws. Web buckling 6 inches from reinforcer.
FlangeS40-4	Web buckling starting at upper corner of reinforcer through punchout. Break in top flange at screws.
FlangeS40-5	Web buckling starting at upper corner of reinforcer through punchout. Break in top flange at screws.
FlangeS11-1	Break in bottom and top flanges. Web buckling starting at upper corner through punchout. Screws in top flange sheared off.
FlangeS11-2	Brash tension of top flange at support.
WebG11-1	Shear failure at patch. Hole shape began as rectangular, deformed to parallelogram. Tension breakage of flange at top left and bottom right corners, which were forced outwards. Compression failure at top right corner, which was forced inwards.
WebG11-2	Same as WebG11-1

Name	Failure Description
WebDG11-1	Failure next to patch towards center of beam. Delaminaton of flange and web at top. Splintering of bottom web. Web buckling in two places - one from top to bottom of wood flange approximately 12 inches from patch and one from top flange to center of patch at a 45 degree angle.
WebDG11-2	Failure at center of joist (approximately 9 feet from left end). Bending failure in the flange and associated web buckling.
WebDG11-3	Same as WebDG11-2
WebDG11-4	Same asWebDG11-2. Web buckling wrinkle went through a knockout in the web.
WebDG11-5	Large failure area extending from the edge of the patch. Failure area was 46 inches from left end to 68 inches from left end. At 68 inches from left end, there was a bending failure in the flange. There were two web failures, one extending from the top to bottom of the wood flange and another from the top wood flange to the patch at a 45 degree angle.
Web90-1	Failure in wood flange on the top left side. Compression type failure.
Web90-2	Failure in wood flange on the top left side. Compression type failure.
WebS90-1	Web separation at butt joint under support
WebS90-2	Web buckling under load support near punchout. Break in bottom and top flanges.
