

**BEHAVIOR DURING CONSTRUCTION OF RAMP B BRIDGE OVER I-40 IN
NASHVILLE, TN**

A Thesis
Presented to
The Academic Faculty

By

Julia Catherine Dykas

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science in Civil Engineering

Georgia Institute of Technology
May 2012

**BEHAVIOR DURING CONSTRUCTION OF RAMP B BRIDGE OVER I-40 IN
NASHVILLE, TN**

Approved by:

Dr. Roberto T. Leon, Advisor
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Donald W. White
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Lawrence F. Kahn
School of Civil and Environmental Engineering
Georgia Institute of Technology

Date Approved: April 2, 2012

ACKNOWLEDGEMENTS

I came into this research project in the last year of my undergraduate career at Georgia Tech, and it played a large role in my decision to remain here for my masters. I learned a lot from my trips to Nashville to assist with the instrumentation of the bridge and observing the construction process that I don't think I could have experienced in any other way. I would like to thank my advisor, Dr. Roberto T. Leon for encouraging me to begin this research project as an undergraduate and pushing me forward throughout my masters.

I would like to thank Dr. Donald W. White for his continual encouragement and feedback throughout this project. I would also like to thank my final committee member, Dr. Lawrence F. Kahn, for his feedback and revisions. Finally, I would like to thank Dr. Jochen Teizer for getting me involved in research.

The success of a field instrumentation project depends primarily on the collaboration of a large and diverse group of people. I would like to thank TDOT for their sponsorship and support throughout the project. In particular Mr. Ed Wasserman (former Civil Engineering Director, Department of Transportation, TDOT) and Mr. Tim Huff (CE Manager I, TDOT) are gratefully acknowledged. Mr. Mike Brown, TDOT Regional Maintenance Supervisor, and his staff are thanked for their helpful assistance with providing fully-loaded trucks necessary for the live load testing of the completed bridge structure. Finally, I would like to thank the former Tennessee Commissioner of Transportation, Mr. Gerald F. Nicely, for recognizing the importance of this research.

Thanks to Mr. Jeremy Mitchell, Mr. Dennis Howell, and Mr. Joe Howell of Bell and Associates Construction L.P., as well as to all Bell employees and subcontractors,

for their outstanding efforts at facilitating all field instrumentation tasks, for their cheerful attitude, and for helpful suggestions throughout the project.

Similar thanks are due to all employees of Powell Construction Company, particularly Mr. Harold West, Mr. Mike Trent, and Mr. David Horton, without whose wholehearted collaboration along with Bell Construction, none of the research would have been possible. Thanks is owed to all Powell erection crews, whose care in handling all equipment during the project resulted in less than a 2% loss of instrumentation.

Thanks are also given to Mr. Chris Price, Mr. Jeremy Duckett and Mr. Ben Bristol of PDM Palatka for their help during the first few weeks of the project.

The entire project would not have been possible without the timely technical help from Applied Geomechanics Inc. and in particular of Ms. Naia Susek, who spent a week in the field with the team setting up all the equipment, and continued to be available during the remainder of the project, answering technical questions at all hours of the day and night.

I owe a major thanks to the graduate and undergraduate students who spent nights and weekends traveling to Nashville to support this enterprise. The work of graduate students Towhid Bhuyah, Cagri Ozgur, Juan Jimenez and Andres Sanchez is gratefully acknowledged. In addition, the tremendous help of undergraduate students Kevin Mayer and Fabio Molina is gratefully acknowledged. Thanks go to Cliff Bishop for his help with the recovery of various instrumentation from the bridge at the conclusion of the project.

Finally, I would like to thank my parents, Bill and Lorrie Dykas, for supporting me in everything I do and not balking when I decided to add a second major a year before I should have graduated or when I decided to stay in school to pursue my masters. I would like to thank my fiancé, Will Gloss, for always being there for me.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
SUMMARY	xviii
CHAPTER 1: PROJECT DESCRIPTION	1
1.1 Introduction	1
1.2 Project Description.....	2
1.3 Ramp B.....	3
1.4 Project Tasks	11
1.5 Report Organization.....	13
CHAPTER 2: INSTRUMENTATION OF THE GIRDERS	14
2.1 Introduction	14
2.2 Gage Placement Design.....	15
2.3 Data Acquisition Systems	25
2.3.1 Applied Geomechanics System.....	25
2.3.1.1 <i>Geokon Model 4000</i> Vibrating Wire Strain Gage.....	25
2.3.1.2 <i>Applied Geomechanics Model 904T</i> Clinometer	27
2.3.1.3 <i>Applied Geomechanics Model 797</i> Multiplexer Unit	29
2.3.1.4 <i>Campbell Scientific CR1000</i> Measurement and Control System	29
2.3.2. Leica TCRP 1201+ Robotic Total Station.....	29
2.4 Field Instrumentation of Girders	30
2.4.1 Gage Attachment Procedure	30
2.4.2 Data Acquisition Boxes	33
2.4.3 Electrical Power	35
2.4.4 Target Placement.....	35
CHAPTER 3: CONSTRUCTION OF THE BRIDGE	38
3.1 Introduction	38
3.2 Erection and Construction Procedure and Sequencing.....	38
3.2.1 Steel Erection.....	38
3.2.2 Concrete Deck Formwork and Placement.....	64
CHAPTER 4: FIELD MEASUREMENTS DURING CONSTRUCTION OF THE BRIDGE	71
4.1 Construction Stresses.....	71
4.1.1 Data Collection Adjustments.....	72
4.1.2 Change in Stress Due to Temperature	73
4.1.4 Change in Stress During Concrete Placement.....	77
4.2 Vertical Displacements During Construction	78
4.2.1 Vertical Displacements Due to Changes in Temperature.....	78
4.2.2 Vertical Displacements During Concrete Placement.....	79
CHAPTER 5: FIELD MEASUREMENTS DURING LIVE LOAD TESTING OF THE BRIDGE	81
5.1 Introduction	81

5.1.1 Loading Condition B.....	82
5.1.2 Loading Condition C.....	82
5.1.3 Loading Condition D.....	83
5.2 Live Load Test.....	87
5.3 Live Load Stresses.....	88
5.4 Live Load Displacements.....	88
CHAPTER 6: COMPARISON OF PREDICTED VS. MEASURED BRIDGE RESPONSES.....	91
6.1 Finite Element Analysis Model.....	91
6.2 Erection of Girder 170A14.....	93
6.2.1 Lifting.....	93
6.2.2 Before Connection of Cross Frames.....	97
6.2.3 After Connection of Cross Frames.....	99
6.3 Live Load.....	100
6.3.1 Loading Condition B8.....	101
6.3.2 Loading Condition C8.....	105
6.3.3 Loading Condition D7.....	108
CHAPTER 7: CONCLUSIONS.....	112
7.1 Measured Responses during Construction.....	112
7.2 Measured Responses during Live Load Test.....	113
7.3 Comparison of Predicted Vs. Measured Bridge Responses.....	113
APPENDIX A: INSTRUMENTATION.....	115
APPENDIX B: CONSTRUCTION DATA.....	124
Construction of Span 1.....	125
Construction of Span 2.....	129
Construction of Span 3.....	137
Construction of Span 5.....	139
Construction of Span 6.....	141
Construction of Span 7.....	143
Construction of Span 8.....	143
APPENDIX C: CONCRETE PLACEMENT DATA.....	148
Concrete Placement Stage 1.....	149
Concrete Placement Stage 2.....	152
Concrete Placement Stage 3.....	155
APPENDIX D: LIVE LOAD DATA.....	157
Stress During Live Load Test.....	158
Displacement During Live Load Test.....	165
APPENDIX E: ORIGINAL ERECTION PLAN.....	174
APPENDIX F: ORIGINAL PLATE GIRDER PRODUCTION SCHEDULE.....	194
WORKS CITED.....	201

LIST OF TABLES

Table 1: Start times of live load cases	159
---	-----

LIST OF FIGURES

Figure 1: Project Location	3
Figure 2: Computer Generated View of Project	4
Figure 3: View (Looking West) of Ramp B during Load Testing	5
Figure 4: Elevation of Ramp B	6
Figure 5: Typical Cross-Sectional Dimensions	7
Figure 6: Typical Plate Girder Details (Fabrication Drawing from PDM)	8
Figure 7: Typical Plate Girder Details (Fabrication Drawing from PDM)	9
Figure 8: Typical cross-frame, showing the drops in elevation between the girders.....	9
Figure 9: Shop drawing for girder 169B14 indicating sweep and camber profile of the girder	10
Figure 10: Desired instrumentation level for each girder	16
Figure 11: Plan View of Ramp B over I-40	18
Figure 12: Instrumentation Lines 1-4	19
Figure 13: Instrumentation Lines 5-8	20
Figure 14: Instrumentation Lines 9-12	21
Figure 15: Instrumentation Lines 13-16	22
Figure 16: Instrumentation Lines 17-20	23
Figure 17: Instrumentation Lines 21-24	24
Figure 18: Vibrating Wire Strain Gage (Geokon, Inc.).....	26
Figure 19: Jig used to ensure proper alignment of nuts for strain gage	27
Figure 20: Clinometer in enclosure and working principle	28
Figure 21: Leica total station and support equipment	30
Figure 22: Nuts for two strain gages and support bracket for clinometer have been welded to the girder and are ready for installation of the instrumentation.....	32
Figure 23: Girder with one strain gage and one clinometer installed	32
Figure 24: Data Acquisition Boxes	33
Figure 25: View inside one of the data acquisition boxes shown the CR1000, the power supply, and the radio transmitter	34
Figure 26: Downloading of data remotely from one of the data acquisition boxes.....	34
Figure 27: Installation of solar panels at Bent No. 2	35
Figure 28: Underside of bridge showing reflective targets attached to bottom flanges...	36
Figure 29: Layout of targets used for robotic total station measurements of spans 7 and 8.	36
Figure 30: Initial reading of reference target taken to orient the total station	37
Figure 31: Site plan showing crane location	40
Figure 32: Lifting of Girder 105A1	41
Figure 33: Holding of Girder 105A1 by the 175-ton and 40-ton cranes.....	41
Figure 34: Lifting of Girder 110A2	42

Figure 35: Girders 105A1 and 110A2 located on supports, spliced together, and held by cranes	42
Figure 36: Cribbing under Girder 105A1	43
Figure 37: One Cross Frame Attached Between Girders 104B1 and 105A1.....	44
Figure 38: All Cross-Frames Attached Between Girders 104B1 and 105A1.....	44
Figure 39: Lifting of Girder 109B2	45
Figure 40: Workers Splicing Girders 109B2 and 110B1.....	45
Figure 41: Placement of Girder 108C2	46
Figure 42: View showing two cranes holding the third girder line while making the splice between 103C1 and 108C2	46
Figure 43: Positioning of girder 120A4 in Preparation for Splicing to Girder 115A3	48
Figure 44: 150-ton Lattice Boom Lifting Crane Being Released from Girder 115A3.....	49
Figure 45: Use of a come-along between girders 120A4 and 119B4 near Bent 1	49
Figure 46: Installation of bearing line cross-frame between girders 119B4 and 118C4 at Bent 1	50
Figure 47: Installation of cross-frames between Girders 117D4 and 116E4.....	50
Figure 48: Positioning of Girder 125A5	51
Figure 49: Positioning of Girder 130A6	52
Figure 50: View showing girder 125A5 being stabilized by a holding crane and the lifting crane released to pick girder 124B5	53
Figure 51: Positioning of Girder 124B5	53
Figure 52: View of the 175-ton lifting crane located on the south side of I-40 just prior to the lifting of girder 131E7 (Photo taken from the Robertson Ave. bridge).....	55
Figure 53: Lifting of Girder 131E7	56
Figure 54: Splicing of Girders 131E7 and 136E8.....	56
Figure 55: View of Span 5 with girders 145A9 and 150A10 up, with the lifting cranes still engaged, and with the holding crane attached to 145A9	57
Figure 56: Connection of Girder 156E12 to Girder 151E11	58
Figure 57: View of Shoring Tower after Placement of Girder 162D13	59
Figure 58: Lifting of Girder 167D14.....	60
Figure 59: Cribbing Placed Between Top of Shoring Tower and Bottom of Girders	61
Figure 60: Shoring tower at span 7 after removal of cribbing	62
Figure 61: Twisting in Girder 175A15.....	62
Figure 62: View of come along on girder 175A15	63
Figure 63: View of the cross frame with missing connection plate.....	64
Figure 64: Light gage metal strap attached to the top flange of fascia girder	65
Figure 65: Light-gage metal strap attached to longitudinal light-gage angles on opposite side of fascia girder	66
Figure 66: Top view of strap detail showing metal deck forms screwed to light-gage angles.....	66
Figure 67: View of attachment to light-gage angles from below.....	67
Figure 68: Strap, light-gage angles at flange tips, deck support angle welded to light-gage angles at flange tips, and screw fastening of metal deck forms to support angle ..	67

Figure 69: Metal decking partially installed	68
Figure 70: Concrete formwork supported by overhang brackets	68
Figure 71: Reinforcing and screed in place, awaiting concrete.....	69
Figure 72: Concrete placement during coolest part of the day	70
Figure 73: Sample calculation of stress and temperature.....	72
Figure 74: Change in stress and temperature over 36 hours.....	75
Figure 75: Change in stress of girder 165 during construction of span 8.....	76
Figure 76: Change in stress and temperature in girder 155 during stage 1 of the concrete deck placement	77
Figure 77: Vertical deflection due to change in temperature.....	79
Figure 78: Vertical deflection of exterior girders during first concrete placement.....	80
Figure 79: Force distribution of truck used during live load testing	81
Figure 80: Truck positioning for load case B.....	84
Figure 81: Truck positioning for load case C.....	85
Figure 82: Truck positioning for load case D.....	86
Figure 83: Stress in girder 170A14 during live load test	89
Figure 84: Vertical deflection of girder 170A14 near connection to girder 175A15 due to live load	90
Figure 85: Simulation model	92
Figure 86: Girder 170A14 being lifted	94
Figure 87: Girder 170A14 being lifted	94
Figure 88: Comparison locations on girder cross section	95
Figure 89: Stress in bottom flange of girder 170A14 during lifting	96
Figure 90: Stress in top flange of girder 170A14 during lifting	97
Figure 91: Comparison of stress in bottom flange of girder 170A14 before cross frames	98
Figure 92: Comparison of stress in top flange of girder 170A14 before cross frames	99
Figure 93: Comparison of Stress in Bottom Flange of Girder 170A14 after cross frames	100
Figure 94: Comparison of Stress in Top Flange of Girder 170A14 After Cross Frames	100
Figure 95: Comparison of Stress in Bottom Flange of Outside Girder During Loading Condition B8.....	102
Figure 96: Comparison of stress in bottom flange of inside girder during loading condition B8	103
Figure 97: Comparison of deflection in outside girder during loading condition B8	104
Figure 98: Comparison of deflection in inside girder during loading condition B8.....	105
Figure 99: Comparison of stress in bottom flange of outside girder during loading C8.	106
Figure 100: Comparison of stress in bottom flange of inside girder during loading C8.	107
Figure 101: Comparison of deflections in bottom flange of outside girder during loading C8.....	107
Figure 102: Comparison of deflections in bottom flange of inside girder during loading C8	108

Figure 103: Comparison of stress in bottom flange of outside girder during loading D7	109
Figure 104: Comparison of stress in bottom flange of inside girder during loading D7.	110
Figure 105: Comparison of deflections in bottom flange of outside girder during loading D7	111
Figure 106: Comparison of deflections in bottom flange of inside girder during loading D7	111
Figure 107: Wiring diagram for data acquisition system	116
Figure 108: Geokon vibrating wire strain gage	117
Figure 109: Description of vibrating wire	118
Figure 110: Vibrating wire specification	119
Figure 111: Theory of operation for vibrating wire strain gages	120
Figure 112: Temperature correction for vibrating wire strain gages	121
Figure 113: Description of Applied Geomechanics Model 904-T clinometer	122
Figure 114: Description of Applied Geomechanics Model 904-T clinometer	123
Figure 115: Stress in girder 104B1, instrumentation line 1 during construction of span 1	125
Figure 116: Temperature in girder 104B1, instrumentation line 1 during construction of span 1	125
Figure 117: Rotation in girder 104B1, instrumentation line 1 during construction of span 1	125
Figure 118: Stress in girder 105A1, instrumentation line 1 during construction of span 1	126
Figure 119: Temperature in girder 105A1, instrumentation line 1 during construction of span 1	126
Figure 120: Stress in girder 109B2, instrumentation line 2 during construction of span 1	126
Figure 121: Temperature in girder 109B2, instrumentation line 2 during construction of span 1	127
Figure 122: Rotation in girder 109B2, instrumentation line 3 during construction of span 1	127
Figure 123: Stress in girder 110A2, instrumentation line 2 during construction of span 1	127
Figure 124: Temperature in girder 110A2, instrumentation line 2 during construction of span 1	128
Figure 125: Stress in girder 110A2, instrumentation line 3 during construction of span 1	128
Figure 126: Temperature in girder 110A2, instrumentation line 3 during construction of span 1	128
Figure 127: Stress in girder 101E1, instrumentation line 1 during construction of span 2	129
Figure 128: Temperature in girder 101E1, instrumentation line 1 during construction of span 2	129

Figure 129: Stress in girder 104B1, instrumentation line 1 during construction of span 2	129
Figure 130: Temperature in girder 104B1, instrumentation line 1 during construction of span 2	130
Figure 131: Rotation in girder 104B1, instrumentation line 1 during construction of span 2	130
Figure 132: Stress in girder 105A1, instrumentation line 1 during construction of span 2	130
Figure 133: Temperature in girder 105A1, instrumentation line 1 during construction of span 2	131
Figure 134: Stress in girder 109B2, instrumentation line 2 during construction of span 2	131
Figure 135: Temperature in girder 109B2, instrumentation line 2 during construction of span 2	131
Figure 136: Stress in girder 110A2, instrumentation line 2 during construction of span 2	132
Figure 137: Temperature in girder 110A2, instrumentation line 2 during construction of span 2	132
Figure 138: Stress in girder 110A2, instrumentation line 3 during construction of span 2	132
Figure 139: Temperature in girder 110A2, instrumentation line 3 during construction of span 2	133
Figure 140: Stress in girder 114B3, instrumentation line 4 during construction of span 2	133
Figure 141: Temperature in girder 114B3, instrumentation line 4 during construction of span 2	133
Figure 142: Rotation in girder 114B3, instrumentation line 4 during construction of span 2	134
Figure 143: Stress in girder 116E4, instrumentation line 5 during construction of span 2	134
Figure 144: Temperature in girder 116E4, instrumentation line 5 during construction of span 2	134
Figure 145: Stress in girder 116E4, instrumentation line 6 during construction of span 2	135
Figure 146: Temperature in girder 116E4, instrumentation line 6 during construction of span 2	135
Figure 147: Stress in girder 119B4, instrumentation line 5 during construction of span 2	135
Figure 148: Temperature in girder 119B4, instrumentation line 5 during construction of span 2	136
Figure 149: Stress in girder 119B4, instrumentation line 6 during construction of span 2	136

Figure 150: Temperature in girder 119B4, instrumentation line 6 during construction of span 2	136
Figure 151: Stress in girder 111E3, instrumentation line 4 during construction of span 3	137
Figure 152: Temperature in girder 111E3, instrumentation line 4 during construction of span 3	137
Figure 153: Rotation in girder 111E3, instrumentation line 4 during construction of span 3	137
Figure 154: Stress in girder 116E4, instrumentation line 5 during construction of span 3	138
Figure 155: Temperature in girder 116E4, instrumentation line 5 during construction of span 3	138
Figure 156: Stress in girder 116E4, instrumentation line 6 during construction of span 3	138
Figure 157: Temperature in girder 116E4, instrumentation line 6 during construction of span 3	139
Figure 158: Stress in girder 145A9, instrumentation line 13 during construction of span 5	139
Figure 159: Temperature in girder 145A9, instrumentation line 13 during construction of span 5	139
Figure 160: Stress in girder 150A10, instrumentation line 14 during construction of span 5	140
Figure 161: Temperature in girder 150A10, instrumentation line 14 during construction of span 5	140
Figure 162: Stress in girder 150A10, instrumentation line 15 during construction of span 5	140
Figure 163: Temperature in girder 150A10, instrumentation line 15 during construction of span 5	140
Figure 164: Stress in girder 145A9, instrumentation line 13 during construction of span 6	141
Figure 165: Temperature in girder 145A9, instrumentation line 13 during construction of span 6	141
Figure 166: Stress in girder 150A10, instrumentation line 14 during construction of span 6	141
Figure 167: Temperature in girder 150A10, instrumentation line 14 during construction of span 6	142
Figure 168: Stress in girder 150A10, instrumentation line 15 during construction of span 6	142
Figure 169: Temperature in girder 150A10, instrumentation line 15 during construction of span 6	142
Figure 170: Stress in girder 165A13, instrumentation line 19 during construction of span 7	143

