APPENDIX A

SURVEY INTERVIEW FORMS

A.1 Copy of DOT Questionnaire

NCHRP Project 12-81

Evaluation of Fatigue on the Serviceability of Highway Bridges

The objective of this project is to revise and update Section 7 "Fatigue Evaluation of Steel Bridges" of the *AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges*. The research team includes Drs. Mark Bowman and Robert Connor of Purdue University, Gongkang Fu of Wayne State University, and Edward Zhou of URS Corporation. The revised Section 7 is required to reflect state of the art and the practice, addressing several aspects not covered by the current specs. To accomplish this goal, we need your kind assistance in understanding the current state of the art and the practice for evaluation of fatigue on the serviceability of highway bridges. We gratefully appreciate your response to the following questionnaire, which may need to involve personnel of different units in your organization. For your convenience, you may return multiple copies answered by various units. Please return the questionnaire by e-mail, fax, or US mail to:

Dr. Mark Bowman, PE; bowmanmd@ecn.purdue.edu

School of Civil Engineering, Purdue University, 550 Stadium Mail Drive

West Lafayette, IN 47907; (765)494-0395(fax); (765)494-2220(voice)

Please return this questionnaire by June 27, 2008

Respondent Information:

Name:____________________Title:____________________ email:____________________

Organization:____ Phone:_______________

Name:____________________Title:____________________ email:____________________

Organization:____ Phone:_______________

Please feel free to attach more material or sheets if the spaces provided are inadequate. In case you are unable to answer some of these questions, you may leave them unanswered, but please return this questionnaire with the above section filled. Thank you!

I. General Practice of Steel Bridge Fatigue Evaluation

I-1. Approximately how many steel bridges in the population within your jurisdiction require fatigue evaluation? _________. Does your answer cover not only state/province owned bridges but also local owned ones? ☐ Yes ☐ No. If yes, please give the approximate number of those requiring fatigue evaluation not owned by the state/province. _________. What are common types of structures requiring fatigue evaluation? Truss ☐. Two-beam bridges ☐. Multi-beam bridges ☐. Other (specify) ____.

I-2. How frequently does your agency perform analytical steel bridge fatigue evaluation? ☐ Annually. ☐ Biennially. ☐ Other (specify) ___________________________________.

I-3. Which specifications does your agency utilize and/or accept for steel bridge fatigue evaluation?

☐ AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges (the Manual).

☐ AASHTO Guide Specifications for Fatigue Evaluation of Existing Steel Bridges (the Guide).

☐ Others. Please specify: ____

Please provide the reason(s) for using the specifications indicated:____________________

____.

I-4. Do the specifications you use meet your needs? ☐ Yes ☐ No. If no, please identify areas where improvement is needed and explain why: ______________________________

____. Would you be willing to provide fatigue evaluation examples to this study if requested? ☐ Yes ☐ No.

I-5. Does your agency have WIM truck weight data with a time stamp 0.01 seconds or shorter? ☐Yes. ☐No. ☐Don't know. Comments: ___________________________________.

II. Methods of Estimating Load-induced Fatigue Life

II-1. Which load model does your agency use for steel bridge fatigue evaluation?

☐ The fatigue truck of the Manual (AASHTO LRFD fatigue design truck)

☐ WIM truck data.

☐ Other (specify:) ____

Please provide the reason(s) for using the indicated model/method: ____________________

____

II-2. Has your agency observed fatigue cracks associated with tack welds? ☐Yes. ☐No. Does your agency perform fatigue evaluation for tack welds? ☐Yes. ☐No. If yes, please provide more details of how the evaluation is performed (e.g., fatigue strength category assigned, specifications used)____.

II-3. Has your agency observed fatigue cracking due to primary stresses in any of the following members? (Do not include cracking due to out-of-plane distortion in your response. Distortion induced fatigue is covered in Section III.)

Riveted girders ☐Yes. ☐No. Riveted primary truss members ☐Yes. ☐No.

Riveted connections ☐Yes. ☐No. If yes, describe connection details: _____________.

Welded girders ☐Yes. ☐No. Welded primary truss members ☐Yes. ☐No.

Other (specify) ____.

II-4. Does your agency regularly perform fatigue evaluation for steel bridges? ☐Yes. ☐No. If yes, please provide more details of how the evaluation is performed ___________________

____.

Has your agency used methods other than those prescribed in the Manual and Guide for steel bridge fatigue evaluation, such as a facture mechanics approach? ☐No. ☐Yes. If yes, please specify the method(s):____.

II-5. In cases where your evaluation reveals zero or negative remaining fatigue life, yet there is no evidence of cracking on the bridge, what is your agency's policy regarding this inconsistency? ____.

II-6. For steel truss and two-girder bridges, how many lanes of load do you use for fatigue evaluation if there are more than one traffic lane on the bridge? ☐ One lane. ☐ Two lanes. ☐ As many lanes as available ☐ Other. Please specify:_______________________________.

Please explain the reason(s) for your current practice:____.

II-7. Has your agency used field measurements (e.g., strain or displacement) for steel bridge fatigue evaluation?

☐ Never ☐ Yes, by in-house personnel. ☐ Yes, by external consultants ☐ Other. Please specify: ____.

Do you think the Manual and the Guide provide adequate guidance for such practice? ☐Yes. ☐No. If no, in which areas would you like to see improvements? _____________________

____.

II-8. Has your agency considered the in-situ condition of a bolted or welded detail in estimating its remaining fatigue life? For example, consideration of internal defects, corrosion, material toughness, etc.

☐Don't know. ☐Yes. ☐No.

III. Methods of Treating Distortion-induced Fatigue Cracks and Estimating Life

III-1. Has your agency experienced distortion-induced fatigue cracking?

☐ Don't know ☐ No. If no, please skip to Section IV below.

☐ Yes. If yes, is it more often observed than load-induced fatigue cracking? ☐Yes. ☐No.

III-2. When a distortion-induced fatigue crack is identified, do you ☐ repair or retrofit, ☐ monitor, and/or ☐ take other action (specify:) ______________________________________

____.

III-3. If your agency performs repair or retrofit for distortion-induced fatigue cracks, please provide more details of the repair/retrofit schemes, or a contact person who is familiar with the details. ____.

III-4. For distortion-induced fatigue cracking observed, have you performed further analysis to estimate the time to possible facture? ☐ No. ☐ Yes. If yes, please describe the approach used.

____.

IV. Retrofit and Repair for Fatigue Cracks

IV-1. Does your agency retrofit or repair details that cracked due to fatigue? ☐Yes. ☐No. If yes, please provide details for repairing and/or retrofitting fatigue cracks used and/or a contact person for more detailed information ____

____.

V. Further Comments and/or Information

V-1. If you are aware of any efforts to improve steel bridge fatigue evaluation or any study relevant to this subject, not necessarily limited to those associated with your agency, please kindly provide contact information below for us to acquire more details.

Subject____

Name:________________Title:_______________Phone:_______________email:_______________

Organization:____

You have completed this survey. Please return by June 27, 2008. Thank you!

A.2 Summary of Survey Results

I. General Practice of Steel Bridge Fatigue Evaluation

I-1. Approximately how many steel bridges in the population within your jurisdiction require fatigue evaluation?

Of states that did not respond "zero", the average number of bridges was 1200. Seven out of the twenty-one respondents said "zero" or that their state did not perform fatigue evaluations.

Does your answer cover not only state/province owned bridges but also local owned ones?

8 Yes

12 No.

6 NR.

If yes, please give the approximate number of those requiring fatigue evaluation not owned by the state/province.

Only 4 states gave a number other than 0 or no response. The average of these states was 930 bridges

What are common types of structures requiring fatigue evaluation?

Description	Yes	No	NR
Truss	13	5	8
Two-Beam Bridges	16	2	8
Multi-Beam Bridges	13	6	8

Other (specify)

2 states responded steel caps need to be checked and 1 state said that tied arches were of concern. Only 1 respondent indicated that box girders were of concern.

I-2. How frequently does your agency perform analytical steel bridge fatigue evaluation?

0 Annually.

1 Biennially.

Other (specify)

Nearly all respondents said that fatigue evaluations were only performed when cracks were found during inspection and 2 states do not perform any analysis', retrofits are simply performed to repair the cracks.

I-3. Which specifications does your agency utilize and/or accept for steel bridge fatigue evaluation?

Description	Yes	No	NR
AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges (The Manual)	11	9	6
AASHTO Guide Specifications for Fatigue Evaluation of Existing Steel Bridges (The Guide)	16	5	6

Others. Please specify:

Only 2 states reported using other documents, NCRHP 286, NCHRP 302, and NCHRP 299.

Please provide the reason(s) for using the specifications indicated

5 of the states that responded, roughly half, said that they do not use LRFR because they do not have experience using it. The 2 states which use other methods then LRFR and the guide both responded that basing fatigue life off of 1 document was not practical and that several sources were preferred.

I-4. Do the specifications you use meet your needs?

14 Yes

5 No.

7 NR.

If no, please identify areas where improvement is needed and explain why:

Several states who answered yes to question I-4 also responded here. All responses indicated that the calculations are overly conservative.

Would you be willing to provide fatigue evaluation examples to this study if requested?

4 Yes
8 No.
14 NR.

I-5. Does your agency have WIM truck weight data with a time stamp 0.01 seconds or shorter?

5 Yes.
10 No.
7 Don't know.

Comments: **2 states responded that WIM data was collected but at longer intervals**

II. Methods of Estimating Load-induced Fatigue Life

II-1. Which load model does your agency use for steel bridge fatigue evaluation?

Description	Yes	No	NR
Manual Fatigue Truck (LFRD)	12	6	8
WIM Truck Data	5	13	8

Other (specify:)

2 states reported using the guide truck, several others said that only load test data was used

Please provide the reason(s) for using the indicated model/method:

A variety of responses were given here. The most common were that states did not want to use the LFRD spec to evaluate bridges designed using ASD, and that using WIM data gave actual values that could not otherwise be reliably estimated.

II-2. Has your agency observed fatigue cracks associated with tack welds?

13 Yes.

10 No.

3 NR.

Does your agency perform fatigue evaluation for tack welds?

3 Yes.

17 No.

5 NR.

If yes, please provide more details of how the evaluation is performed (e.g., fatigue strength category assigned, specifications used)

2 states responded that tack welds are defined as Category E details evaluated with AASHTO or state specific specs.

II-3. Has your agency observed fatigue cracking due to primary stresses in any of the following members? (Do not include cracking due to out-of-plane distortion in your response. Distortion induced fatigue is covered in Section III.)

Description	Yes	No	NR
Riveted Girders	5	18	3
Riveted Primary Truss Members	4	18	4
Riveted Connections	7	17	2
Welded Girders	17	8	1
Welded Primary Truss Members	7	13	6

If yes for Riveted Connection, describe connection:

Several respondents indicated that stringer or floor beam connections to girders showed signs of fatigue. 2 states said that corrosion caused the connections to become fatigued.

II-4. Does your agency regularly perform fatigue evaluation for steel bridges?

3 Yes.

20 No.

3 NR

If yes, please provide more details of how the evaluation is performed

Very few states answered this question, those that did said that fracture mechanics was used.

Has your agency used methods other than those prescribed in the Manual and Guide for steel bridge fatigue evaluation, such as a facture mechanics approach?

5 Yes.
17 No.
4 NR.

If yes, please specify the method(s):

<u>All respondents who answered yes said that fracture mechanics had been used for evaluation.</u>

II-5. In cases where your evaluation reveals zero or negative remaining fatigue life, yet there is no evidence of cracking on the bridge, what is your agency's policy regarding this inconsistency?

<u>Nearly all respondents indicated that nothing would be done unless cracks were present. If cracks were present a retrofit plan would be devised.</u>

II-6. For steel truss and two-girder bridges, how many lanes of load do you use for fatigue evaluation if there are more than one traffic lane on the bridge?

<u>7</u> One lane.

<u>1</u> Two lanes.

<u>4</u> As many lanes as available

<u>5</u> Other. Please specify:

<u>Very few states gave specifics here, those that did said that they would load closest to actual load data to produce the most realistic situation for that particular bridge</u>

Please explain the reason(s) for your current practice

<u>There were no responses to this question</u>.

II-7. Has your agency used field measurements (e.g., strain or displacement) for steel bridge fatigue evaluation?

Description	Yes	No	NR
Never	10	14	2
Yes: In-house	7	17	2
Yes: External Consultants	11	13	2

Other :**2 respondents said that University research groups had performed measurements.**

Do you think the Manual and the Guide provide adequate guidance for such practice?

5 Yes.

5 No.

16 NR.

If no, in which areas would you like to see improvements?

All respondents that replied no indicated that the calculations were too conservative.

II-8. Has your agency considered the in-situ condition of a bolted or welded detail in estimating its remaining fatigue life? For example, consideration of internal defects, corrosion, material toughness, etc.

6 Yes.

11 No.

7 Don't know.

III. Methods of Treating Distortion-induced Fatigue Cracks and Estimating Life

III-1. Has your agency experienced distortion-induced fatigue cracking?

21 Yes.
4 No. If no, please skip to Section IV below.
1 NR.

If yes, is it more often observed than load-induced fatigue cracking?

15 Yes.
4 No.
7 NR.

III-2. When a distortion-induced fatigue crack is identified, do you

21 repair or retrofit,

16 monitor

5 NR.

All 20 states that responded to this question said that they repair/retrofit and 14 of those states also monitor. Several of these states indicated that they would repair/retrofit major cracks and monitor minor cracks.

III-3. If your agency performs repair or retrofit for distortion-induced fatigue cracks, please provide more details of the repair/retrofit schemes, or a contact person who is familiar with the details.

____.

III-4. For distortion-induced fatigue cracking observed, have you performed further analysis to estimate the time to possible facture?

5 Yes.

15 No.

6 NR.

If yes, please describe the approach used

.

Respondents indicated strain measurements would be taken and then fracture mechanics or finite elements models would be used to estimate.

IV. Retrofit and Repair for Fatigue Cracks

IV-1. Does your agency retrofit or repair details that cracked due to fatigue?

21 Yes.

2 No.

3 NR.

If yes, please provide details for repairing and/or retrofitting fatigue cracks used and/or a contact person for more detailed information

____.

V. Further Comments and/or Information

V-1. If you are aware of any efforts to improve steel bridge fatigue evaluation or any study relevant to this subject, not necessarily limited to those associated with your agency, please kindly provide contact information below for us to acquire more details.

A.3 Copy of Fatigue Expert Questionnaire

NCHRP Project 12-81

Evaluation of Fatigue on the Serviceability of Highway Bridges

1. Are you aware of any new steel fatigue test results/data (constant or variable amplitude) that we should include in the updated version of the Manual (or any other steel bridge fatigue evaluation and design specifications)? If yes, could you please provide some information on how we may be able to obtain the data? ______________________________
____
____

2. Which areas in Section 7 of the Manual (or any steel bridge fatigue evaluation and design specifications) should be revised / updated to reflect latest research and development progress? If any please also briefly explain why. ______________________________
____
____

3. Are there measures that you would suggest to address negative fatigue lives when evaluating a structural detail? If so please briefly explain why. ______________________
____
____

4. What may be future changes / revisions for Section 7 of the Manual (or any steel bridge fatigue evaluation and design specifications), and why?______________________________
____
____

5. If you have any further comments relevant to NCHRP Project 12-81, please provide them here.____
____
____

Please return to the survey to:

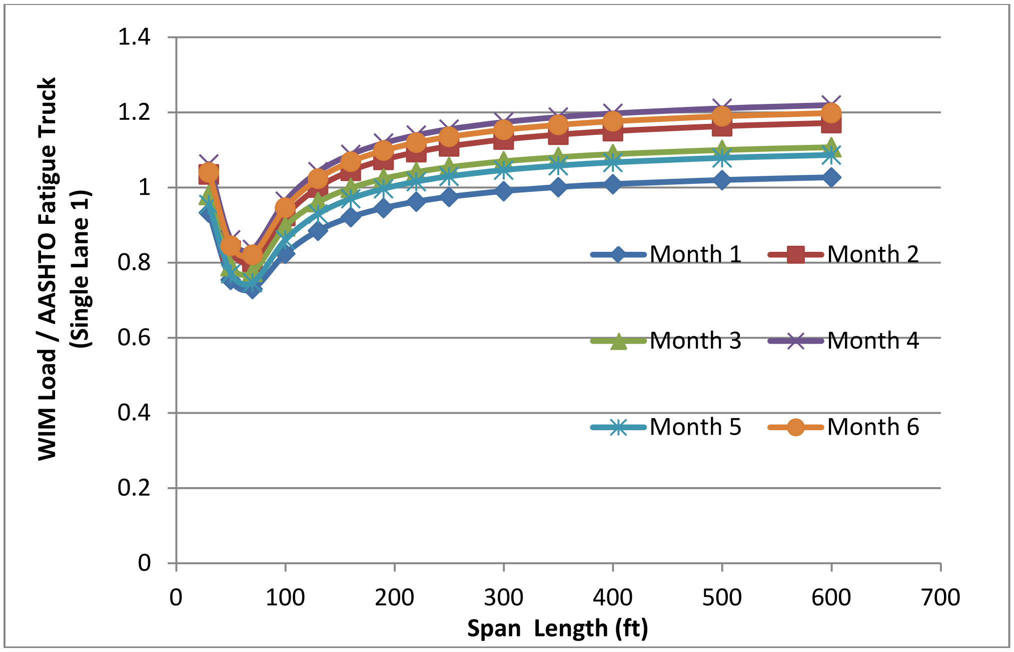
Dr. Mark Bowman, PE; bowmanmd@ecn.purdue.edu

School of Civil Engineering, Purdue University, 550 Stadium Mail Drive

West Lafayette, IN 47907; (765)494-0395(fax); (765)494-2220(voice)

APPENDIX B

AASHTO FATIGUE TRUCK VALIDATION ANALYSIS RESULTS



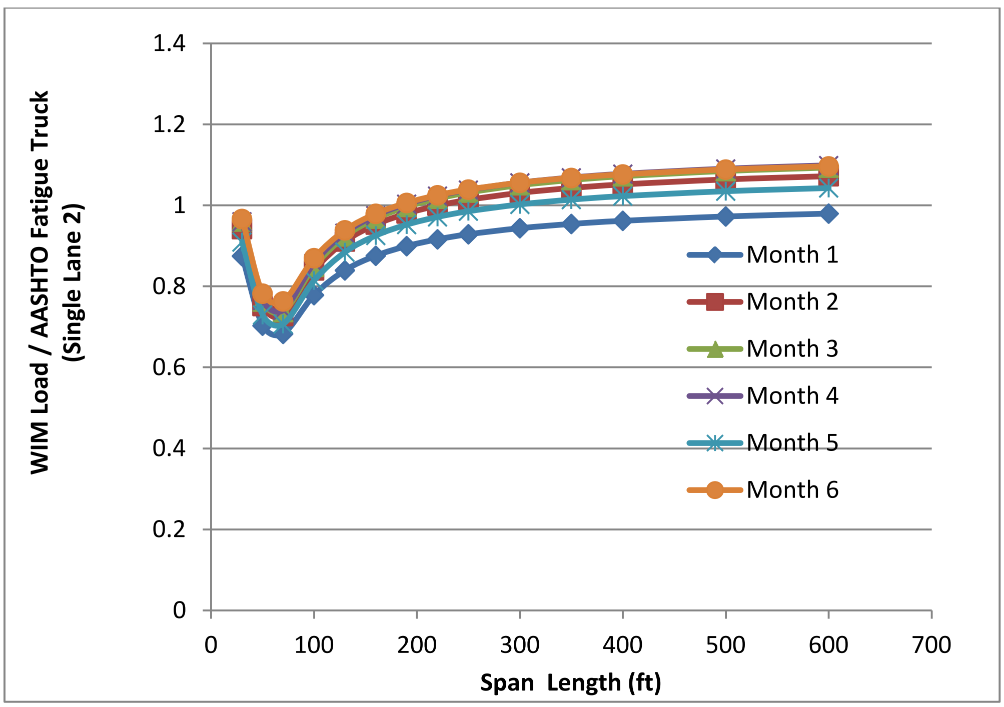
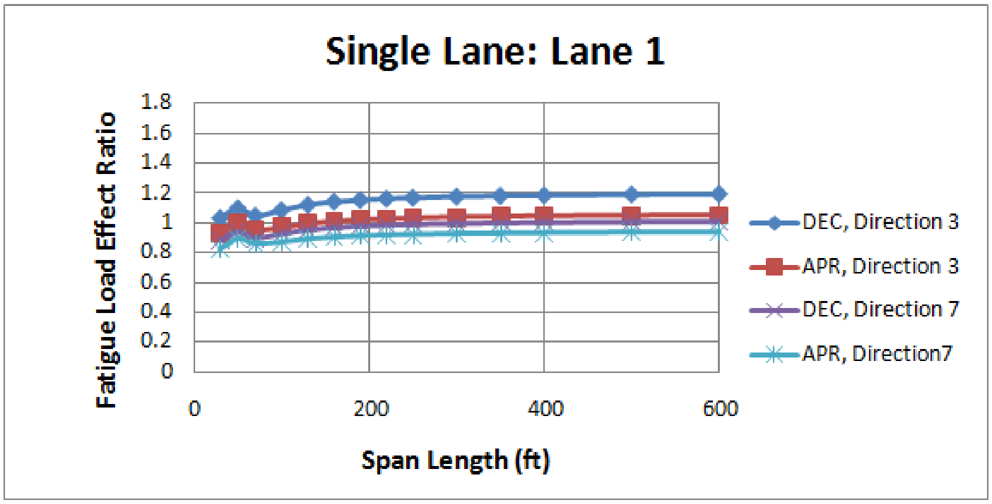


Figure B-1 Ratio of WIM Load Effect and AASHTO Fatigue Truck Load Effect for Single Lanes: New York Site 8280 in Year 2003 with 2 Lanes (ADTT=1,386/lane)
(left) Lane 1; (right) Lane 2



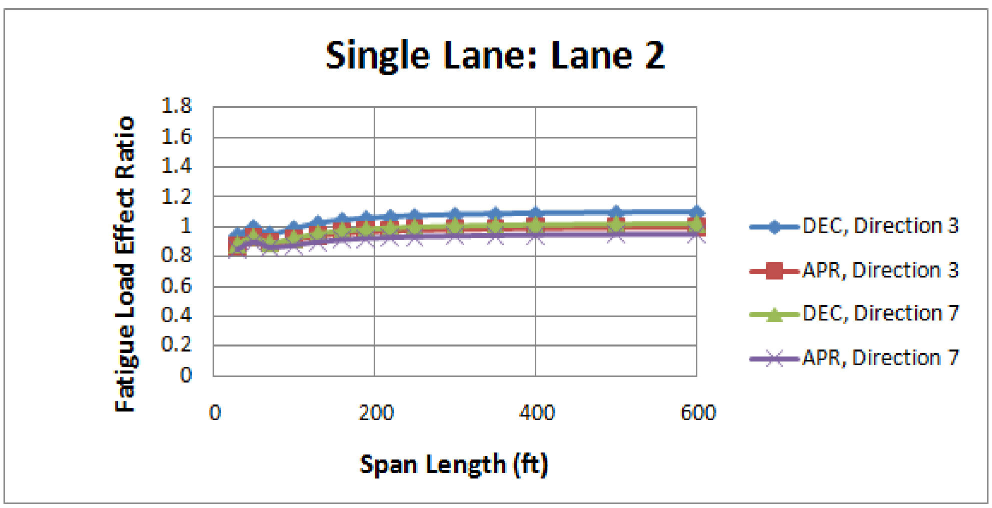
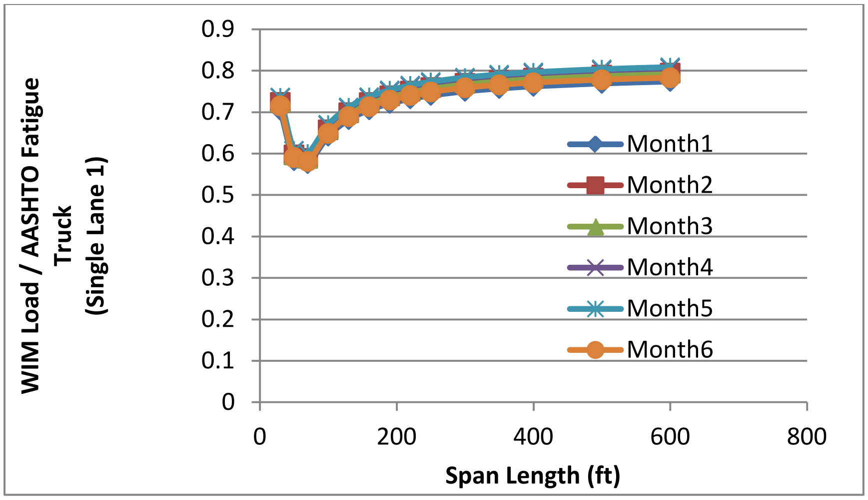
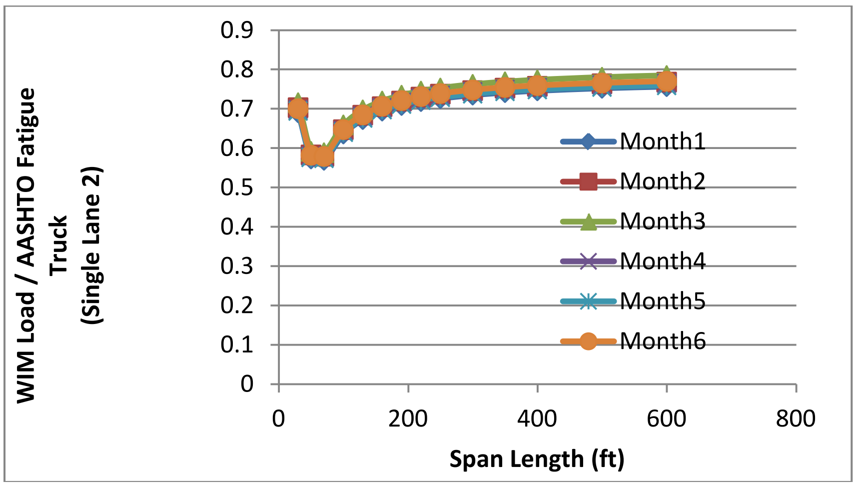