WebS90-3	Web buckling near support. Break in top and bottom flange.
WebS90-4	Failure in web butt joint and splintering of the top and bottom flanges.
WebS90-5	Web failure under support through punchout. Break in bottom flange.
WebS60-1	Web crushing about 6 inches from reinforcer. Break in bottom flange.
WebS60-2	Break in bottom flange.
WebS40-1	Break in bottom flange. Web separation in hole cut due to butt joint. Shear failure forming parallelogram of reinforcer.
WebS40-2	Break in bottom flnage. Shear over hole area forming parallelogram of reinforcer. Top flange screws pulled out of sheathing.
WebS40-3	Break in bottom and top flanges. Failure of butt joint near hole.
WebS40-4	Web crushing. Horizontal shear in top flange at the web-flange interface. Break at bottom web corner. Bending of reinforcer.
WebS40-5	Buckling of beam. Top flange broke. Reinforcer bent out of plane. Horizontal shear in flange.
WebS40-6	Break in the bottom flange and top. Web crushing under support.
WebS11-1	Beam buckling. Horizontal shear in flange.
WebS11-2	Beam buckling. Horizontal shear in flange.
WebS11-3	Beam buckling. Horizontal shear in flange.

Load-Deflection Plots of Specimens



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3000
2000
1000
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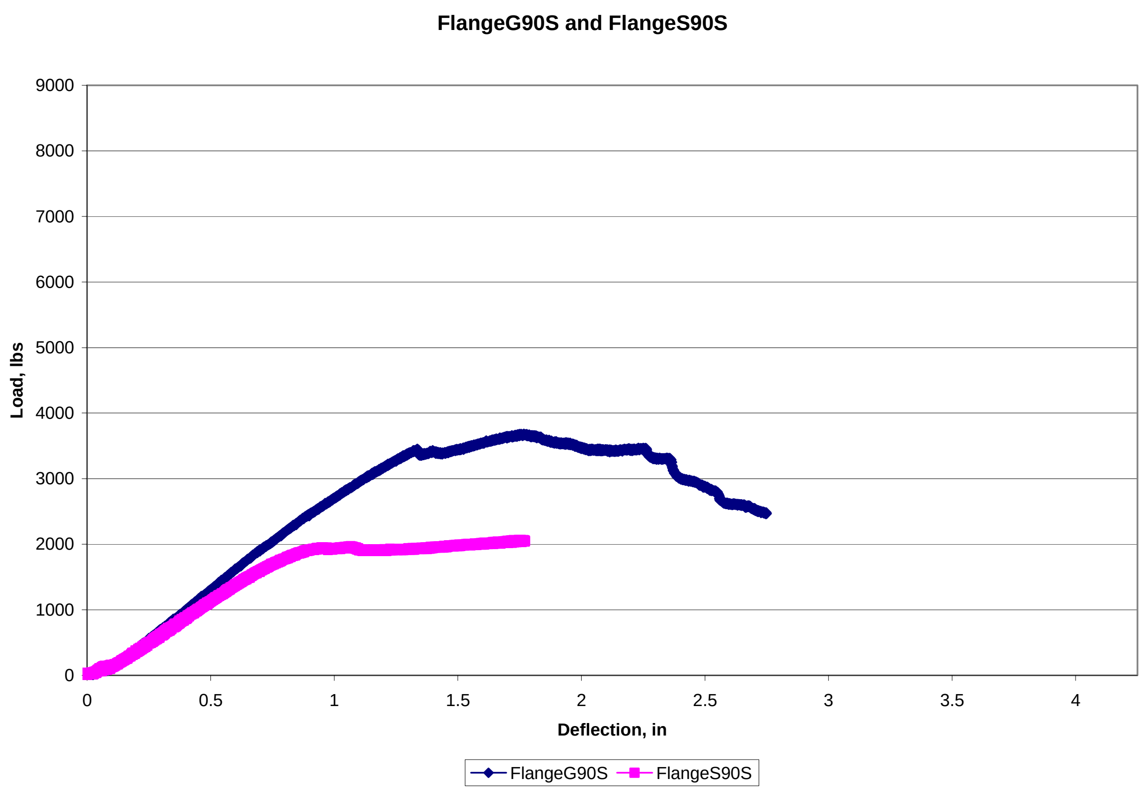