Figure 171: Temperature in girder 165A13, instrumentation line 19 during construction of span 7	143
Figure 172: Stress in girder 155A11, instrumentation line 16 during construction of span 8	143
Figure 173: Temperature in girder 155A11, instrumentation line 16 during construction of span 8	144
Figure 174: Stress in girder 160A12, instrumentation line 17 during construction of span 8	144
Figure 175: Temperature in girder 160A12, instrumentation line 17 during construction of span 8	144
Figure 176: Stress in girder 160A12, instrumentation line 18 during construction of span 8	144
Figure 177: Temperature in girder 160A12, instrumentation line 18 during construction of span 8	145
Figure 178: Stress in girder 170A14, instrumentation line 20 during construction of span 8	145
Figure 179: Temperature in girder 170A14, instrumentation line 20 during construction of span 8	145
Figure 180: Stress in girder 170A14, instrumentation line 21 during construction of span 8	145
Figure 181: Temperature in girder 170A14, instrumentation line 21 during construction of span 8	146
Figure 182: Stress in girder 170A14, instrumentation line 22 during construction of span 8	146
Figure 183: Temperature in girder 170A14, instrumentation line 22 during construction of span 8	146
Figure 184: Stress in girder 175A15, instrumentation line 24 during construction of span 8	146
Figure 185: Temperature in girder 175A15, instrumentation line 24 during construction of span 8	147
Figure 186: Rotation in girder 175A15, instrumentation line 24 during construction of span 8	147
Figure 187: Stress in girder 161E13, instrumentation line 19 during concrete placement 1	149
Figure 188: Temperature in girder 161E13, instrumentation line 19 during concrete placement 1	149
Figure 189: Stress in girder 171E15, instrumentation line 23 during concrete placement 1	149
Figure 190: Temperature in girder 171E15, instrumentation line 23 during concrete placement 1	150
Figure 191: Stress in girder 171E15, instrumentation line 24 during concrete placement 1	150

Figure 192: Temperature in girder 171E15, instrumentation line 24 during concrete placement 1.....	150
Figure 193: Displacement in girders 171E15-175A15 near connection to 166E14-170A14 during concrete placement 1	151
Figure 194: Displacement in girders 171E15-175A15 at mid span during concrete placement 1.....	151
Figure 195: Displacement of inside girder during concrete placement 1	151
Figure 196: Temperature in girder 104B1, instrumentation line 1 during concrete placement 2.....	152
Figure 197: Stress in girder 101E1, instrumentation line 1 during concrete placement 2	152
Figure 198: Temperature in girder 101E1, instrumentation line 1 during concrete placement 2.....	152
Figure 199: Stress in girder 104B1, instrumentation line 1 during concrete placement 2	153
Figure 200: Temperature in girder 104B1, instrumentation line 1 during concrete placement 2.....	153
Figure 201: Stress in girder 111E3, instrumentation line 4 during concrete placement 2	153
Figure 202: Temperature in girder 111E13, instrumentation line 4 during concrete placement 2.....	154
Figure 203: Stress in girder 114B3, instrumentation line 4 during concrete placement 2	154
Figure 204: Temperature in girder 114B3, instrumentation line 4 during concrete placement 2.....	154
Figure 205: Stress in girder 167D14, instrumentation line 22 during concrete placement 3	155
Figure 206: Temperature in girder 167D14, instrumentation line 22 during concrete placement 3.....	155
Figure 207: Stress in girder 170A14, instrumentation line 22 during concrete placement 3	155
Figure 208: Temperature in girder 170A14, instrumentation line 22 during concrete placement 3.....	156
Figure 209: Displacement in girders 171E15-175A15 at connection to girders 166E14-170A14 during concrete placement 3	156
Figure 210: Displacement in girders 171E15-175A15 at mid span during concrete placement 3.....	156
Figure 211: Stress in girder 101E1, instrumentation line 1 during live load test	158
Figure 212: Stress in girder 104B1, instrumentation line 1 during live load test	158
Figure 213: Stress in girder 106E2, instrumentation line 2 during live load test	158
Figure 214: Stress in girder 109B2, instrumentation line 3 during live load test	158
Figure 215: Stress in girder 111E3, instrumentation line 4 during live load test	159
Figure 216: Stress in girder 114B3, instrumentation line 4 during live load test	159

Figure 217: Stress in girder 116E4, instrumentation line 6 during live load test	159
Figure 218: Stress in girder 119B4, instrumentation line 5 during live load test	159
Figure 219: Stress in girder 119B4, instrumentation line 6 during live load test	160
Figure 220: Stress in girder 125A5, instrumentation line 7 during live load test	160
Figure 221: Stress in girder 125A5, instrumentation line 8 during live load test	160
Figure 222: Stress in girder 125A5, instrumentation line 9 during live load test	160
Figure 223: Stress in girder 130A6, instrumentation line 10 during live load test	161
Figure 224: Stress in girder 135A7, instrumentation line 11 during live load test	161
Figure 225: Stress in girder 140A8, instrumentation line 12 during live load test	161
Figure 226: Stress in girder 145A9, instrumentation line 13 during live load test	161
Figure 227: Stress in girder 150A10, instrumentation line 15 during live load test	162
Figure 228: Stress in girder 155A11, instrumentation line 16 during live load test	162
Figure 229: Stress in girder 160A12, instrumentation line 17 during live load test	162
Figure 230: Stress in girder 160A12, instrumentation line 18 during live load test	162
Figure 231: Stress in girder 161E13, instrumentation line 19 during live load test	163
Figure 232: Stress in girder 165A13, instrumentation line 19 during live load test	163
Figure 233: Stress in girder 167D14, instrumentation line 20 during live load test	163
Figure 234: Stress in girder 170A14, instrumentation line 20 during live load test	163
Figure 235: Stress in girder 171E15, instrumentation line 23 during live load test	164
Figure 236: Stress in girder 171E15, instrumentation line 24 during live load test	164
Figure 237: Stress in girder 175A15, instrumentation line 23 during live load test	164
Figure 238: Stress in girder 175A15, instrumentation line 24 during live load test	164
Figure 239: Displacement of target 1 during live load test	165
Figure 240: Displacement of target 2 during live load test	165
Figure 241: Displacement of target 3 during live load test	165
Figure 242: Displacement of target 4 during live load test	166
Figure 243: Displacement of target 5 during live load test	166
Figure 244: Displacement of target 2111 during live load test	166
Figure 245: Displacement of target 2121 during live load test	167
Figure 246: Displacement of target 2141 during live load test	167
Figure 247: Displacement of target 2211 during live load test	167
Figure 248: Displacement of target 2221 during live load test	168
Figure 249: Displacement of target 2241 during live load test	168
Figure 250: Displacement of target 2231 during live load test	168
Figure 251: Displacement of target 2321 during live load test	169
Figure 252: Displacement of target 2411 during live load test	169
Figure 253: Displacement of target 2421 during live load test	169
Figure 254: Displacement of target 2441 during live load test	170
Figure 255: Displacement of target 2511 during live load test	170
Figure 256: Displacement of target 2521 during live load test	170
Figure 257: Displacement of target 2541 during live load test	171
Figure 258: Displacement of target 2551 during live load test	171
Figure 259: Displacement of target 2561 during live load test	171

Figure 260: Displacement of target 2611 during live load test	172
Figure 261: Displacement of target 2621 during live load test	172
Figure 262: Displacement of target 2641 during live load test	172
Figure 263: Displacement of target 2651 during live load test	173
Figure 264: Displacement of target 2661 during live load test	173
Figure 265: Displacement span 2 during live load test.....	173

SUMMARY

The construction of curved I-girder bridges generally requires detailed attention to the steel erection plan as well as the deck placement sequence. There is limited quantitative information available on the performance of large curved bridges under construction. This study seeks to address this limitation through the study of a curved ramp I-girder bridge. The bridge under study is the last of several bridges needed to complete the interchange between I-40 and Briley Parkway (TN SR155) in western Nashville, TN.

The study consists of three parts. First, the bridge was instrumented and its behavior during construction was monitored using vibrating wire strain gages, clinometers, and a robotic total station. Through these technologies it was possible to monitor changes in strain/stress, angle of rotation, and deflections throughout the girder erection, installation of concrete formwork, and concrete placement. Second, a static load test of the completed bridge was conducted using ten trucks loaded to a total weight of 72 kips each, during which measurements of the stress/strain and deflections were acquired. Finally, the collected data was compared to analytical results obtained from a 3D finite element analysis (FEA) model to assess the correlation between measurements and refined analytical predictions. The refined 3D FEA predictions are used as a baseline for evaluation of various simplified analysis methods in a parallel National Cooperative Highway Research Program project, NCHRP 12-79, Guidelines for Analytical Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges. Overall, the comparisons show that the 3D FEA model provides a reasonable approximation of the bridge's behavior in terms of both stresses and deflections.

CHAPTER 1: PROJECT DESCRIPTION

1.1 Introduction

The design of curved I-girder bridges generally requires detailed attention to the steel erection plan as well as the deck placement sequence. As noted in a 2008 progress report for NCHRP Project 12-79 (unpublished):

At larger span lengths, tighter curvatures and/or sharper skews, control of the constructed geometry is a critical attribute of the engineering of steel deck-girder bridges. Significantly curved and/or skewed bridges generally exhibit significant 3D deflections and rotations. Longer span bridges tend to be affected more substantially by dead load effects, potentially resulting in more significant stability considerations during construction. In curved and skewed structures, these effects are manifested predominantly in the second-order amplification of the deflections and internal stresses. During intermediate erection stages, it is important that the physical component stresses (including any significant second-order effects) are limited such that there is no significant onset of inelastic deformations and no component strength limits are exceeded. Control of the geometry during the placement of the deck is an essential consideration in the construction of curved and skewed deck-girder bridges.

There is scant quantitative information on the performance of large curved bridges under construction. The current NCHRP Project 12-79 is addressing this issue from the analytical standpoint. This project intends to verify this analytical approach by obtaining field data during the construction of a bridge with a tight curvature. The project consists of:

- Instrumenting and monitoring girder stresses and deformations during construction of a large, continuous curved bridge (Ramp B over I-40, Nashville, TN).
- Comparing the results with those from analytical work in NCHRP 12-79 to assess the ability of refined 3D FEA models to predict the behavior during different stages of construction. (These models are then used as a baseline for evaluation of various simplified methods of analysis in the NCHRP 12-79 research.)
- Providing a detailed set of data from a series of static load tests on the completed bridge to calibrate simple and advanced models for completed curved I-girder bridges.

1.2 Project Description

The bridge under study is the last of the several bridges needed to complete the interchange between I-40 and Briley Parkway (TN SR155) in western Nashville, TN (Figure 1). Briley Parkway is a four-lane, median-divided, access-controlled roadway which serves as an additional northern loop around Nashville and provides direct access to several of its tourist attractions, including Opryland. TDOT traffic counts estimate 42,000 vehicles use this interchange each day, in addition to the 100,000 vehicles that travel this stretch of I-40 daily.

Major improvements to this interchange began in the late 1990s, and concluded with the opening of Ramp B, the bridge under study, in the summer of 2010. Ramp B provides direct freeway-to-expressway movements between eastbound I-40 and northbound Briley Parkway (SR 155), eliminating the need for traffic to enter White Bridge Road and its bridge over I-40.

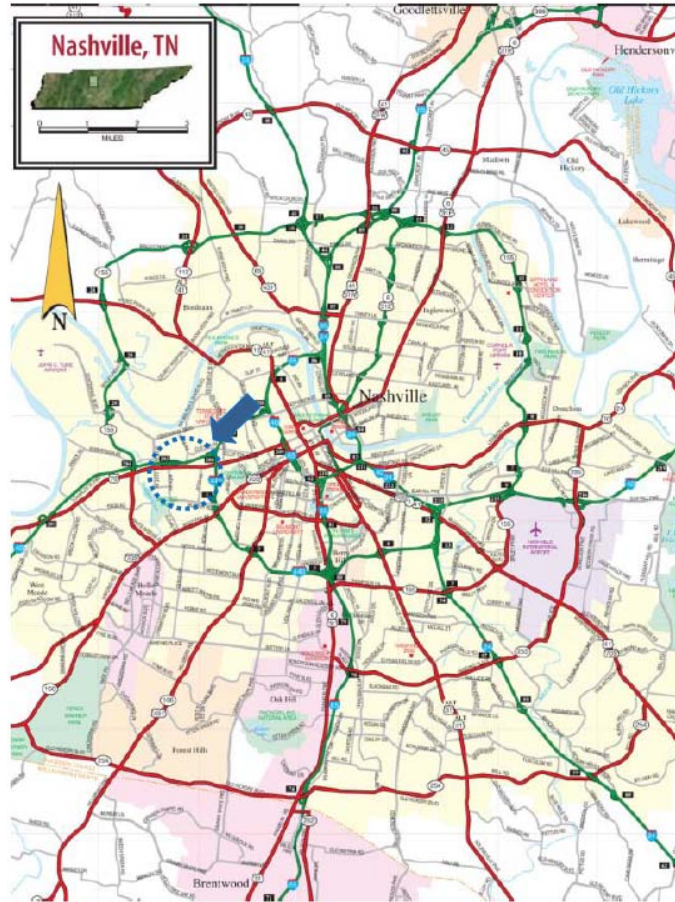


Figure 1: Project Location

Phase Two of the I-40 interchange project was funded by the American Recovery and Reinvestment Act (ARRA). The project was awarded to Bell & Associates (Brentwood, TN) in June 2009. The project also includes the construction of three noise barrier walls, the replacement of the White Bridge Road bridge over I-40, five retaining walls, and the replacement of the pedestrian bridge located just west of the interchange. The \$32 million project was completed in late summer 2010, and employed nearly 350 workers at the height of its construction.

1.3 Ramp B

Ramp B is an eight-span, curved steel girder composite bridge with a total length of 462.3m (1516'-9"). As shown in Figure 2, Ramp B is the exit from eastbound I-40 to

northbound Briley Parkway. Ramp B first goes over exit Ramp G and White Bridge Road, then turns sharply over I-40 and Ramp E (Figure 3), before joining Ramp D at its northern end.



Figure 2: Computer Generated View of Project



Figure 3: View (Looking West) of Ramp B during Load Testing

Ramp B was designed in accordance with AASHTO Standard Specifications for Highway Bridges (2002) and the AASHTO Guide Specifications for Horizontally Curved Steel Girder Highway Bridges (2003), including seismic provisions (Category A; Seismic coefficient = 0.075g), as a single lane, 80 kph bridge. As the elevation in Figure 4 shows, Ramp B rises sharply from its beginning abutment at a slope of +3.342% to its maximum height of about 5.8m above its horizontal chord at Bent 4, before dropping at -3.551% to finish about 2.5m above its horizontal chord at Bent 7.

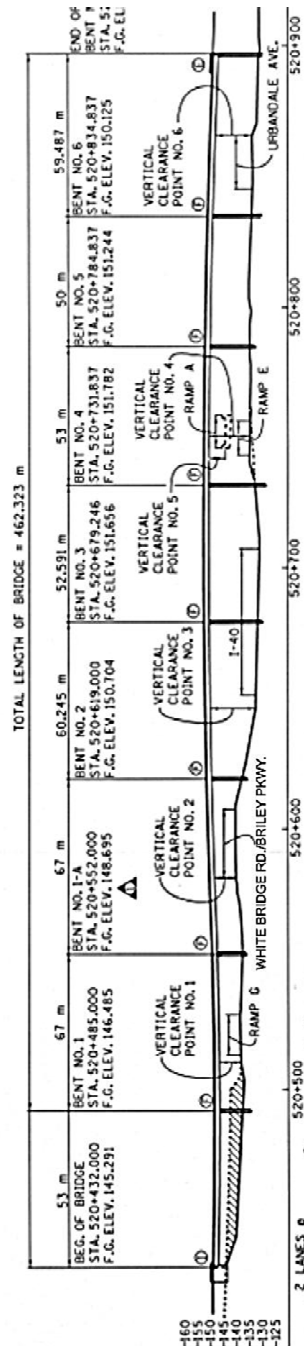


Figure 4: Elevation of Ramp B

Ramp B is a composite I-girder bridge consisting of five steel plate girders of approximately 1800mm (70”) in height, with a cast-in-place concrete slab approximately 210mm (8¼”) thick, and a total width of about 13210mm (43’-4”) on metal deck forms. The roadway width is 12150mm (39’-9”), with a girder spacing of 2660mm (8’-8”) as

shown in Figure 5. The minimum specified concrete strength is 21MPa (3 ksi), and all reinforcement steel is Grade 400 (60 ksi) meeting A615M. Full composite action was achieved by the use of 22.2mm (7/8”) diameter shear studs meeting AASHTO 169 and ASTM A108 standards.

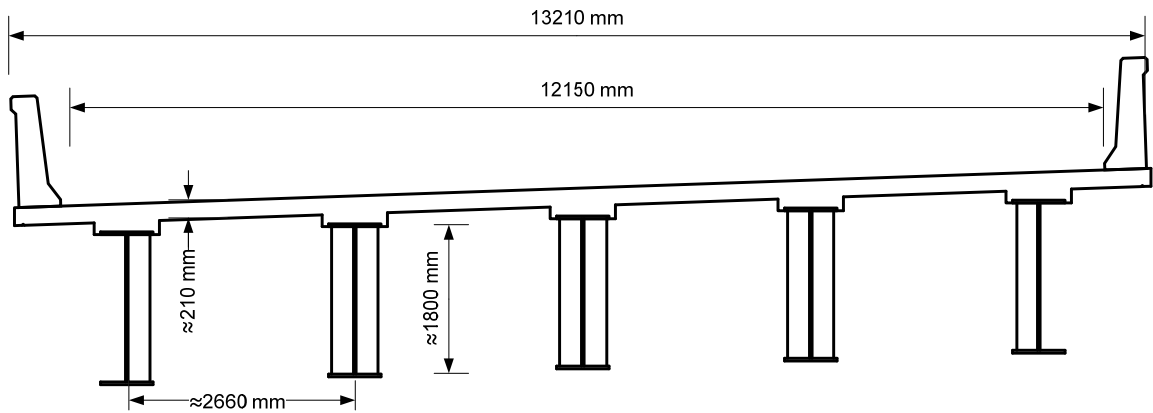


Figure 5: Typical Cross-Sectional Dimensions

The welded plate girders have webs consisting of 1727mm by 13 mm plates and flanges ranging from 610mm by 27mm to 610mm by 83mm plates (webs are 67.5” by ½”, and flanges ranging from 24” by 1” to 24” by ¾”). All steel plates are 345MPa (50 ksi.) meeting AASHTO M270 and ASTM709 requirements. All welding is per AWS 1.5-2002, The girders were cambered to offset dead load deflections and vertical curves. Details of a typical girder are shown in Figure 6 and Figure 7.

Some key characteristics of this bridge are its relatively small radius of curvature, which is as low as 136.85m (449’), and its high superelevations, which reach differences of over 1 meter across the 13.2m deck (3.3ft. in 43.2 ft.). The girders were fabricated by PDM Bridge, PLL at their Palatka (FL) facility and all tolerances were checked by TDOT inspectors before they were shipped to the site. Figure 8 shows a typical detail of the single-piece intermediate cross-frames employed for this bridge. Figure 9 shows a

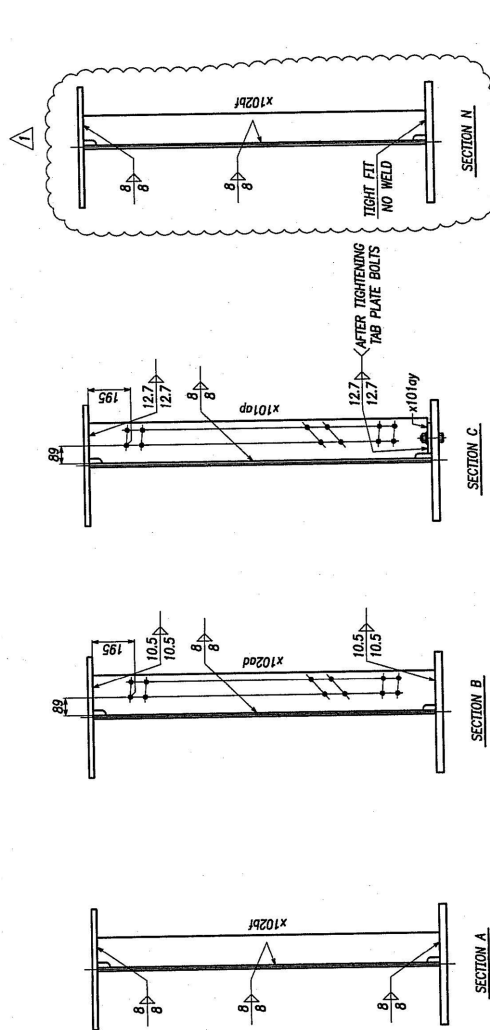


Figure 7: Typical Plate Girder Details (Fabrication Drawing from PDM)

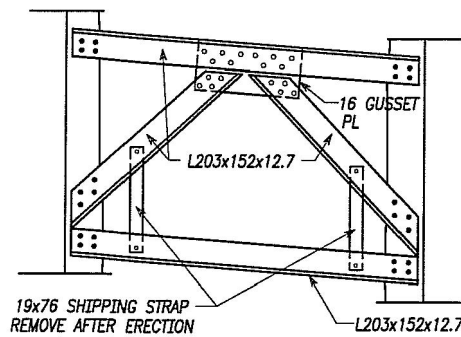


Figure 8: Typical cross-frame, showing the drops in elevation between the girders

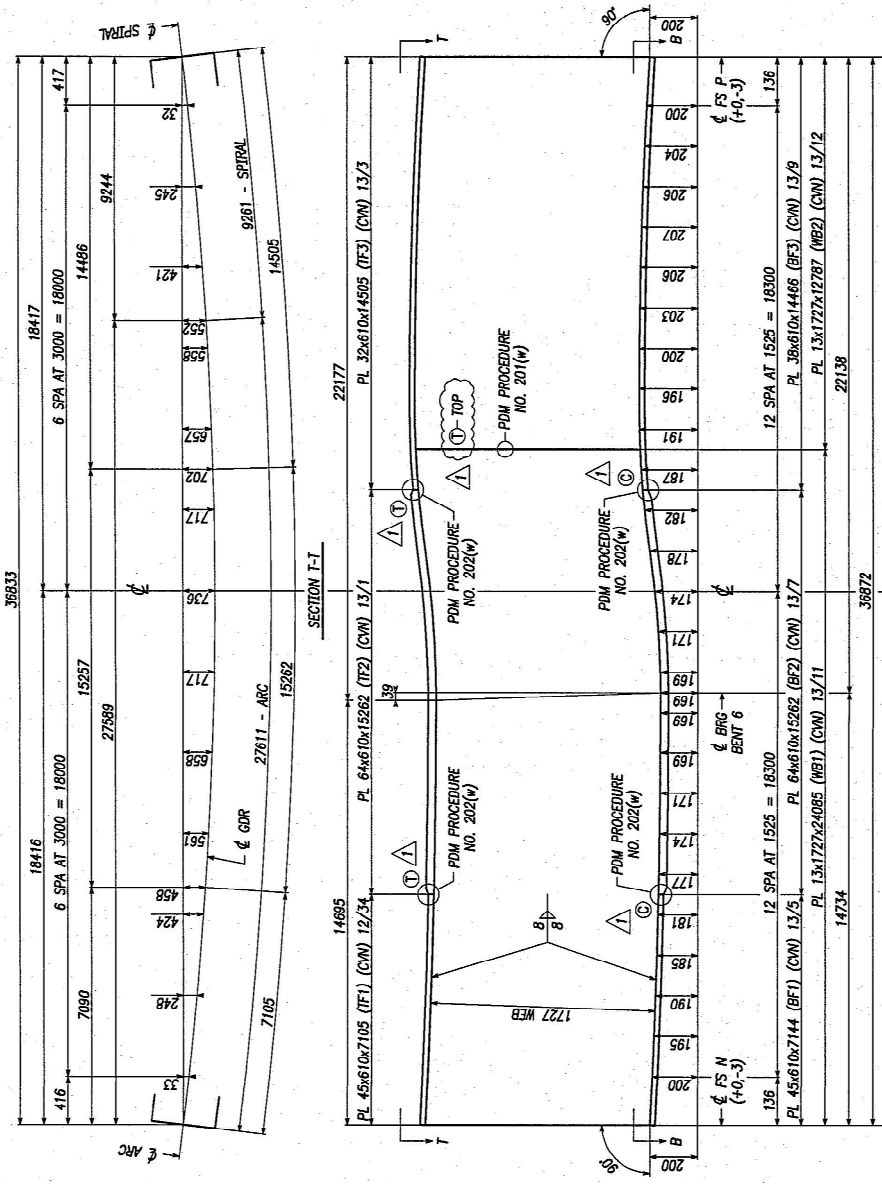


Figure 9: Shop drawing for girder 169B14 indicating sweep and camber profile of the girder

1.4 Project Tasks

The project consisted of the following tasks:

Task 1: Instrumentation Plan: This task entailed the development of an instrumentation plan to ensure that the sensors would provide the resolution and robustness necessary for this field application. Details of this task are given in Chapter 2 and in Appendix A.