Figure B-2 Ratio of WIM Load Effect and AASHTO Fatigue Truck Load Effect for New York Site 8382 in Year 2003: Single Lanes 1 and 2 (ADTT=875/lane)





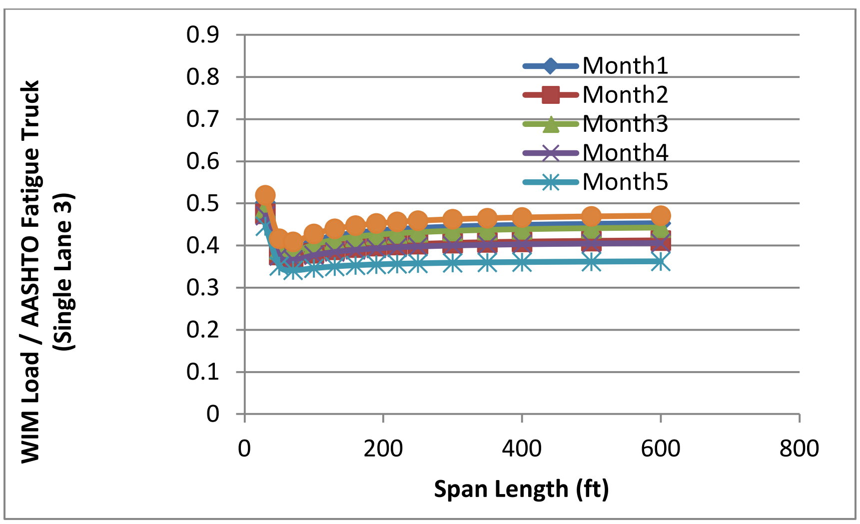
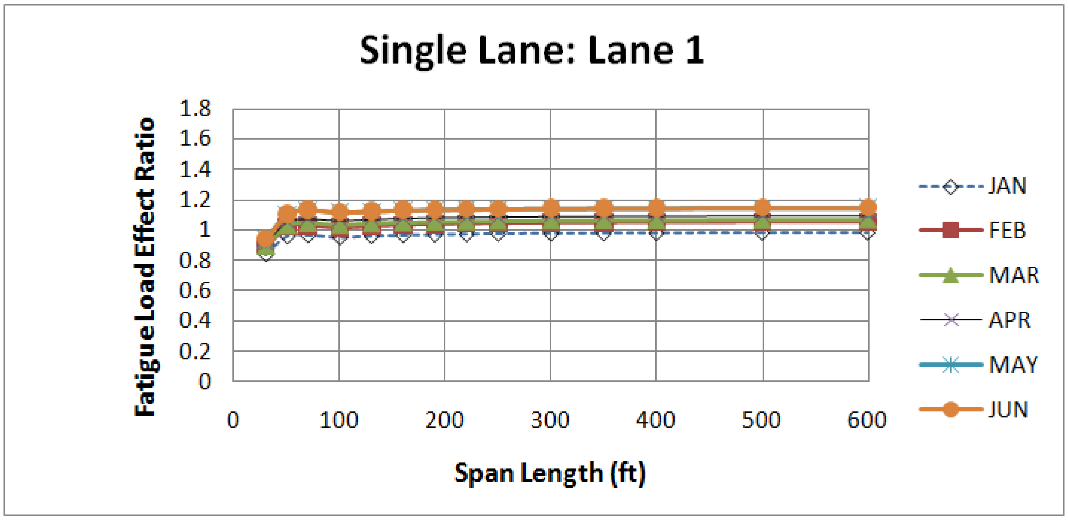


Figure B-3 Ratio of WIM Load Effect and AASHTO Fatigue Truck Load Effect for Single Lanes: California Site 710-SB in 2007 with 3 Lanes (ADTT = 4,703/lane)
(left) Lane 1; (middle) Lane 2; (tight) Lane 3



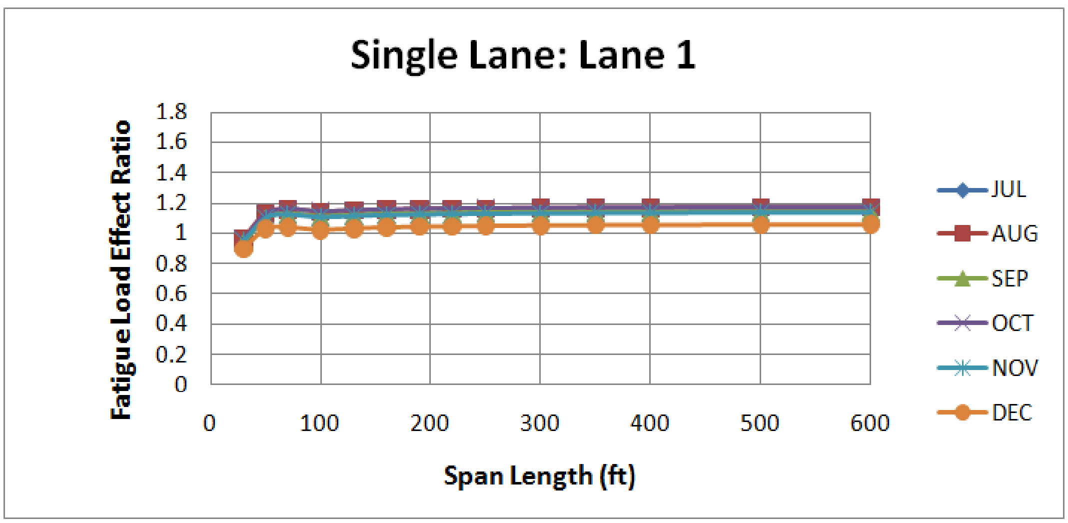
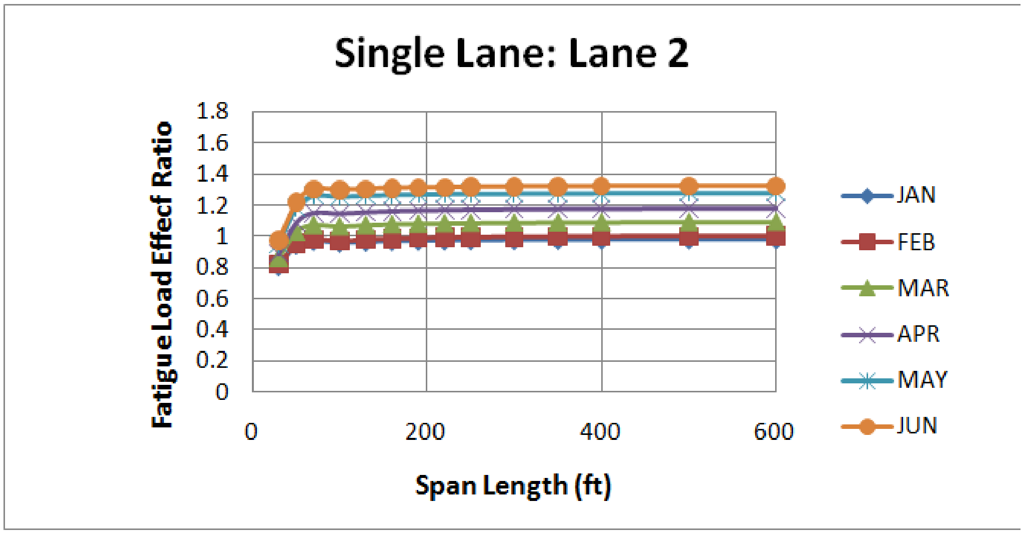


Figure B-4 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for Michigan Site 829209 in Year 2007: Single Lane 1 (ADTT=2,450/lane)



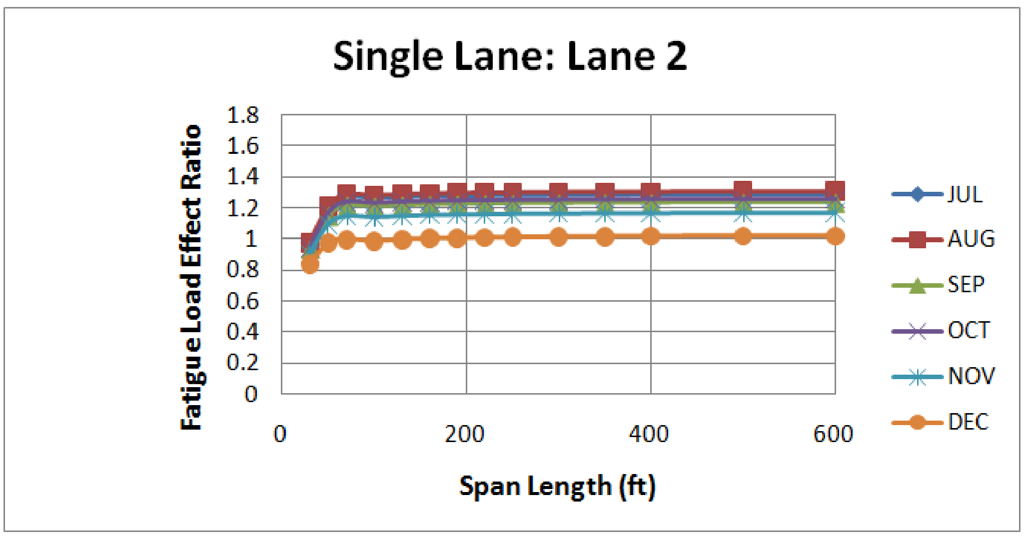


Figure B-5 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for Michigan Site 829209 in Year 2007: Single Lane 2 (ADTT=2,450/lane)

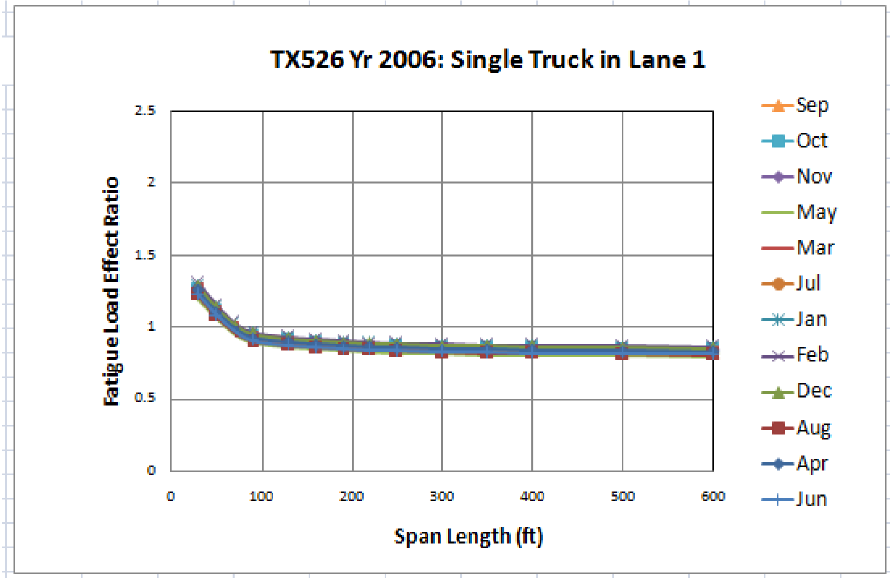


Figure B-6 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 2-lane Texas Site for (a) Lane 1 in 2006 (ADTT= 61/lane)

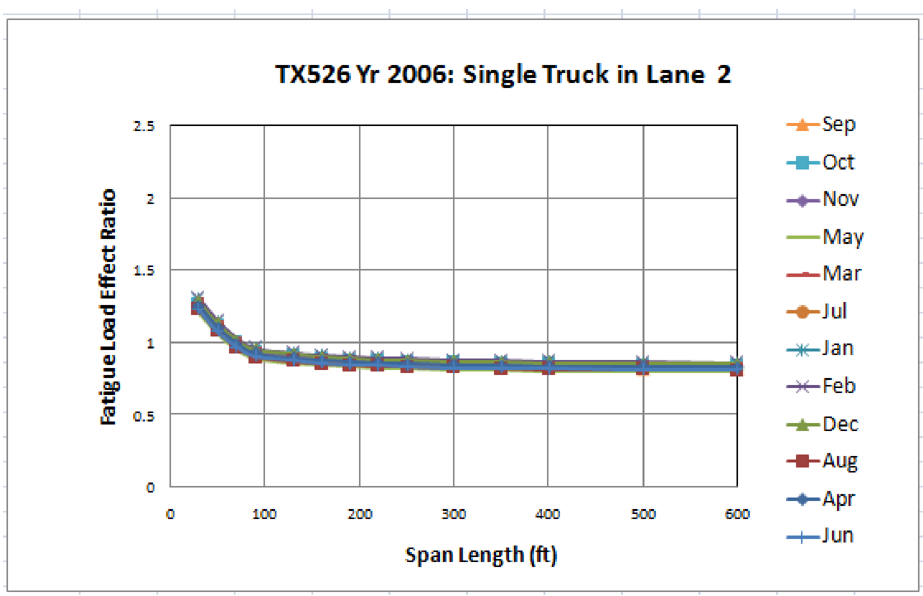


Figure B-6 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 2-lane Texas Site for (b) Lane 2 in 2006 (ADTT= 61/lane)

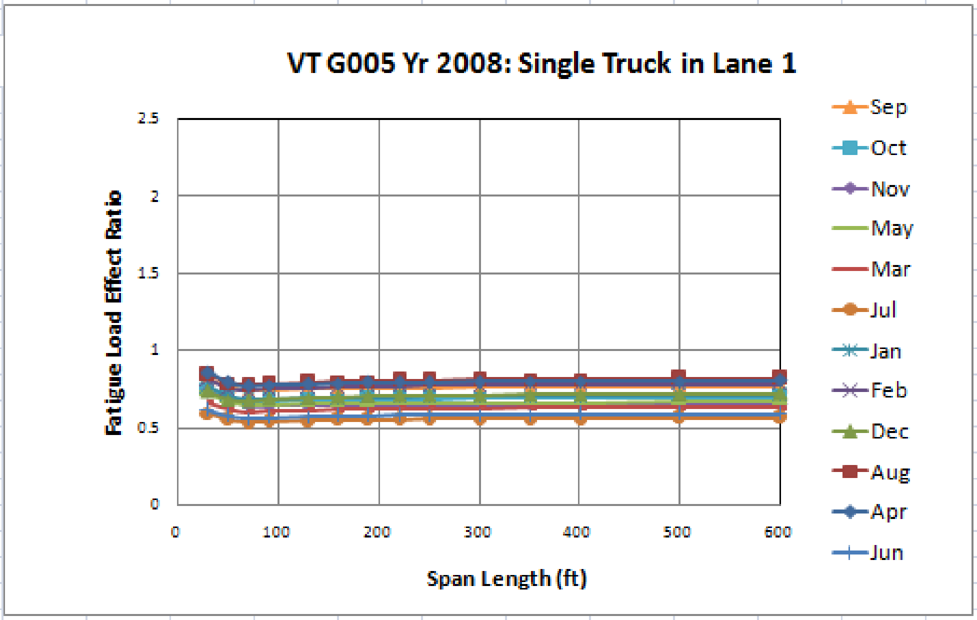


Figure B-7 Ratio of WIM Truck Load Effect vs. AASHTO Fatigue Truck Load Effect for A 2-lane Vermont Site for (a) Lane 1 (ADTT= 131/lane)

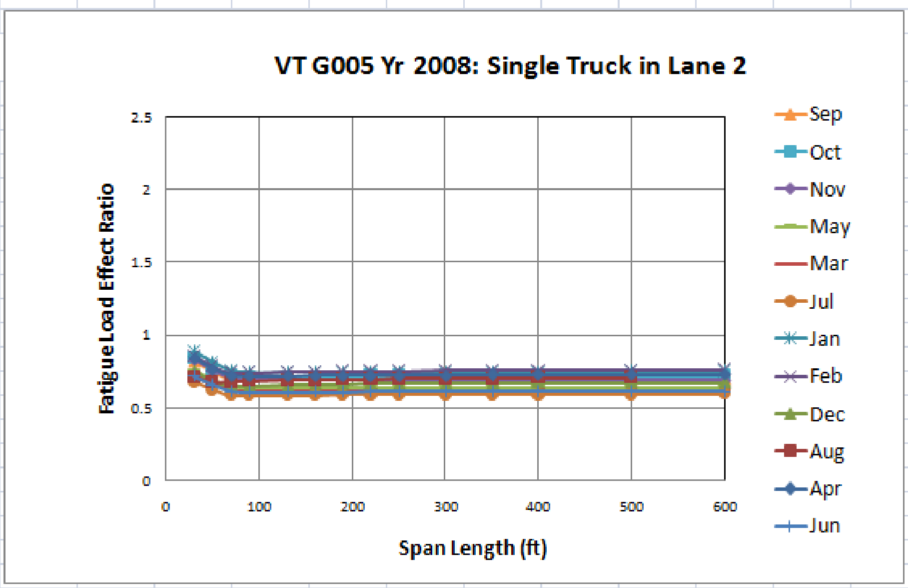


Figure B-7 Ratio of WIM Truck Load Effect vs. AASHTO Fatigue Truck Load Effect for A 2-lane Vermont Site for (b) Lane 2 (ADTT= 131/lane)

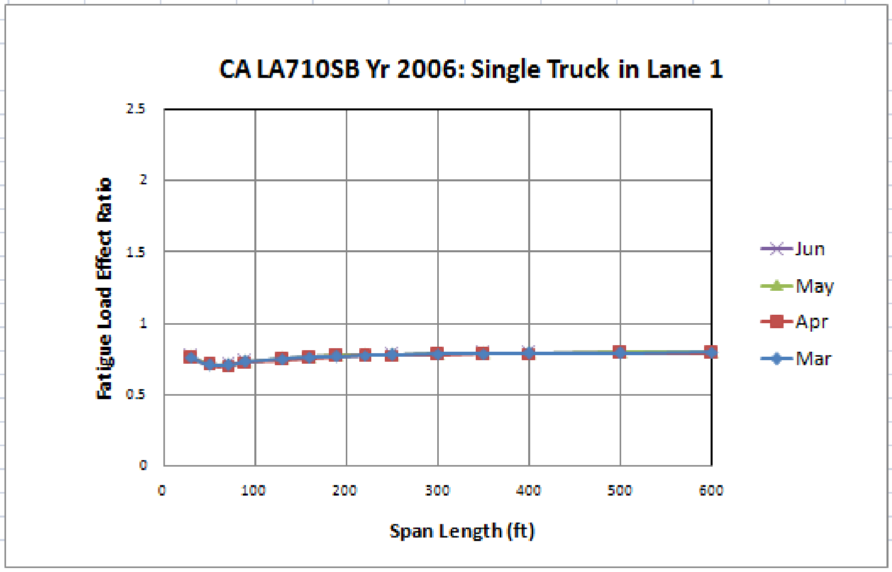


Figure B-8 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 3-lane California Site for (a) Lane 1 (ADTT=4,667/lane)

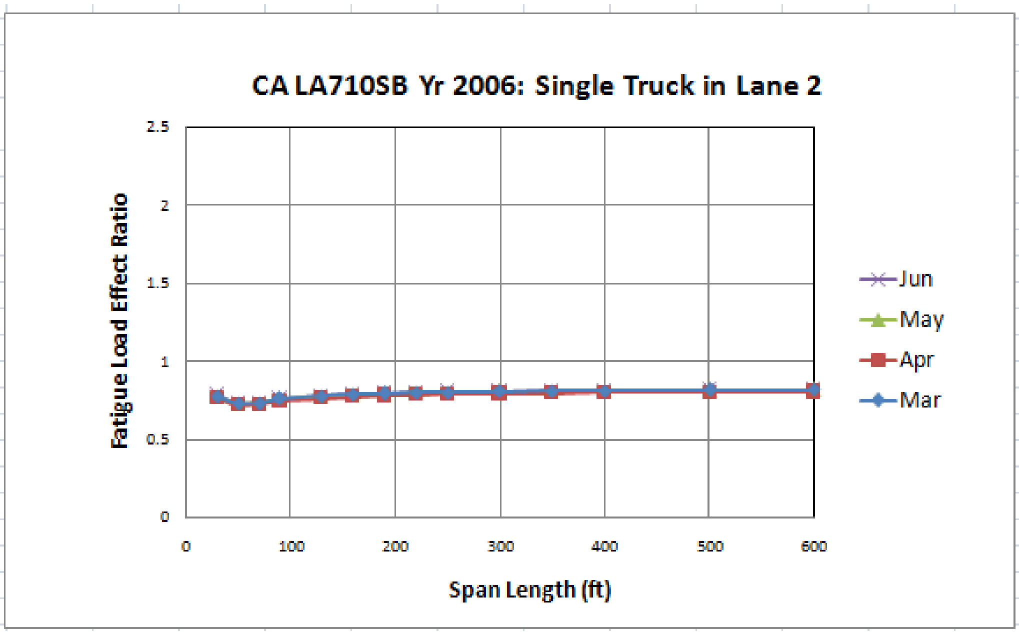


Figure B-8 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 3-lane California Site for (b) Lane 2 (ADTT=4,667/lane)

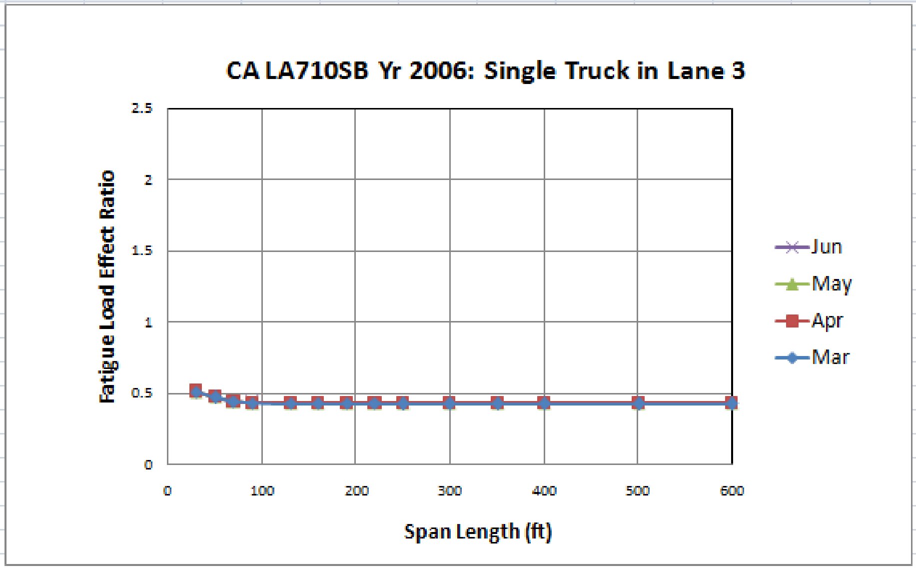


Figure B-8 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 3-lane California Site for (c) Lane 3 (ADTT=4,667/lane)