3
3.5
4
TN-1
TN-2
TN-3
TN-4
TN-5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Load, lbs
Deflection, in
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7000
6000
5000
4000
3000
2000
1000
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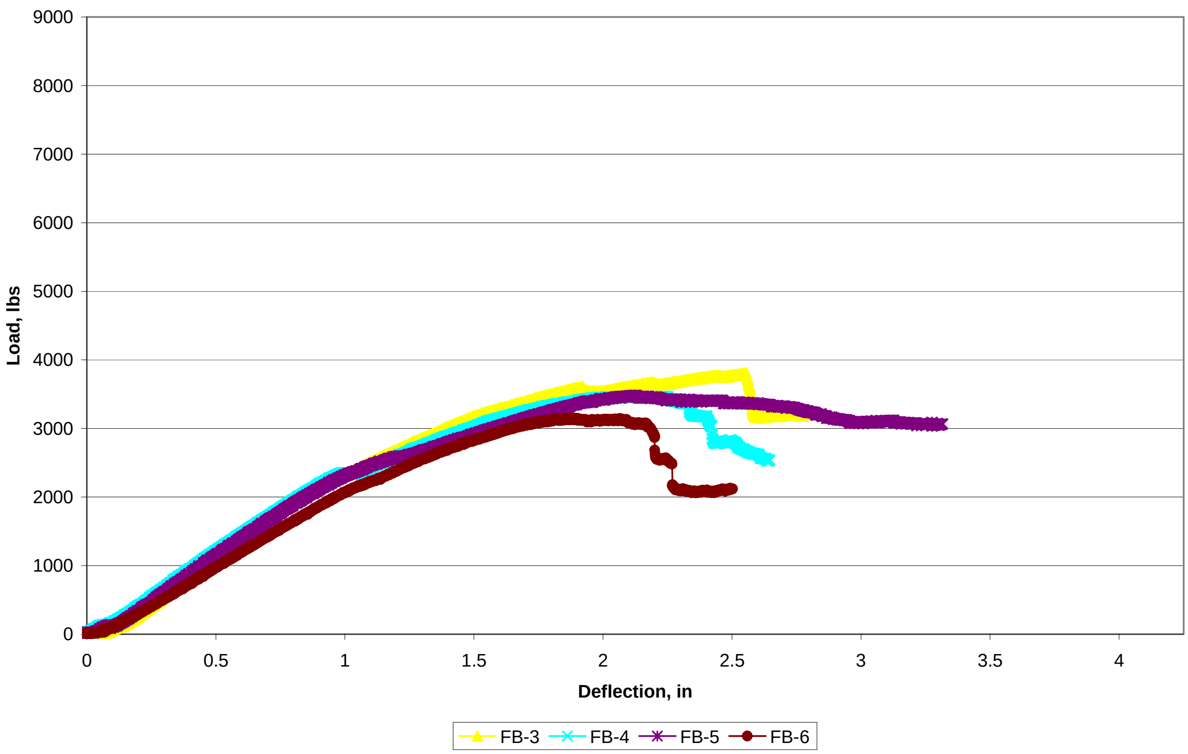
0.5
1
1.5
2
2.5
3
3.5
4
FlangeG90S
FlangeS90S

Flange90S



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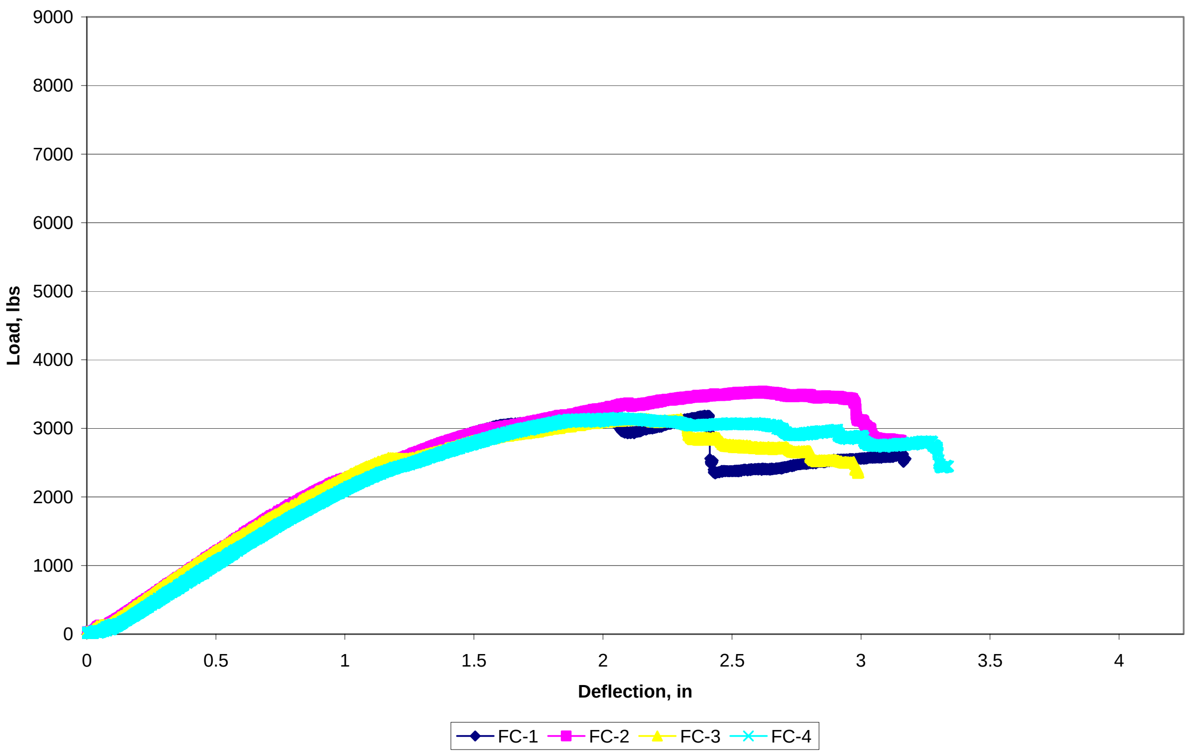

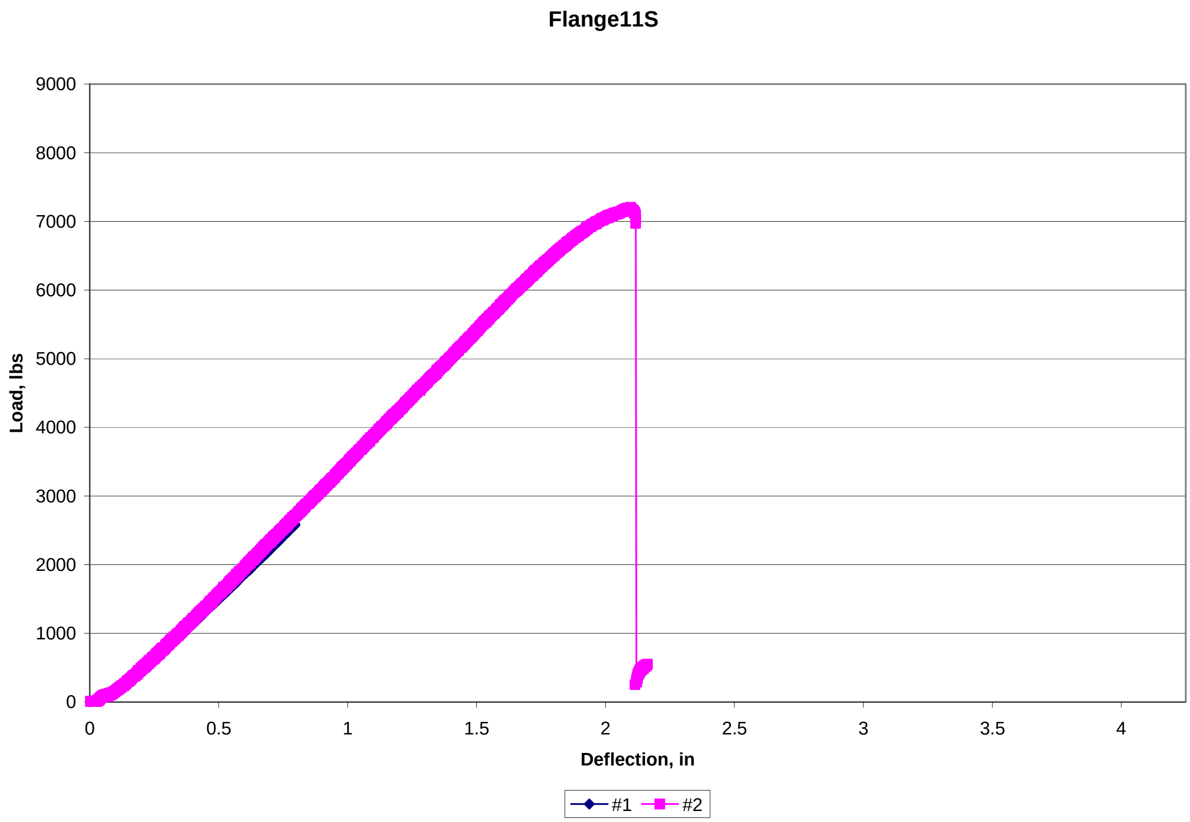
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6000
5000
4000
3000
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Load, lbs