Task 2: Coordination with Fabricator and Construction Company: A series of meetings and teleconferences were arranged with the fabricator (PDM), the contractor (Bell Construction), and the erector (Powell Erectors) to coordinate efforts throughout the project. The objectives of this task were two-fold: (a) minimizing impact of the instrumentation during erection, and (b) coordinating installation of the instrumentation between time of delivery of the girders to Nashville and their erection.

Task 3: Acquisition of Hardware: Because of the short time lag between the granting of the contract and the beginning of erection (less than one month), most of the instrumentation was acquired from a sole source, Applied Geomechanics Inc. The system was turnkey, incorporating wireless technology as described in Chapter 2.

Task 4: Installation and Verification of Hardware: Initially the largest portion of the instrumentation was to be done at the fabricator's shop in Florida, prior to shipping of the girders. Due to the very tight delivery schedule and the sequence of fabrication, this turned out to be impossible and all instrumentation after the first week of the project took place in Nashville, as described in Chapter 2.

Task 5: Data Acquisition at the Fabricator's Yard: The original project contemplated a number of tests on individual and pairs of girders to be conducted at the fabricator's yard to obtain baseline readings with the girders both in their cambered, no-load condition and under simplified lifting situations. This data set was to be correlated to FE studies to

ensure that reasonable readings were obtained. Unfortunately, for the logistical reasons described above, it was only possible to carry out this task for two of the first sets of five girders. As a result, baselines for the data had to be back-calculated.

Task 6: Verification of Instrumentation at Site: The instrumentation was checked as the girders arrived at the construction site to verify it was working well and to make any necessary repairs possible before erection began.

Task 7: Erection and Construction Monitoring: As construction progressed, the instruments were monitored and data acquired for a variety of erection and loading conditions. Records were kept of the erection procedure, which sometimes differed significantly from the original plans. This aspect of the project is described in Chapter 3 and Appendix E. The instrumentation tracked construction stresses through the end of the casting of the slab. Some of the instrumentation was kept live for a period of several months afterwards to assess long-term effects due to creep and shrinkage. The data acquired during this period are described in Chapter 4 and in Appendices B and C.

Tasks 8: Proof Testing of the Bridge: Prior to the bridge opening to traffic, a static load test of the bridge was conducted using trucks loaded with gravel. A large number of load positions and combinations were used to assess the capabilities of different models to predict live load distributions. These data are described in Chapter 5 and Appendix D.

Task 9: Correlation with Analytical Studies: The results of the field studies were correlated with the results from advanced finite element analyses to determine the ability of the different methods to predict the stresses and deflections. Comparisons between analytical and measured stresses are given in Chapter 6.

1.5 Report Organization

This report describes the instrumentation and data acquisition work on an eight-span continuous, sharply curved steel girder bridge in Nashville, TN. The report is divided into seven chapters and seven appendices. The first chapter presents a brief description of the overall project. This is followed by chapters describing the instrumentation procedures, the erection sequence, the experimental results for the construction and live load testing phases, respectively, and the correlation of analysis predictions with the measurements. The final chapter gives the main conclusions and recommendations. Descriptions of the instrumentation, all the collected data, and the original fabrication and erection plans are presented in the appendices.

CHAPTER 2: INSTRUMENTATION OF THE GIRDERS

2.1 Introduction

The preliminary instrumentation plan was based on the best available information at the time of the contract execution (December 15, 2009). As common in field installations, this plan represented a compromise between maximizing the density of instrumentation to obtain the best resolution of the data and minimizing both cost of the equipment and installation time. A key requirement by the owner was that the instrumentation work should not result in any additional construction costs or delays.

For the initial planning, the main constraints were that the GT team would have access to the girders:

- for only 72 hours for instrumenting at the Palatka (FL) PDM fabrication plant before they were shipped each week,
- for only a few minutes to conduct final checks at the construction site before they were lifted from the trucks,
- as soon as possible after the girders were installed and secured, but that access would be subject to all construction site safety regulations as well as permission of the erector.

In the end, several factors led to drastic changes to the instrumentation plan in the field.

The two main factors impacting the plan were:

- The girders were being fabricated and finished in a just-in-time fashion by PDM; the planned 72 hours of access to the girders at the Palatka plant were clearly unfeasible from the first week. After the first two weeks, all instrumentation was shifted to a storage site on I-840 south of Nashville. In general the team had access to the girders for less than 12 hours before they were shipped from this

storage facility to the site for erection. This meant that the team had to work nights and in less than ideal conditions for robust instrumentation.

- The original erection scheme, as conveyed to the GT team (see Appendix E), consisted of lifting two longitudinal girders simultaneously. This meant that in the original instrumentation plan little or no splicing of cables would be needed and that the placement of the junction boxes would be considerably simplified. In the end, the girders were erected individually and in a sequence different from originally proposed. The resulting primary problem was that extensive splicing of cables was needed. As well known, any splicing of cables has the potential for individual failure as well as errors in placement of the individual cables. The latter was a particular concern in this project as 60-pin connectors were used, requiring extreme care and patience in their fabrication.

These problems were not surprising, as any field instrumentation project will have similar issues. In the end, the excellent cooperation between TDOT, Bell Construction and its subcontractors, including Powell Erectors, meant that the project was completed with minimal problems.

2.2 Gage Placement Design

The total number of instruments deployed (approximately 248) was the minimum desirable so that a sufficient number of cross-sections along the bridge could be instrumented. In the original experimental design 22 critical sections, each with 5 girders, were considered as necessary to properly monitor the bridge during construction. At each of these locations at least 8 strain sensors and 3 bidirectional tilt meters would be needed on each girder to characterize the elastic distribution of strains if some measure of the torsional and distorsional contributions were desirable (Figure 10). This total number of sensors was far larger than possible both in terms of time and budget. In the

end, only 3 out of the 5 girder lines were instrumented, with a maximum of 6 strain gages and 2 rotational devices used on each girder. The final number of sensors represents less than 20% of the total desired.

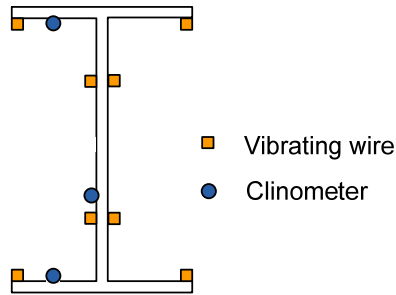


Figure 10: Desired instrumentation level for each girder

In the end, 214 vibrating wire strain gages and 34 clinometers were attached to the bridge's steel girders along 24 instrumentation lines. The instrumentation lines consisted of sequential cross sections through the bridge along which the strain gages and clinometers were installed. Figure 11 shows a plan view of the bridge with the spans and instrumentation lines labeled. The configuration of the gages for each line of instrumentation is shown in Figure 12 through Figure 17 where the small round symbols numbered 1-6 indicate vibrating wire strain gages and the larger square symbols numbered 7-8 indicate clinometers. The clinometers were moved as the construction proceeded, as only 12 sensors of this type were available.

The numbers shown below the cross-section profiles in Figure 12 through Figure 17 indicate the girder (i.e., shipping piece) numbers. The bridge is five girders wide, and the numbering begins at the inside of the curve for the first group of five shipping pieces, proceeds to the outside of the curve, and then begins with the inside of the curve for the next group of five shipping pieces. Each shipping piece is also assigned a letter, A-E, and an additional number, 1-15. The letter designates the location of the shipping piece within the bridge cross section, where A represents the girder line at the outermost curve

and E represents the girder line at the innermost curve. The final number represents the sequence of the shipping piece along the length of the bridge, with 1 representing the group of shipping pieces at the southern-most (starting) end of the bridge and 15 representing the group at the northern-most end of the bridge. All the spans contain two shipping pieces except for span 8, which only contains one. For example, span 1 contains ten total shipping pieces, two for each of its five girder lines. The first group of shipping pieces begins at 101E1 (referred to as girder 101, located at girder line E on the inside of the curve) and ends at 105A1 (referred to as girder 105, located at girder line A on the outside of the curve), while the second group of shipping pieces begins at 106E2 (referred to as girder 106, located at girder line E on the inside of the curve) and ends at 110A2 (referred to as girder 110, located at girder line A at the outside of the curve).

Lines of instrumentation are labeled on the drawing as IL # and data collection boxes are shown as squares labeled B #.

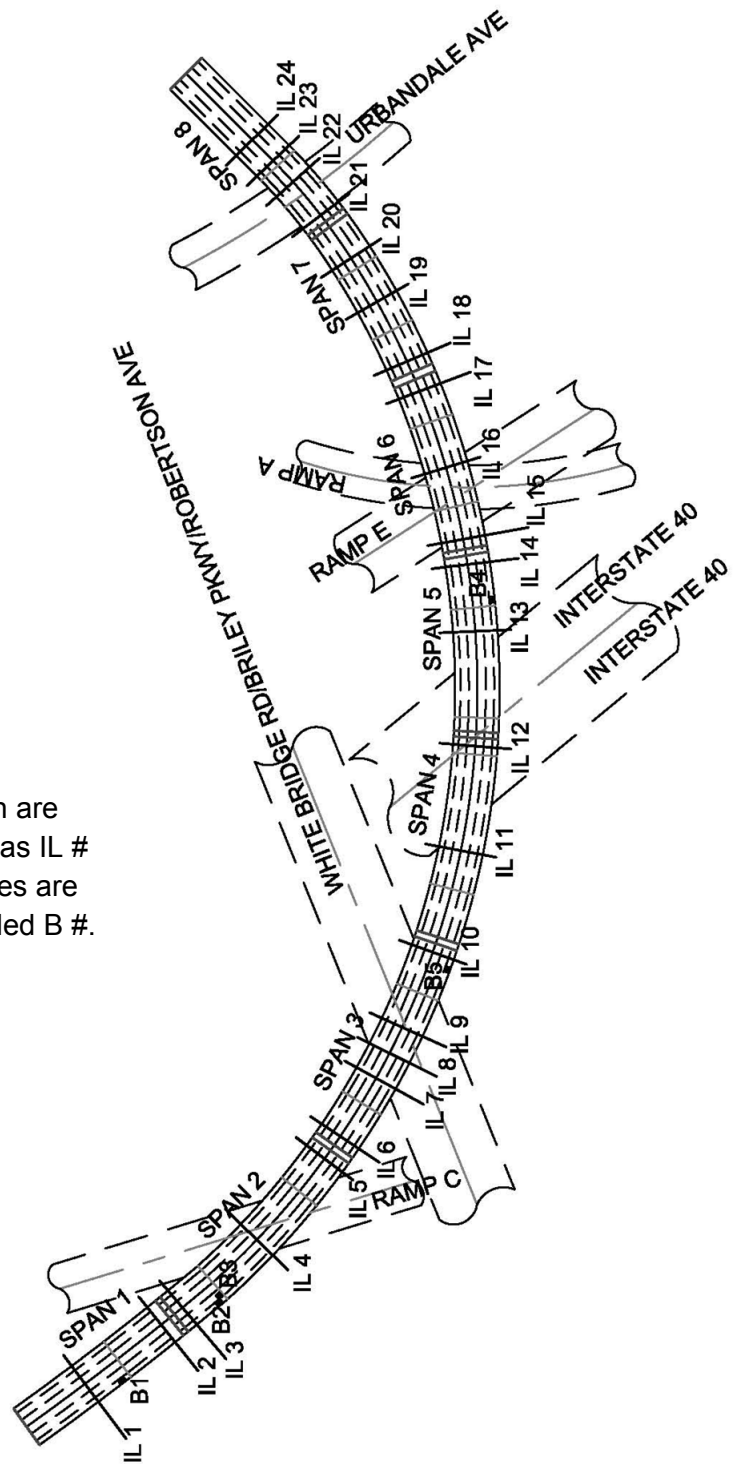


Figure 11: Plan View of Ramp B over I-40.

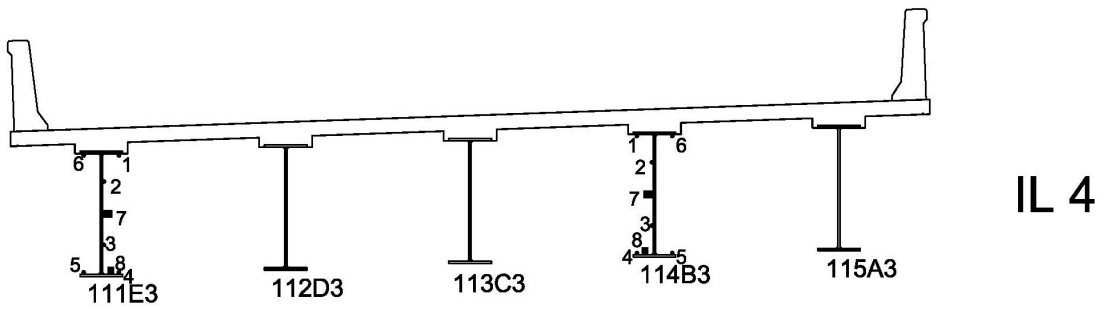
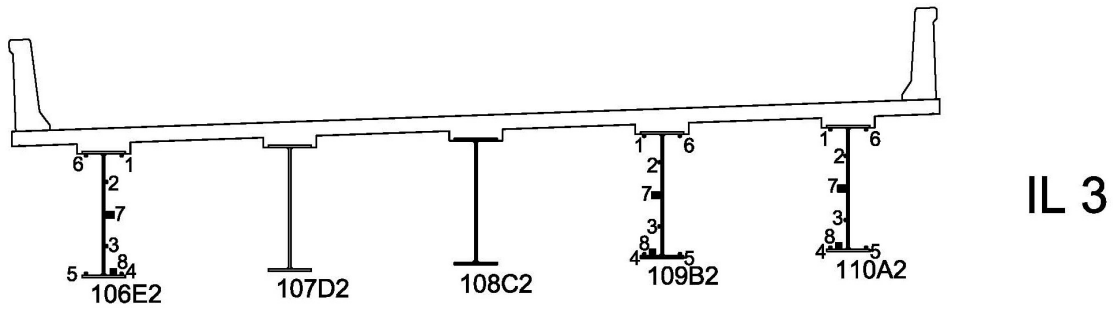
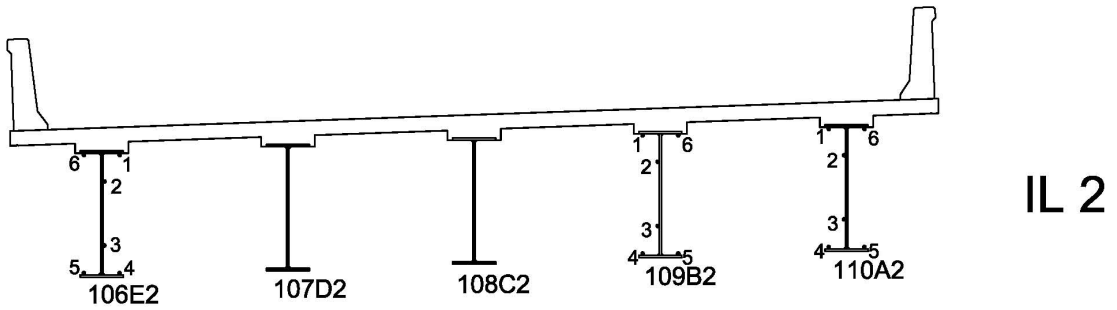
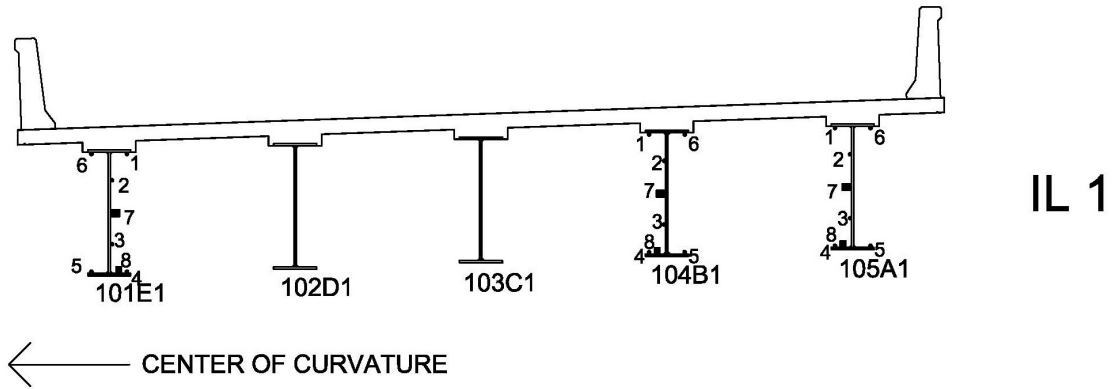