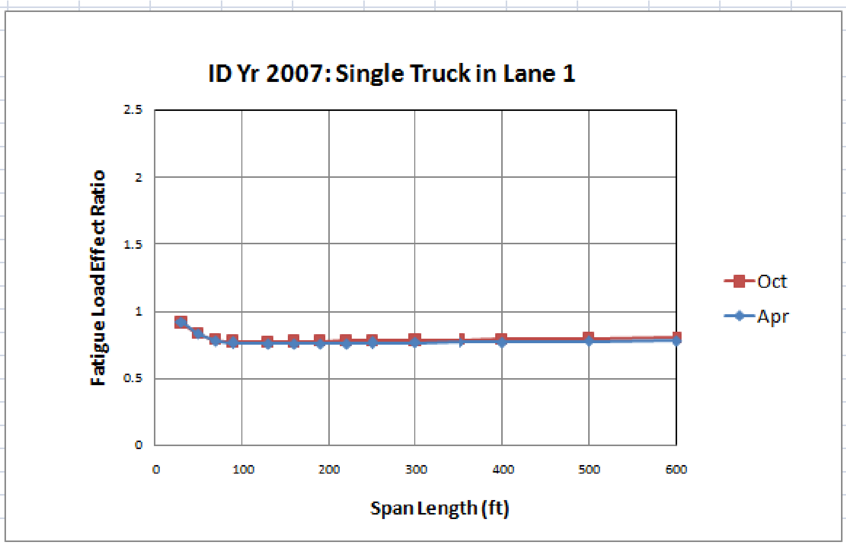


Figure B-9 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 3-lane Idaho Site (a) for Lane 1 (ADTT=367/lane)

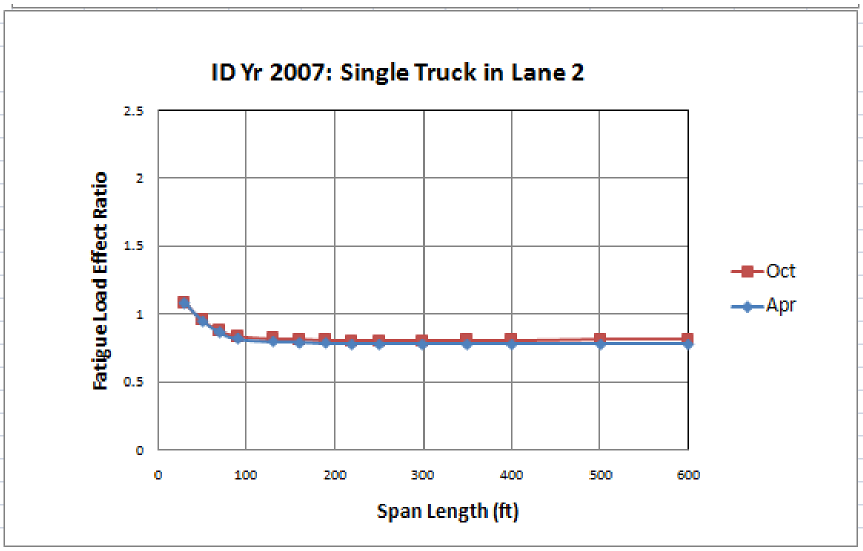


Figure B-9 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 3-lane Idaho Site (b) for Lane 2 (ADTT=367/lane)

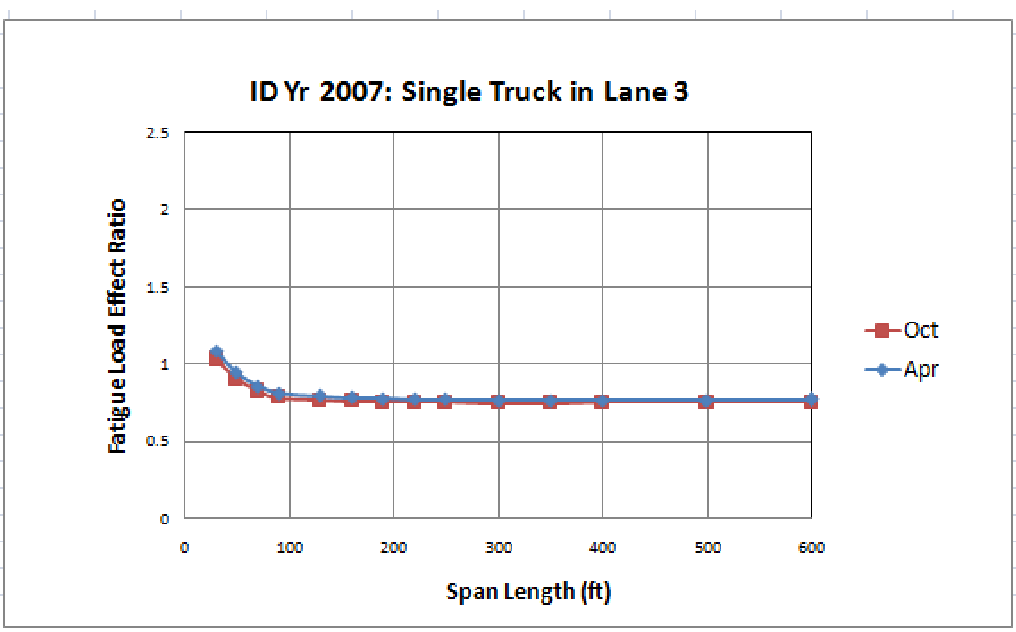


Figure B-9 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 3-lane Idaho Site (c) for Lane 3 (ADTT=367/lane)

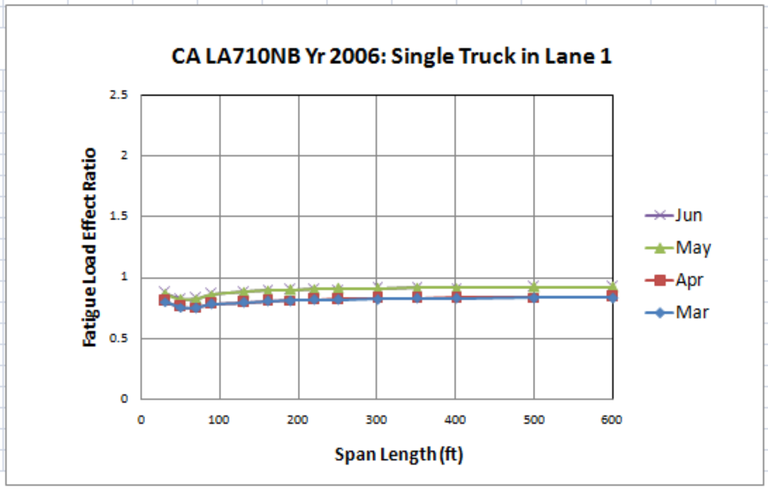


Figure B-10 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane California Site (a) for Lane 1 (ADTT=3,550/lane)

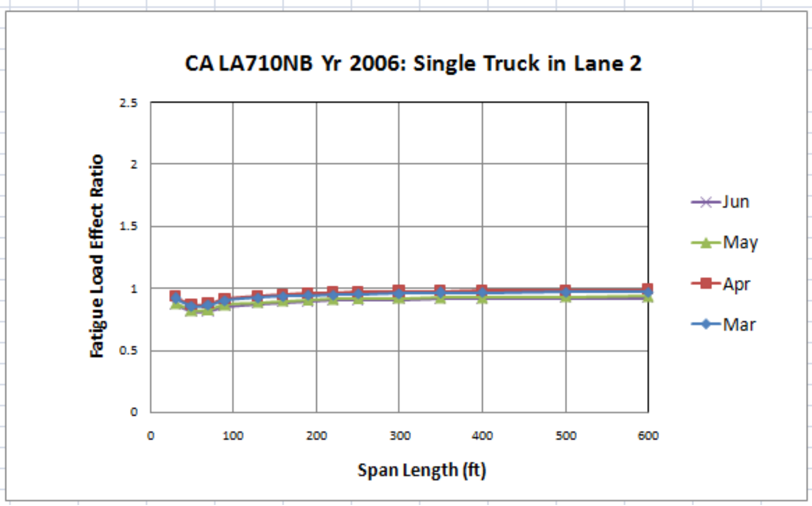


Figure B-10 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane California Site (b) for Lane 2 (ADTT=3,550/lane)

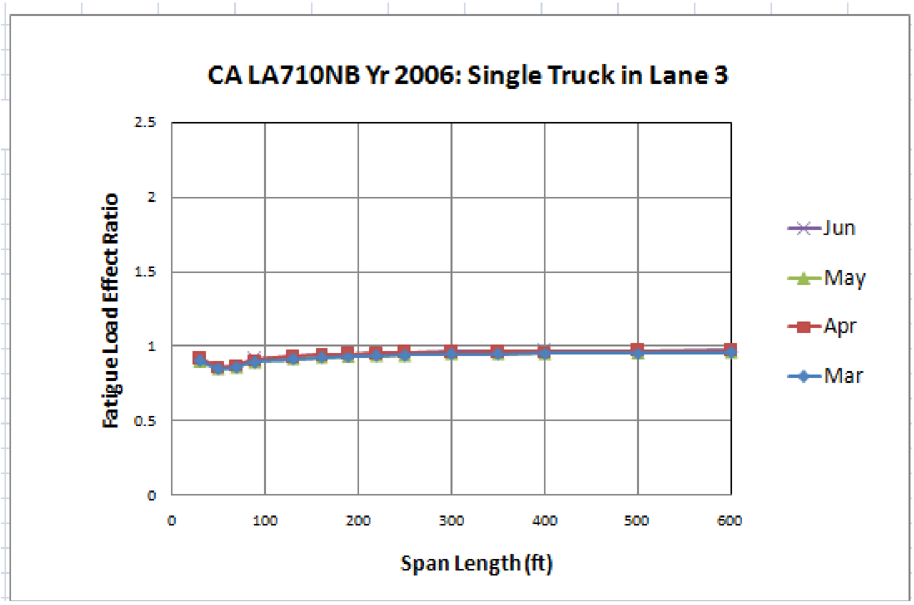


Figure B-10 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane California Site (c) for Lane 3 (ADTT=3,550/lane)

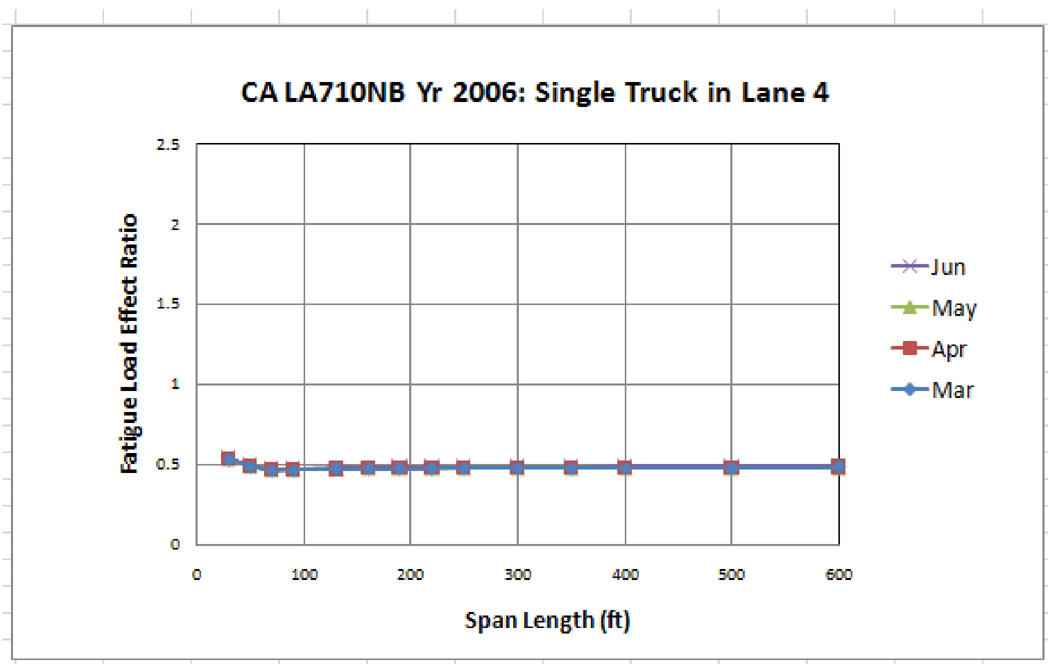


Figure B-10 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane California Site (d) for Lane 4 (ADTT=3,550/lane)

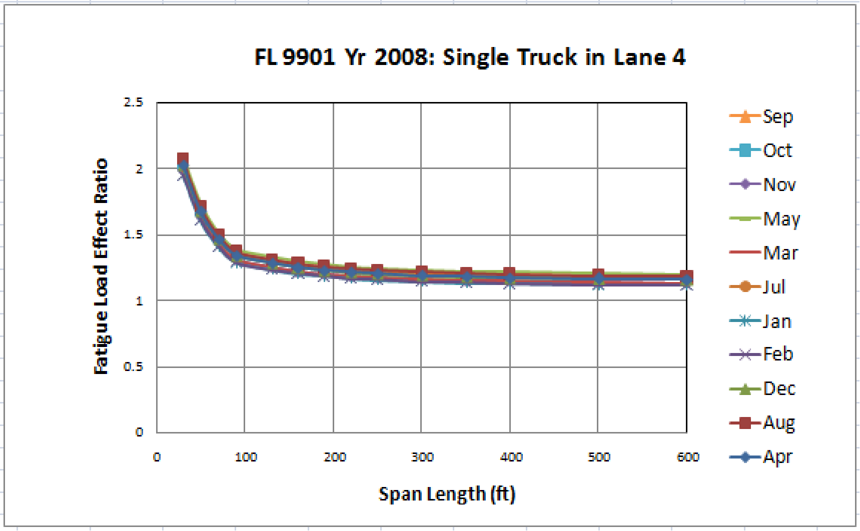


Figure B-11 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane Florida Site (a) for Lane 1 (ADTT=1,250/lane)

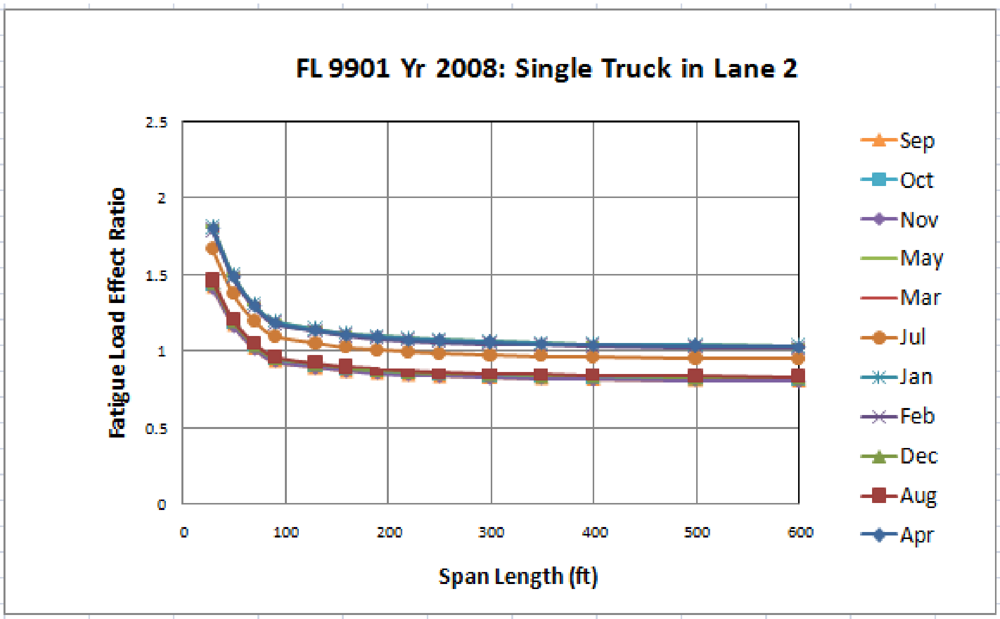


Figure B-11 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane Florida Site (b) for Lane 2 (ADTT=1,250/lane)

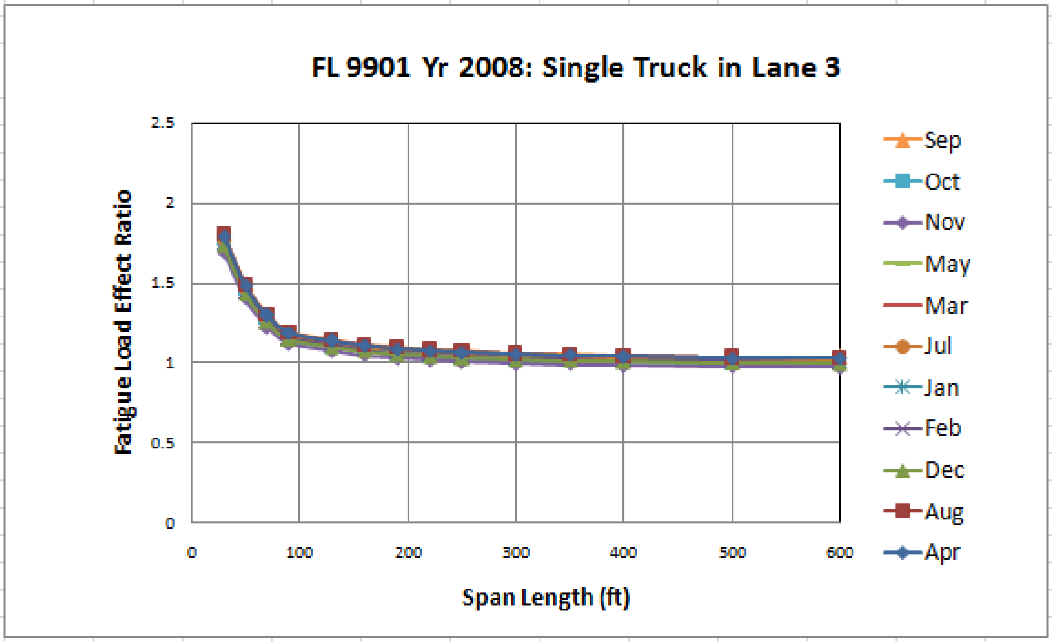


Figure B-11 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane Florida Site (c) for Lane 3 (ADTT=1,250/lane)

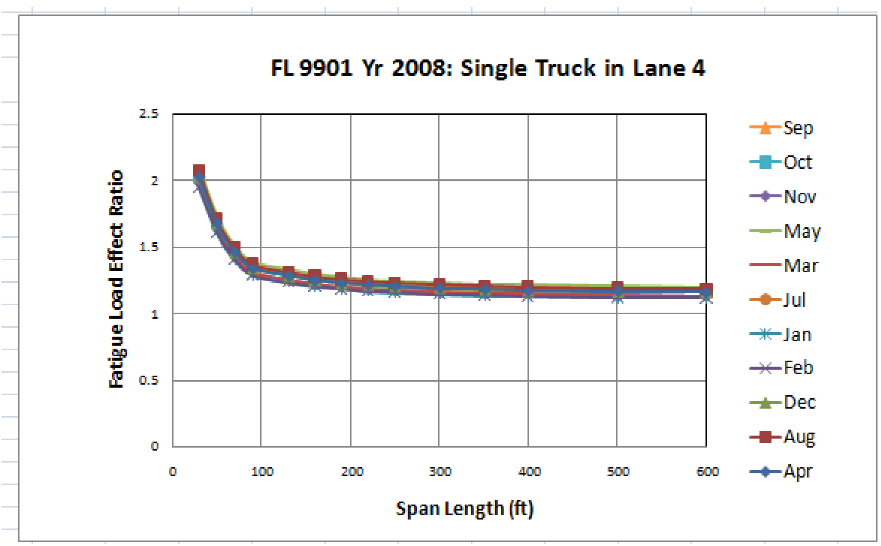


Figure B-11 Ratio of WIM Truck Load Effect and AASHTO Fatigue Truck Load Effect for A 4-lane Florida Site (d) for Lane 4 (ADTT=1,250/lane)

APPENDIX C

TACK WELD TESTS

C.1 Tack Weld Test Matrix and Results Summary

The test matrix for the program is shown in Table C-1. Here ‘MP’ denotes modified position tack weld specimen where the leading line of tack welds is shifted such that the tack weld toes are in line with the center of the adjacent bolt holes. ‘FT’ indicates specimen where the bolts are fully tightened along with the welds being in the modified position. The sign convention used for the tack weld test specimens is show in Figure C-1 as follows:

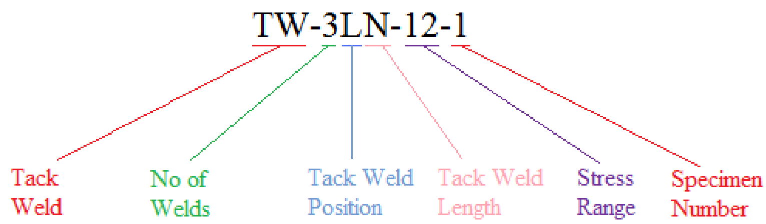


Figure C-1: Specimen Naming Convention

Seventeen specimens were tested. The tack welds were deposited by an American Welding Society certified welder. The welding was performed using Shielded Metal Arc Welding (SMAW) with a Miller Syncrowave 351 machine. The SMAW electrode used for fabricating the tack welds is 1/8 inch diameter E7018 H4R electrode. Normal length tack welds ‘N’ are about an inch in length while long welds ‘L’ are about 1.5 inches in length. Tack weld position can be longitudinal ‘L’ i.e. parallel to the edges to the lap plates or can be transverse ‘T’ i.e. on the top horizontal edge of the lap plates, perpendicular to the direction of the applied force.

No. of Tack Welds	Tack Weld Position	Tack Weld Length	No. of Specimens Tested at S_r Value		
			20 ksi	12 ksi	12 ksi
2	L	<1-in		2	
3	L	<1-in	3	3	2 (FT)
2	L	<1-in		3 (MP)	
2	T	<1-in		2	
3	L	>1-in		2	

Table C-1: Tack Weld Test Program Matrix

The summary of the results of the tack weld tests is shown in Table C-2.

S.No.	**Specimen**	**Elapsed Cycles** (* denotes runouts)	**Stress (ksi)**	**Specimen Condition**
1	TW-3LN-12-1	5,253,000*	12	No cracks
2	TW-3LN-12-2	5,103,000*	12	No cracks
3	TW-3LN-12-3	6,316,000	12	Crack at weld toe spreading into bolt hole
4	TW-3LN-20-1	1,066,000	20	Crack at weld toe spreading into bolt hole
5	TW-3LN-20-2	843,000	20	Crack at weld toe spreading into bolt hole
6	TW-3LN-20-3	1,294,000	20	Crack at weld toe just starting to spread into plate thickness
7	TW-3LL-12-1	6,223,000*	12	No cracks
8	TW-3LL-12-2	6,243,000	12	Crack at weld toe spreading into bolt hole
9	TW-2LN-12-1	8,324,000	12	Crack at weld toe, crack length 21/32 inch
10	TW-2LN-12-2	8,259,000	12	Two cracks; one remaining at weld toe and the other spreading ¼ inch into plate thickness
11	TW-2LM-12-1	7,061,000	12	Crack at weld toe spreading into bolt hole
12	TW-2LM-12-2	6,507,000	12	Three cracks; Two cracks spreading into bolt hole and the other spreading ¼ inch across plate width.
13	TW-2LM-12-3	7,400,000	12	Two cracks; one spreading into bolt hole and the other spreading 1/8 inch across plate width.
14	TW-3LF-12-1	7,667,000*	12	No cracks
15	TW-3LF-12-2	7,546,000*	12	No cracks
16	TW-2TN-12-1	5,513,000	12	Crack at weld toe spreading into bolt hole
17	TW-2TN-12-2	7,570,000*	12	No cracks

Table C-2: Results of Tack Weld Tests (for Net Section Stress)

C.2 Tack Weld Test Results

Shown in the following are geometrical details and observations for each test specimen.

Specimen TW-3LN-12-1 (Specimen 1):

This is the initial test specimen for the tack weld tests.

Weld Parameter Conditions

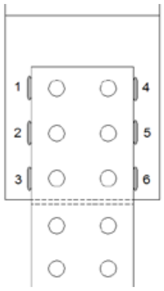


Figure C-2: Tack Weld Configuration

This specimen has three longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

The specimen did not experience any fatigue cracking.

Cycles till failure or test completion

The test was stopped after 5,253,000 cycles of loading.

Specimen TW-3LN-20-1 (Specimen 2):
Weld Parameter Conditions

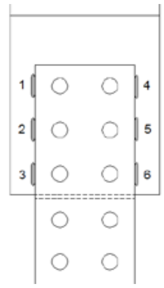


Figure C-3: Tack Weld Configuration

This specimen has three longitudinal welds of normal length on each side.

Load Conditions
Subjected to a 20 ksi stress range on the net section with an R-ratio of 0.1.
Observed cracks, photos, anomalies if any
Two fatigue cracks were observed in the lower tack welds. The fatigue cracks started in the toe of the welds and spread into the splice plate transversely. This is a more critical fatigue failure case than if the crack spreads longitudinally along the length of the tack weld.