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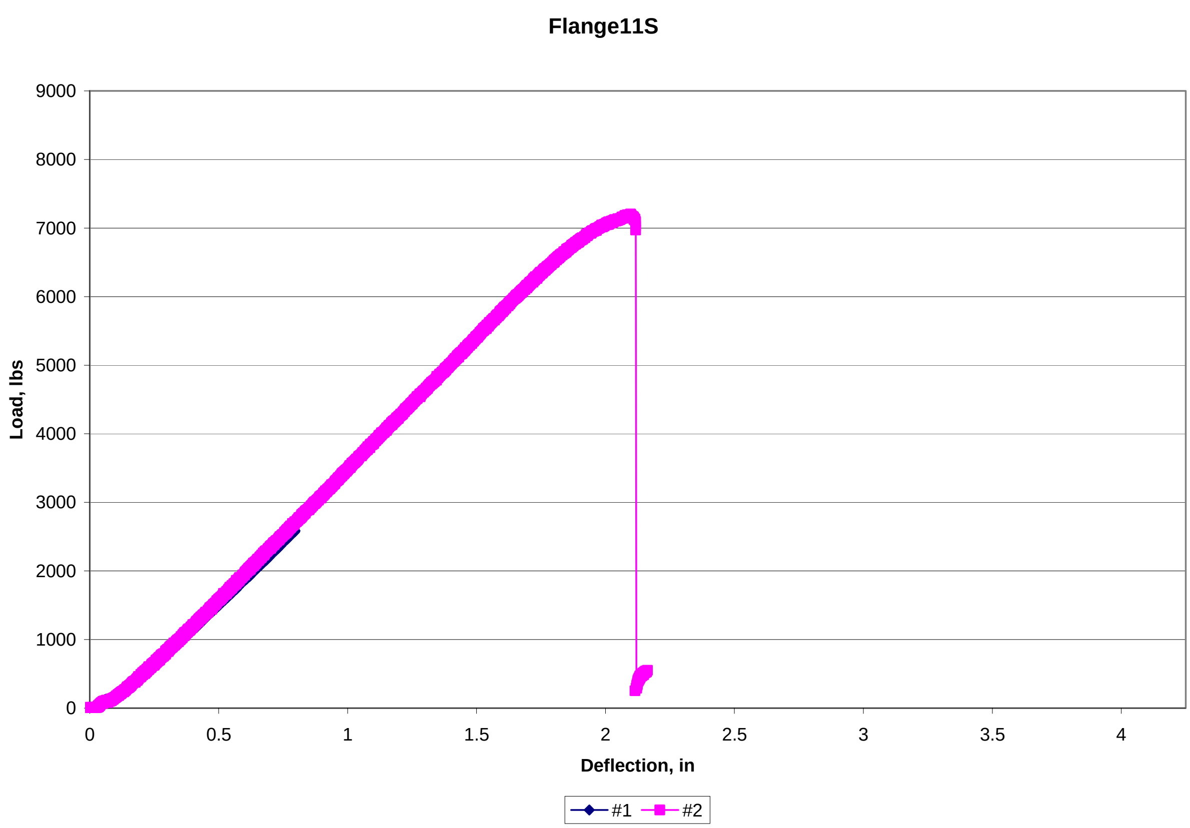
2.5
3
3.5
4
Deflection, in
#1
#2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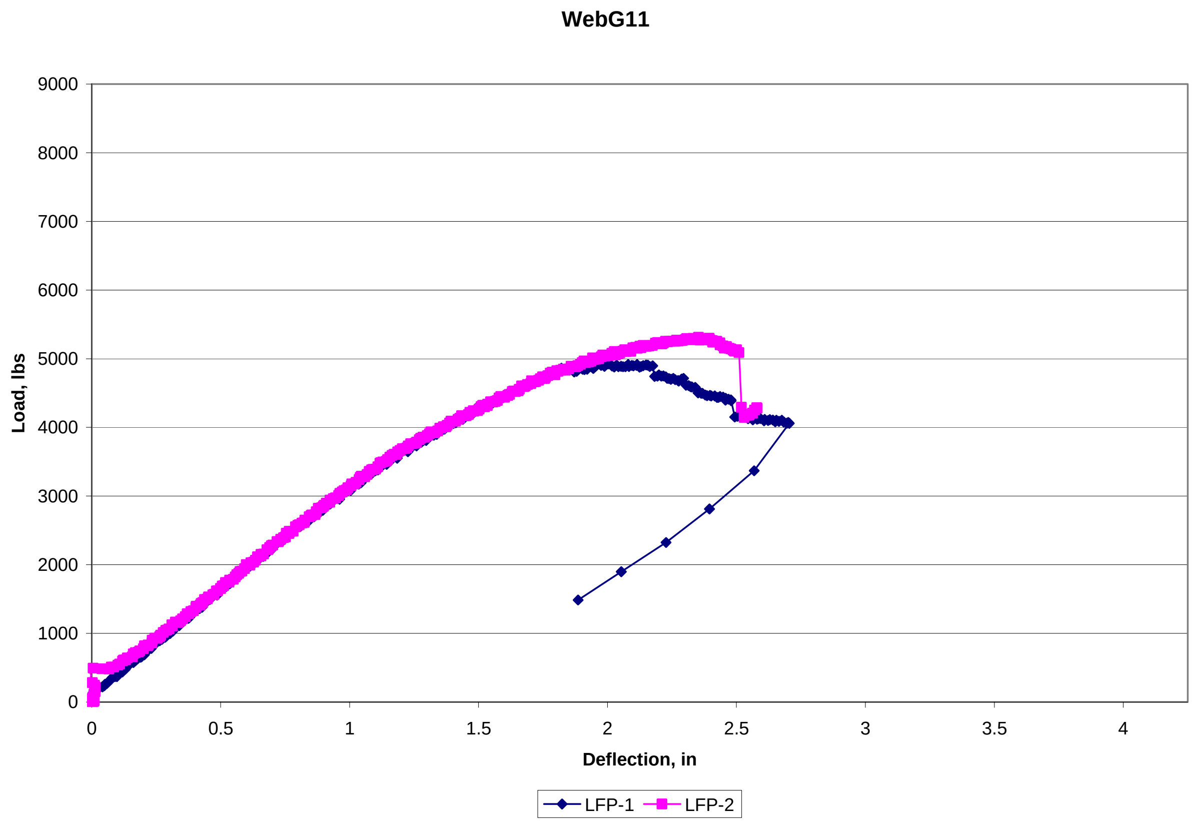
#2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2
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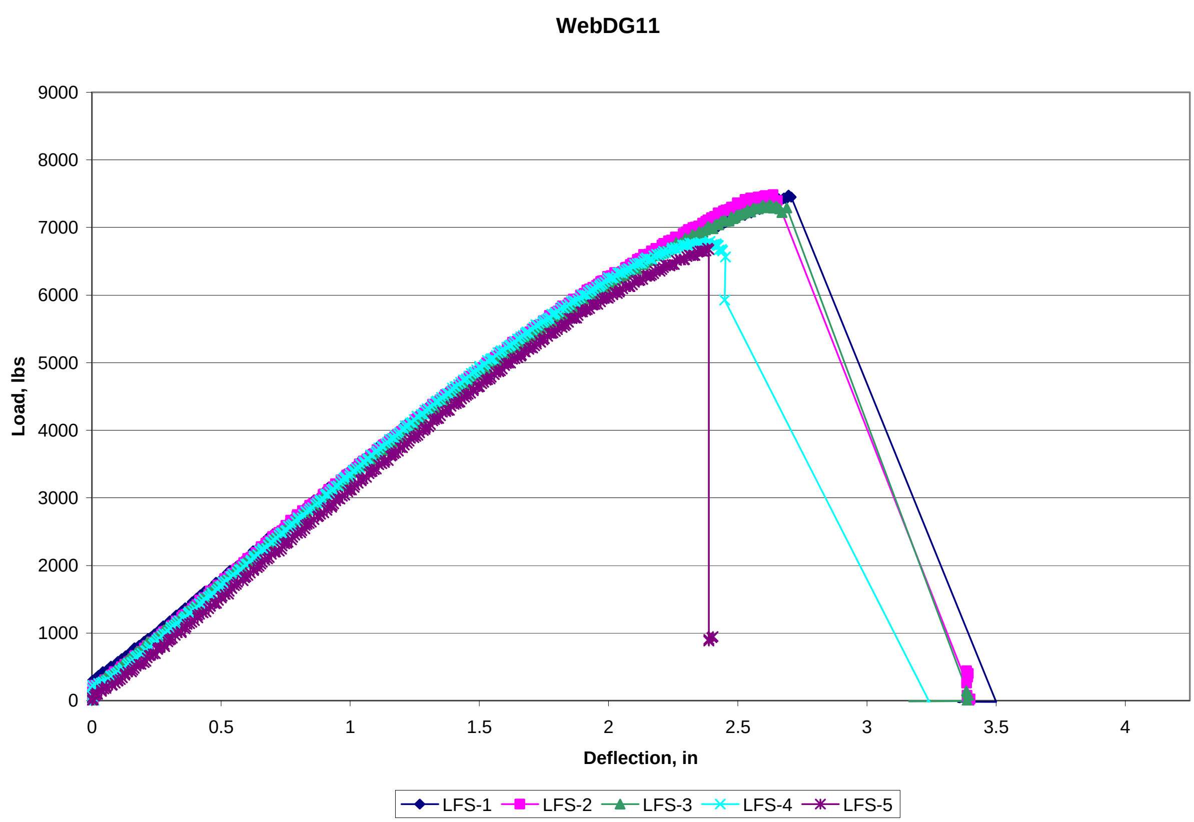
3.5
4
Deflection, in
LFP-1
LFP-2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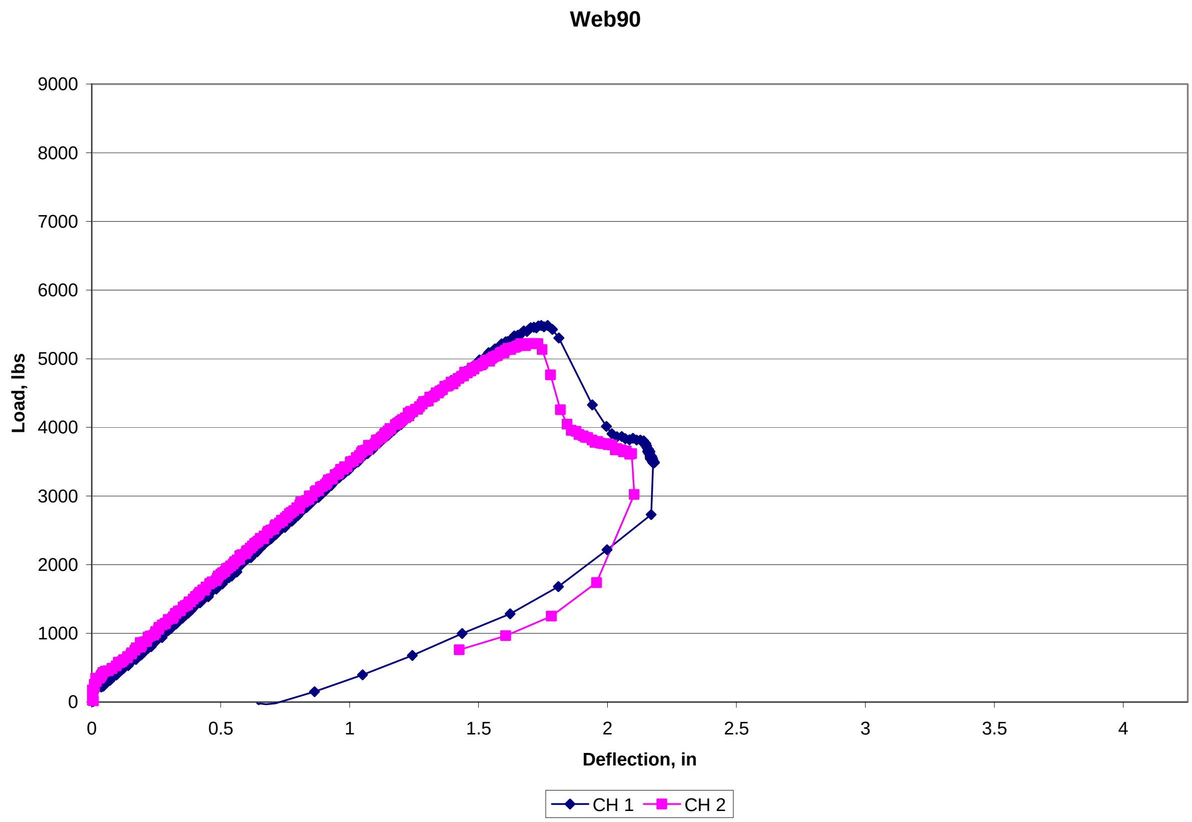
Deflection, in
LFS-1
LFS-2
LFS-3
LFS-4
LFS-5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4000
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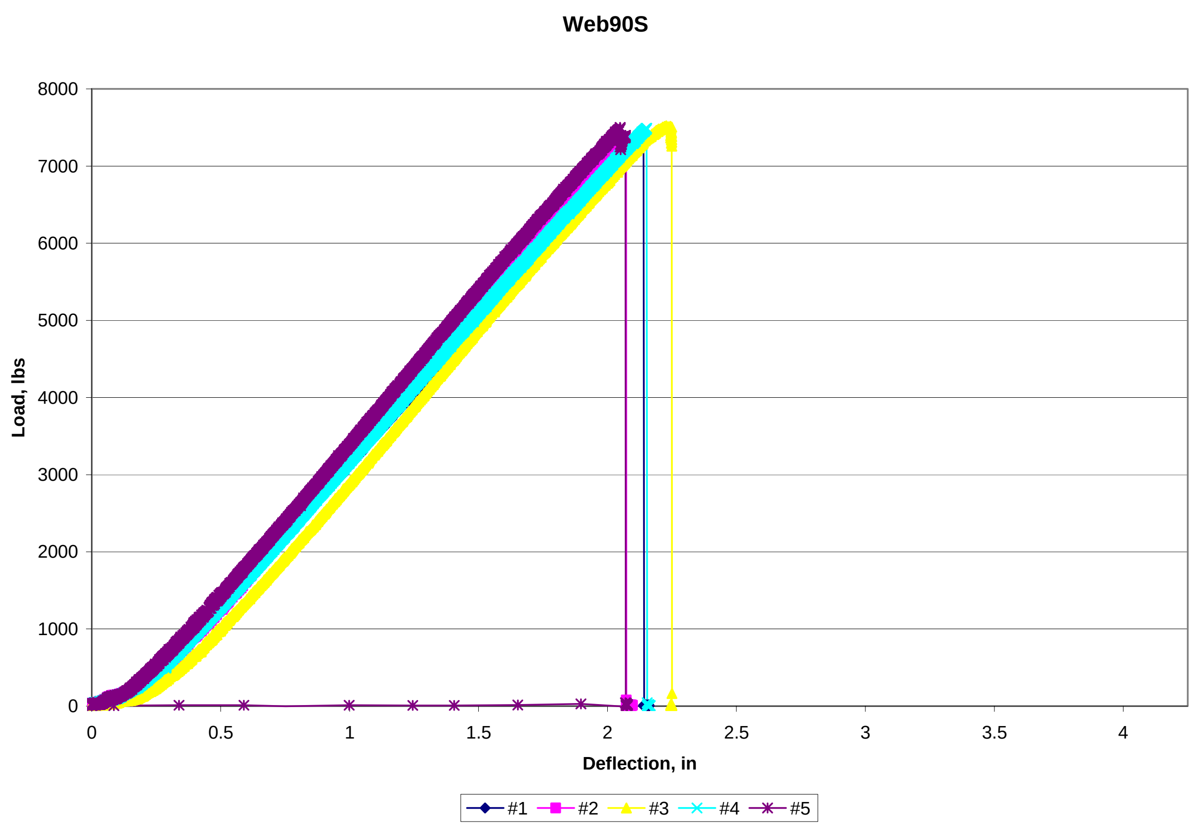