Figure 12: Instrumentation Lines 1-4

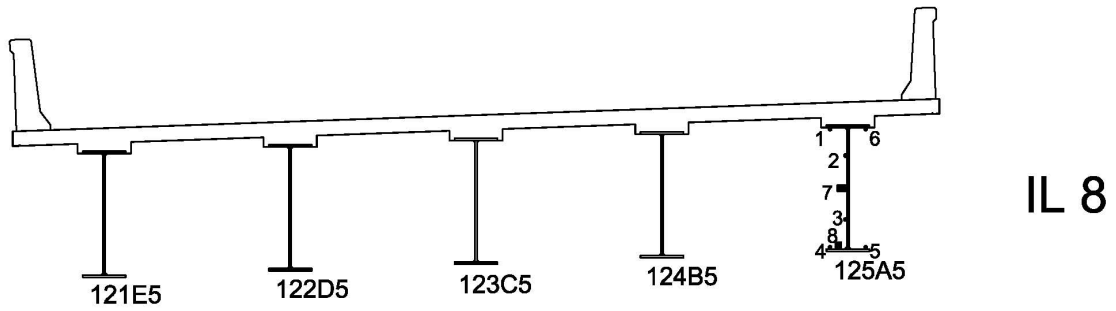
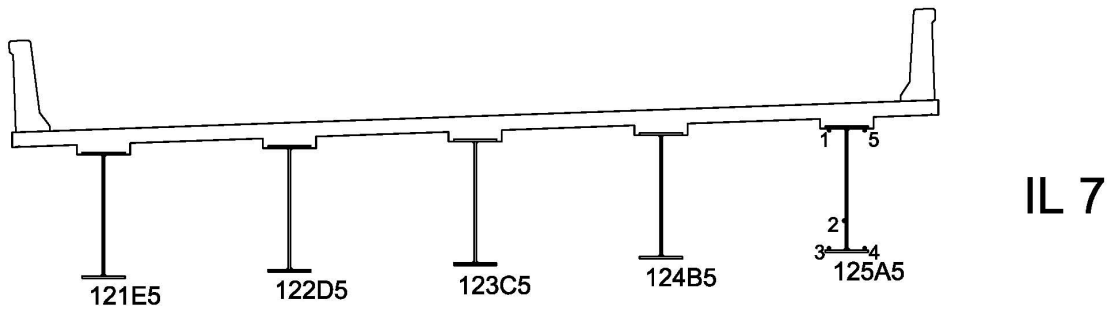
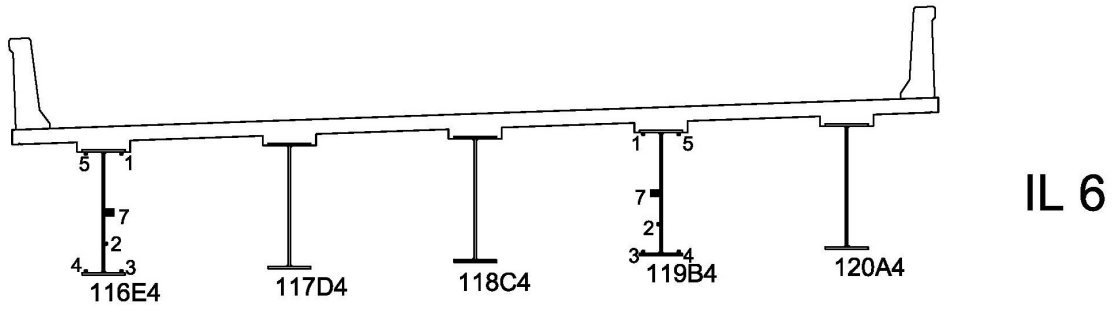
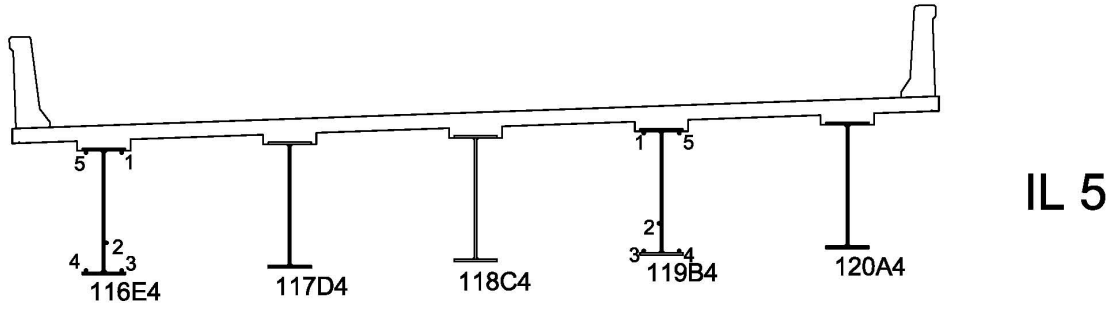


Figure 13: Instrumentation Lines 5-8

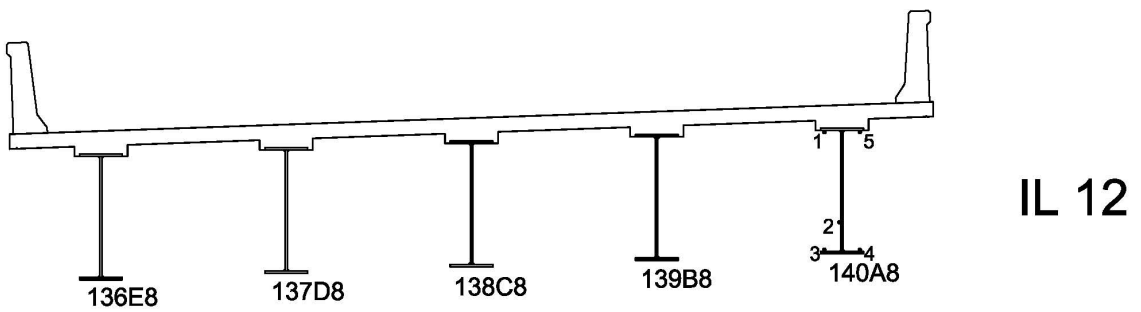
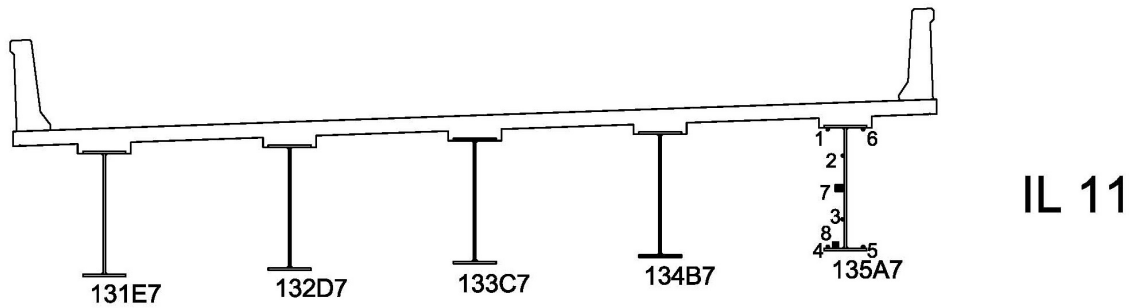
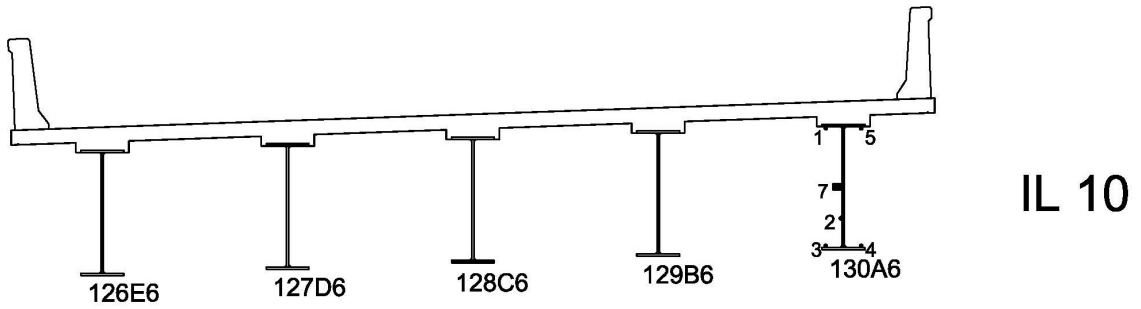
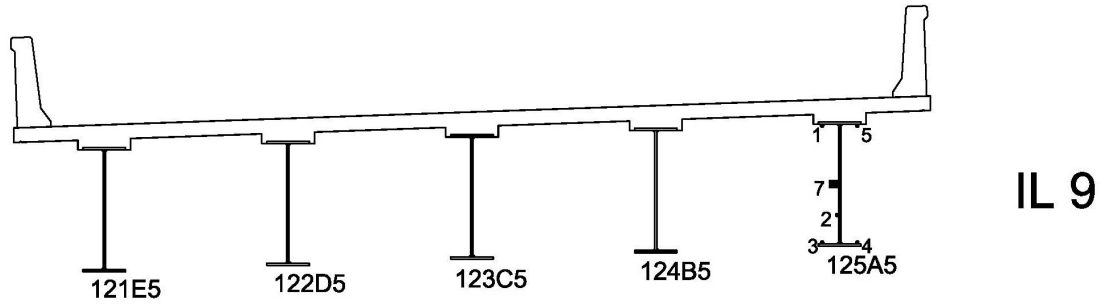


Figure 14: Instrumentation Lines 9-12

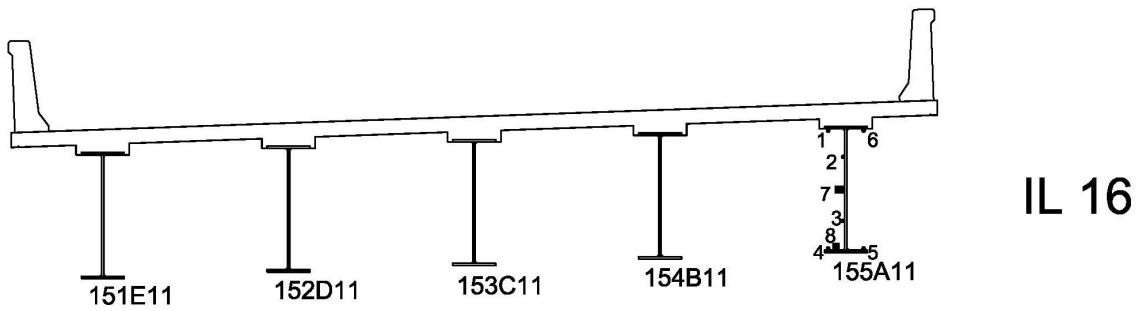
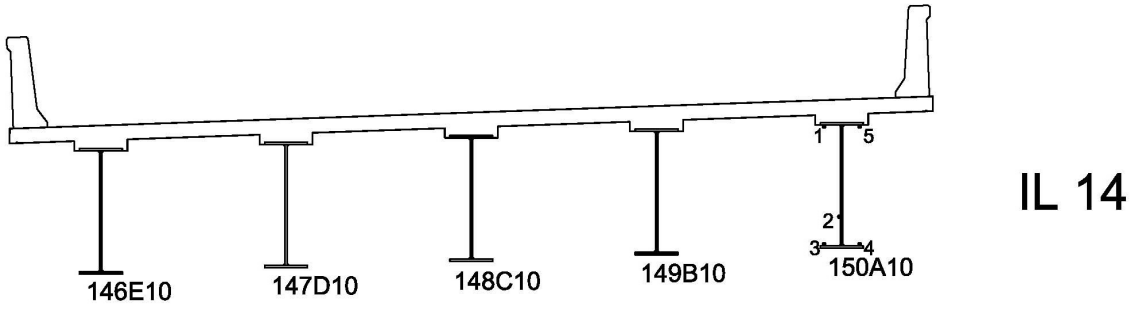
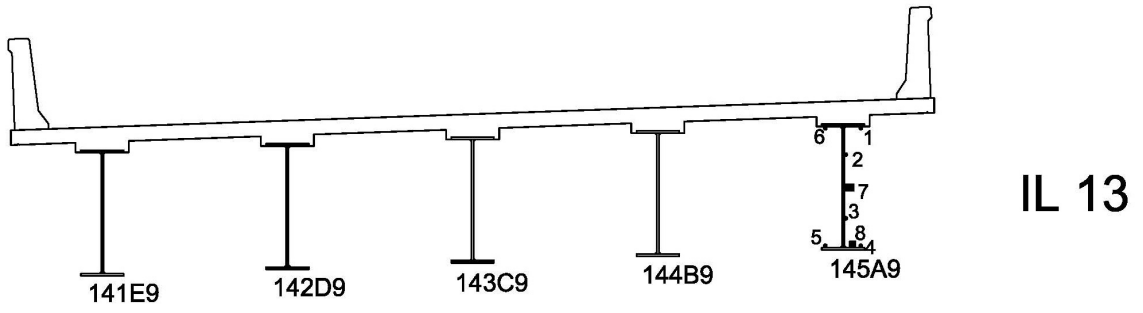


Figure 15: Instrumentation Lines 13-16

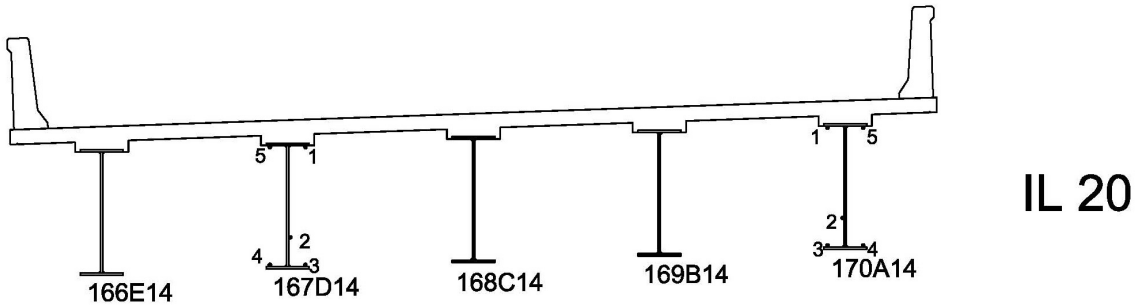
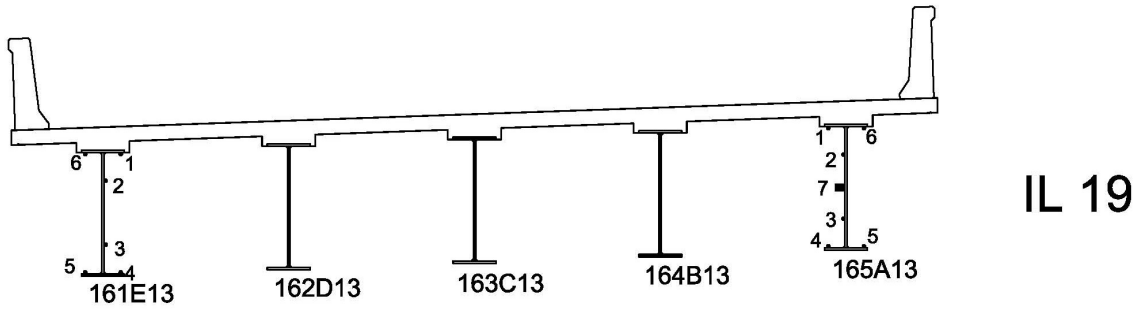
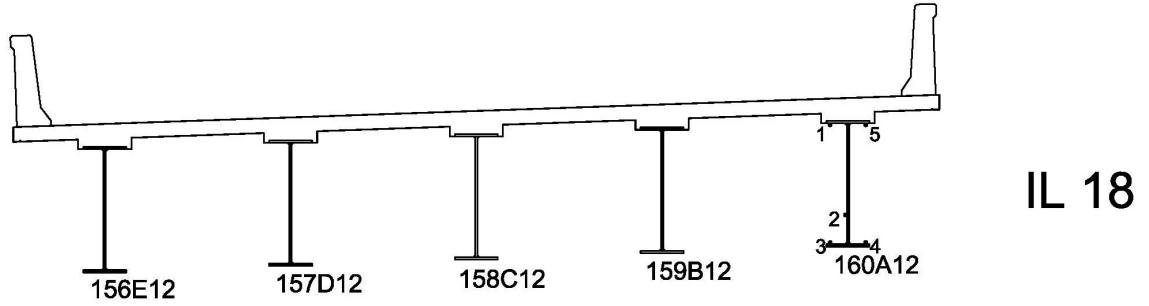
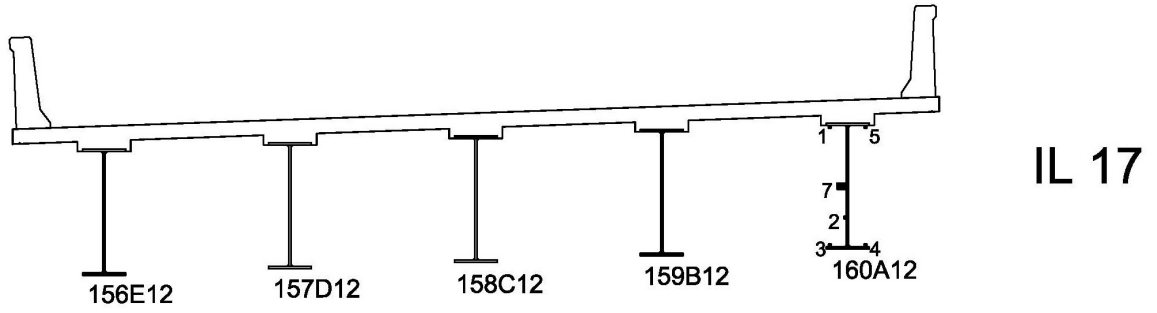
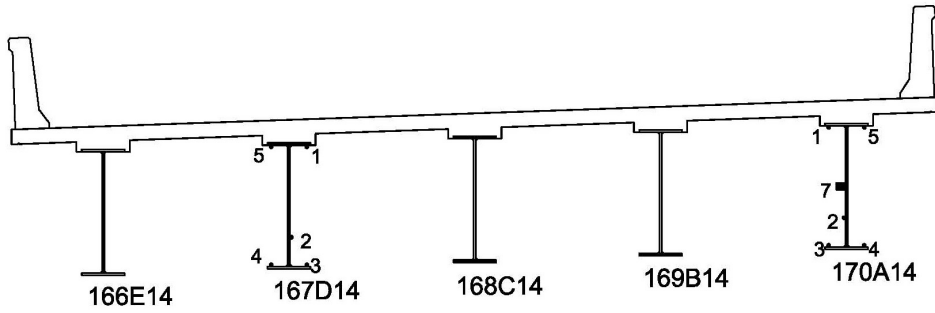
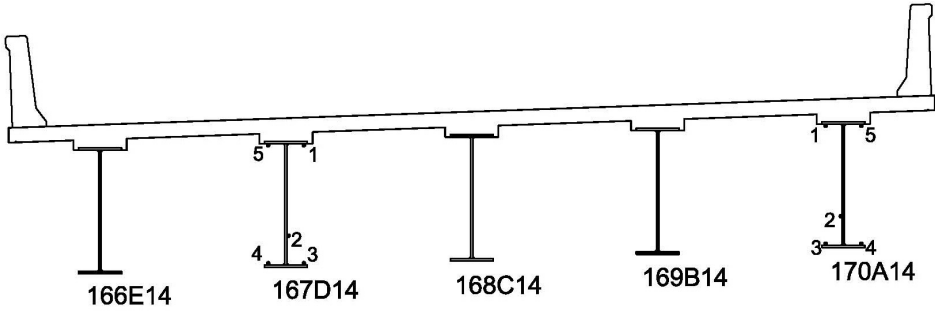


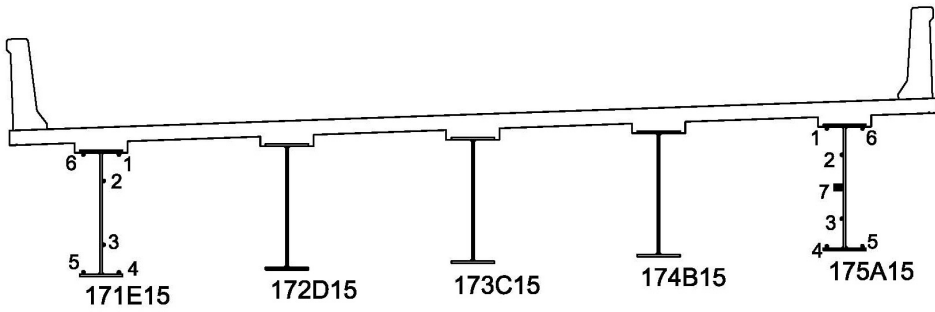
Figure 16: Instrumentation Lines 17-20



IL 21



IL 22



IL 23



IL 24

Figure 17: Instrumentation Lines 21-24

2.3 Data Acquisition Systems

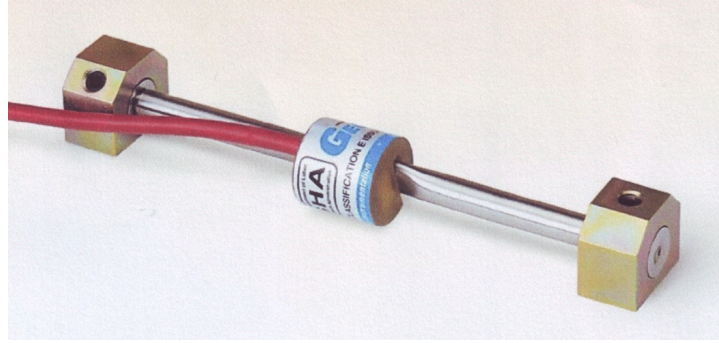
Two types of data acquisition systems were used. The first system was for the sensors attached to the bridge, which consisted of vibrating wire strain gages (*Geokon Model 4000*) and clinometers (*Applied Geomechanics Model 904T*). These sensors were connected to multiplexer units (*Applied Geomechanics Model 797*) which were in turn monitored by a datalogger (*Campbell Scientific CR1000 Measurement and Control Datalogger.*). Datasheets for this equipment are included in Appendix A. This system was powered by external solar cells that recharged internal batteries.

The other system consisted of a series of global displacement measurements conducted with a robotic total station (*Leica TCRP 1201*).

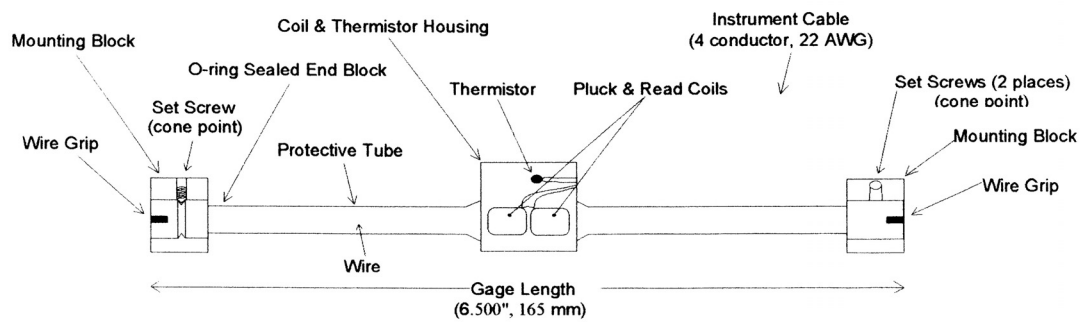
2.3.1 Applied Geomechanics System

2.3.1.1 Geokon Model 4000 Vibrating Wire Strain Gage

The girder strains were measured using vibrating wire strain gages (Figure 18). The vibrating wire gage uses a known length of steel wire that is tensioned between two mounting blocks. The blocks are welded to the steel surface being studied, which in this case is the steel girder, using an alignment jig (Figure 19). In turn, the gages are attached to the mounting blocks with set screws. The measuring system works by monitoring the change in vibration frequency of the wire as the mounting blocks move relative to one another in response to strains in the base material.