Fig C-4: Fatigue crack in lower right weld on front side of specimen spreading transversely into the splice plate

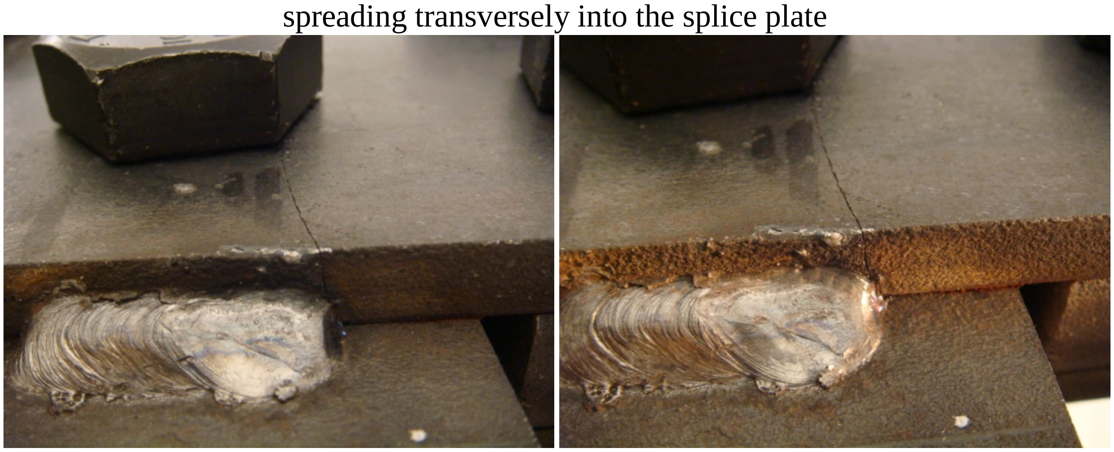


Fig C-5: Fatigue crack in lower left weld on back side of specimen spreading transversely into the splice plate

Cycles till failure or test completion

Failure occurred after 1,066,000 cycles were completed.

Specimen TW-3LN-20-2 (Specimen 3):

Weld Parameter Conditions

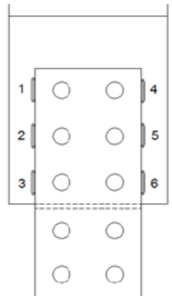


Figure C-6: Tack Weld Configuration

This specimen has three longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 20 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

One crack initiated at lower right weld toe on back face and spread into the adjacent bolt hole.

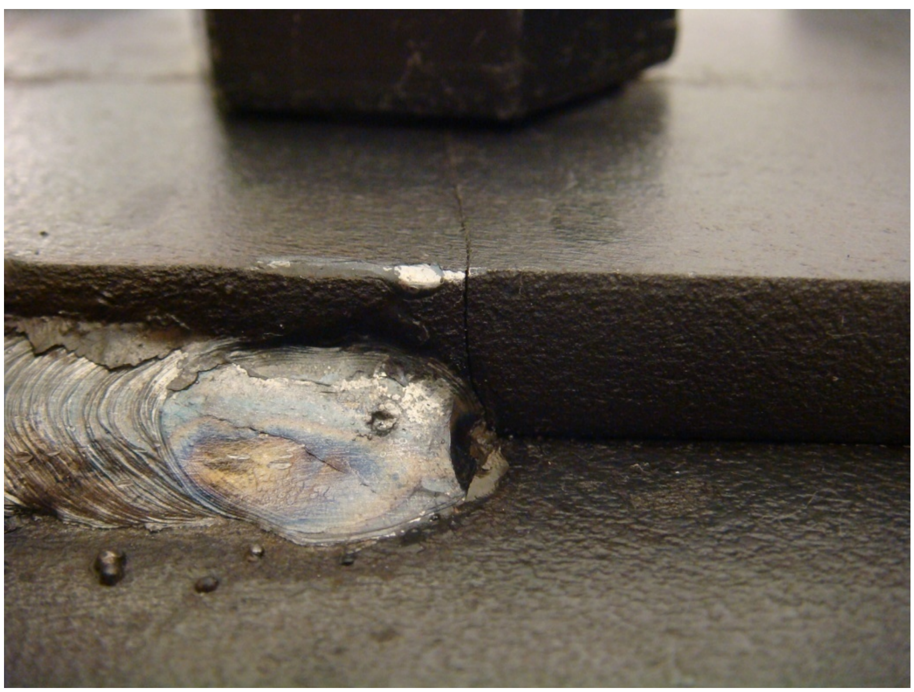


Figure C-7: Fatigue crack at lower right tack weld toe on back face for specimen TW-3LN-20-2

Cycles till failure or test completion

Failure occurred after 843,000 cycles of loading.

Specimen TW-3LN-12-2 (Specimen 4):

Weld Parameter Conditions

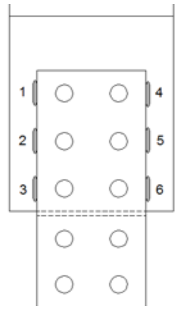


Figure C-8: Tack Weld Configuration

This specimen has three longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

This specimen did not experience any fatigue cracking.

Cycles till failure or test completion

The test was stopped after 5,103,000 cycles of loading.

Specimen TW-3LN-20-3 (Specimen 5):

Weld Parameter Conditions

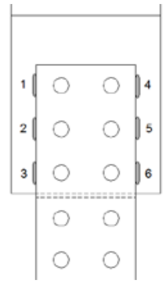


Figure C-9: Tack Weld Configuration

This specimen has three longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 20 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

Once crack at lower left tack weld toe on front face just starting to spread into plate thickness.

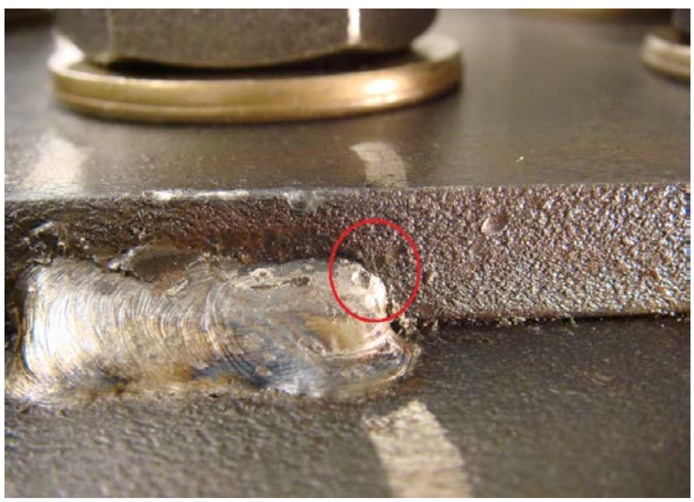


Figure C-10: Front face lower left tack weld toe crack for specimen TW-3LN-20-3

Cycles till failure or test completion

The test was stopped after 1,294,000 cycles of loading. Testing was stopped prematurely due to a power surge that caused electrical overloading which shut off the actuator’s controller. This had caused some bending of the test specimen.

Specimen TW-3LN-12-3 (Specimen 6):

Weld Parameter Conditions

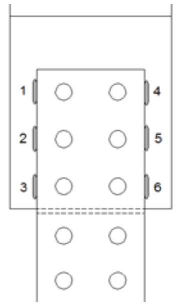


Figure C-11: Tack Weld Configuration

This specimen has three longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

One crack at front face lower right weld toe spreading into bolt hole.

Figure C-12: Fatigue crack at front face lower right tack weld toe for specimen TW-3LN-12-3

Cycles till failure or test completion

Failure occurred after 6,316,000 cycles of loading.

Specimen TW-3LL-12-1 (Specimen 7):

Weld Parameter Conditions

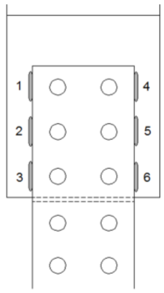


Figure C-13: Tack Weld Configuration

This specimen has three longitudinal welds of longer length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

This specimen did not experience any fatigue cracking.

Cycles till failure or test completion

The test was stopped after 6,223,000 cycles of loading.

Specimen TW-2LN-12-1 (Specimen 8):

Weld Parameter Conditions

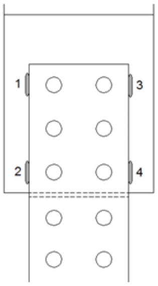


Figure C-14: Tack Weld Configuration

This specimen has two longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

One crack at back face lower left weld toe that grew to a length of 21/32 inches.

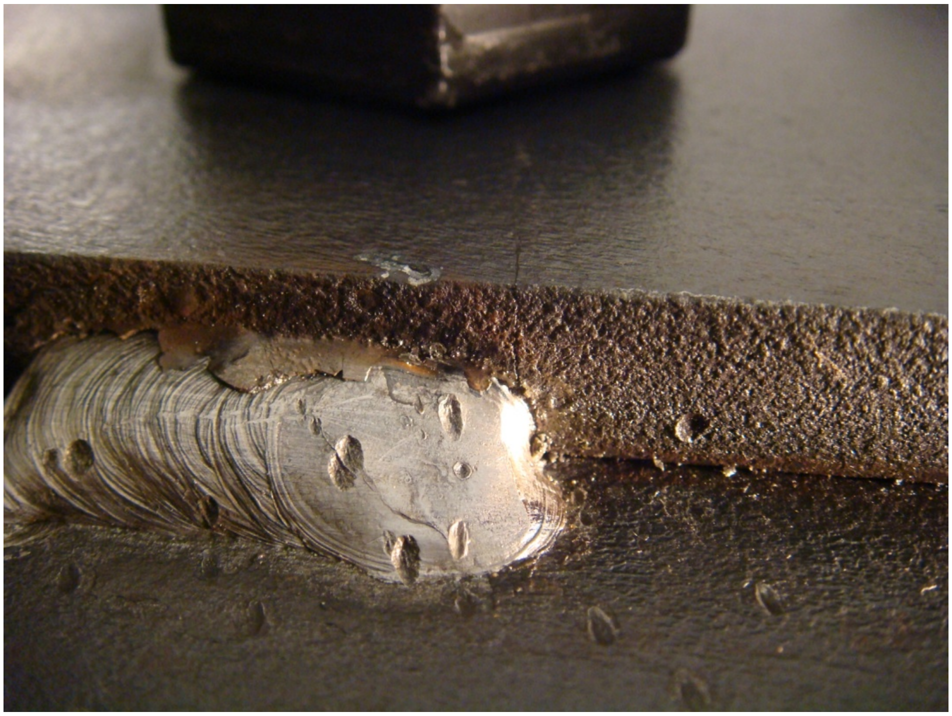


Fig C-15: Fatigue crack at tack weld toe for specimen TW-2LN-12-1

Cycles till failure or test completion

The test was stopped after 8,324,000 cycles of loading.

Specimen TW-2LN-12-2 (Specimen 9):

Weld Parameter Conditions

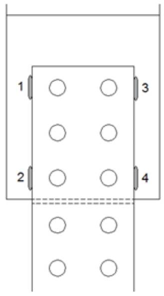


Figure C-16: Tack Weld Configuration

This specimen has two longitudinal welds of normal length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

Two cracks initiated at back face lower left weld toe and on front face lower left weld toe. Crack at front face lower left weld remained at weld toe while the other spread ¼ inches into the plate thickness.

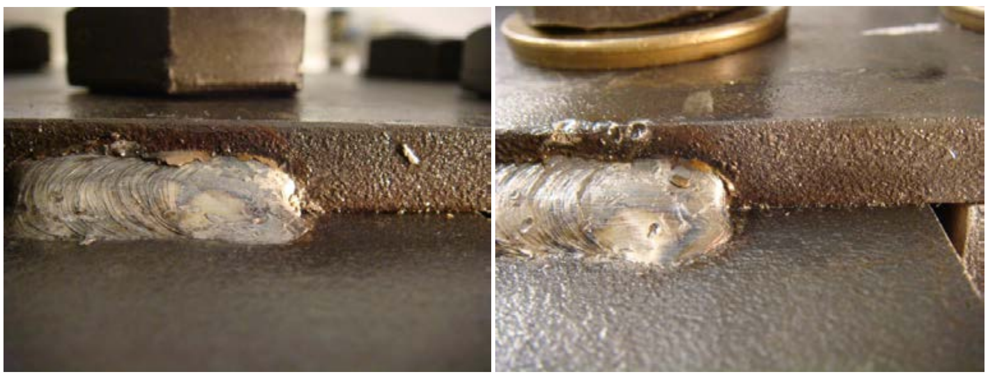


Fig C-17: Specimen TW-2LN-12-2 Cracks Initiating at Weld Toe (Back face lower left weld and front face lower left weld)

Cycles till failure or test completion

Test was stopped after 8,259,000 cycles of loading.

Specimen TW-3LL-12-2 (Specimen 10):

Weld Parameter Conditions

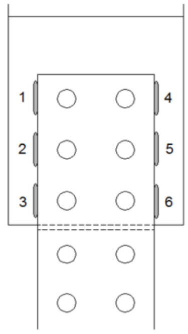


Figure C-18: Tack Weld Configuration

This specimen has three longitudinal welds of longer length on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

One crack at front face lower right weld toe spreading into bolt hole.

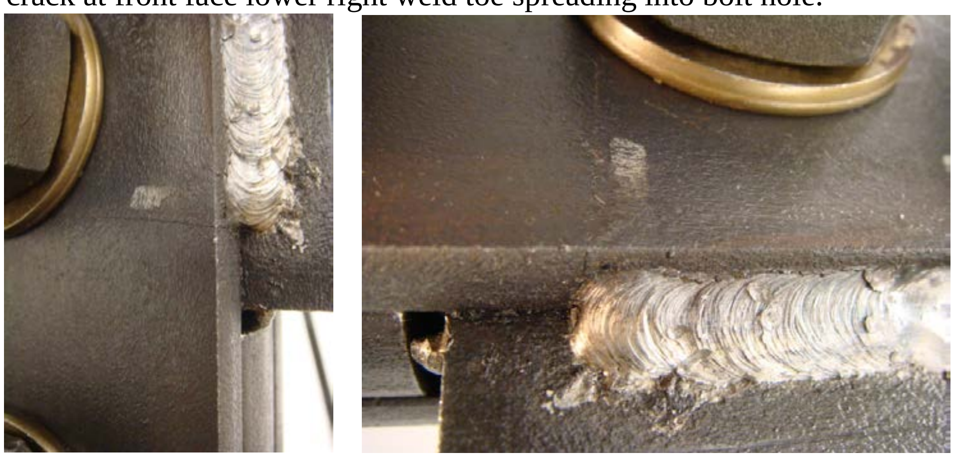


Fig C-19: Specimen TW-3LL-12-2 Weld Cracks

Cycles till failure or test completion

Failure was reached after 6,243,000 cycles of loading.

Specimen TW-2LM-12-1 (Specimen 11):

Weld Parameter Conditions

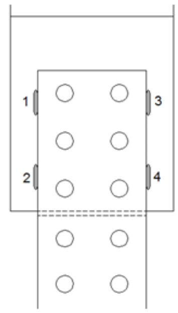


Figure C-20: Tack Weld Configuration

This specimen has two longitudinal welds of normal length in a modified position on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

Once crack at back face lower left weld toe spreading into bolt hole.

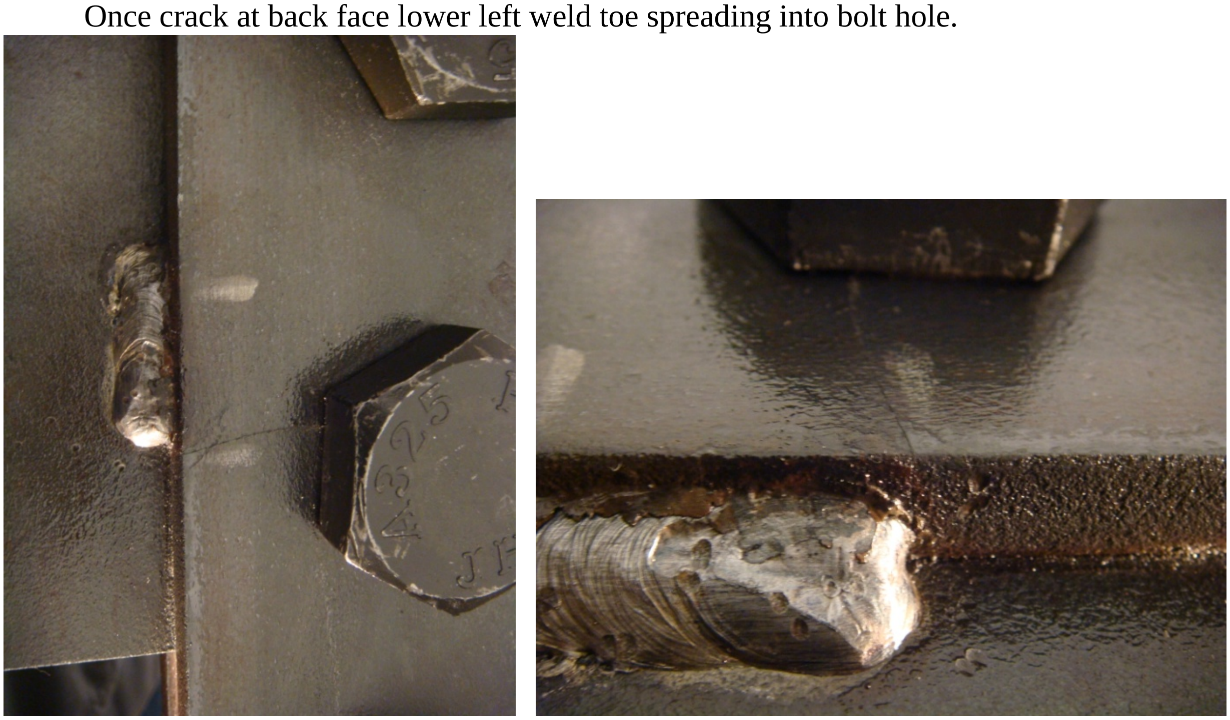


Fig C-21: Specimen TW-2LM-12-1 Crack

Cycles till failure or test completion

Failure occurred after 7,061,000 cycles of loading.

Specimen TW-2LM-12-2 (Specimen 12):

Weld Parameter Conditions

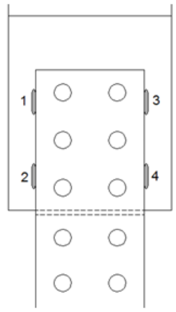


Figure C-22: Tack Weld Configuration

This specimen has two longitudinal welds of normal length in modified position on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

Three cracks; Two cracks at front face lower left weld toe and back face lower left weld toe spreading into bolt hole and the other at back face lower right weld toe spreading ¼ inch across plate width.

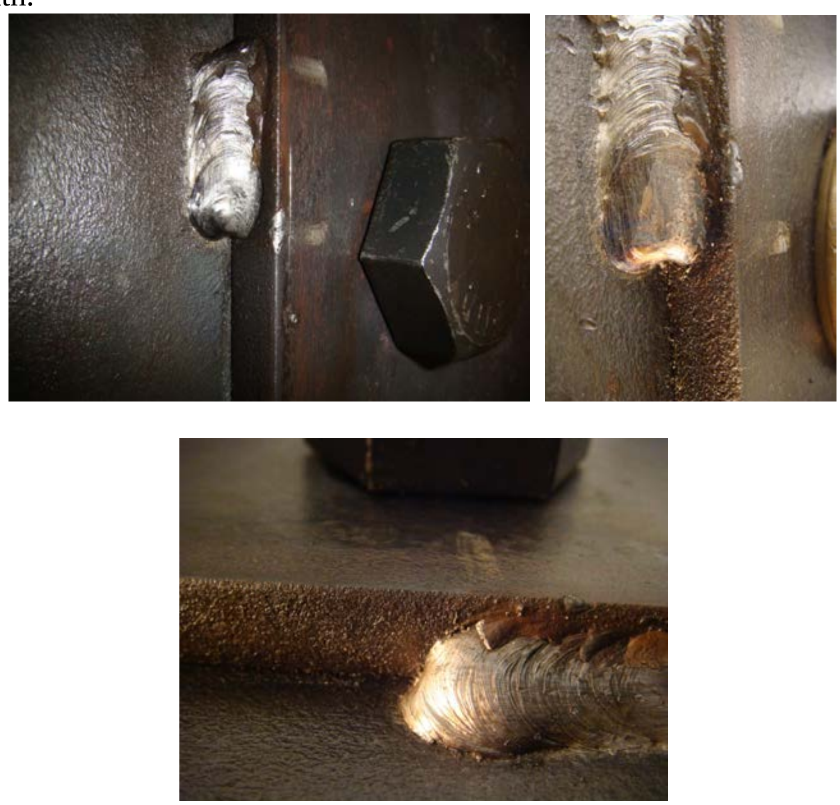


Fig C-23: Specimen TW-2LM-12-2 Tack Weld Cracks

Cycles till failure or test completion

Failure occurred after 6,507,000 cycles of loading.

Specimen TW-2LM-12-3 (Specimen 13):

Weld Parameter Conditions

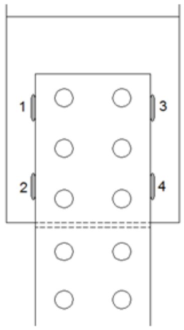


Figure C-24: Tack Weld Configuration

This specimen has two longitudinal welds of normal length in modified position on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

Two cracks; one at back face lower right weld toe spreading into bolt hole and the other at back face lower left weld toe spreading 1/8 inch across plate width.

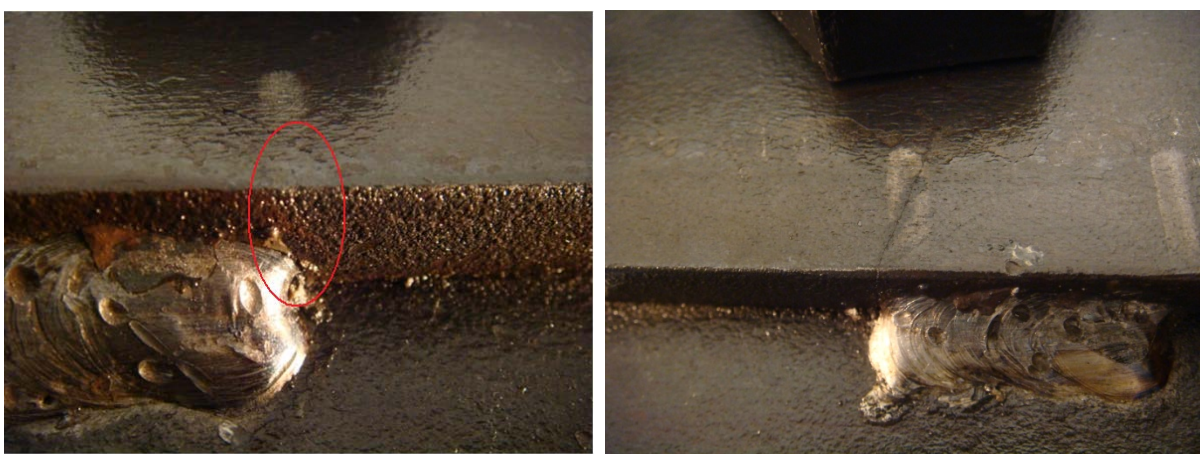


Fig C-25: Specimen TW-2LM-12-3 Tack Weld Cracks

Cycles till failure or test completion

The test was stopped after 7,400,000 cycles of loading.

Specimen TW-3LF-12-1 (Specimen 14):

Weld Parameter Conditions

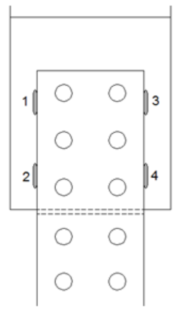


Figure C-26: Tack Weld Configuration

This specimen has three longitudinal welds of normal length with fully tightened bolts on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

This specimen did not experience any fatigue cracking.

Cycles till failure or test completion

The test was stopped after 7,667,000 cycles of loading.

Specimen TW-3LF-12-2 (Specimen 15):

Weld Parameter Conditions

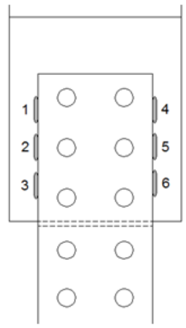


Figure C-27: Tack Weld Configuration

This specimen has three longitudinal welds of normal length with fully tightened bolts on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

This specimen did not experience any fatigue cracking.

Cycles till failure or test completion

The test was stopped after 7,546,000 cycles of loading.

Specimen TW-2TN-12-1 (Specimen 16):

Weld Parameter Conditions

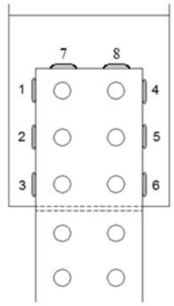


Figure C-28: Tack Weld Configuration

This specimen has two transverse welds of normal length and three longitudinal welds on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

Crack at back face lower right weld toe spreading into bolt hole.

Figure C-29: Longitudinal weld fatigue crack in specimen TW-2TN-12-1

Cycles till failure or test completion

Failure occurred after 5,513,000 cycles of loading.

Specimen TW-2TN-12-2 (Specimen 17):

Weld Parameter Conditions

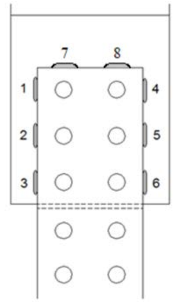


Figure C-30: Tack Weld Configuration

This specimen has two transverse welds of normal length and three longitudinal welds on each side.