3
3.5
4
Deflection, in
CH 1
CH 2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3.5
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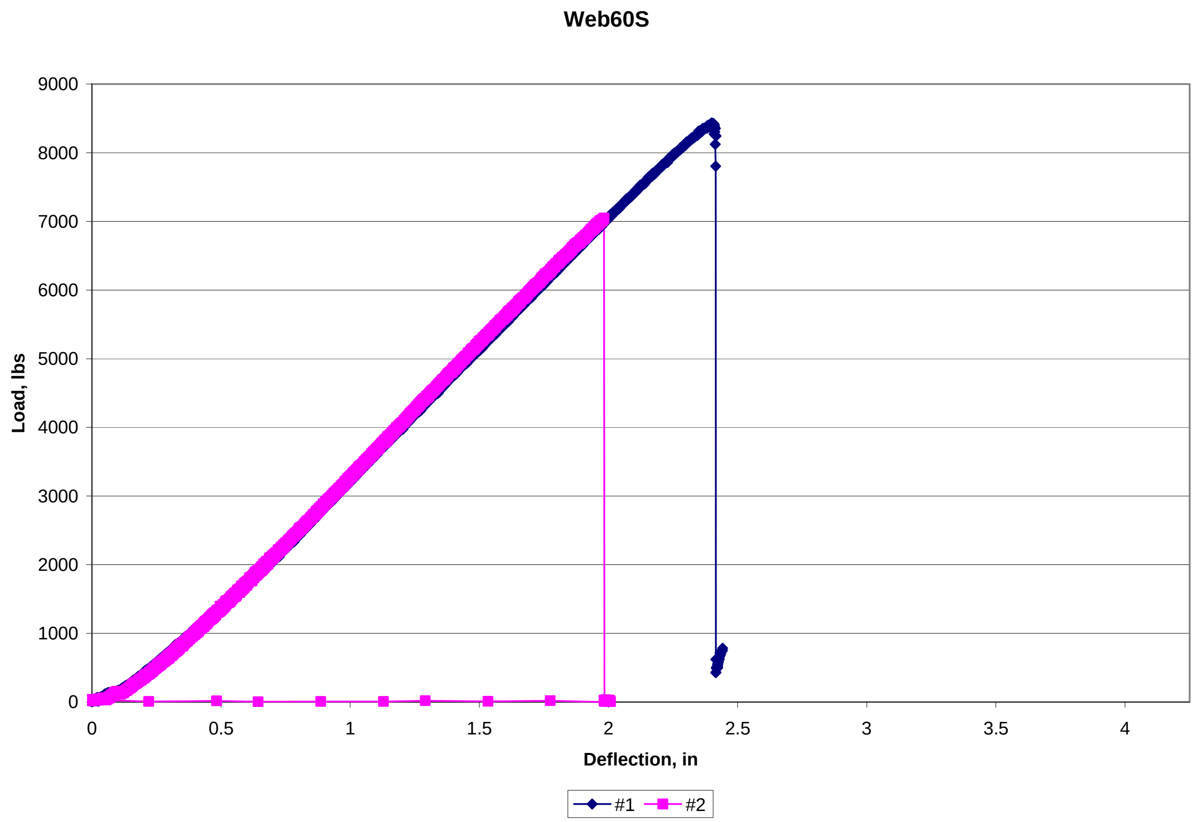
Deflection, in
#1
#2
#3
#4
#5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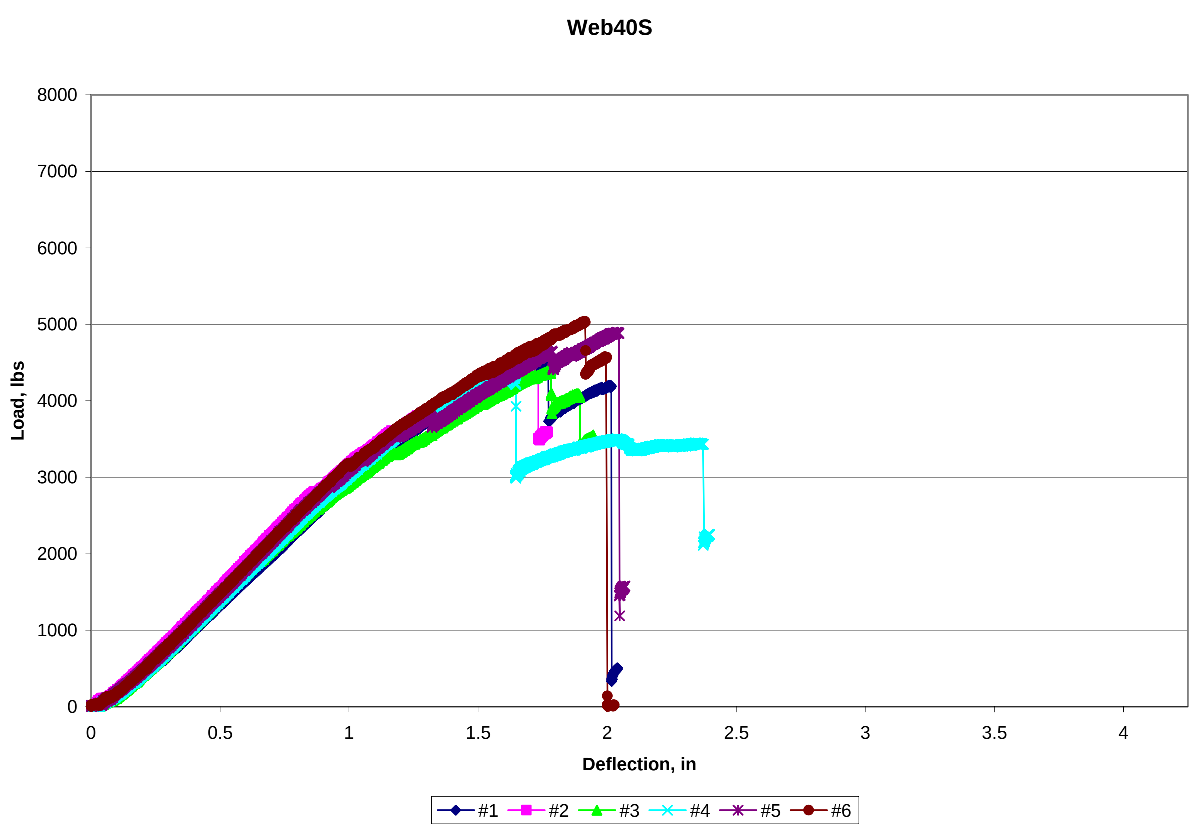
3
3.5
4
Deflection, in
#1
#2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Deflection, in
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#3
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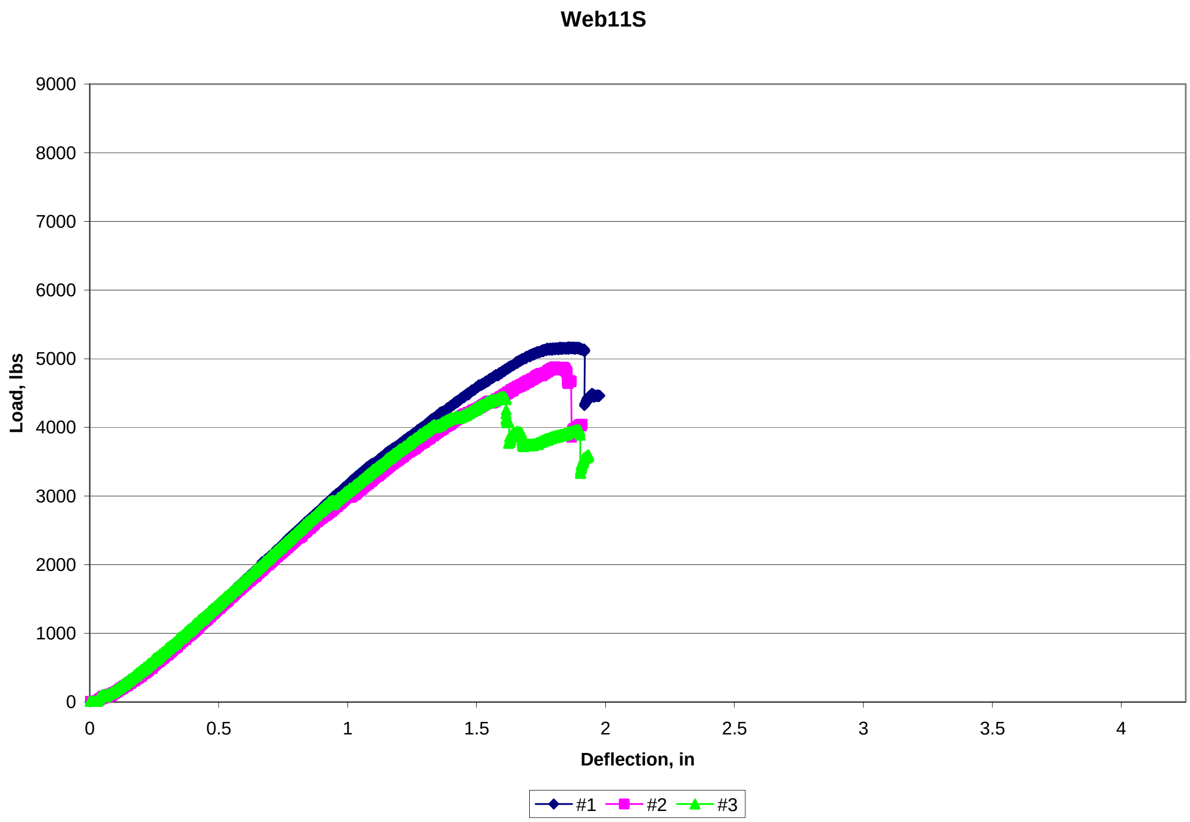
#6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2.5
3
3.5
4
Deflection, in
#1
#2
#3