(a) View



(b) Schematic

Figure 18: Vibrating Wire Strain Gage (Geokon, Inc.)

Vibrating wire sensors have numerous advantages over conventional electrical resistance strain gages, primarily in terms of robustness, long-term stability, and absence of zero shifts due to connection and disconnection of cables. Their main disadvantage is that tracking of temperatures is necessary as temperature changes result in elongation or contraction of the sensing wire. Vibrating wire gages are ideal for monitoring small changes in strain under static loading, but are not suitable for measurement of dynamic or rapidly changing strain.

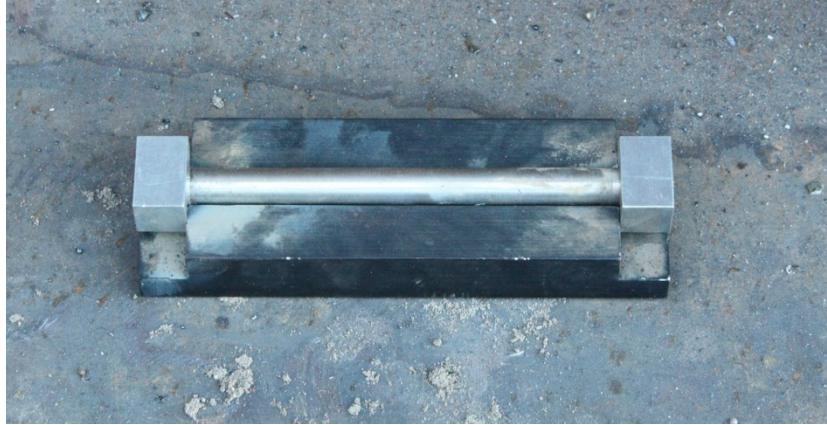


Figure 19: Jig used to ensure proper alignment of nuts for strain gage

Once the gage is securely attached to the girder, an initial reading is taken. If the initial support conditions are known, the initial reading can be used to determine the true zero reading, which is the nominal reading when the strain is zero. Readings are taken at regular intervals as loads are applied to the structure. If the true zero reading is known, these additional readings can be used to determine the absolute strain at that location in the structure due to the particular loading. If the true zero reading is not known, the subsequent readings can be used to determine the change in strain associated with changes in loading. Based on the assumption of linear elastic behavior, the strains (both absolute and relative) can be converted to stresses using Young's modulus of elasticity (E).

Each vibrating wire strain gage also contains an internal thermistor, or temperature probe. This measurement is needed to eliminate the effects of changes in ambient temperature. The thermistor gives a varying resistance output, which is converted to a temperature reading.

2.3.1.2 Applied Geomechanics Model 904T Clinometer

The *Applied Geomechanics* 904T clinometers are biaxial gravity referenced tilt meters (Figure 20). They are electrolytic tilt sensors comprised of a glass vial containing

a conductive liquid and five platinum-clad electrodes. AC resistance is measured along different paths through the sensor. As the sensor tilts, the liquid covers and uncovers the electrodes, changing the resistance. The arrangement of the electrodes allows the electronics to determine the direction and magnitude of rotation in two orthogonal vertical planes (X and Y). A temperature sensor is also included in each clinometer pack. The Model 904-TS used has a range of $\pm 25^\circ$ with an accuracy of 0.01° (0.000175 rad.)

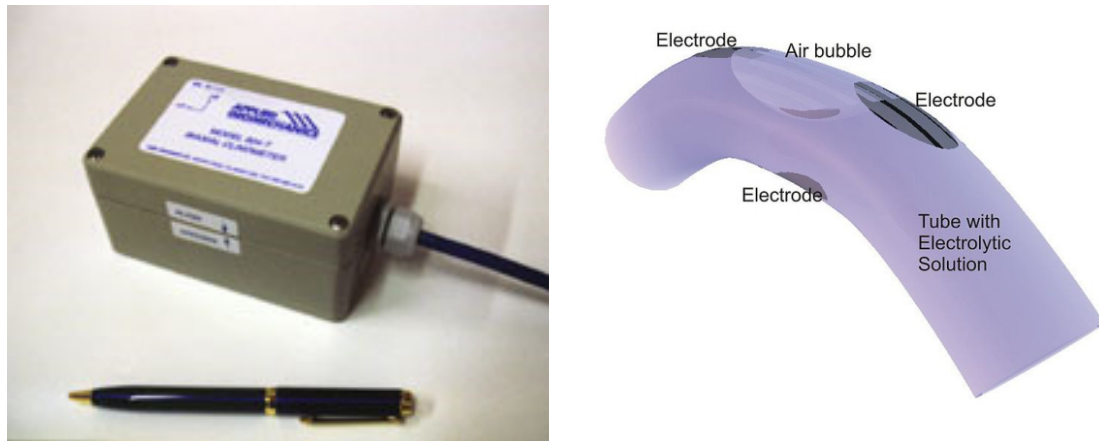


Figure 20: Clinometer in enclosure and working principle

Each clinometer is calibrated individually and a scale factor is determined by the manufacturer. It is also possible to measure and remove the bias, which is defined as the difference between the true angle and the angle reported by the clinometer when it is level. The bias is a constant value that is different for each clinometer, and is subtracted from the reported angle to obtain the true angle. It was determined that because the girders were not level or at a known angle when the clinometers were installed, it would not be possible to determine the absolute angle of the girder even with the bias corrected. For that reason, the bias was left in place and the data were used to determine changes in angle during different construction stages.

2.3.1.3 Applied Geomechanics Model 797 Multiplexer Unit

The *Applied Geomechanics* Multiplexer Unit allows simultaneous measurements of up to ten biaxial tilt meters and 32 vibrating wire strain gages. The unit routes power to the gages and clinometers and sequentially multiplexes their signals into common input terminals that are routed to the datalogger. The multiplexer is rated for temperatures ranging from -25° to +50°C.

2.3.1.4 Campbell Scientific CR1000 Measurement and Control System

The *Campbell Scientific CR1000* Measurement and Control System can measure any sensor with an electrical response, making it ideal for the vibrating wire strain gages. The data are stored in the unit's 4MB memory until it can be transferred to an external storage device such as a notebook computer via a wireless system. A benefit of the CR1000 system is that when data are transferred to an external device, the files are copied rather than moved. This allows multiple users to have access to the system without compromising data or needing to coordinate data collection activities. If the system runs out of memory the oldest data files are overwritten first, minimizing the likelihood of overwriting data before they have been copied to an external storage device.

2.3.2. Leica TCRP 1201+ Robotic Total Station

The *Leica TCRP 1201+* is a quick, easy to use total station with a range of over 1000 meters. The total station can be set up and operated by one person, and requires less than five seconds to collect a measurement. The total station was used in conjunction with reflective targets placed at key points on the bridge girders. Figure 21 shows the total station and some of its support equipment, including a reference target, power supplies, and carrying cases.



Figure 21: Leica total station and support equipment

2.4 Field Instrumentation of Girders

2.4.1 Gage Attachment Procedure

The steel girders were fabricated at a large fabrication plant owned by PDM Bridge, LLC in Palatka, Florida. The initial plan called for instrumentation of the girders to take place at the fabrication plant prior to their arrival on site, but due to fabrication delays this could only be done for the first span, consisting of girders 101E1-110A2. For most of these girders, manual readings of the strain gages were taken at the plant and the locations of the supports were recorded; thus true zero readings could be found.

For the rest of the girders, the instrumentation was installed in Nashville, Tennessee shortly before erection of the girders. In this case, installation of the gages occurred while the girder was on the delivery truck. The locations of the supports, including wood blocking and clamps from the crane, were measured and a manual reading was taken before the girder was lifted. Girders 115A3 and 120A4 were on the instrumentation plan but arrived at the site immediately prior to erection and could not be

instrumented. For similar scheduling reasons, there were no manual readings taken for girders 125A5, 130A6, 135A7, or 140A8 before they were erected.

The location of each strain gage was measured with a ruler and triangle and marked with chalk. The nuts were welded to the girder first, and then the strain gage was inserted and secured in place. A jig, shown in Figure 19, was used to ensure that the nuts were welded onto the girder at the proper spacing and alignment.

Support brackets for the clinometers were similarly located and welded onto the girders. Figure 22 shows a girder after welding of the nuts and bracket is complete but before installation of the sensors. As shown in the figure, strain gages are installed toward the top and bottom of the web and the clinometer is located at the center of the web. Figure 23 shows a girder with the instruments installed. Cables were secured to the girder to prevent them from catching on anything during construction and to minimize visibility of the instrumentation from the ground. This was initially done using duct tape, but after the erection of the first span, a switch was made to adhesive backed plastic clips and zip ties.



Figure 22: Nuts for two strain gages and support bracket for clinometer have been welded to the girder and are ready for installation of the instrumentation

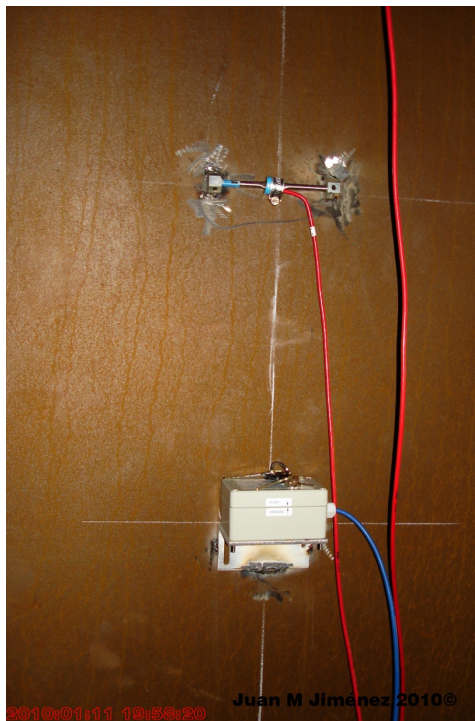


Figure 23: Girder with one strain gage and one clinometer installed

2.4.2 Data Acquisition Boxes

The data acquisition boxes were first mounted to a wooden frame, which was then attached to the girder. Typically each wooden frame held three boxes, one housing the datalogger and two housing the multiplexers for a set of clinometers and vibrating wire strain gages, respectively. A schematic of the boxes and their interconnections is shown in Appendix A, and a photo of an installed set of boxes is shown in Figure 24. On girders holding one of these sets of boxes, the gages could be connected and readings taken immediately upon installation, allowing for data collection during the erection of the girder. For all other girders, the connection back to the data acquisition boxes had to be made after erection with the use of a scissors lift or aerial platform. Once this connection was made, the data was collected via wireless transmission from the boxes. Figure 25 is a view inside of one of the data acquisition boxes, showing the CR1000, a power supply, and a radio transmitter. Figure 26 shows the downloading of data from one of the boxes to a notebook personal computer.



Figure 24: Data Acquisition Boxes

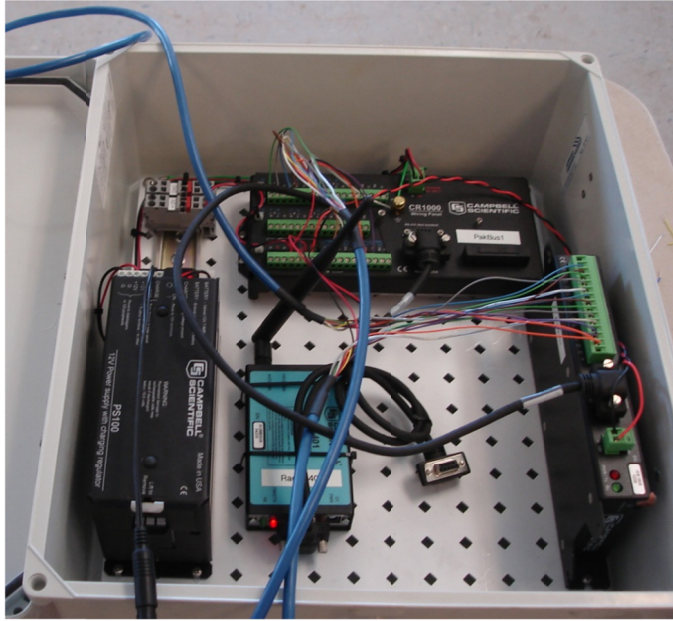


Figure 25: View inside one of the data acquisition boxes shown the CR1000, the power supply, and the radio transmitter



Figure 26: Downloading of data remotely from one of the data acquisition boxes

2.4.3 Electrical Power

Electrical power for the data acquisition boxes was provided from batteries recharged from four solar panels positioned at the site. Figure 27 shows a solar panel mounted at Bent No. 2. The total station also utilized rechargeable batteries which could either be charged from a standard wall socket or from a small diesel generator.



Figure 27: Installation of solar panels at Bent No. 2

2.4.4 Target Placement

Reflective targets were attached to the girders in spans 7 and 8 in order to take measurements with the total station, as shown in Figure 28. These were placed while the girders were on still on the truck when possible, and after girder erection otherwise. The targets were magnetic, so no adhesive was needed to attach them, but a silicone sealant was applied around the edges of each target to help prevent weather damage. Figure 29 shows the layout of the targets. Figure 30 shows an operator taking an initial reading of a reference target before taking measurements of the bridge.



Figure 28: Underside of bridge showing reflective targets attached to bottom flanges

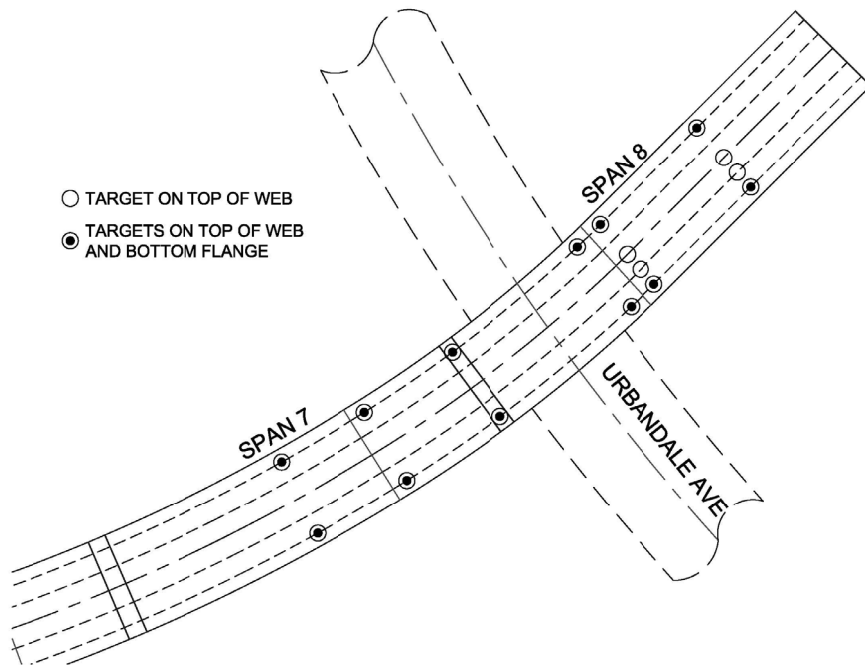


Figure 29: Layout of targets used for robotic total station measurements of spans 7 and 8.



Figure 30: Initial reading of reference target taken to orient the total station

CHAPTER 3: CONSTRUCTION OF THE BRIDGE

3.1 Introduction

This chapter describes the construction phases through which data were acquired.

3.2 Erection and Construction Procedure and Sequencing

3.2.1 Steel Erection

The erection procedure called for the use of a 175-ton crane, a 150-ton lattice boom crane, and a 40-ton crane. The two larger cranes were to be used for lifting the girders, with the use of spreader beams, while the 40-ton crane was to be used to hold a girder in place to stabilize it until the cross frames could be attached to secure it to the adjacent girder.

The order of girder erection for each span was driven by the site constraints and the corresponding location of the cranes. Some changes to the original erection procedure were made during construction, and are noted below.

Overview of Erection Procedure

Erection activities started at Abutment No. 1 on the southwest end of the bridge on Saturday, January 16. Using cranes, spreader beams, round slings, Crosby Clamp-Co. Model NS-25 25 ton capacity beam clamps, and other rigging, all the girder field sections were positioned and spliced in the air. The crane placement was as shown in Figure 31, from the preliminary proposal by Powell Construction, with the exception of a few deviations as described in the following sections. This figure also labels the various bents along the length of the bridge as well as the inside and outside girder designations throughout the bridge, as explained above. The cranes used on the project included a

KRUPP KMK 5175 175 Ton Hydraulic Crane, a P&H 9150 150 Ton (Lattice Boom) Truck Crane, and a Grove TMS 300B 40 Ton Hydraulic Crane.

The erection proceeded each day during the weekends, and involved installing two field sections for each span on each of the girder lines, with the second field section cantilevering over the next bridge pier. A holding crane was used for release of the lifting cranes until two girder lines were placed and connected by cross-frames. However, generally after two girder lines were connected by cross-frames, no holding cranes were used.

All of the fasteners were installed at the splices and at the cross-frame connections during the assembly of the structure. Full tensioning of the bolts followed in the subsequent days after the erection of the steel for each span, and prior to the erection of the next span. The cross-frames were installed between girder lines by flying them in with a smaller crane. After the first girder line was erected, generally the cross-frames were installed one-by-one from the starting end of the bridge after each field section was spliced to the previous field section.

Span 1

- The erection of the girders began on January 16, 2010 with span 1, starting with the outermost girder, girder 105A1.
- Girder 105A1 was lifted by the 175-ton crane, as shown in Figure 32, and placed on the abutment at the start of the bridge. After this, it was held in place by the 175-ton crane and the 40-ton crane (see Figure 33).
- At this stage it was realized that the 40-ton crane did not have sufficient capacity to boom out to the required positions, and was replaced by a larger truck crane.

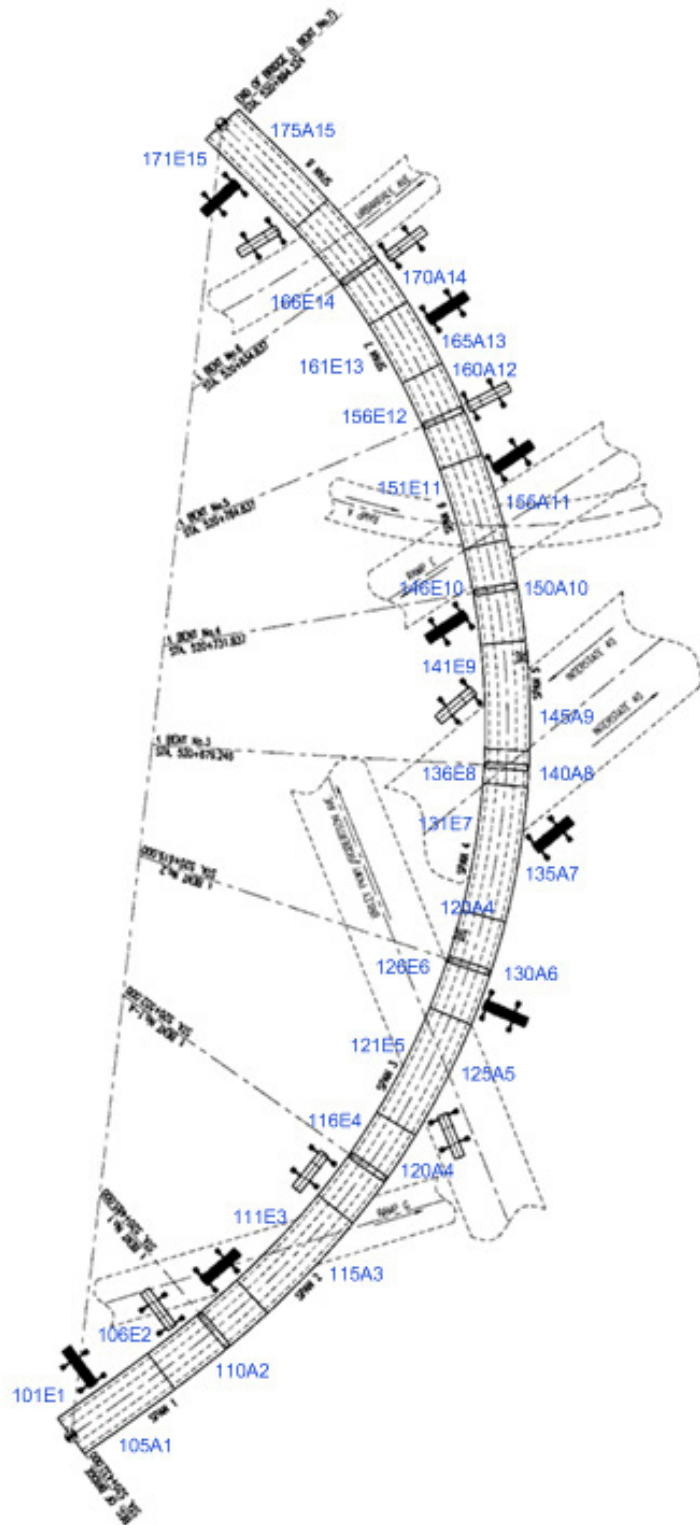


Figure 31: Site plan showing crane location



Figure 32: Lifting of Girder 105A1



Figure 33: Holding of Girder 105A1 by the 175-ton and 40-ton cranes

- Girder 110A2 was then hoisted using the 150-ton boom crane with a 40 foot long spreader beam, as shown in Figure 34.



Figure 34: Lifting of Girder 110A2

- The splice between girders 105A1 and 110A2 was bolted. Figure 35 is a photo of Girders 105A1 and 110A2 at this stage of the erection.



Figure 35: Girders 105A1 and 110A2 located on supports, spliced together, and held by cranes

- Cribbing was placed under girder 105A1, as shown in Figure 36, allowing the 175-ton crane to be released to lift girder 104B1. Note that the cribbing was not indicated in the erection plan.