Load Conditions

Subjected to a 12 ksi stress range on the net section with an R-ratio of 0.1.

Observed cracks, photos, anomalies if any

This specimen did not experience any fatigue cracking.

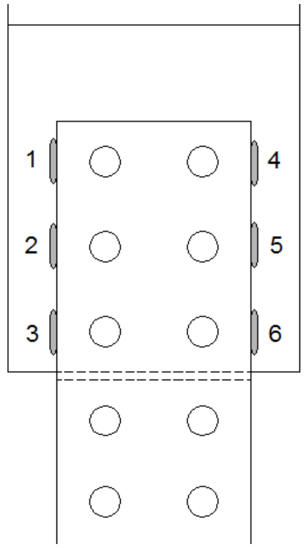
Cycles till failure or test completion

The test was stopped after 7,570,000 cycles of loading.

C.3 Tack Weld Dimensions

The dimensions of the tack welds for each test specimen are shown on the following pages. The sizes reported are an average value based upon three measurements for each weld. Face 1 and 2 refer to the welds on the front and back sides of the main plate.

Specimen 1 (TW-3LN-12-1)

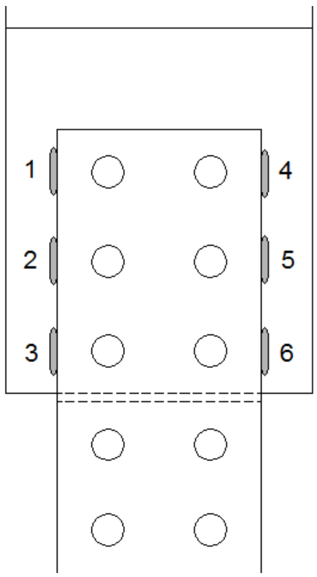


Splice Plate:
Width: 5.985 in
Thickness: 0.37 in, 0.37 in

Main Plate:
Thickness: 0.763 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.205	1.375	1	0.24	1.125
2	0.215	1.3125	2	0.225	1.125
3	0.2075	1.3125	3	0.225	1.25
4	0.205	1.3125	4	0.25	1
5	0.2025	1.25	5	0.23	1.25
6	0.2425	1.25	6	0.2425	1.125

Specimen 2 (TW-3LN-20-1)

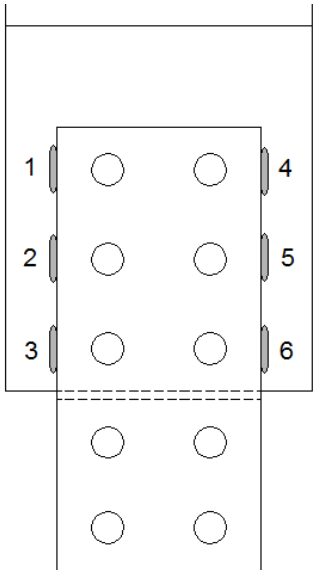


Splice Plate:
Width: 5.986 in
Thickness: 0.369, 0.37 in

Main Plate:
Thickness: 0.762 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.205	1.375	1	0.205	1.375
2	0.2375	1.375	2	0.1925	1.375
3	0.1975	1.375	3	0.1825	1.25
4	0.1875	1	4	0.17	1.25
5	0.2	1.375	5	0.2175	1.375
6	0.1875	1.25	6	0.195	1.25

Specimen 3 (TW-3LN-20-2)

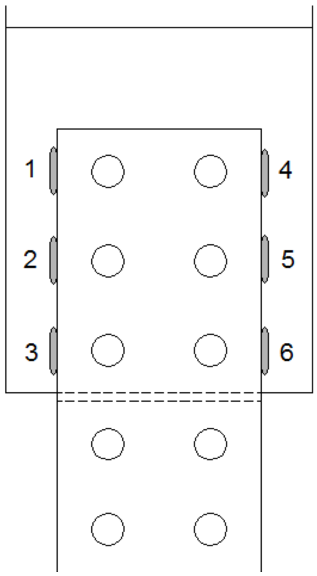


Splice Plate:
Width: 5.987 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.762 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2025	1.375	1	0.19	1.625
2	0.19	1.375	2	0.19	1.25
3	0.1775	1.5	3	0.175	1.25
4	0.1825	1.375	4	0.1875	1.375
5	0.1625	1.375	5	0.1875	1.375
6	0.2025	1.25	6	0.1975	1.25

Specimen 4 (TW-3LN-12-2)

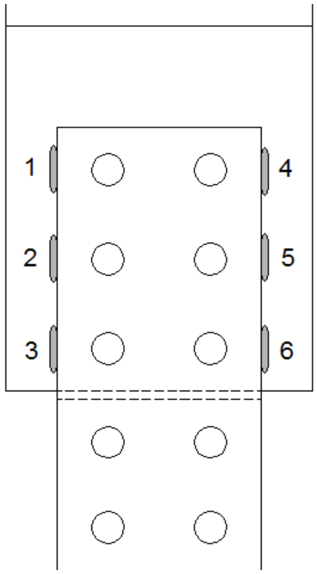


Splice Plate:
Width: 5.982 in
Thickness: 0.369, 0.37 in

Main Plate:
Thickness: 0.761 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2475	1.125	1	0.2	1.1875
2	0.22	1.1875	2	0.215	1.125
3	0.2325	1.125	3	0.2425	1.125
4	0.1975	1.125	4	0.25	1.0625
5	0.2	1.1875	5	0.2325	1.125
6	0.21	0.875	6	0.215	1.0625

Specimen 5 (TW-3LN-20-3)

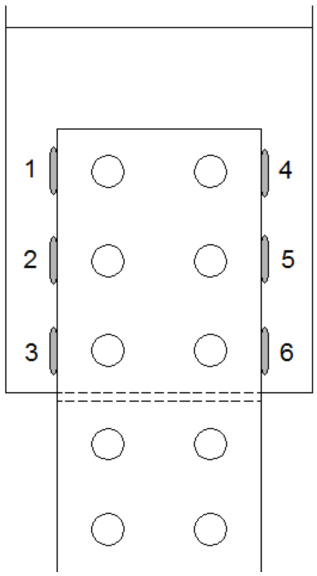


Splice Plate:
Width: 5.977 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.758 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.215	1	1	0.18	1.1875
2	0.2375	1	2	0.205	1
3	0.1875	1	3	0.1725	1.125
4	0.205	1	4	0.195	1.125
5	0.205	1	5	0.1825	1.1875
6	0.1975	1	6	0.195	1.125

Specimen 6 (TW-3LN-12-3)

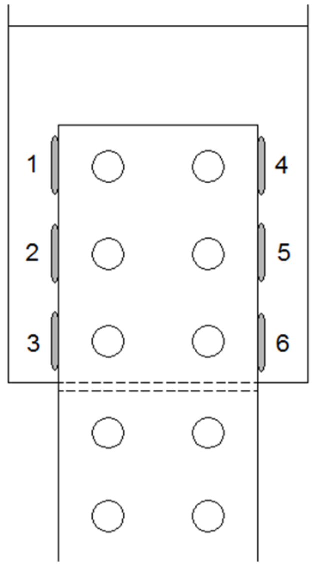


Splice Plate:
Width: 5.982 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.759 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.1875	1.1875	1	0.2075	1.1875
2	0.1975	1.1875	2	0.2025	1.125
3	0.1925	1.125	3	0.2175	1.125
4	0.2125	1.0	4	0.205	1
5	0.1725	1.125	5	0.19	1.0625
6	0.185	1.0	6	0.175	1.125

Specimen 7 (TW-3LL-12-1)

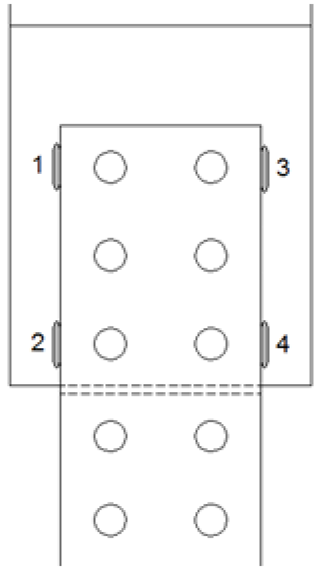


Splice Plate:
Width: 5.988 in
Thickness: 0.366, 0.367 in

Main Plate:
Thickness: 0.759 in

Face 1			**Face 2**		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2013	1.745	1	0.22	1.761
2	0.2175	1.576	2	0.2075	1.820
3	0.2	1.658	3	0.2275	1.585
4	0.2125	1.624	4	0.215	1.726
5	0.1988	1.8	5	0.185	1.677
6	0.1888	1.581	6	0.1875	1.6

Specimen 8 (TW-2LN-12-1)

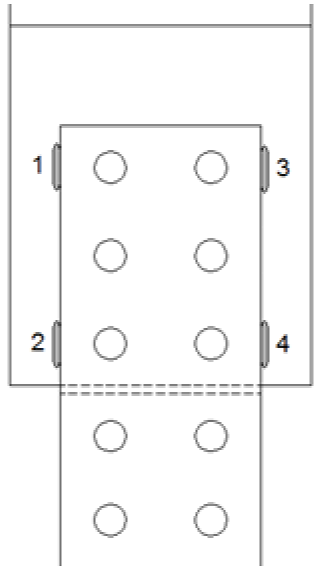


Splice Plate:
Width: 5.986 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.758 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.175	0.982	1	0.1625	1.076
2	0.1925	1.156	2	0.21	1.098
3	0.1975	1.010	3	0.185	1.1
4	0.18	0.964	4	0.2275	1.137

Specimen 9 (TW-2LN-12-2)

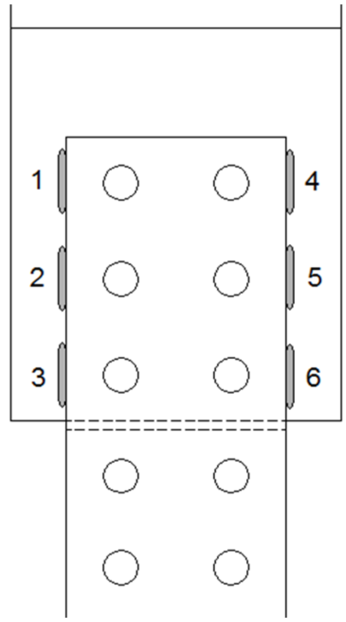


Splice Plate:
Width: 5.985 in
Thickness: 0.37, 0.369 in

Main Plate:
Thickness: 0.758 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.1925	1.325	1	0.1975	1.285
2	0.195	1.13	2	0.1975	1.12
3	0.2025	1.188	3	0.2175	1.168
4	0.2	1.133	4	0.2225	1.085

Specimen 10 (TW-3LL-12-2)

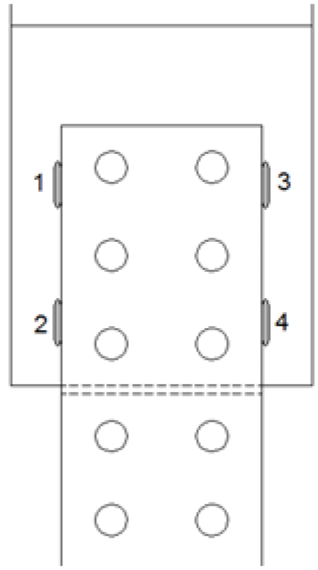


Splice Plate:
Width: 5.990 in
Thickness: 0.372, 0.374 in

Main Plate:
Thickness: 0.757 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2225	1.67	1	0.205	1.736
2	0.2125	1.625	2	0.2225	1.596
3	0.2075	1.383	3	0.21	1.667
4	0.22	1.654	4	0.2075	1.787
5	0.2125	1.505	5	0.215	1.636
6	0.21	1.665	6	0.2175	1.590

Specimen 11 (TW-2LM-12-1)

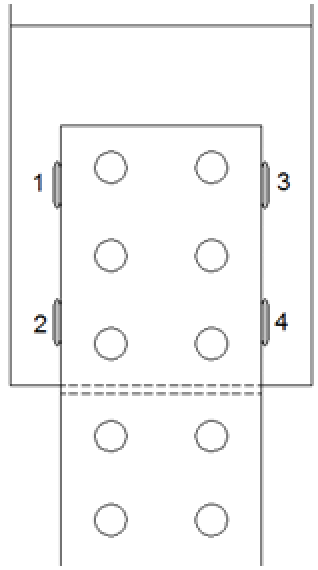


Splice Plate:
Width: 5.981 in
Thickness: 0.372, 0.37 in

Main Plate:
Thickness: 0.762 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.189	1.12	1	0.201	1.285
2	0.2275	1.145	2	0.238	1.12
3	0.195	1.055	3	0.214	1.168
4	0.185	1.175	4	0.1875	1.085

Specimen 12 (TW-2LM-12-2)

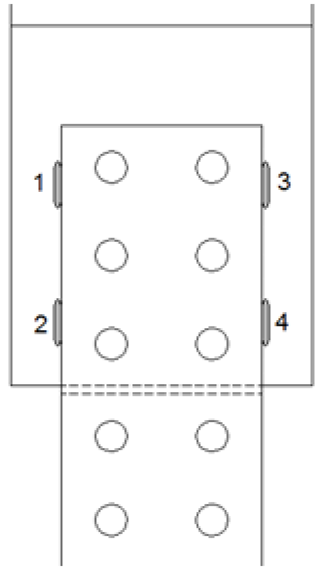


Splice Plate:
Width: 5.981 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.76 in

Face 1			**Face 2**		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2325	1.07	1	0.2375	1.135
2	0.21	1.063	2	0.215	1.120
3	0.2025	1.214	3	0.2225	1.232
4	0.225	1.103	4	0.2125	1.142

Specimen 13 (TW-2LM-12-3)

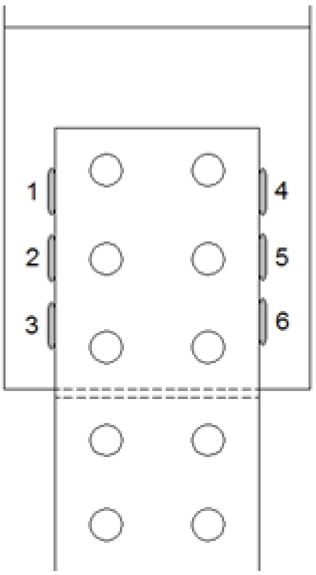


Splice Plate:
Width: 5.984 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.76 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.209	1.098	1	0.2025	1.103
2	0.22	1.102	2	0.2125	1.086
3	0.225	1.167	3	0.2075	0.998
4	0.1925	1.124	4	0.21	1.134

Specimen 14 (TW-3LF-12-1)

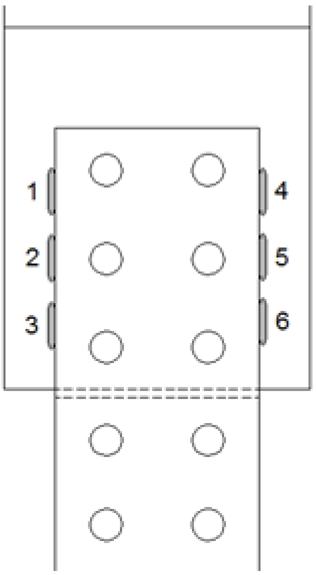


Splice Plate:
Width: 5.983 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.76 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2025	1.113	1	0.179	1.140
2	0.1975	1.240	2	0.1963	1.0
3	0.205	1.040	3	0.2113	1.040
4	0.2125	1.205	4	0.235	1.116
5	0.18	1.095	5	0.215	1.107
6	0.1863	1.075	6	0.1825	1.035

Specimen 15 (TW-3LF-12-2)

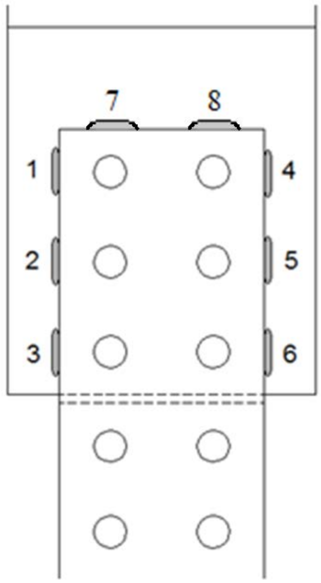


Splice Plate:
Width: 5.981 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.76 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.185	1.125	1	0.214	1.285
2	0.1825	1.015	2	0.18	1.285
3	0.199	1.145	3	0.203	1.125
4	0.176	1.140	4	0.178	1.10
5	0.18	1.180	5	0.178	1.11
6	0.169	1.010	6	0.16	1.11

Specimen 16 (TW-2TN-12-1)

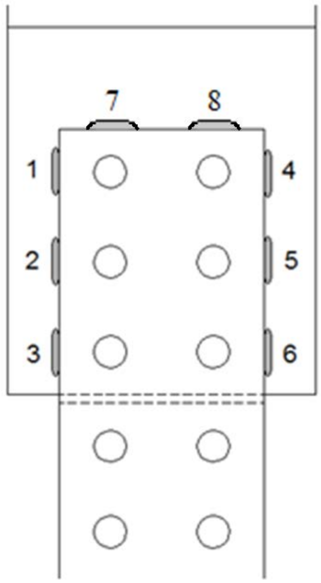


Splice Plate:
Width: 5.985 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.76 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2025	1.22	1	0.205	1.01
2	0.1925	1.16	2	0.21	1.16
3	0.21	1.19	3	0.24	1.19
4	0.1925	1.21	4	0.2225	1.13
5	0.185	1.26	5	0.19	1.12
6	0.185	1.29	6	0.1875	1.04
7	0.165	1.24	7	0.1925	1.15
8	0.175	1.28	8	0.1775	1.16

Specimen 17 (TW-2TN-12-2)



Splice Plate:
Width: 5.979 in
Thickness: 0.37, 0.37 in

Main Plate:
Thickness: 0.76 in

Face 1			Face 2		
Tack Weld	**Size (in)**	**Length (in)**	**Tack Weld**	**Size (in)**	**Length (in)**
1	0.2225	1.16	1	0.215	1.235
2	0.21	1.26	2	0.205	1.125
3	0.23	1.225	3	0.235	1.235
4	0.215	1.245	4	0.23	1.265
5	0.2175	1.255	5	0.2	1.125
6	0.2075	1.19	6	0.2225	1.17
7	0.155	1.22	7	0.1775	1.17
8	0.15	1.13	8	0.175	1.2

APPENDIX D

DISTORTION INDUCED FATIGUE TESTS

D.1 Finite Element Analysis of Distortion Induced Fatigue Test Specimen

Finite element modeling was used to assess the length (size) of subcomponent needed for the experimental test program. First, a model was made using a web width 96-in wide by 34-in deep, as shown in Figure D-1. A 3-in gap was introduced between the end of the connection plate and the flange plate. Then, as shown in Figure D-2, three points of concern were monitored: Point 1 is located at the end of the connection plate, Point 2 is in the web gap midway between the end of the connection plate and the flange, and Point 3 is located at the web-to-flange junction. Two additional models were also made with web plates of 24-in wide by 34-in deep and 18-in wide by 34-in deep. The stresses developed at the three points of concern were monitored when a concentrated load was applied 9-in above the end of the connection plate.

The stress contours for the 24-in wide plate is shown in Figure D-3. A comparison of the stresses for these three subcomponent widths with three different transverse load levels applied are shown in Tables D-1 to D-3 for transverse load levels of 2-kips, 5-kips, and 8-kips, respectively. As can be seen by comparing the results in the three tables, there is not a drastic difference between the stresses at the three points of concern for the three different subcomponent widths. This is not too surprising since the local behavior near the web gap is the parameter being primarily monitored, and the web plate width for all three models is wide enough so as to not influence the local stress results where the fatigue crack will form. Based upon this comparison, a web width of 24-in was found to be adequate for the experimental test program.

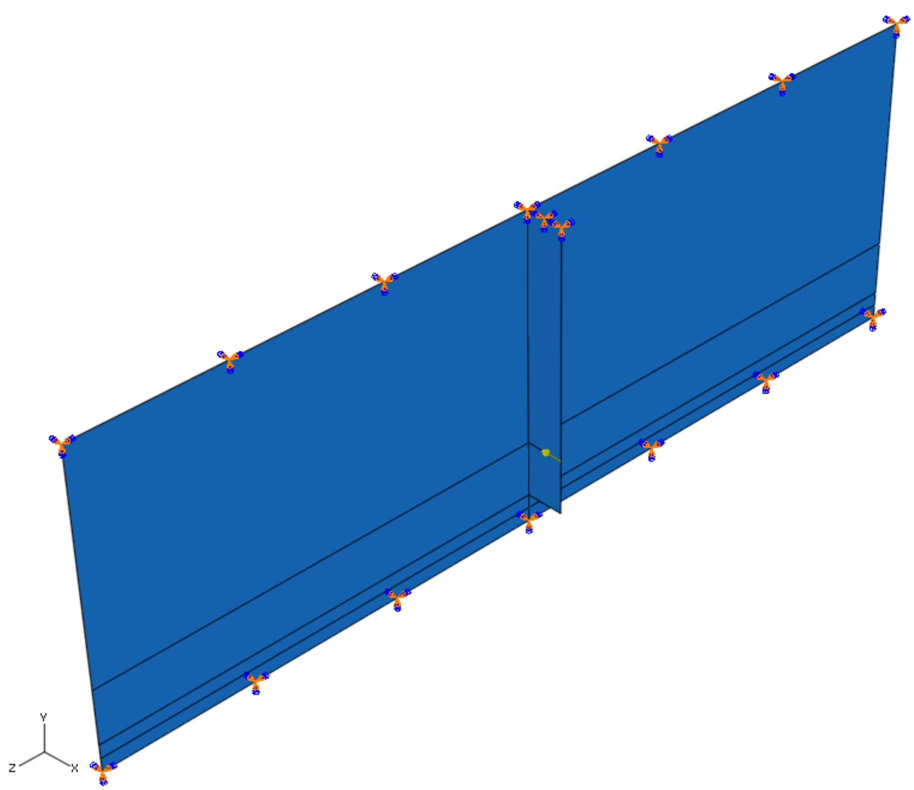


Figure D-1: Finite Element Model with 96-in x 34-in Subcomponent Web Plate

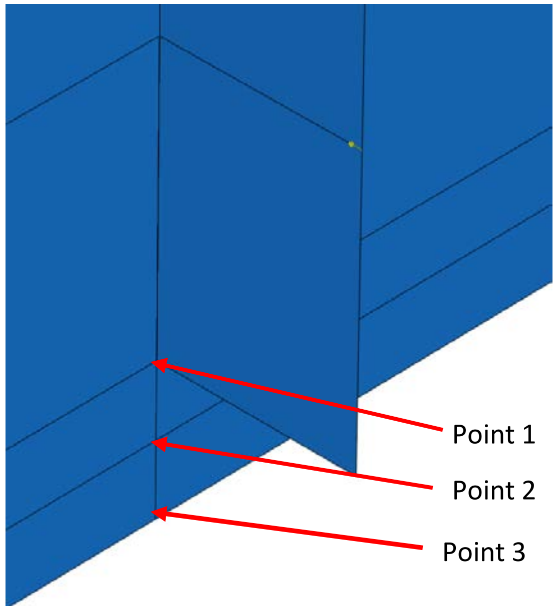


Figure D-2: View of Web Gap Region with Points of Concern

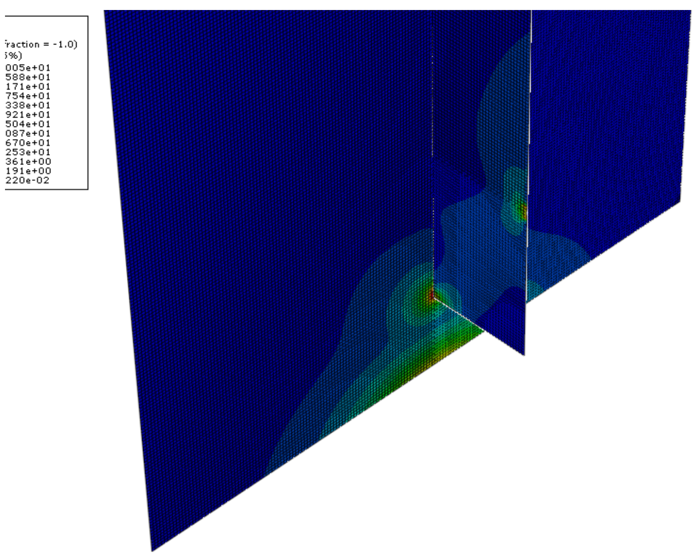


Figure D-3: Stresses in the Web Gap Region for 24-in Wide WebModel with 5-kip Load

Point	Mises Stress (ksi)		
	96-in x 34-in Web	24-in x 34-in Web	18-in x 34-in Web
1	20.95	21.10	21.34
2	5.11	5.15	5.19
3	14.88	14.99	15.13

Table D-1: Stresses in Web Gap for 2-kip Transverse Load

Point	Mises Stress (ksi)		
	96-in x 34-in Web	24-in x 34-in Web	18-in x 34-in Web
1	46.64	46.78	47.00
2	12.84	12.94	13.05
3	37.13	37.40	37.76

Table D-2: Stresses in Web Gap for 5-kip Transverse Load

Point	Mises Stress (ksi)		
	96-in x 34-in Web	24-in x 34-in Web	18-in x 34-in Web
1	50.07	50.06	50.06
2	20.99	21.15	21.35
3	50.00	50.00	50.00

Table D-3: Stresses in Web Gap for 8-kip Transverse Load

D.2 Distortion Fatigue Tests Work Plan

The following sign convention will be used for the specimens:

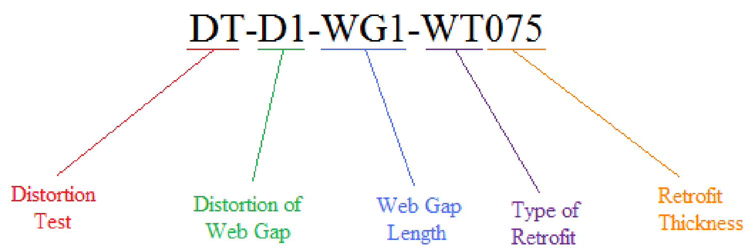


Figure D-4: Specimen Naming Convention

Here, D1 stands for web gap distortion of 0.01 inch, D2 stands for web gap distortion of 0.02 inch; D3 stands for web gap distortion of 0.075 inch; WG1 stands for web gap length of 1.5 inches, WG2 stands for web gap length of 0.75 inches; Types of retrofit: WT, double angle DA, single angle SA; Retrofit thickness 075 indicates 0.75 inch; Retrofit Thickness 0625 indicates 0.625 inch.

A matrix illustrating the test variables that were studied is shown in Table D-4. Table D-5 shows the forces and the number of cycles loaded on the specimens during pre-cracking and after retrofit. Table D-6 provides the values of the lengths of all cracks observed in the specimens after completing pre-cracking and after completion of the testing of the retrofitted specimen. Here, every specimen has two web gaps at each end. Each end has been labeled “1” and “2”. Also every end has two sides, each on either side of the stiffener. Each side has been labelled “1” and “2”. Hence, for stiffener-to-web weld cracks, there are four possible crack locations: 1-2, 1-2, 2-1, 2-2. While for the web-to-flange weld cracks, there are two crack locations, Side 1 and Side 2 at the two ends of the specimen. Similarly, since every specimen has two retrofits, cracks are possible at each retrofit.

Connection Type	Detail Thickness (inch)	Differential Distortion, 0.01 in		Differential Distortion, 0.02 in	
		Web Gap, ¾ in	Web Gap, 1-1/2 in	Web Gap, ¾ in	Web Gap, 1-1/2 in
WT	1/2		X		X
			X		X
	3/4	X	X		X
		X	X		X
			X(RH)		
			X(RH)		
			X(B)		
			X(B)		
		Differential Distortion, 0.0075		Differential Distortion, 0.01	
DA	5/8	X		X	
		X		X	
	3/4	X			
		X			
SA	3/4	X		X	
		X		X	
	1	X			
		X			

Notes: WT = W-Tee Section;
DA = Double Angle;
SA = Single Angle;
RH = Retrofit Hole;
B = Revised Bolt Detail

Table D-4: Matrix of Test Variables for Differential Distortion Subassembly Testing

Sr. No	Specimen	Condition*	Distortion (in)	Force (kip)	No. Of Cycles
1	DT-D1-WG1-WT075	P R	0.01	9.6 20	3,066,000 10,479,000
2	DT-D1-WG1-WT050	P R	0.01	13.1 20	2,395,000 5,356,000
3	DT-D2-WG1-WT075	P R	0.02	24.7 40	710,000 5,129,000
4	DT-D2-WG1-WT050	P R	0.02	24.9 40	970,000 5,049,000
5	DT-D1-WG1-WTRH075	P R	0.01	8.75 20	3,770,000 5,039,000
6	DT-D1-WG2-WT075	P R	0.01	20.4 40	1,996,000 5,113,000
7	DT-D1-WG1-WTB075	P R	0.01	9.8 20	3,403,000 10,327,000
8	DT-D3-WG2-DA0625	P R	0.0075	14.7 30	12,676,000 5,254,000
9	DT-D1-WG2-DA0625	P R	0.01	29.6 40	5,955,000 4,345,000
10	DT-D3-WG2-DA075	P R	0.0075	14.9 30	5,034,400 5,179,000
11	DT-D1-WG2-SA075	P R	0.01	30 40	1,178,000 5,308,000
12	DT-D3-WG2-SA075	P R	0.0075	18.9 30	8,960,000 10,235,000
13	DT-D3-WG2-SA100	P R	0.0075	27 30	925,000 5,153,000

*P: Pre-cracking; R: After Retrofit

Table D-5: Distortion Test Specimen Forces and Cycles for Pre-cracking and After Retrofit

Sr. No	Specimen	Condition*	No. Of Cycles	Stiffener-to-Web Weld Cracks (inch)				Web-to-Flange Weld Crack		Retrofit Crack	
				1-1	1-2	2-1	2-2	Side 1	Side 2	Side 1	Side 2
1	DT-D1-WG1-WT075	P	3,066,000	28/32	1-1/8	1-1/8	1-6/32	-	-	-	-
		R	10,479,000	28/32	1-1/8	1-1/8	1-6/32	-	-	-	-
2	DT-D1-WG1-WT050	P	2,395,000	7/8	3/8	9/16	1/8	-	-	-	-
		R	5,356,000	7/8	3/8	9/16	1/8	-	-	-	-
3	DT-D2-WG1-WT075	P	710,000	3/4	3/4	7/16	3/4	-	-	-	-
		R	5,129,000	1-1/16	13/16	1-1/16	1-7/8	-	-	-	-
4	DT-D2-WG1-WT050	P	970,000	-	3/16	3/16	1/16	6-5/8	-	-	-
		R	5,049,000	-	3/16	5/16	1/16	10-3/4	-	-	-
5	DT-D1-WG1-WTRH075	P	3,770,000	1/2	6/16	5/8	5/8	-	-	-	-
		R	5,039,000	1/2	6/16	5/8	5/8	-	-	-	-
6	DT-D1-WG2-WT075	P	1,996,000	9/16	9/16	3/8	9/16	-	-	-	-
		R	5,113,000	1-7/8	3-1/4	4-1/2	4-1/4	-	-	-	-
7	DT-D1-WG1-WTB075	P	3,403,000	1/2	5/8	5/8	5/8	-	-	-	-
		R	10,327,000	1/2	15/16	5/8	5/8	-	-	-	-
8	DT-D3-WG2-DA0625	P	12,676,000	3/4	1/2	-	5/8	-	-	-	-
		R	5,254,000	3/4	1/2	-	5/8	-	-	-	-
9	DT-D1-WG2-DA0625	P	5,955,000	7/16	5/8	3/16	11/16	-	-	-	-
		R	4,345,000	7/16	5/8	3/16	11/16	8-3/8	9-3/4	-	-
10	DT-D3-WG2-DA075	P	5,034,400	1/2	9/16	1/2	5/8	-	-	-	-
		R	5,179,000	1/2	9/16	1/2	5/8	-	-	-	-
11	DT-D1-WG2-SA075	P	1,178,000	5/8	1/2	1/2	3/4	-	-	-	-
		R	5,308,000	5/8	1/2	1-1/8	1	8-1/2	5-1/8	7/8	-
12	DT-D3-WG2-SA075	P	8,960,000	7/8	1-1/2	1/4	3/4	-	-	-	-
		R	10,235,000	-	3-1/2	-	-	4-3/8	6-3/4	2-1/4	2-3/8
13	DT-D3-WG2-SA100	P	925,000	1/4	5/8	5/8	5/16	6-1/8	-	-	-
		R	5,153,000	1/4	5/8	5/8	5/16	6-1/8	-	-	-

*P: Pre-cracking; R: After Retrofit ; '-' indicates no crack was observable at the location.

Table D-6: Observed Crack Lengths After pre-cracking and after completion of testing of the Retrofitted Specimen

D.3 Distortion Fatigue Test Results

Description of Failure

The distortion fatigue tests consist of two phases. In the first phase, the specimen in pre-cracked at a fixed distortion. Cracks form either at the weld toes of stiffener-to-web weld or web-to-flange weld near the web gaps at both ends of the specimen. After the cracks propagate to a length of about 0.5 inch, the cycling is stopped. In the next phase, the ends of the specimen are retrofitted and the specimen is cycled at approximately double the load needed initially for pre-cracking the specimen. The test is stopped after completing a minimum of 5 million cycles or until the specimen or retrofit experiences fatigue cracks that prevent the test from being continued further.

Specimen DT-D1-WG1-WT075 (Specimen 1)

Specimen Parameters

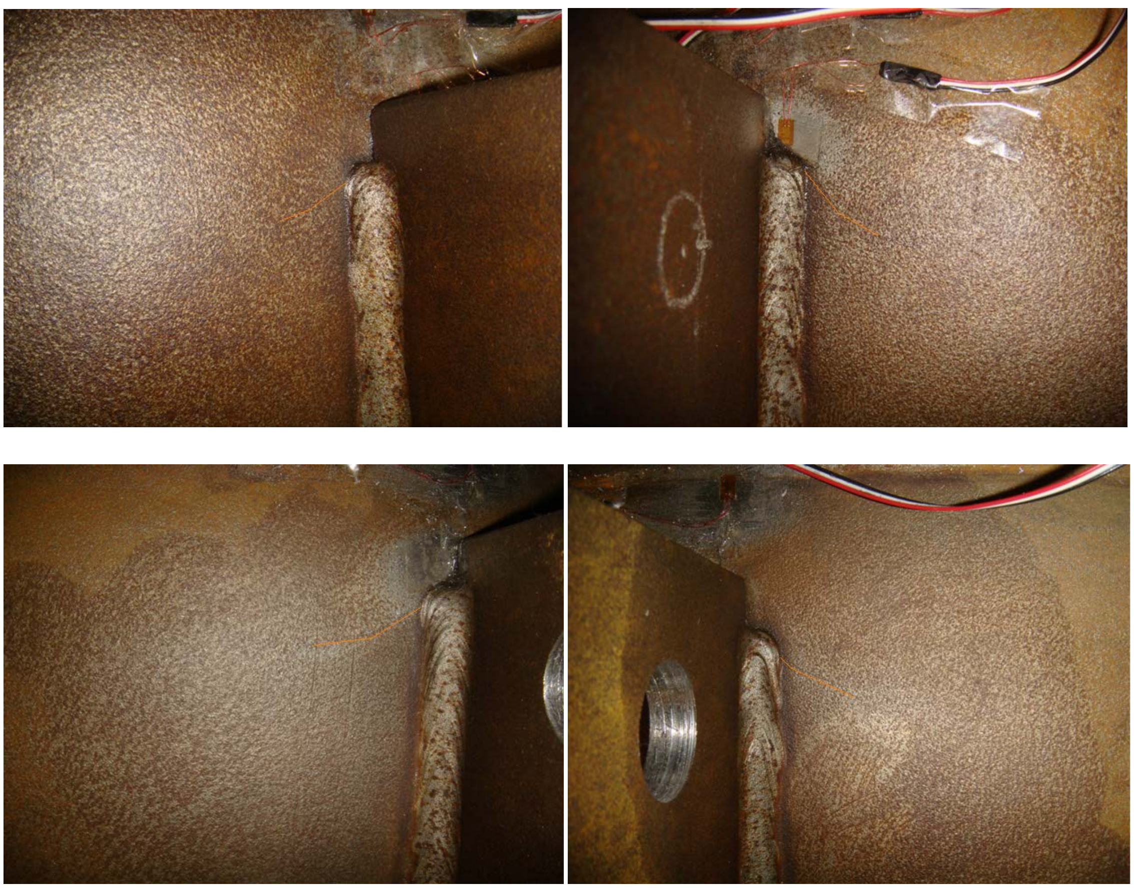
This specimen is the initial specimen for the distortion fatigue tests. The specimen has web gaps of 1.5 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches with an initial load of 9.8 kips which later reduced to 6 kip as cracks formed in the specimen. A total of 3,066,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends.

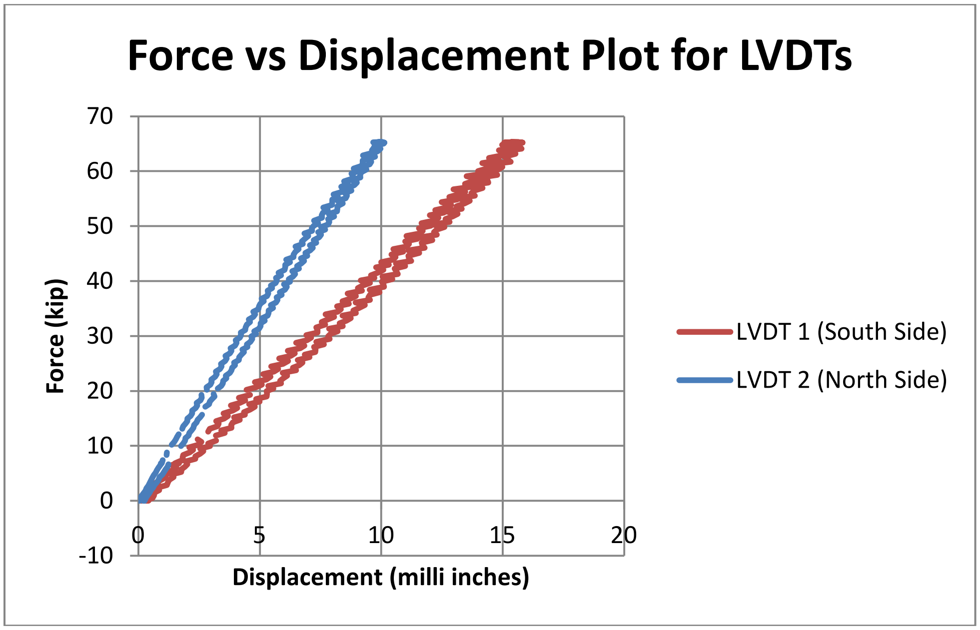


Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.75 inches.

Post-Retrofit Distortion Conditions

The load at end of pre-cracking of 6 kips was doubled and a constant load of 12 kips was applied on the retrofitted specimen for 5,330,000 cycles. There were no new cracks or any observable crack growth in the specimen or the retrofits. The load was then increased to 20 kips, which is approximately double of the initial pre-cracking load of 9.6 kips, and 5,149,000 additional cycles were applied without any observable crack growth.



Post-Retrofit Crack Conditions

No new cracks or crack growth was observed in either the specimen or the retrofits.

Specimen DT-D1-WG1-WT050 (Specimen 2)

Specimen Parameters

The specimen has web gaps of 1.5 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches. A total of 2,395,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends.

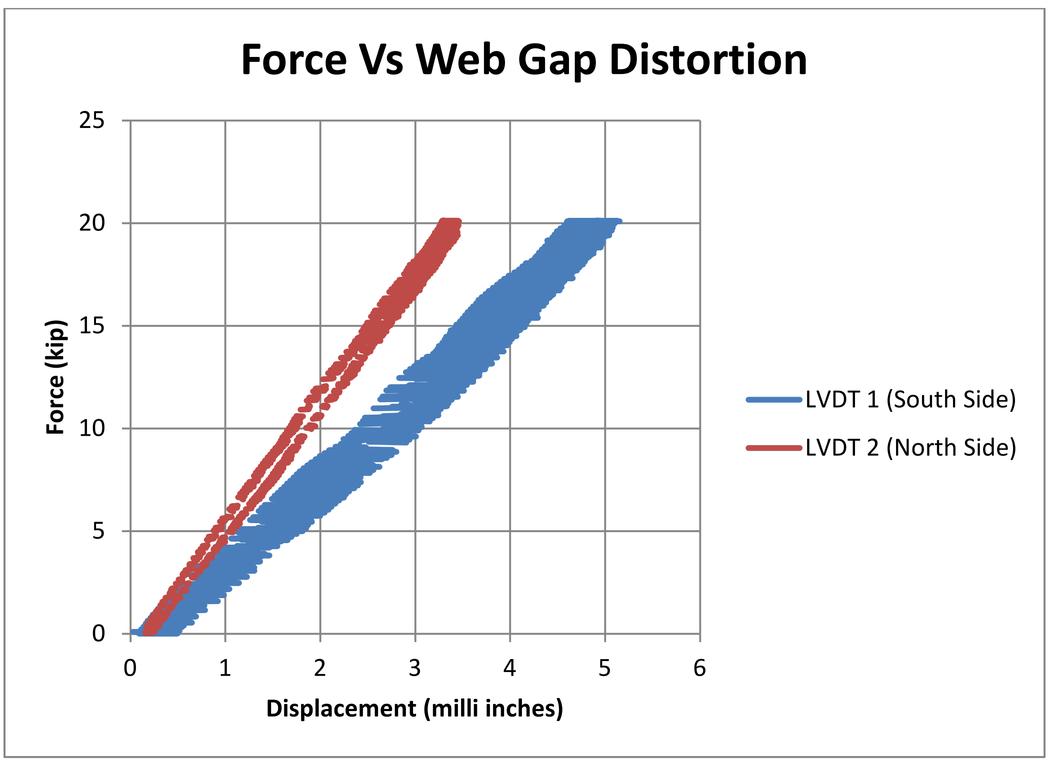



Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.50 inches.

Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 20 kips after retrofitting. A total of 5,356,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks or crack growth was observed in either the specimen or the retrofits.

Specimen DT-D2-WG1-WT075 (Specimen 3)

Specimen Parameters

The specimen has web gaps of 1.5 inches.

Pre-cracking Distortion Conditions

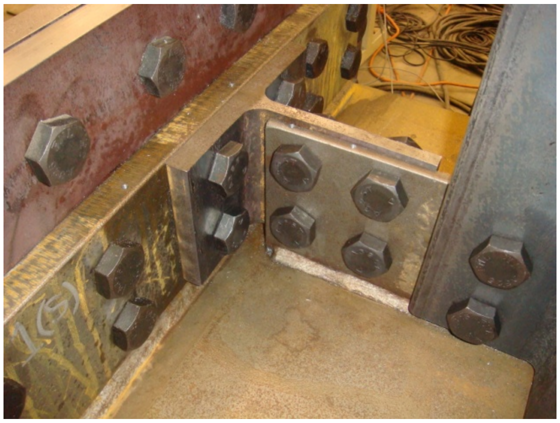
This specimen was subject to a constant web gap distortion of 0.02 inches. A total of 710,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends.

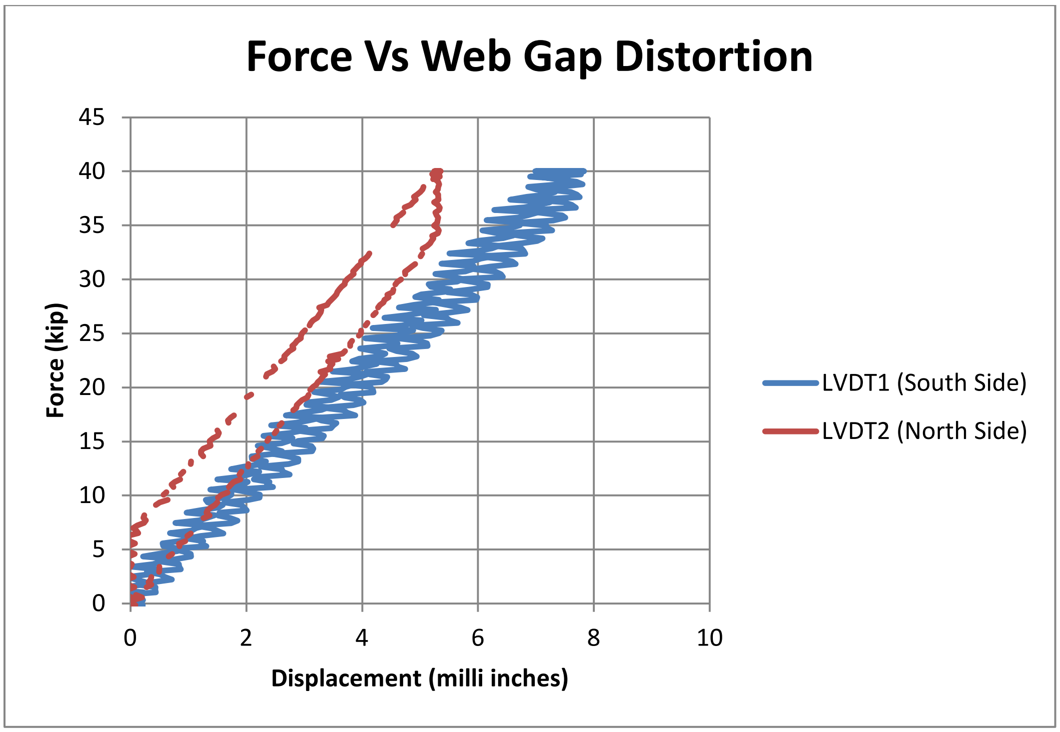
Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.75 inches.



Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 40 kips after retrofitting for 5 million cycles. A total of 5,129,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

Cracks in the web of the retrofit had grown in length at the end of cycling.



Specimen DT-D2-WG1-WT050 (Specimen 4)

Specimen Parameters

The specimen has web gaps of 1.5 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.02 inches. A total of 970,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

Cracks initiated at the web-to-flange weld toe at one end and at the stiffener-to-web weld toes at the other end.

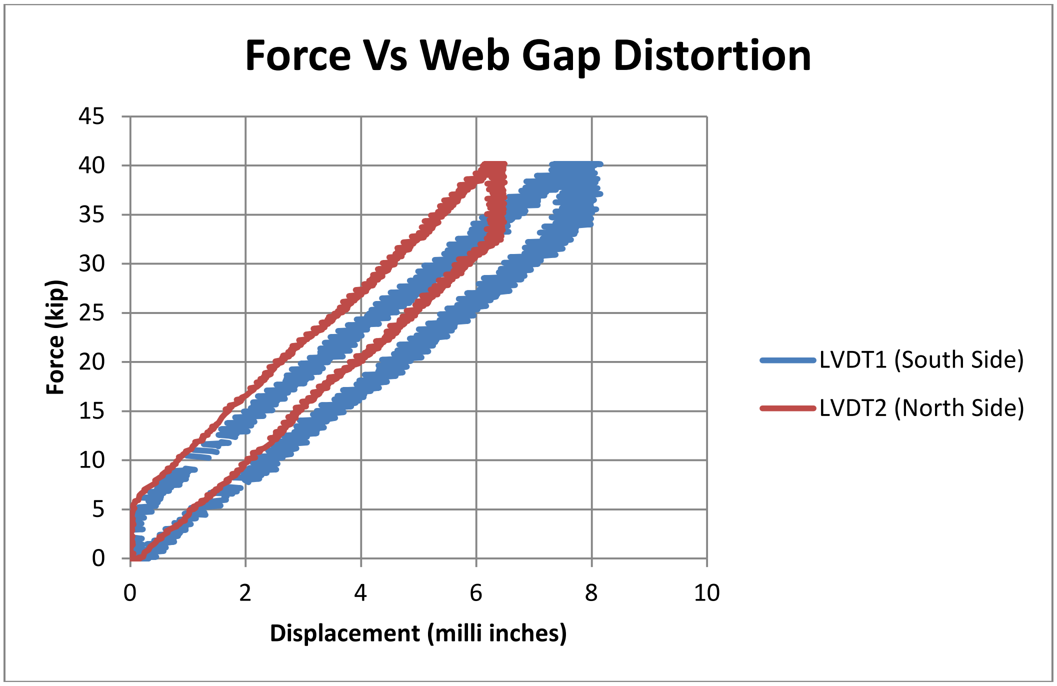
Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.50 inches.

Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 40 kips after retrofitting for 5 million cycles. A total of 5,049,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

The crack along the web-to-flange weld line grew in length but the cracks on the stiffener-to-web weld on the other side did not grow.