Figure 36: Cribbing under Girder 105A1

- After girder 104B1 was hoisted into position at the abutment, the cross frames between 105A1 and 104B1 were installed. Figure 37 shows the first three girders erected with the first cross frame in place between girders 104B1 and 105A1. Figure 38 shows all of the cross-frames installed between these field sections. The cross-frames were generally installed one-by-one in progression from the starting end of the field sections.



Figure 37: One Cross Frame Attached Between Girders 104B1 and 105A1

- At this time the crane holding girder 105A1 was released and relocated to girder 104B1. The 150-ton lattice boom crane was cut loose from girder 110A2 and used to hoist girder 109B2, shown in Figure 39.



Figure 38: All Cross-Frames Attached Between Girders 104B1 and 105A1.



Figure 39: Lifting of Girder 109B2

- The splice between girders 104B1 and 109B2 was made, as shown in Figure 40, and the cross frames between girders 109B2 and 110A2 were then connected. This completed the erection operations on January 16.



Figure 40: Workers Splicing Girders 109B2 and 110B1

- Girders 103C1 and 108C2 were erected in a similar manner but without the use of the holding crane (see Figure 41 and Figure 42). (The erector determined that the holding crane was unnecessary after the cross frames had been installed between the first two girder lines.)



Figure 41: Placement of Girder 108C2



Figure 42: View showing two cranes holding the third girder line while making the splice between 103C1 and 108C2

- On January 18, 2010 girders 102D1, 107D2, 101E1, and 106E2 were installed in that order in a similar manner to those erected the previous day.
- During the weekend of February 27-28, data collection box 2 was removed from span1, girder 110A2 so that it could be installed on span 7.

Span 2

- The second span was constructed on January 23, 2010, using similar procedures to span 1.
- The only notable difference in the erection of span 2 is that the spreader beams used during construction of the first span were replaced with lifting straps. The lifting straps were used for the remainder of construction for all spans.
- Starting with the outside girder line, girder 115A3 was lifted and spliced to girder 110A2.
- Girder 120A4 was then lifted and spliced to girder 115A3, as shown in Figure 43. A separate 175-ton holding crane was attached to girder 115A3 so that the 150-ton lattice boom crane could be released to lift girder 114B3, as shown in Figure 44.



Figure 43: Positioning of girder 120A4 in Preparation for Splicing to Girder 115A3

- Girder 114B3 and 119B4 were then erected using the same steps. Figure 45 shows the use of a come-along between girders 120A4 and 119B4 during the installation of the cross-frames. The remaining three girder lines were then installed to complete span 2. Figure 46 shows the installation of the bearing line cross-frame between girders 119B4 and 118C4. Figure 47 shows the installation of cross-frames between Girders 117D4 and 116E4. The bearing line cross-frames were installed as multiple pieces, whereas the intermediate cross-frames each were a single piece.



Figure 44: 150-ton Lattice Boom Lifting Crane Being Released from Girder 115A3



Figure 45: Use of a come-along between girders 120A4 and 119B4 near Bent 1



Figure 46: Installation of bearing line cross-frame between girders 119B4 and 118C4 at Bent 1



Figure 47: Installation of cross-frames between Girders 117D4 and 116E4

Span 3

- The erection of the third span was delayed due to snow conditions in Nashville. The girders were originally supposed to be erected on January 30-31, 2010 but did not get erected until February 6-7.
- The erection plans called for this span to be completed in the opposite order of the first two, that is, from the inside span to the outside span. This was changed on site and the construction took place in the same order as the previous two.
- Erection began with girder 125A5, hoisted by the 175-ton crane, which was spliced to girder 120A4 as shown in Figure 48.



Figure 48: Positioning of Girder 125A5

- Girder 130A6 was then hoisted over bent 3 by the 150-ton lattice boom crane, shown in Figure 49, and spliced to girder 125A5.

- A holding crane was placed on girder 125A5, allowing the lifting crane to be released to hoist girder 124B5, as shown in Figure 50. Figure 51 shows the positioning of girder 124B5.
- Girder 124B5 was then spliced to girder 119B4 and the cross frames were installed between girders 124B5 and 125A5, after which girder 129B6 was lifted.
- Once girder 129B6 had been spliced to girder 124B5 and the cross frames attached between girders 129B6 and 130A6, the erection continued without the use of a holding crane as with the previous two spans.
- The span was completed with the erection of girders 123C5, 128C6, 122D5, 127D6, 121E5, and 126E6, in that order.



Figure 49: Positioning of Girder 130A6



Figure 50: View showing girder 125A5 being stabilized by a holding crane and the lifting crane released to pick girder 124B5



Figure 51: Positioning of Girder 124B5

Span 4

- Span four was erected on February 13-14, 2010, beginning with the inside girder line (E) and ending with the outside girder line (A). This opposite sequence of erecting the girders was necessary due to site constraints on the crane placement. Figure 52 shows the position of the 175-ton crane on the south shoulder of Interstate 40 just prior to the start of the erection of Span 4.
- The traffic was controlled on Interstate 40 during this erection stage using rolling road blocks.
- The original plan called for the use of a shoring tower for this span, but one was not used.
- Erection started on February 13 with the girders on the inside of the horizontal curve, 131E7 and 136E8, with girder 136E8 sitting over top of bent 3. Figure 53 shows the lifting of girder 131E7 and Figure 54 shows the splicing of girders 131E7 and 136E8.
- Each of the girders was lifted by a single crane, which held the girders in place while they were being spliced.
- A holding crane was attached to girder 131E7 to allow the lifting crane to be utilized for the lifting of girder 132D7.
- Cross frames were then erected between girders 131E7 and 132D7.
- Girder 137D8 was installed in a similar manner, followed by the cross frames between girders 136E8 and 137D8.
- Girders 133C7, 138C8, 134B7, 139B8, 135A7, and 140A8 were erected in the same manner, but without the use of holding cranes.



Figure 52: View of the 175-ton lifting crane located on the south side of I-40 just prior to the lifting of girder 131E7 (Photo taken from the Robertson Ave. bridge)



Figure 53: Lifting of Girder 131E7



Figure 54: Splicing of Girders 131E7 and 136E8

Span 5

- Span 5 was erected on February 20-21 2010, starting with the outside girder line (A) and ending with the inside girder line (E). Figure 55 shows a view of the erection with girder 150A10 being spliced to girder 145A9.



Figure 55: View of Span 5 with girders 145A9 and 150A10 up, with the lifting cranes still engaged, and with the holding crane attached to 145A9

- As with span 4, the traffic on I-40 was controlled during erection through the use of rolling road blocks.
- Also as with span 4, the plans called for use of a shoring tower, but none was utilized.
- The erection procedure was similar to that of the previous spans.

Span 6

- Span 6 was erected on February 27-28, 2010, starting with the inside girder line (E) and ending with the outside girder line (A).
- This span was completed in the same manner as the previous spans, starting with girders 151E11 and 156E12, as shown in Figure 56, and continuing the span with 152D11, 157D12, 153C11, 158C12, 154B11, 159B12, 155A11, and 160A12.



Figure 56: Connection of Girder 156E12 to Girder 151E11

Span 7

- Span 7 was erected on March 6, 2010.
- Due to the relatively long cantilever of the girders over Bent 6 during the erection, a shoring tower was erected just north of Urbandale Avenue.
- Erection began with the inside line (E) and continued until the outside line (A) was installed.

- Girders 161E13 and 166E14 were erected first, and their splices made.
- A 40-ton holding crane was used for girder 161E13 during the lifting of girder 162D13.
- Girder 162D13 was aligned and spliced to 157D12, and the cross frames between girders 161E13 and 162D13 were installed. Figure 57 shows the state of construction after the erection of girder 162D13, with girder 166E14 resting on the shoring tower.
- Girder 167D14 was lifted into position next and spliced to girder 162D13, as shown in Figure 58.



Figure 57: View of Shoring Tower after Placement of Girder 162D13



Figure 58: Lifting of Girder 167D14

- The cross frames between 167D14 and 166E14 were then installed.
- From this point forward, none of the girders were in physical contact with the shoring tower.
- Span 7 was completed with the installation of girders 163C13, 168C14, 164B13, 169B14, 165A13, and 170A14 erected in the same manner.
- Cribbing was placed between the top of the shoring tower and the bottom of the girders to help restrain the cantilever span from oscillating during the subsequent week due to potential wind gusts, as shown in Figure 59.



Figure 59: Cribbing Placed Between Top of Shoring Tower and Bottom of Girders

Span 8

- The girder erection was completed with span 8 on March 13-14, 2010. The cribbing on the shoring tower from span 7 was removed and the shoring tower was dismantled before erection of span 8 began, as shown in Figure 60.
- The girders were erected from the outside girder line (A) to the inside girder line (E).
- Girder 175A15 was hoisted first and spliced to girder 170A14. At this time it was apparent that the girder was exhibiting twisting deformation as it approached the support at bent 7, as shown in Figure 61. A come along, shown in Figure 62, was used to restrain this twisting until the remaining girders were installed.



Figure 60: Shoring tower at span 7 after removal of cribbing



Figure 61: Twisting in Girder 175A15



Figure 62: View of come along on girder 175A15

- The lifting crane was then released from girder 175A15 and girder 174B15 was hoisted, spliced to girder 169B14, and set on the support at bent 7. Once the process of attaching the cross frames between girders 174B15 and 175A15 had started, it was noticed that a connection plate was missing from one of the girders, as shown in Figure 63. Therefore, one of the cross frames could not be fully connected.
- The lifting crane was then released from girder 174B15, and used to hoist girder 173C15.

- Girder 173C15 was spliced to girder 168C14 and the cross frames were attached between girders 173C15 and 174B15.
- Girders 172D15 and 171E15 were erected in the same manner.



Figure 63: View of the cross frame with missing connection plate

3.2.2 Concrete Deck Formwork and Placement

Placement of the metal decking began on March 20, 2010. Decking was attached to girders using a common light-gage strap detail, permitting adjustment of the deck elevations relative to the top-of-steel of the girders along the spans. As observed in prior research (Helwig, 1994), the attachment of the metal decking to the girders with this type of detail nullifies any significant bracing of the top flange of the girders by the metal decking. Placement of the metal decking was completed in mid- to late April. Setting of the overhang brackets began on the weekend of March 27-28 and continued through

May. The deck reinforcing steel was placed after the installation of the metal decking was finished, and was completed in mid June. Details of the straps and angles used to attach the decking are shown in Figure 64 through Figure 68. Figure 69 shows the top of the bridge with a large amount of decking in place but before any reinforcing had been placed. Figure 70 shows the overhang brackets supporting the formwork beyond the outside girder. Figure 71 shows a portion of the bridge with all of the reinforcing in place and the screed set up in preparation for concrete placement.



Figure 64: Light gage metal strap attached to the top flange of fascia girder



Figure 65: Light-gage metal strap attached to longitudinal light-gage angles on opposite side of fascia girder

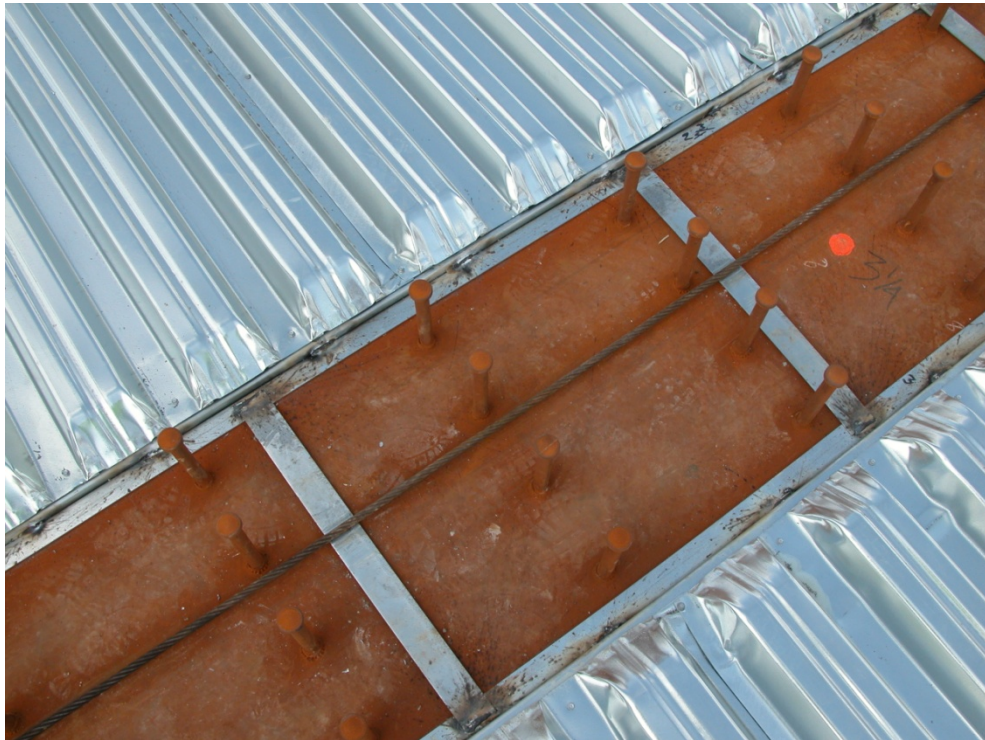


Figure 66: Top view of strap detail showing metal deck forms screwed to light-gage angles



Figure 67: View of attachment to light-gage angles from below

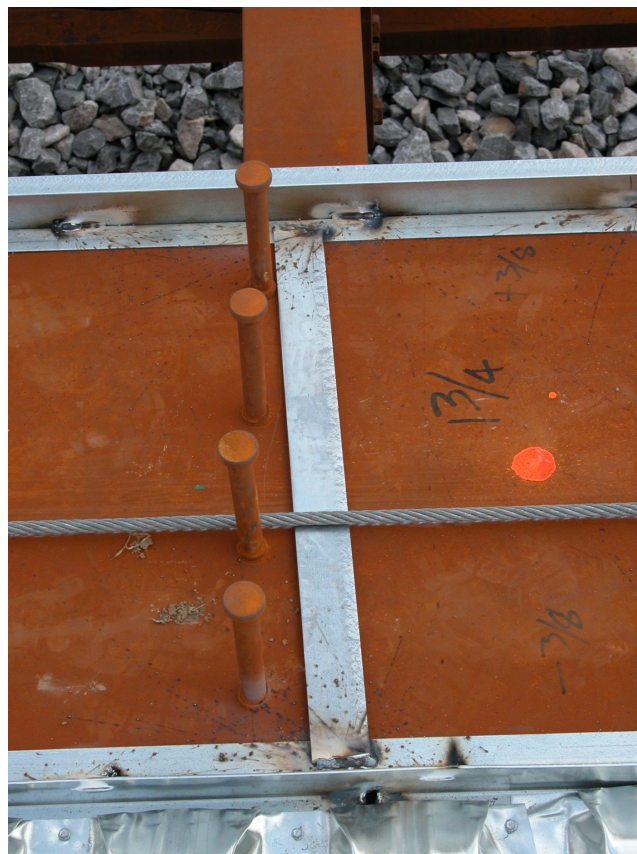


Figure 68: Strap, light-gage angles at flange tips, deck support angle welded to light-gage angles at flange tips, and screw fastening of metal deck forms to support angle



Figure 69: Metal decking partially installed



Figure 70: Concrete formwork supported by overhang brackets



Figure 71: Reinforcing and screed in place, awaiting concrete

The initial plan called for concrete to be placed on spans 1 and 8 first, and continue from each end until the two placements met in the middle. This plan was changed in mid-June at the request of the contractor. The revised deck placement sequence started with the positive moment regions of spans 6-8 for the first section. The second section consisted of the positive moment regions of spans 1-3. The third stage consisted of the negative moment regions of spans 1-3, and the fourth stage was the negative moment regions of spans 6-8. The final stage included all of spans 4 and 5. The concrete placement for each stage was scheduled to begin between 2:00 a.m. and 3:00 a.m. in order to complete the work before the hottest part of the day, as shown in Figure 72.



Figure 72: Concrete placement during coolest part of the day

The first stage of the concrete deck placement started around 3:00 a.m. on July 6, 2010. All of the concrete for the positive moment regions of spans 8, 7, and 6 were placed in that order on July 6. Robotic total station measurements were taken of the targets on spans 7 and 8 every half hour during that time. A final change to the schedule combined the third, fourth, and fifth stages into one pour. On July 8, 2010, the concrete was placed on the positive moment sections of spans 1, 2, and 3. After the last of the positive moment regions had cured for a full week, all of the negative moment regions were placed on July 15, 2012. Total station measurements of the bridge were taken throughout this placement. The work was completed by 10:00 a.m.

CHAPTER 4: FIELD MEASUREMENTS DURING CONSTRUCTION OF THE BRIDGE

This chapter explains typical results acquired during the bridge construction. The complete data set is shown in Appendices B and C.

4.1 Construction Stresses

The system was set up to record strain readings at varying intervals throughout the construction process. While a girder was being erected, the boxes were typically programmed to take readings every five or every ten minutes. It should be noted that it was difficult for the vibrating wire gages to stabilize during some of these operations as the gages are sensitive to traveling waves from impact and crane lifting. During intervals where no construction was taking place readings were taken once every hour.

Readings recorded from the vibrating wire strain gages were returned as resonance frequencies. This frequency was converted to a microstrain value using a formula supplied by the manufacturer. Because linear elastic behavior could be assumed for the bridge, it was possible to convert the microstrain readings to stress readings through multiplication of the strain by Young's modulus of elasticity (29,000 ksi). Figure 73 shows a sample calculation for a single data point.

There were several times when the solar panels were unable to function due to low temperatures or snow. This caused the batteries to drain and power to the data acquisition boxes to be cut off. Data during those time periods were lost, and several of the batteries needed to be replaced as a result.

Girder 106E2, Instrumentation Line 3, on 9/10/2010 at 15:09

Output_1 := 963.0057 Output_2 := 3204.334

$\mu\epsilon_{\text{initial}}$:= 807.6 Temp_{initial} := 12.8

$$\text{Gage_Temp} := \frac{1}{\left(1.4051 \cdot 10^{-3} + 2.369 \cdot 10^{-4} \cdot \ln(\text{Output_2}) + 1.019 \cdot 10^{-7} \cdot \ln(\text{Output_2})^3\right)} - 273.2 = 23.446$$

$$\text{Gage_}\mu\epsilon := (\text{Output_1} - \mu\epsilon_{\text{initial}}) \cdot 4.062 \cdot 0.96 + (\text{Gage_Temp} - \text{Temp}_{\text{initial}}) \cdot 12 = 733.764$$

$$\text{Gage_Stress} := \text{Gage_}\mu\epsilon \cdot \frac{1}{1 \cdot 10^6} \cdot 29000 \text{ ksi} = 21.279 \text{ ksi}$$

Figure 73: Sample calculation of stress and temperature

4.1.1 Data Collection Adjustments

Because of equipment shortages and other construction constraints, some changes to the data acquisition system occurred during the project. Box 2 originally read data from gages on girders 105A1, 110A2, 115A3, and 120A4. This box was disconnected on February 20, 2010, more than halfway through the steel erection, and moved to the other end of the bridge. It was reinstalled on span 7 on the morning of March 7, at which point it was reading data from gages on girders 165A13 and 170A14. Once girder 175A15 had been erected it was also connected to box 2.

Box 6 was taking erroneous temperature readings throughout the entire testing period. The data from this box, which included girders 161E13, 167D14, and 171E15, were corrected by replacing the temperature data with that from two other boxes. The temperature readings were replaced by those from gages experiencing similar sun and wind exposure in order to come as close as possible to the actual temperature.

4.1.2 Change in Stress Due to Temperature

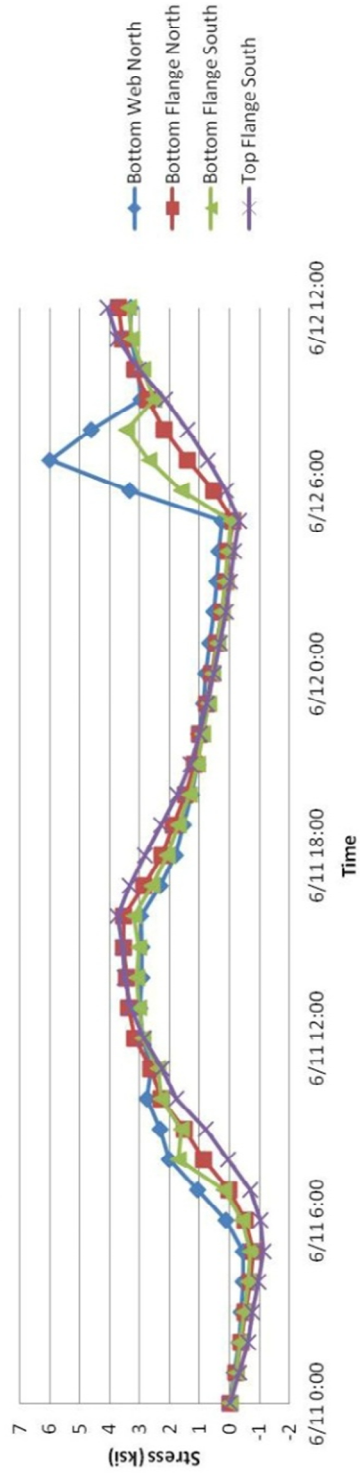
There was a clear correlation between temperature and stress. Figure 74 shows graphs of both stress and temperature from girder 170A14 over a 36 hour period in June 2010. These data were taken at a time when all of the girders had been erected, and most of the concrete formwork was in place. No concrete had been placed on the bridge at that time. The only significant changes in the loading to the bridge during that time were due to temperature fluctuations. The maximum temperature fluctuations measured ranged from about 75°F to 104°F for the south top flange; for the same period, a nearby meteorological station reported temperatures ranging from 76° to 94°F. Spot checking of this type indicated that most thermistors were working properly and that reliable temperature corrections could be made to the data.