Specimen DT-D1-WG1-WTRH075 (Specimen 5)

Specimen Parameters

The specimen has web gaps of 1.5 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches. A total of 3,770,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

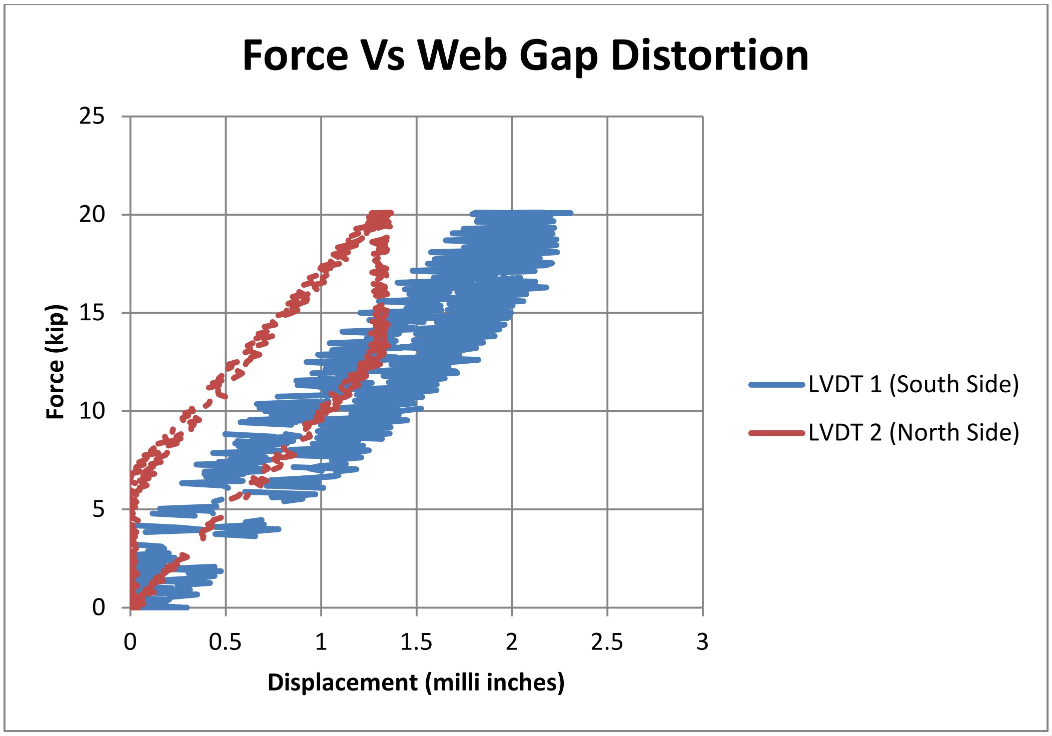
Cracks initiated at the stiffener-to-web weld toes at both ends.

Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.75 inches. Retrofit holes of 1 inch diameter were drilled at both ends in order to remove the crack tip.

Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 20 kips after retrofitting. A total of 5,039,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks or crack growth was observed in either the specimen or the retrofits.

Specimen DT-D1-WG2-WT075 (Specimen 6)

Specimen Parameters

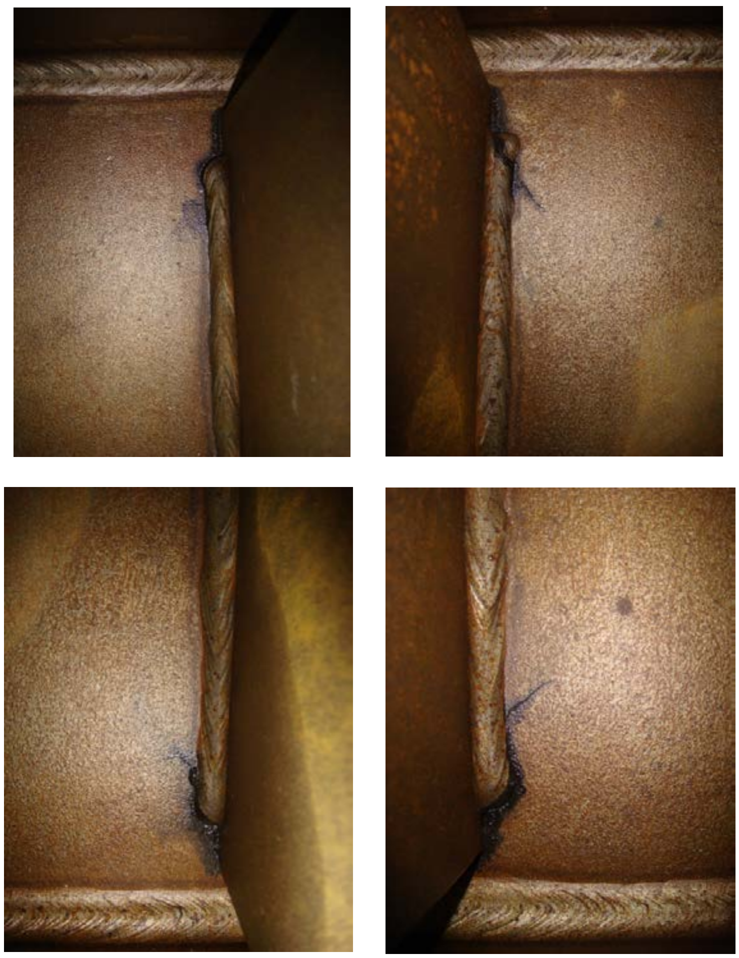
The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches. A total of 1,996,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends.

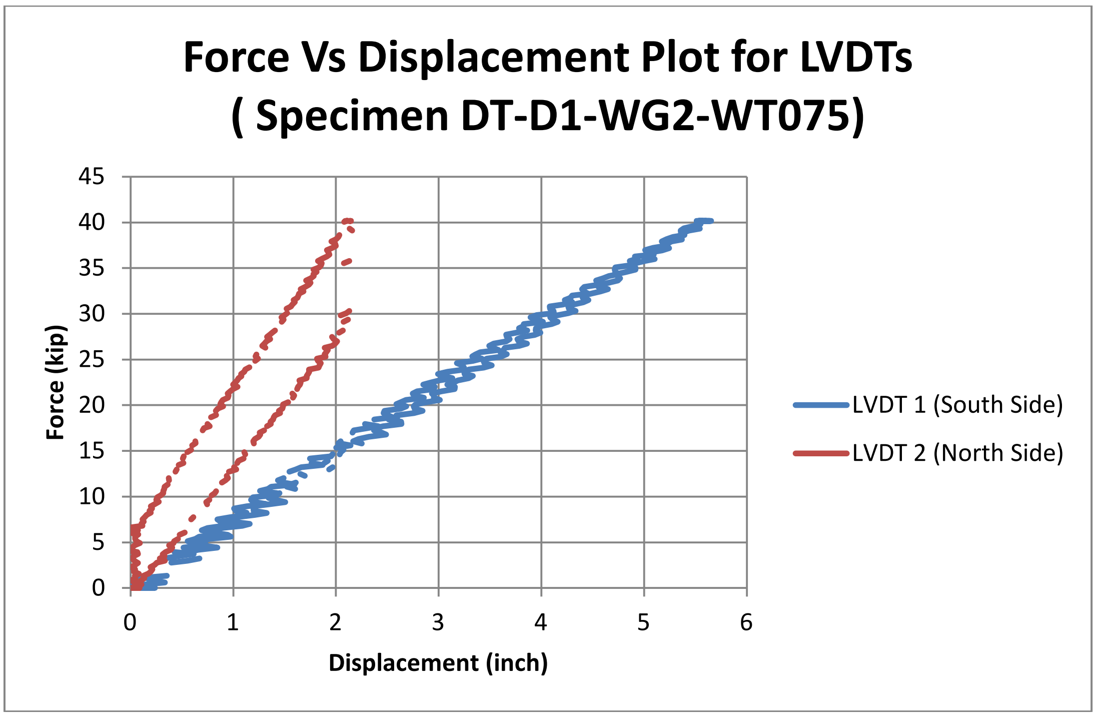


Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.75 inches.

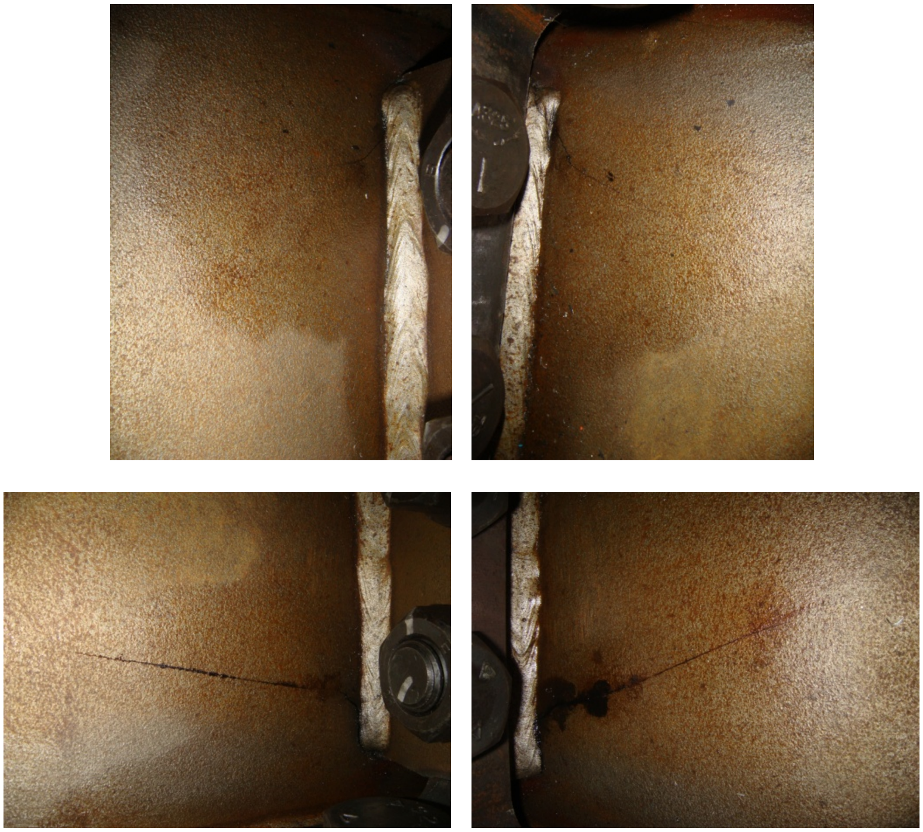
Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 40 kips after retrofitting for 5 million cycles. A total of 5,113,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks initiated in the retrofit. However, the existing cracks at the stiffener-to-web weld toe increased in length.



Specimen DT-D1-WG1-WTB075 (Specimen 7)

Specimen Parameters

The specimen has web gaps of 1.5 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches. A total of 3,403,000 cycles were applied on the specimen.

Pre-retrofit Crack Conditions

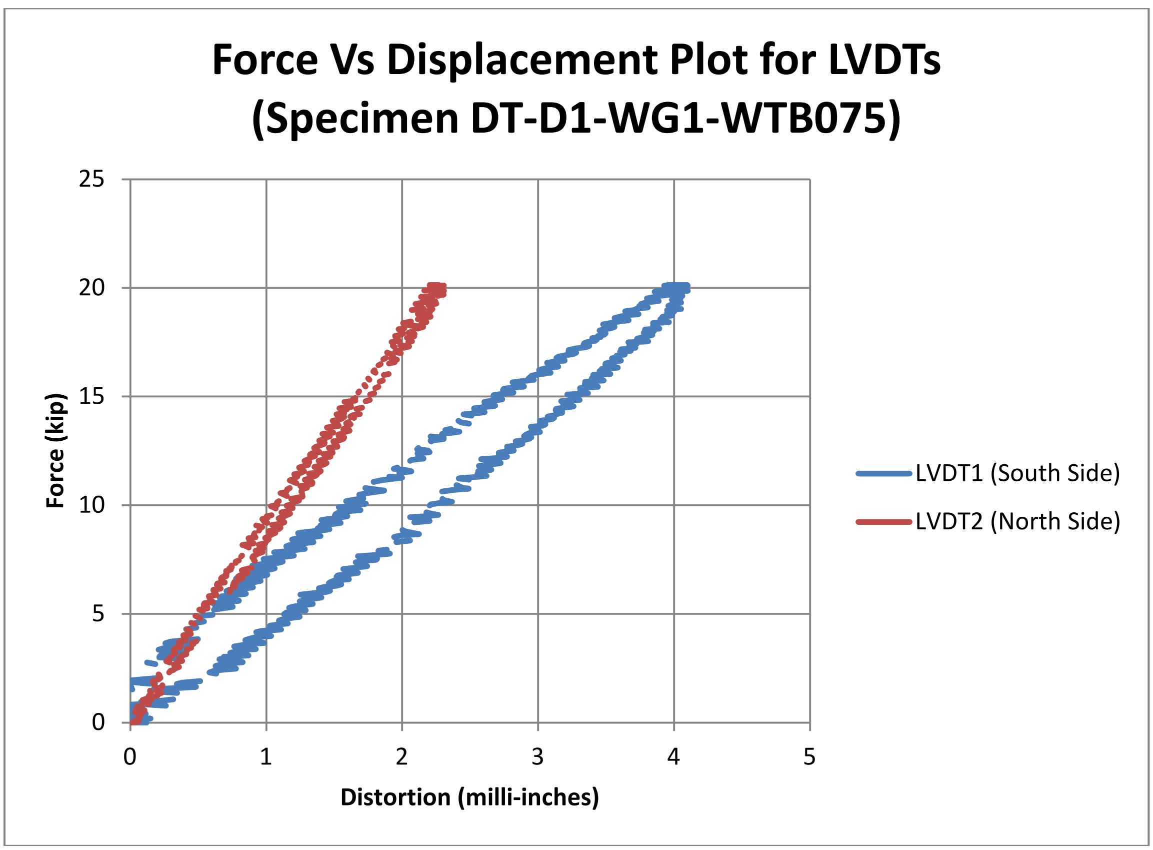
Cracks initiated at the stiffener-to-web weld toes at both ends.

Retrofit Conditions

WT retrofits were installed at both ends. The WTs had a flange thickness of 0.75 inches. Only two bolts were used to attach the retrofit to the stiffener and the specimen flange.

Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 20 kips after retrofitting. A total of 10,327,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks initiated nor did any existing cracks grow significantly in the retrofit.

Specimen DT-D3-WG2-DA0625 (Specimen 8)

Specimen Parameters

The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

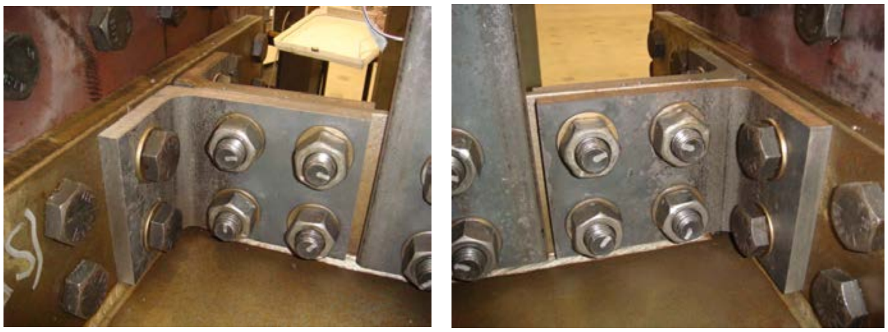
A total of 5,259,000 cycles were initially applied at a constant web gap distortion of 0.005”. Although cracks did form at the weld toes of the stiffener-to-web weld, the cracks remained at the weld toe and did not spread into the web. Hence, the distortion was increased to 0.0075” and 4,074,000 cycles were applied on the specimen. However, again the fatigue cracks did not grow much. Hence, the distortion was again increased to 0.01 inches and a total of 1,728,000 cycles were applied on the specimen. Fatigue cracks grew at one side but not at the other side. Hence, the cracked side was retrofitted and the other side left free. A constant web gap distortion of 0.01 inches was applied on the un-retrofitted side for about 1,615,000 cycles.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends.

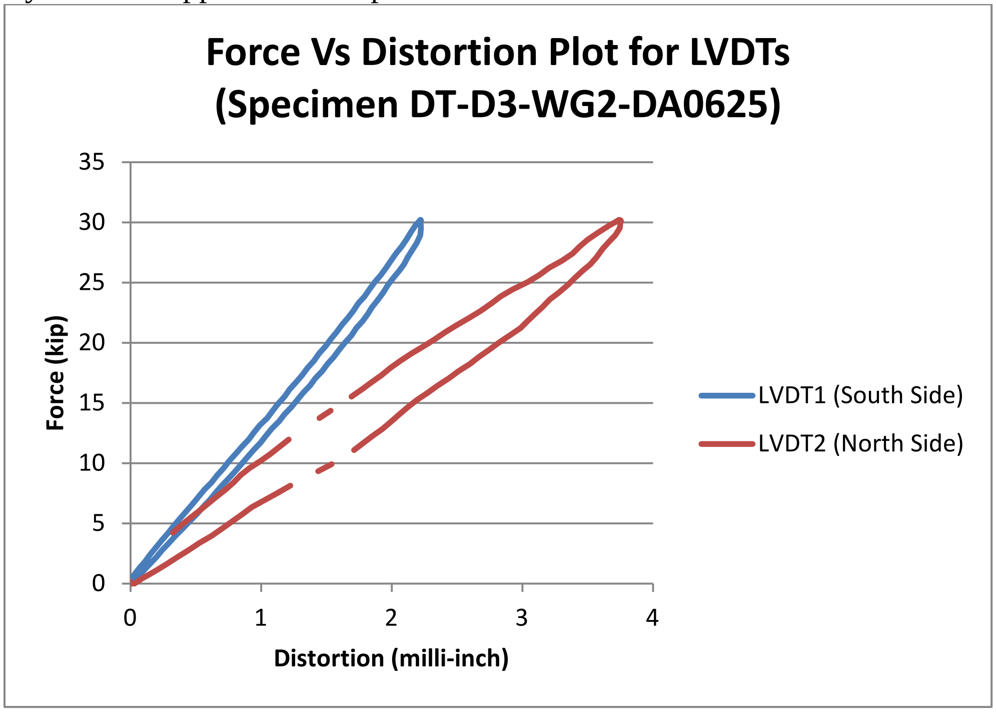
Retrofit Conditions

Double angle retrofits were installed at both ends. The angles had a flange thickness of 0.625 inches.



Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 30 kips after retrofitting. A total of 5,254,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks initiated nor did any existing cracks grow significantly in the retrofit.

Specimen DT-D1-WG2-DA0625 (Specimen 9)

Specimen Parameters

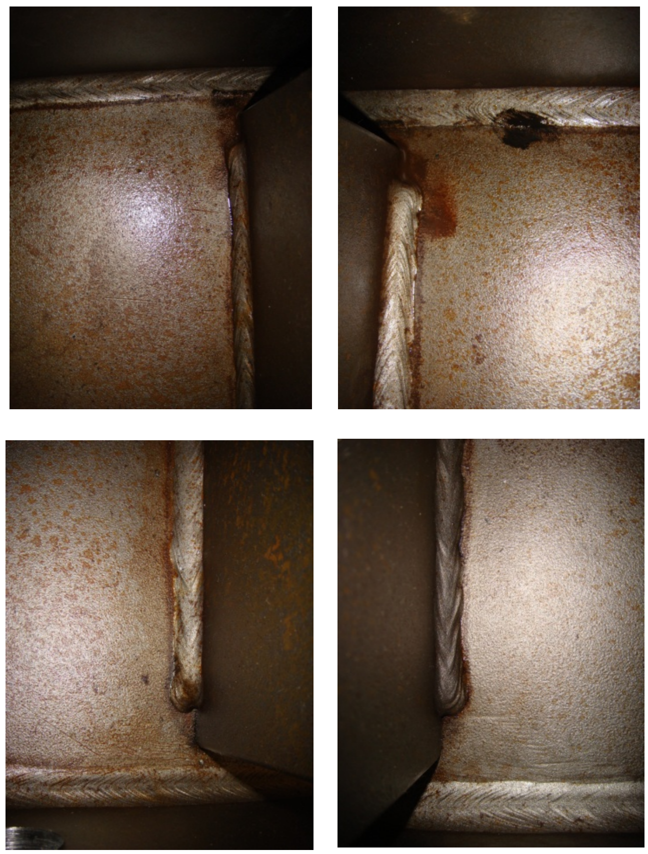
The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches. A total of 1,828,000 cycles were applied before retrofitting one end of the specimen. After that, a total of 4,127,000 cycles were applied on the un-cracked end.

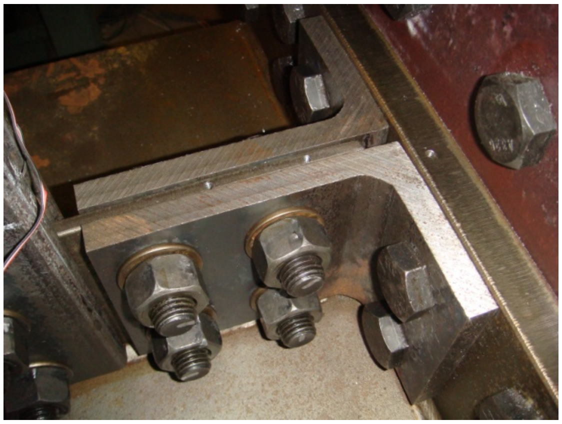
Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends and the web-to-flange weld toe at one end.



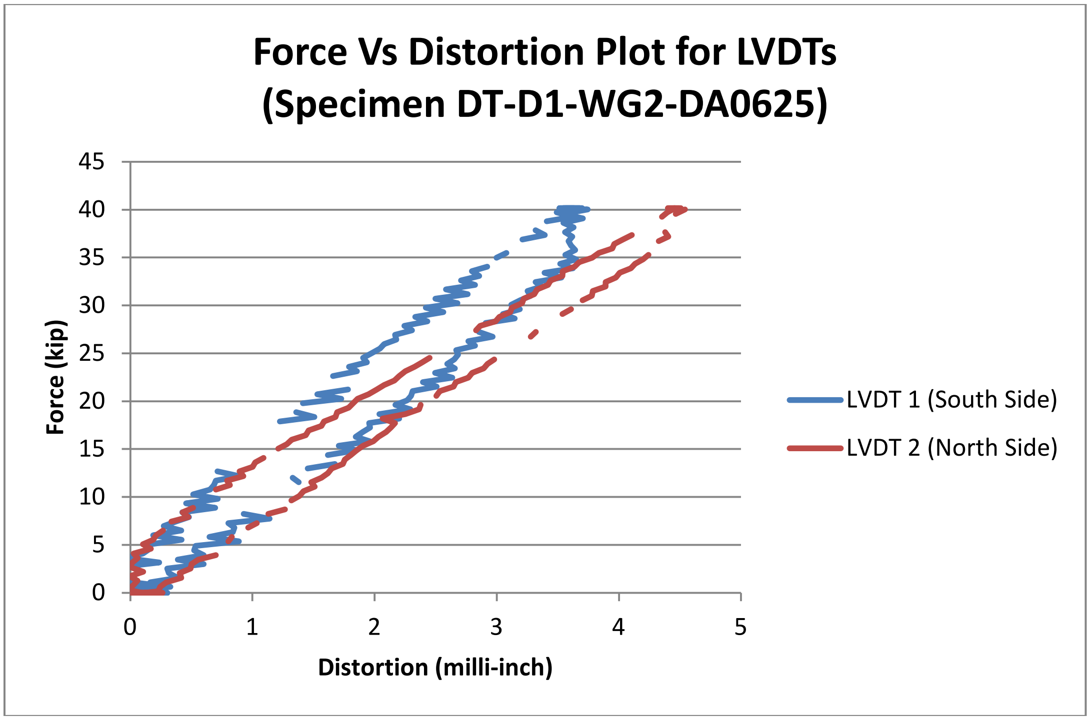
Retrofit Conditions

Double angle retrofits were installed at both ends. The angles had a thickness of 0.625 inches.



Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 40 kips after retrofitting. A total of 4,345,000 cycles were applied on the specimen. The test had to be stopped earlier than 5 million cycles because the stiffener of the specimen cracked completely.



Post-Retrofit Crack Conditions

No new cracks were detected in the retrofit. However, new cracks formed in the web-to-flange weld at one end and the cracks in the web-to-flange welds at both ends grew significantly in length.

Specimen DT-D3-WG2-DA075 (Specimen 10)

Specimen Parameters

The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.0075 inches. A total of 3,151,400 cycles were applied before retrofitting one end of the specimen. After that, a total of 1,883,000 cycles were applied on the un-cracked end.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends.