The data from Figure 74 also indicate that appreciable changes in stress occurred due to these temperature changes. These stresses are produced by the inherent restraints at the support locations as well as by the variations in the temperatures throughout the structure. The magnitude of these changes varied, with the south top flange undergoing a total change of about 5.5 ksi from about 6AM to 5PM. This magnitude can be considered a typical result except for situations where very large changes in air temperature occurred.

In Figure 75, two periods with significant changes are observed. The first period (6AM to 3PM on 3/13/2010) coincides with the removal of the shoring tower from Span 7 (about 6-7AM), initial lifting of girders 175 (about 10-11AM) and 174 (about 3-5PM) and subsequent bolting of the cross frames. After this, the strains remain almost constant through the night. The second period (about 6AM to 2PM on 3/14/2010) represents the erection of the rest of span 8. As the temperatures at midnight on 3/13 and 3/15 are

roughly the same, the vertical shift in the stresses (about 1.5 ksi for the South top flange) can be considered to be the result of the erection process.

Change in Stress of Girder 170A14, Instrumentation Line 21 Over Time



Change in Temp. of Girder 170A14, Instrumentation Line 21 Over Time

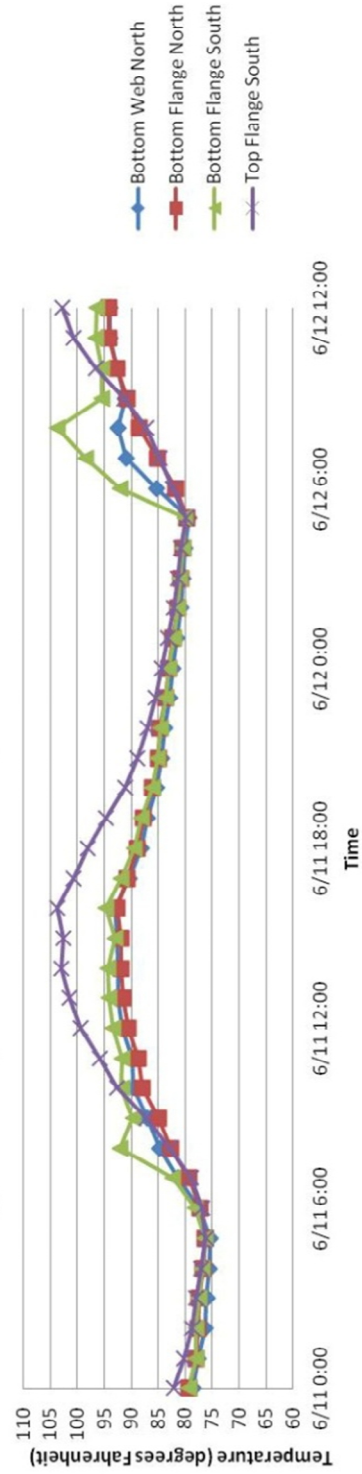
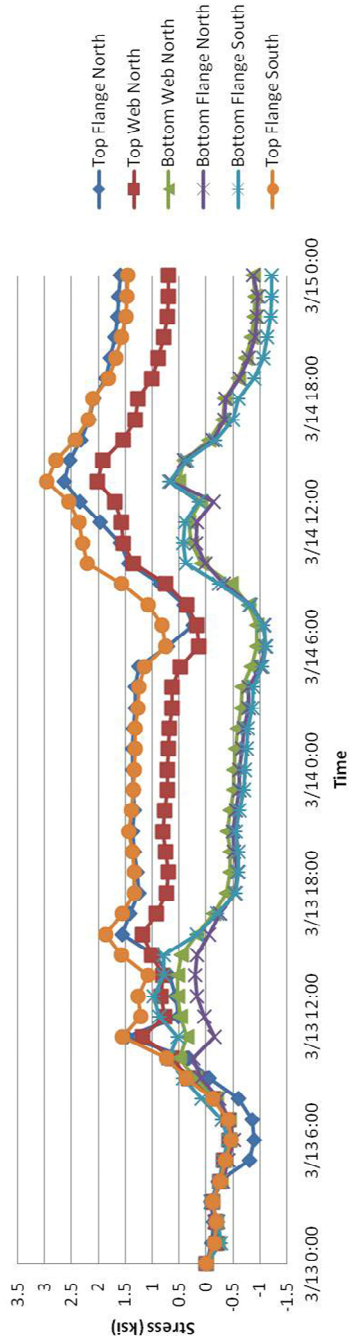


Figure 74: Change in stress and temperature over 36 hours

Stress in Girder 165A13, Instrumentation Line 19 During Construction of Span 8



Temperature in Girder 165A13, Instrumentation Line 19 During Construction of Span 8

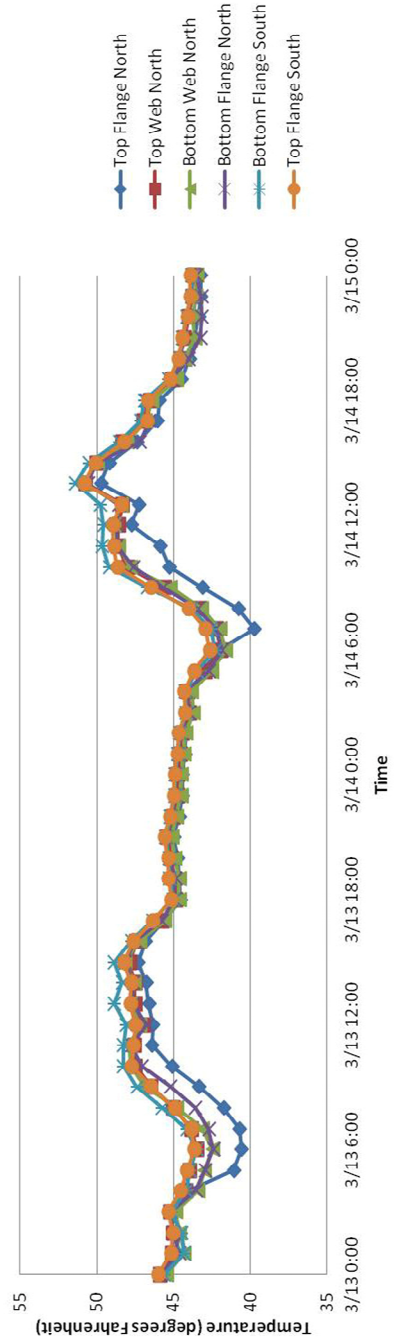


Figure 75: Change in stress of girder 165 during construction of span 8

4.1.4 Change in Stress During Concrete Placement

Strain readings were taken throughout the concrete placement process. Of particular interest were spans 1 and 8. Unfortunately, an error occurred with Box 2 and it did not record any strain or clinometer data from June 24 to July 14, 2010. This includes the first three out of five days of concrete placement. Figure 76 shows the temperature and change in stress in girder 155 during the first round of concrete placement.

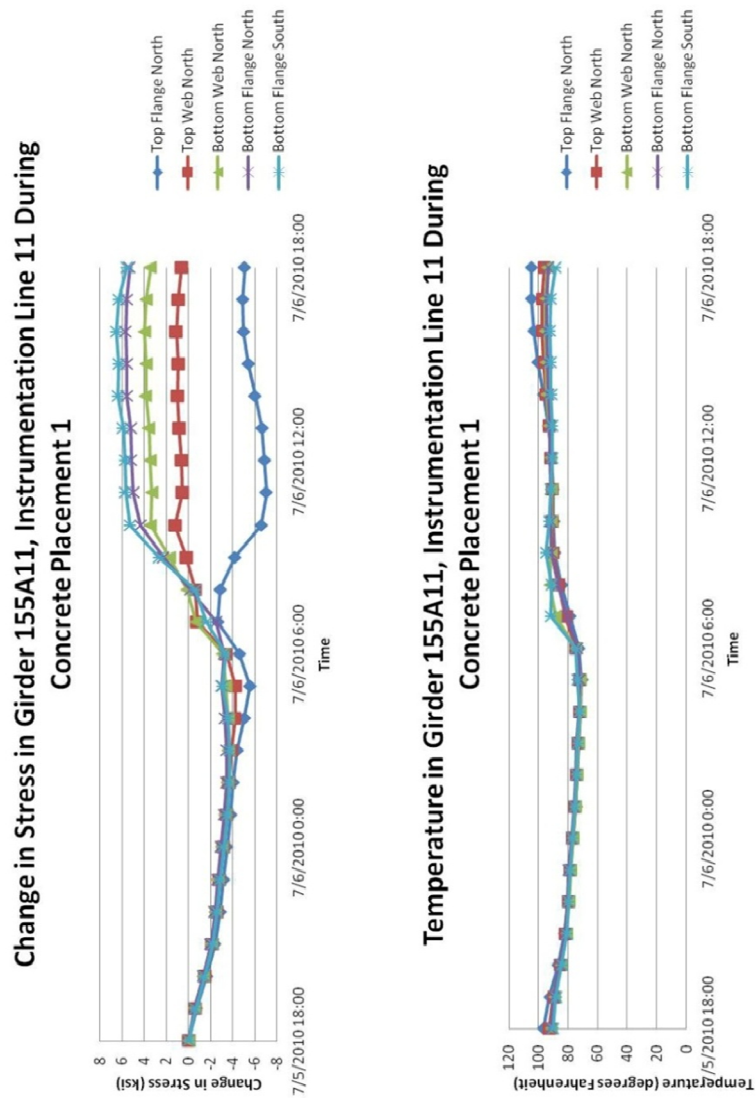


Figure 76: Change in stress and temperature in girder 155 during stage 1 of the concrete deck placement

4.2 Vertical Displacements During Construction

Vertical displacements were measured using the total station. The total station was set up on the sidewalk on the west side of Urbandale Avenue on the south side of the bridge, and the location of the total station was permanently marked on the ground to ensure proper alignment of all measurements. From that location up to 22 targets were visible, with the exact number depending on the location of construction equipment and the movement of the bridge relative to formwork. For readings taken at night time a high powered flashlight was needed in order for the total station operator to locate the targets.

4.2.1 Vertical Displacements Due to Changes in Temperature

A forty-eight hour long experiment was conducted on June 10-12, 2010 during which readings were taken with the robotic total station at regular intervals. Readings were taken every half hour during the day and every hour at night when the assistance of a flashlight was necessary to see the targets. The primary purpose of this experiment was to determine the temperature effects on the bridge by recording the displacements of the targets. At this time, all of the girders were erected, the metal decking was all in place, and the construction crew was in the process of installing the rebar in preparation for the concrete placement. Movement of the girders was evident during this test. One target on the web of the outside girder was visible through the total station at some points during the day, and as the bridge expanded it would slowly move to where it was covered by some of the formwork.

Figure 77 shows selected data from the June readings. All targets included in this example are located on the bottom flange of the girders.

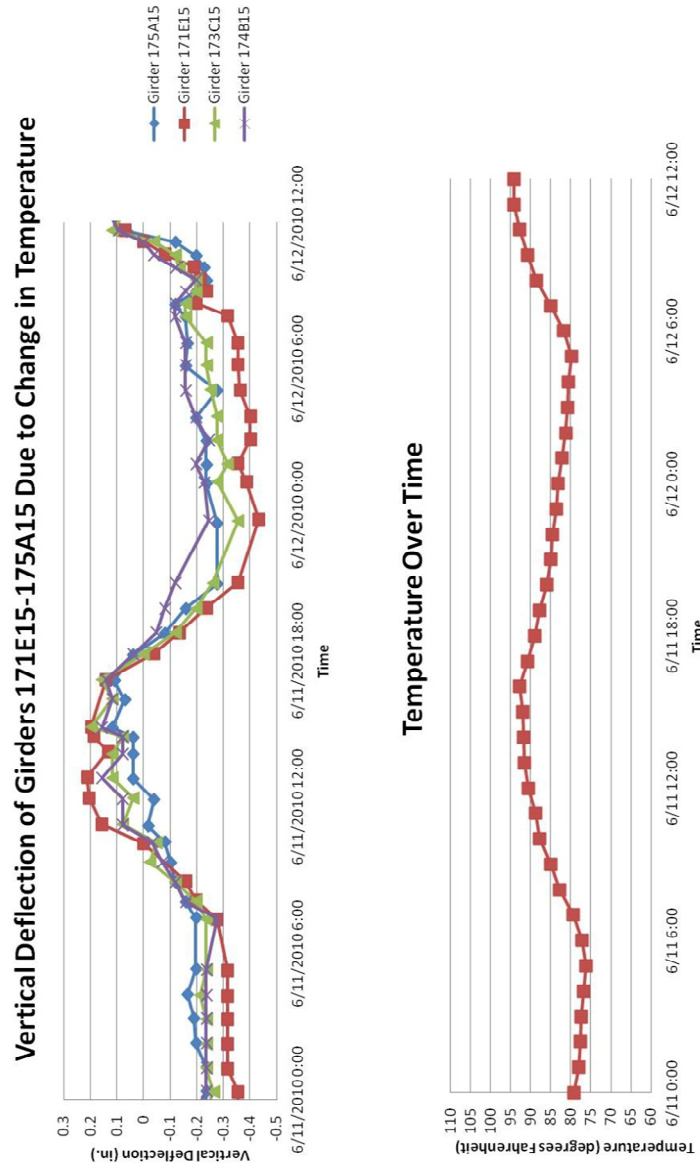


Figure 77: Vertical deflection due to change in temperature

4.2.2 Vertical Displacements During Concrete Placement

Figure 78 shows the vertical deflection of the girders during the placement of the first section of concrete, which was on span 8. It should be noted that the target which

was directly over the pier at bent 6, labeled 170 near 165, did not deflect any significant amount, as expected.

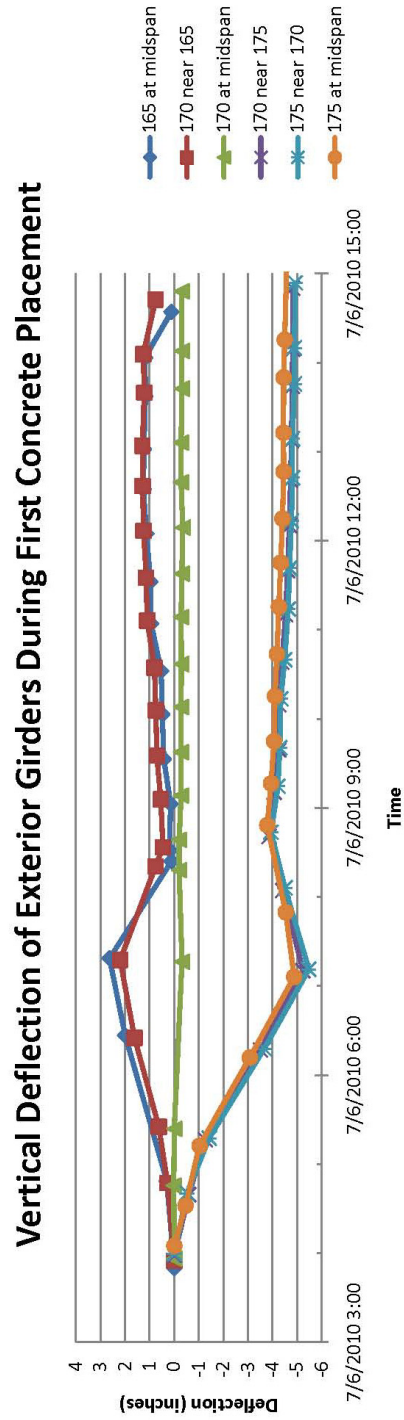


Figure 78: Vertical deflection of exterior girders during first concrete placement

CHAPTER 5: FIELD MEASUREMENTS DURING LIVE LOAD TESTING OF THE BRIDGE

5.1 Introduction

After construction was completed, but before the bridge was opened to traffic, a live load test was conducted. This was completed using ten dump trucks. The trucks were loaded with gravel to a weight of approximately 72 kips each. The trucks were weighed in the morning before the test and again afterward. The locations and magnitudes of the forces applied by the trucks are shown in Figure 79.



Figure 79: Force distribution of truck used during live load testing

Four loading conditions were devised with the objective of achieving the maximum major-axis moments and deflections using two lines of five trucks each, with each of the individual lines placed in the center of a given span. Each loading condition

was to be repeated for each span of the bridge. The loading conditions are identified by a letter, indicating the configuration of the trucks, and a number, indicating the span. For example, load C3 refers to loading condition C centered on span 3. Due to time constraints, truck configuration A was eliminated from the plan the morning of the live load test.

Targets for the robotic total station were already in place on spans 7 and 8 from measurements taken during construction. It was deemed beneficial to have deflection measurements taken at both ends of the bridge, however, so additional targets were installed on span 1 before the start of the test. The truck locations were measured on the bridge using a 100 foot tape measure. The locations were marked using twine and spray paint. For each loading condition, the trucks were driven into place one at a time, and then stopped. The trucks were not moved until the robotic total station team had measured all of the targets, and the data acquisition boxes had collected at least two readings. Before the start of the test the data acquisition boxes were reprogrammed to collect data every 3 minutes.

5.1.1 Loading Condition B

For loading condition B, one line of trucks was placed as close as possible to the outside curve of the bridge. The second line of trucks was located approximately at the mid-width of the bridge cross section, as shown in Figure 80.

5.1.2 Loading Condition C

For loading condition C, one line of trucks was placed as close as possible to the inside curve of the bridge. The second line of trucks was located approximately at the mid-width of the bridge cross-section, as shown in Figure 81.

5.1.3 Loading Condition D

For loading condition D, one line of trucks was placed as close to the inside curve of the bridge as possible. The second line of trucks was placed on the next span as close as possible to the outside curve of the bridge, as shown in Figure 82.