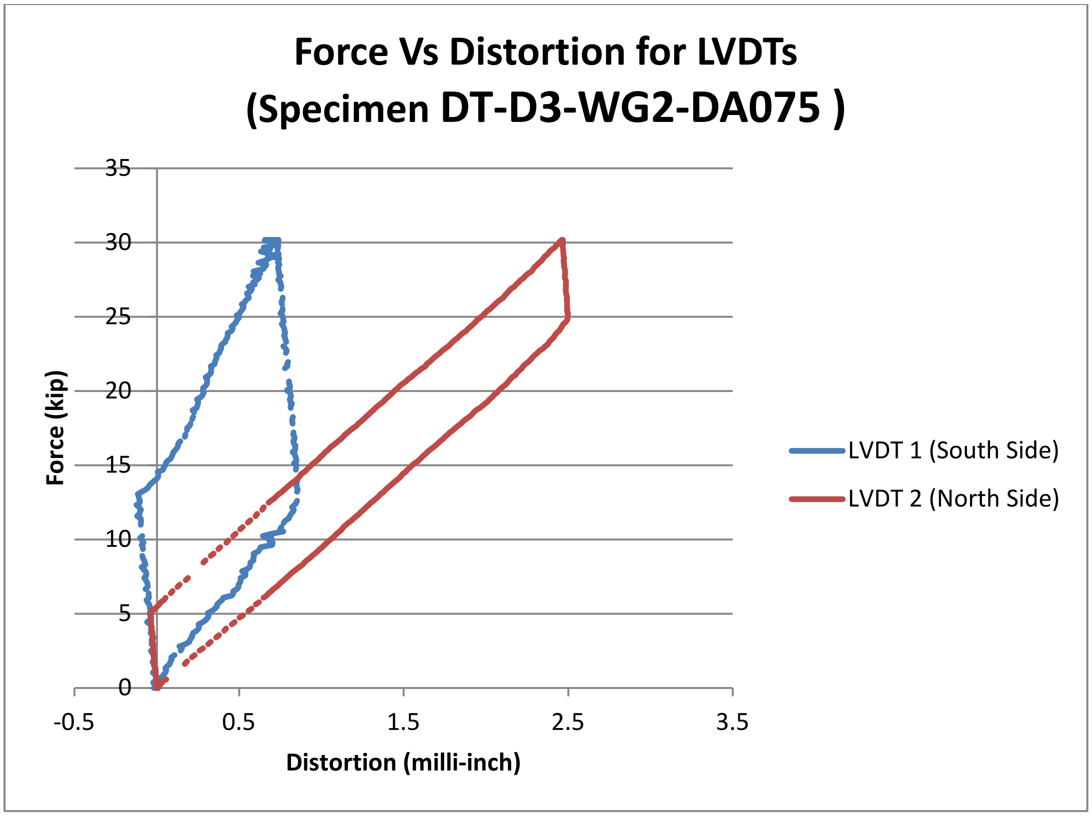


Retrofit Conditions

Double angle retrofits were installed at both ends. The angles had a thickness of 0.75 inches.

Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 30 kips after retrofitting. A total of 5,179,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks initiated nor did any existing cracks grow significantly in the retrofit or the specimen.

Specimen DT-D1-WG2-SA075 (Specimen 11)

Specimen Parameters

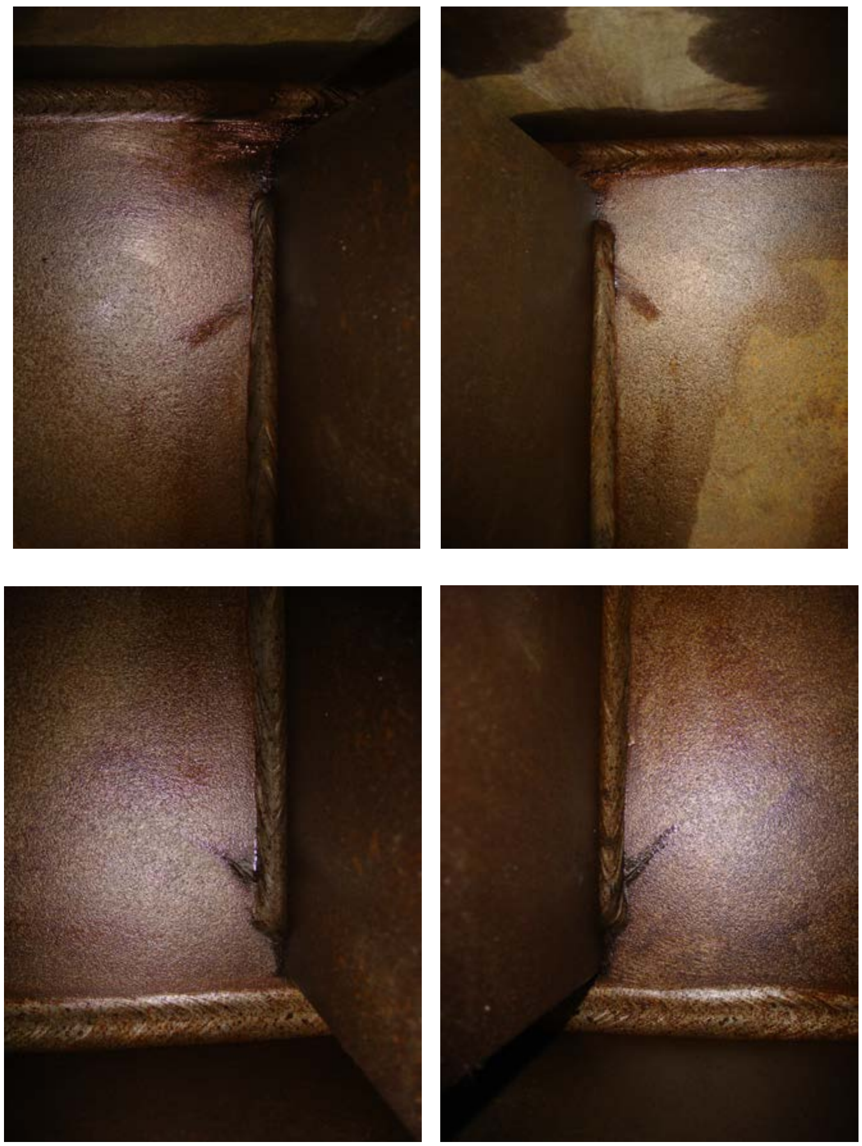
The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches. A total of 1,178,000 cycles were applied.

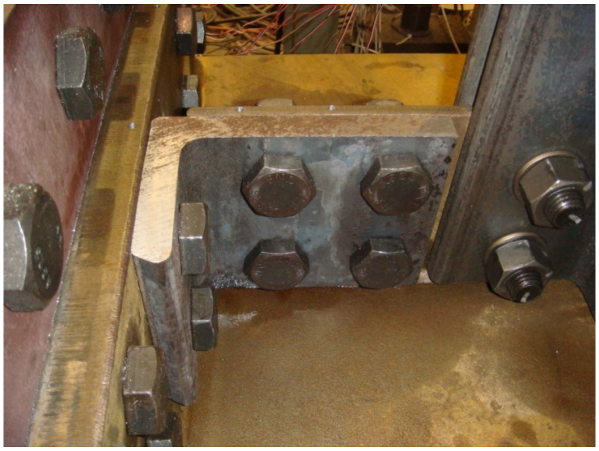
Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends. Although no cracks could be observed at web-to-flange welds at both ends of the specimen, presence of black residue at the weld toes indicated probable presence of cracks.



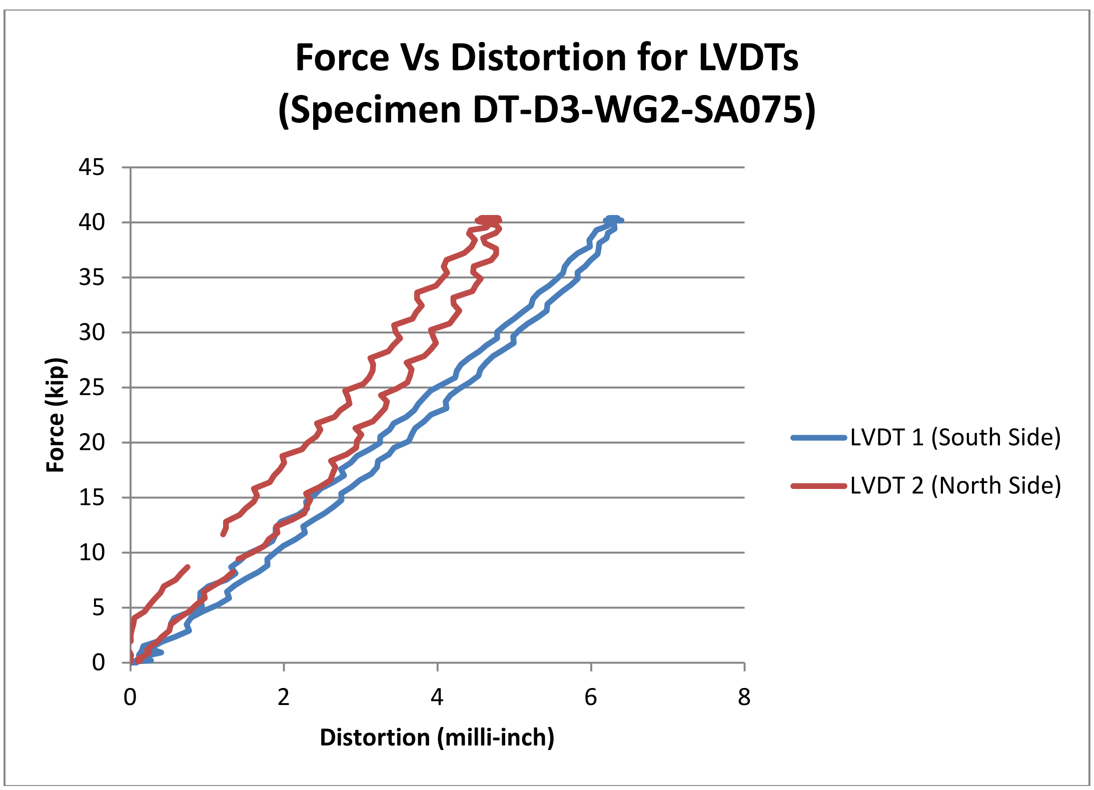
Retrofit Conditions

Single angle retrofits were installed at both ends. The angles had a thickness of 0.75 inches.



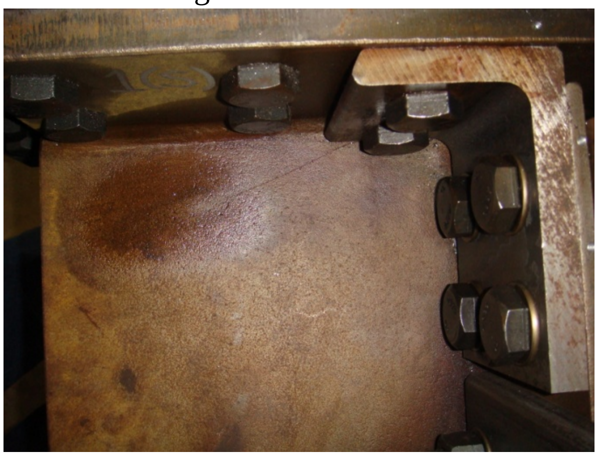
Post-Retrofit Distortion Conditions

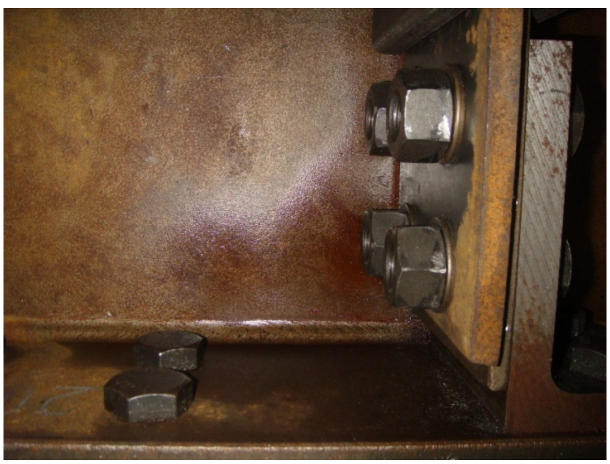
The specimen was cycled at a constant load of 40 kips after retrofitting. Since during cycling, the stiffener cracked completely at one end before completing 5 million cycles, a filler plate was attached between the retrofit angle and the loading angle. As a result, now the load was directly transferred from the loading angle to the retrofit. Testing was resumed and a total of 5,308,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

New cracks formed in the web-to-flange welds at both ends which grew significantly in length. A crack also formed in the retrofit at one end. The crack in the retrofit seemed to initiate on the top side of the flange of the retrofit. The crack spread 0.5 inch into the flange on the top surface and also grew 7/8 inch downwards towards the lower bolt.





Specimen DT-D3-WG2-SA075 (Specimen 12)

Specimen Parameters

The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

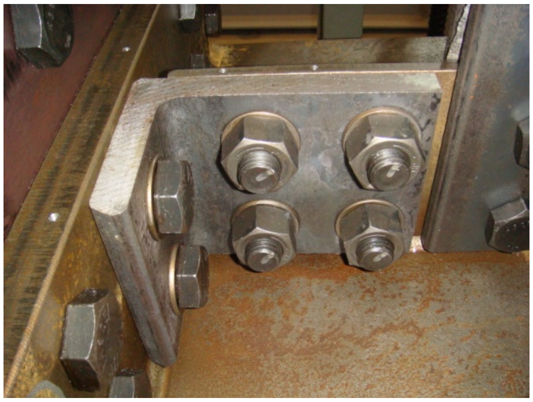
This specimen was subject to a constant web gap distortion of 0.0075 inches. After 502,000 cycles, one of the ends of the specimen where cracking had occurred was retrofitted and cycling resumed on the other side. After 3,644,000 cycles, the distortion was increased to 0.01 inches in order to speed up pre-cracking. A total of 4,814,000 cycles were applied.

Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends. Although no cracks could be observed at web-to-flange welds at both ends of the specimen, presence of black residue at one of the ends at the weld toe indicated probable presence of cracks.

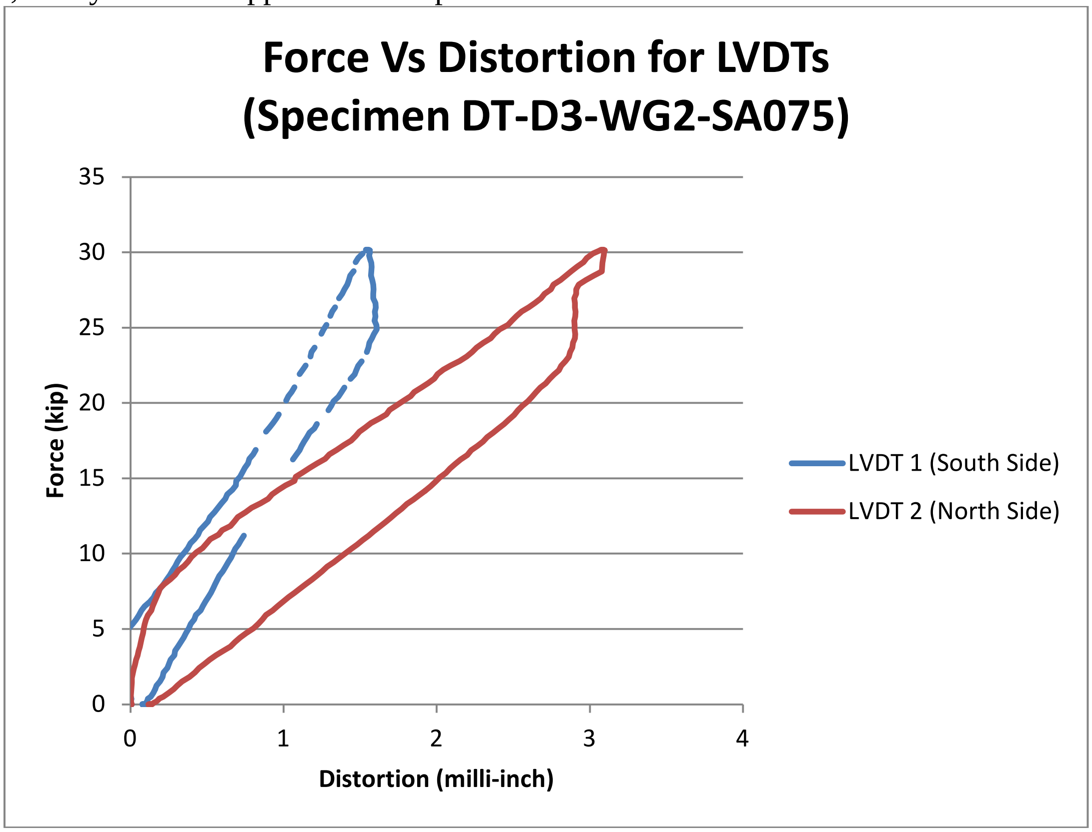
Retrofit Conditions

Single angle retrofits were installed at both ends. The angles had a thickness of 0.75 inches.



Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 30 kips after retrofitting. A total of 10,235,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

New cracks formed in the web-to-flange welds at both ends which grew significantly in length. Cracks also initiated in the single angle retrofits at both ends. The cracks in the retrofits seemed to initiate on the top side of the flange of both the retrofits. The cracks spread into the flange on the top surface and also grew downwards and across into the web-flange junction of the single angle retrofits.

Specimen DT-D3-WG2-SA100 (Specimen 13)

Specimen Parameters

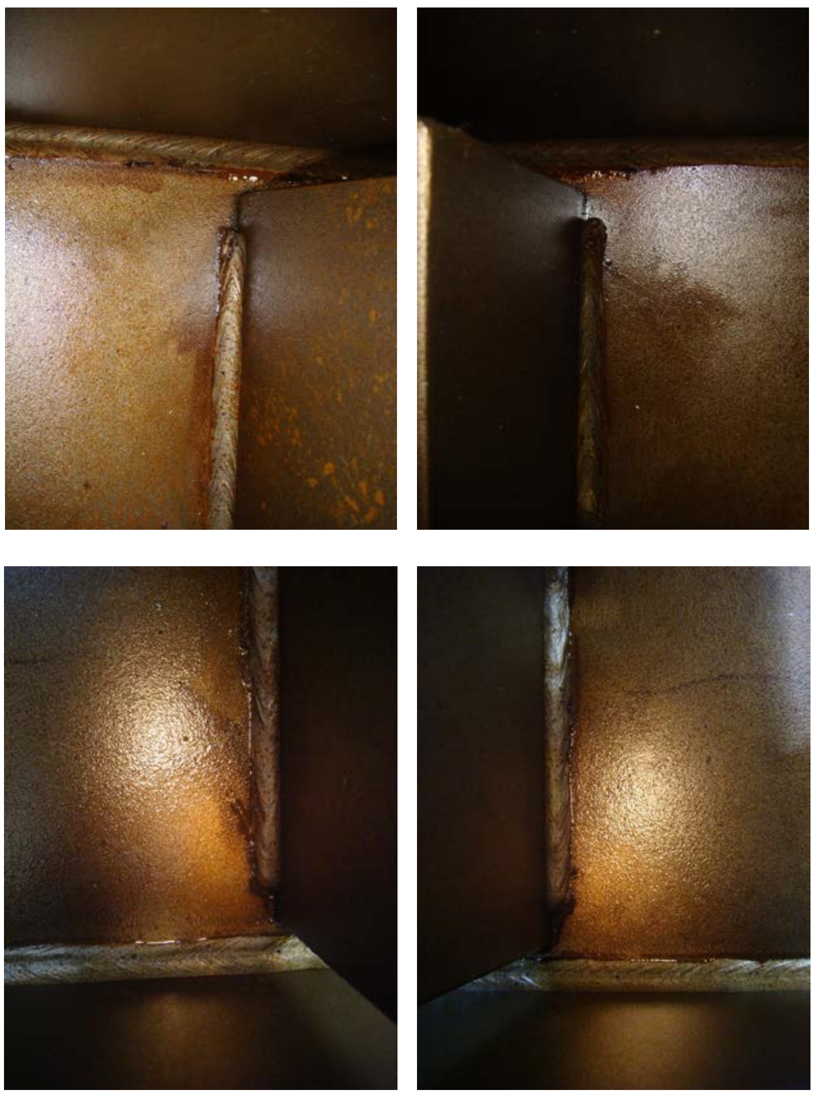
The specimen has web gaps of 0.75 inches.

Pre-cracking Distortion Conditions

This specimen was subject to a constant web gap distortion of 0.01 inches, instead of 0.0075 inches, in order to speed up the time required for pre-cracking. However, in order to maintain the same effect as a pre-cracking carried out at 0.0075 inches, the initial pre-cracking force needed for a 0.0075 inch distortion was used to determine the force needed after retrofit. A total of 925,000 cycles were applied.

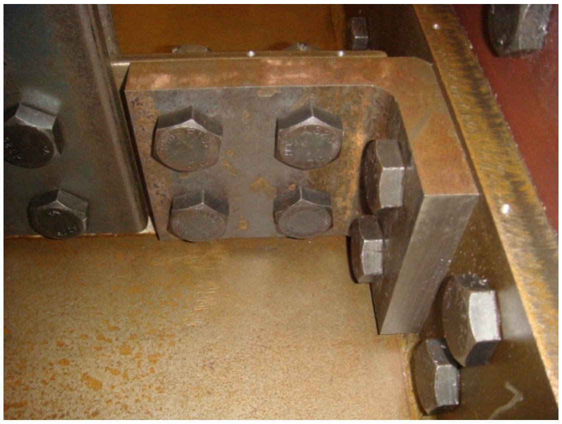
Pre-retrofit Crack Conditions

Cracks initiated at the stiffener-to-web weld toes at both ends. A long web-to-flange weld crack was also observed at one end. However, this crack was present at the weld toe only and was not growing outwards from the weld.



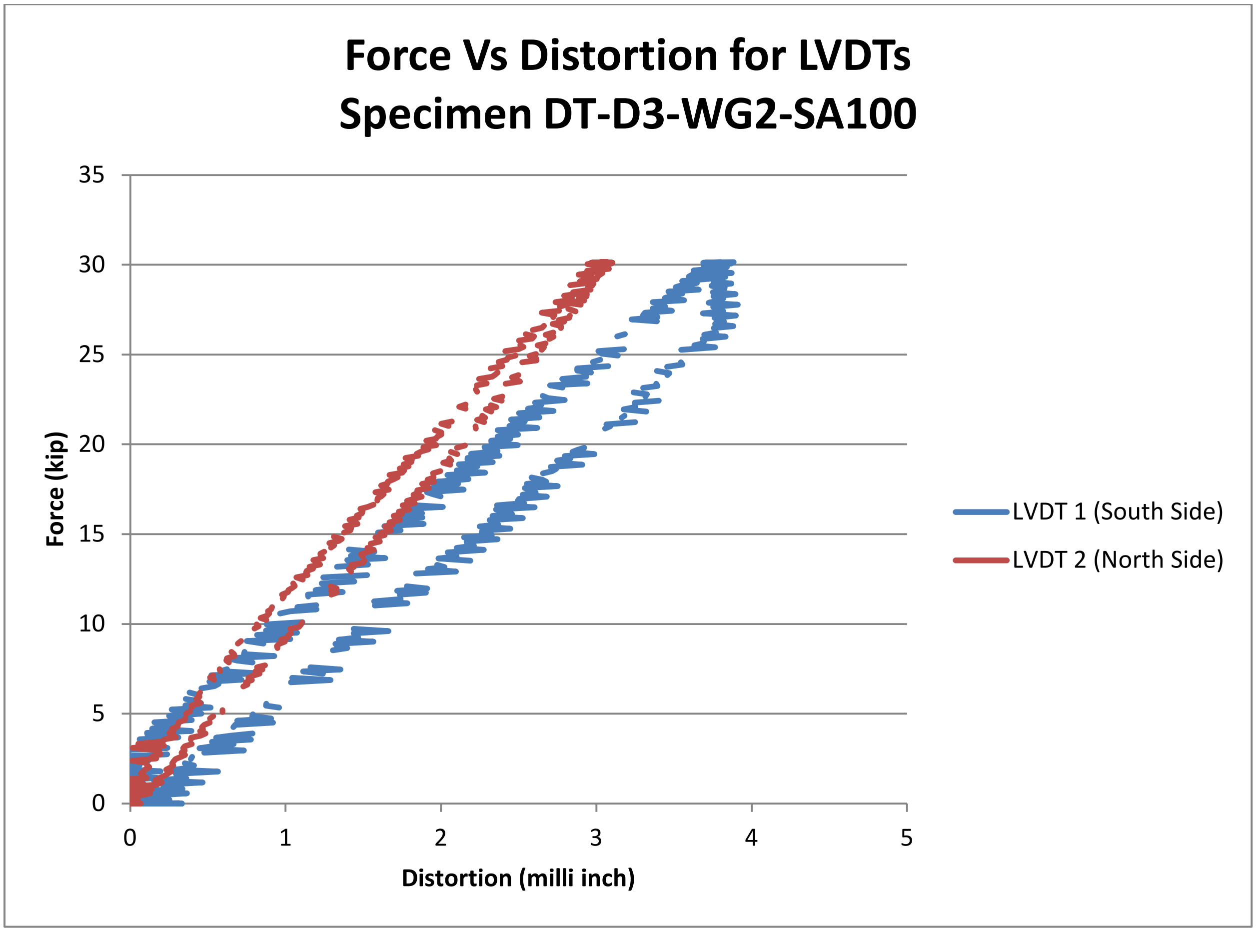
Retrofit Conditions

Single angle retrofits were installed at both ends. The angles had a thickness of 1.00 inch.



Post-Retrofit Distortion Conditions

The specimen was cycled at a constant load of 30 kips after retrofitting. A total of 5,153,000 cycles were applied on the specimen.



Post-Retrofit Crack Conditions

No new cracks formed in the retrofit or the specimen. Nor did any existing fatigue cracks grow in length.