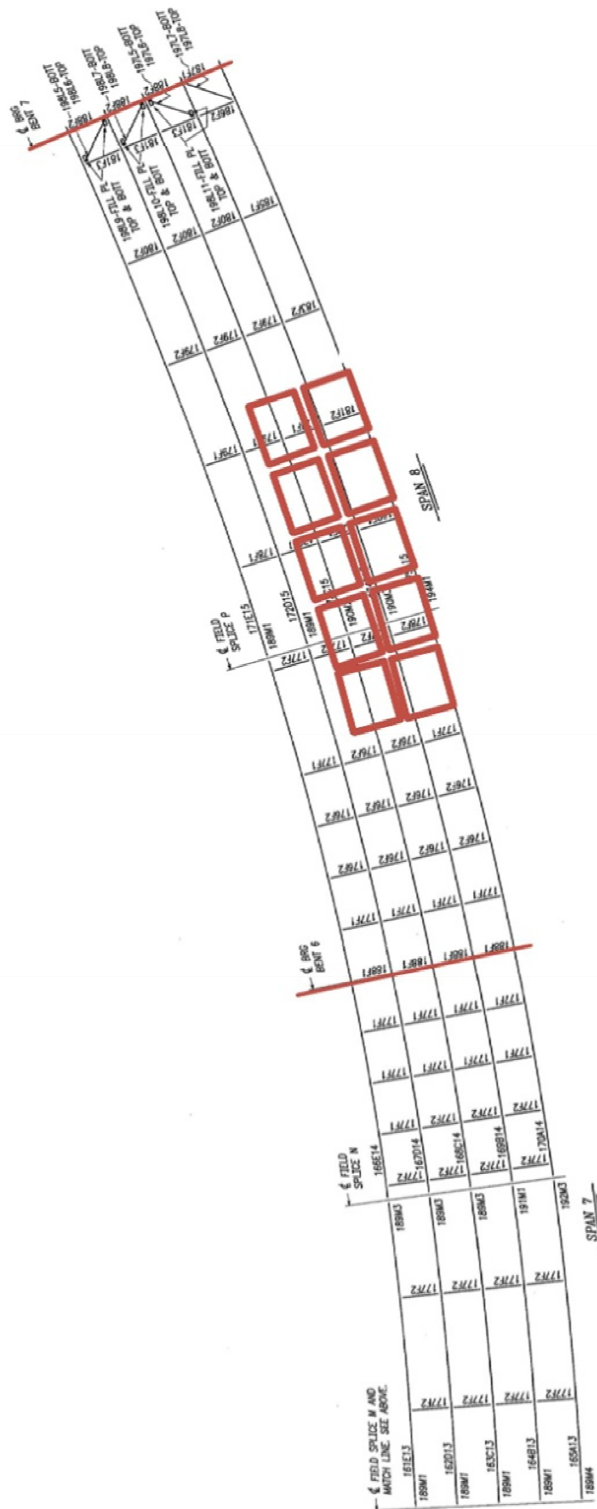


Figure 80: Truck positioning for load case B

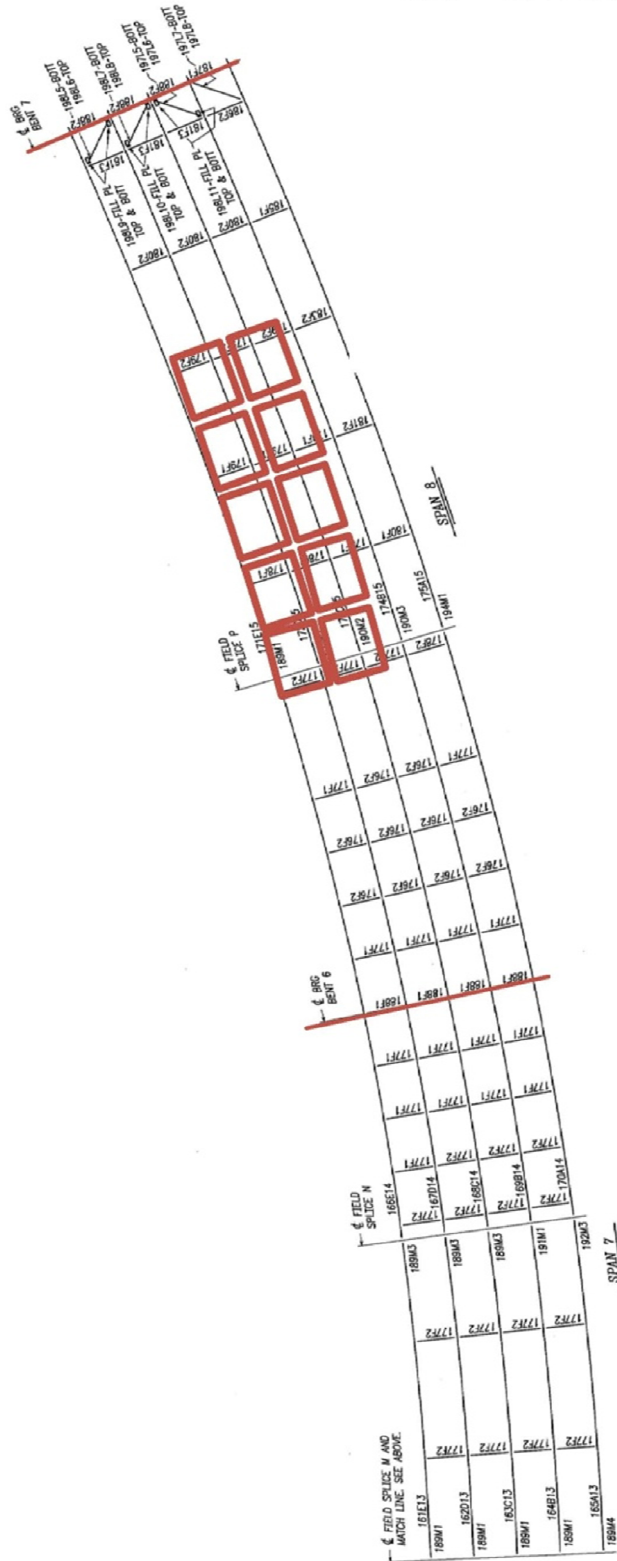


Figure 81: Truck positioning for load case C

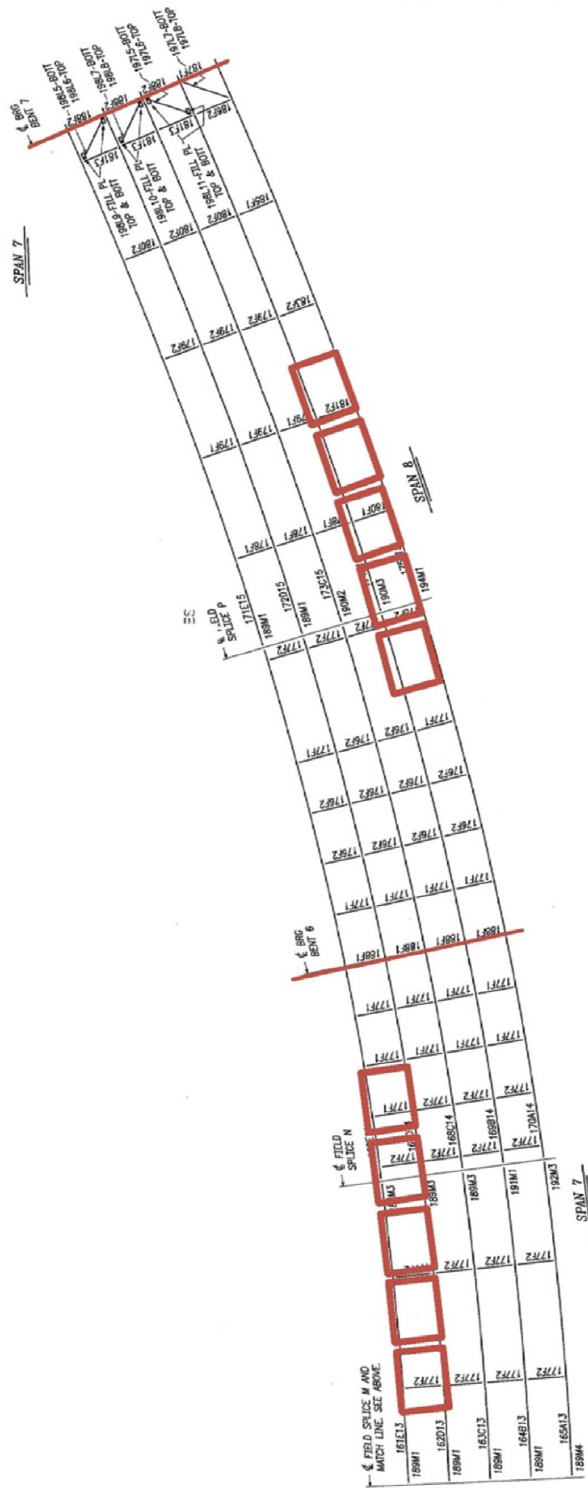


Figure 82: Truck positioning for load case D

5.2 Live Load Test

The *Leica* total station was placed at span 8 in the position it had been in for the construction readings. A second total station was rented and set up near span 1. The plan was to start the test with span 1 and move on to span 2 once all three truck configurations had been done. This was based on the assumption of two working total stations, one at each end of the bridge. It was discovered shortly before the start of the test that the total station near span 1 was incompatible with the targets being used. Rather than move the *Leica* total station, which was already in place at span 8, it was decided to start the test with span 4. The total station was used to take a set of readings before the start of the test to get a zero reading for the bridge deflections.

The test began with loading B4 at 7:30 a.m. Because the center of the bridge was out of range of both total stations, the trucks only needed to stay in place long enough for the computer to collect two readings from the strain gages. Each loading condition took between ten and twenty minutes, including aligning the trucks and collecting data. Beginning with loading C5 total station measurements were incorporated into the procedure, which had very little impact on the overall time needed for each configuration.

It began raining around 11:15 a.m., while the trucks were in configuration B8. The test needed to be stopped temporarily until the rain stopped in order to avoid damaging the total station. The trucks were removed from the bridge during the break. Testing resumed in configuration B8 at 12:45.

After testing was completed for span 8, the trucks were moved off of the bridge and the total station took an additional set of zero readings. The total station was then moved to span 1, where a new set of zero readings was taken.

The live load test began again with loading B1 at 2:09 p.m. Due to the rain delay, configuration D was eliminated from the plan for spans 1-3, as was loading condition C on span 3. Testing concluded at 3:00 p.m., at which time the trucks were moved off of the bridge and a final set of zero readings was taken. The trucks were weighed again before they were unloaded.

5.3 Live Load Stresses

Figure 83 shows the live load stresses in girder 170A14 throughout the live load test. The load cases have been labeled on the graph. Only two readings are highlighted for each load case, though most of the loadings were in place for longer than that.

5.4 Live Load Displacements

Figure 84 shows the vertical deflection in girder 170A14 due to the live load. The trucks were removed from the bridge between loadings D7 and B8 so that the zero reading could be taken.

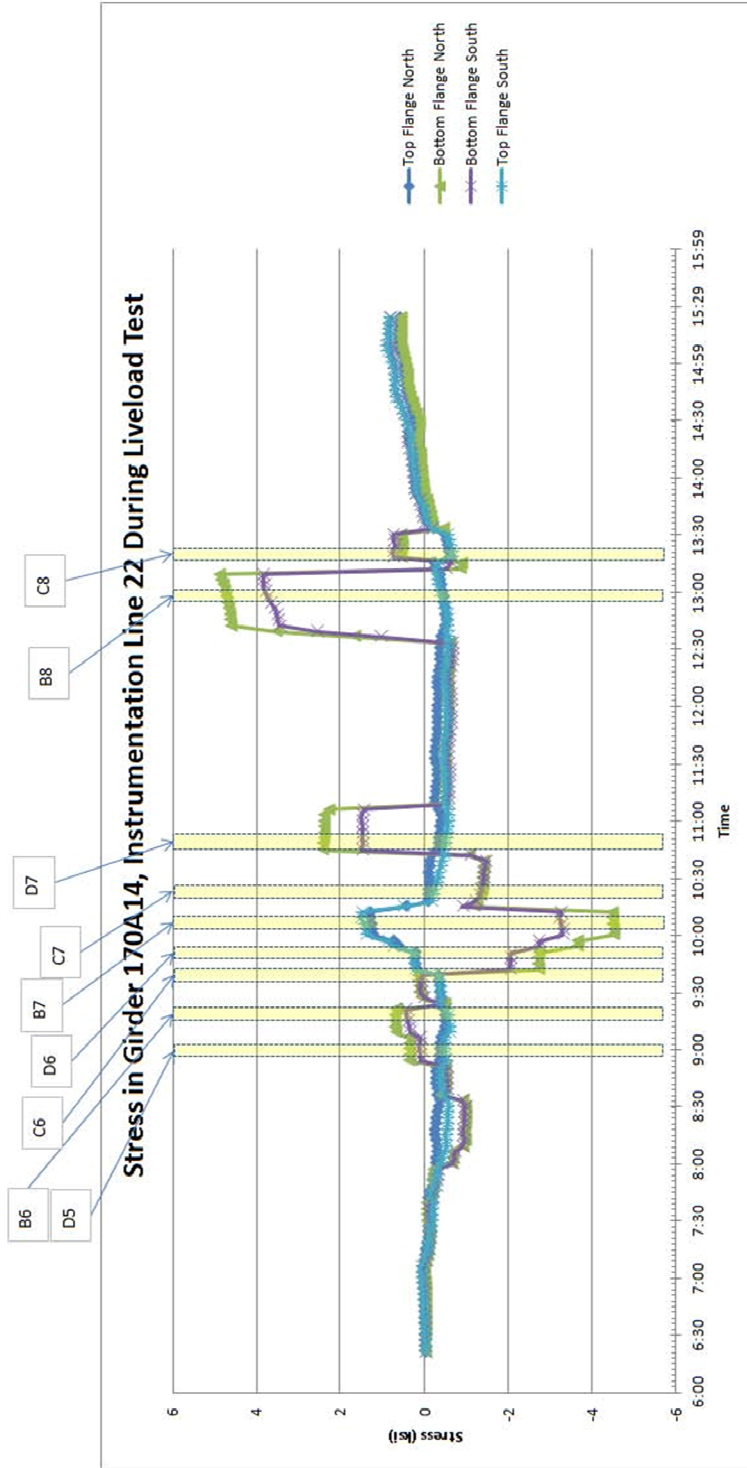


Figure 83: Stress in girder 170A14 during live load test

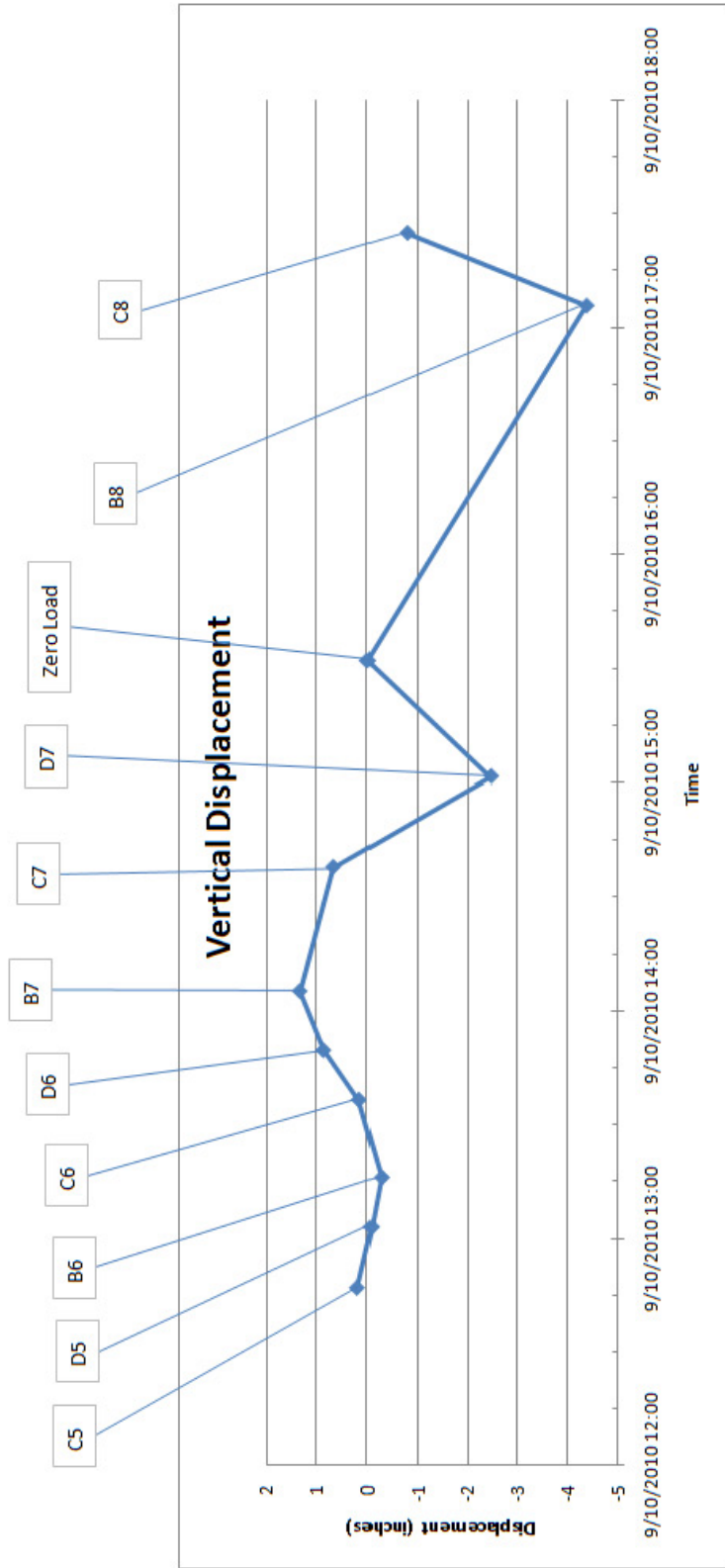


Figure 84: Vertical deflection of girder 170A14 near connection to girder 175A15 due to live load

CHAPTER 6: COMPARISON OF PREDICTED VS. MEASURED BRIDGE RESPONSES

This chapter first describes the finite element model and analysis of the bridge. The following sections then compare the stresses and deflections predicted by the FEA model with the measurements taken by the strain gages and robotic total station during the construction of girder 170A14 and during several stages of the live load test.

6.1 Finite Element Analysis Model

The 3D FEA test simulations were conducted using ABAQUS 6.10 software (Dassault Systèmes 2010) and included all of the important nominal behavioral characteristics of the curved steel composite I-girder bridge. Figure 85 shows an example 3D FEA representation of a portion of an I-girder bridge for elastic geometrically linear (linear elastic) or geometrically nonlinear (second-order elastic) analysis solutions (courtesy of Dr. Cagri Ozgur). All of the bridge components were modeled at their nominal physical geometric locations using their nominal physical dimensions, with the exception that the webs are modeled between the centerlines of the flanges.

The webs are modeled using 12 S4R elements through their depth. The number of elements along the girder length is selected such that each shell element has an aspect ratio close to one. The S4R element is a 4-node quadrilateral displacement-based shell element with reduced integration and a large-strain formulation. Five integration points for the webs of the steel I-girders are used through the thickness of the shell elements.

The flanges of the girders, and the transverse stiffeners (bearing stiffeners, intermediate transverse stiffeners, and cross-frame connection plates) are modeled using the B31 element, which is a two-node beam element compatible with the S4R

shell elements. Cross-frame diagonals are modeled with T31 truss elements while the top and bottom chords are represented by B31 beam elements to maintain the stability of the cross-frames in the direction normal to their plane (since the middle joint of the inverted V-type cross-frames depends on the bending stiffness of the top chord for stability of the chord).

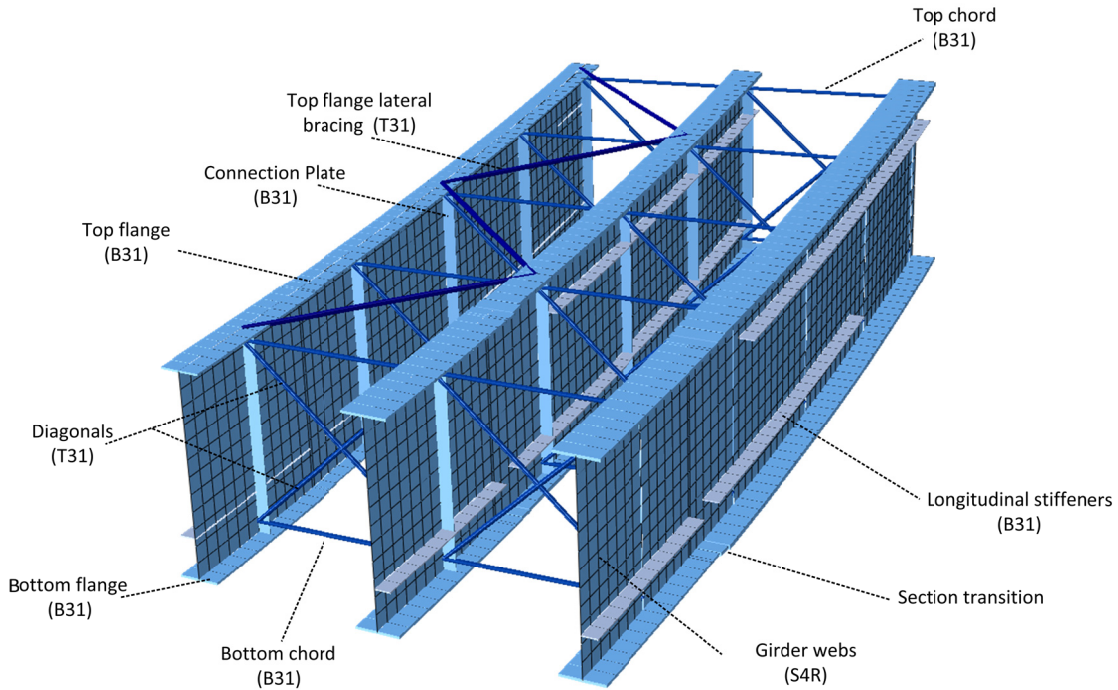


Figure 85: Simulation model

The cross-frame elements are connected to girder webs at the intersection of the centerline of the cross-frame member and the girder web. Longitudinal stiffeners are modeled by using the B31 element. If the elevation of the longitudinal stiffener does not coincide with the web nodes, the “linear” multi-point constraint is used to introduce a new node to define these elements. Lastly, if a flange-level lateral bracing system is used, these members are modeled with T31 truss elements. These truss elements, which represent the flange lateral bracing members, are connected to the girder flanges at the

web-flange juncture, which is typically the designed work point used in practice. For the elastic analyses the modulus of elasticity of the steel is taken as 29000 ksi.

Bearings are modeled as a point vertical support at the web-flange juncture since beam elements are used to model the flanges (the beam element kinematics enforces a linearly varying displacement across the width of the flange). The girder model is generally free to rotate about the point support location, and horizontal displacement constraints representing guided bearings are placed at the point support location. The substructure is modeled as a rigid support, including any temporary towers for construction.

6.2 Erection of Girder 170A14

Girder 170A14 was erected on March 7, 2010 from approximately 11:30am to 12:00pm. Data acquisition Box 2, which had been removed from girder 110A2 on February 27, was reinstalled on girder 170A14 prior to lifting. This allowed the gages to be connected and initial readings to be taken before the girder was lifted into place. The strain gages were programmed to take readings every three minutes during the lifting and connection of the girder. Once the girder was fully connected, the programming was adjusted to take readings every hour.

6.2.1 Lifting

The first set of plots show a comparison of the predicted and measured stresses at four locations on the girder cross section during the lifting stage (shown in Figure 86 and Figure 87).



Figure 86: Girder 170A14 being lifted



Figure 87: Girder 170A14 being lifted

Figure 88 shows the four locations on a typical girder cross section. The points used for the comparison were point A, the tip of the top flange located at the outside radius of curvature of the girder, point B, the tip of the top flange located at the inside radius of curvature, point C, the tip of the bottom flange located at the outside radius of curvature, and point D, the tip of the bottom flange located at the inside radius of curvature. The strain gages were placed at three cross sections of girder 170A14: IL20, IL21, and IL22 (shown in Figure 11). The data from the strain gages were extrapolated from the strain gage locations to the tips of the flange assuming a linear strain distribution.

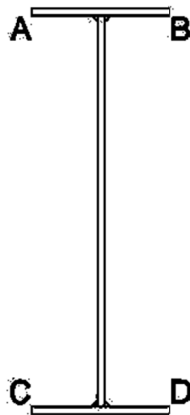


Figure 88: Comparison locations on girder cross section

Figure 89 compares amount of stress in the bottom flange of girder 170A14 predicted by the FEA model (solid lines) with the beam being held by the crane near locations 0.855 and 0.895 and the stresses derived from the strain gage outputs. The y-axis refers to the difference between the stress in the girder in the resting position on the delivery truck and the stress experienced while being lifted by the crane. The crane

moved the girder continuously from the truck to the connection location, so it was not possible to isolate a single reading from the strain gages. Instead, all of the readings for a particular gage between 11:30am and 12:00pm have been plotted in a single vertical line. The difference between the minimum and maximum measured values for point D correlate well with the change in stress predicted by the FEA model, showing the same sign and magnitudes within 0.75 ksi of the expected values. The corresponding relationship for point C is less clear. The sign of the measured stress is not the same as for the FEA model for two of the instrumentation locations and the magnitude differs by as much as 1.5ksi

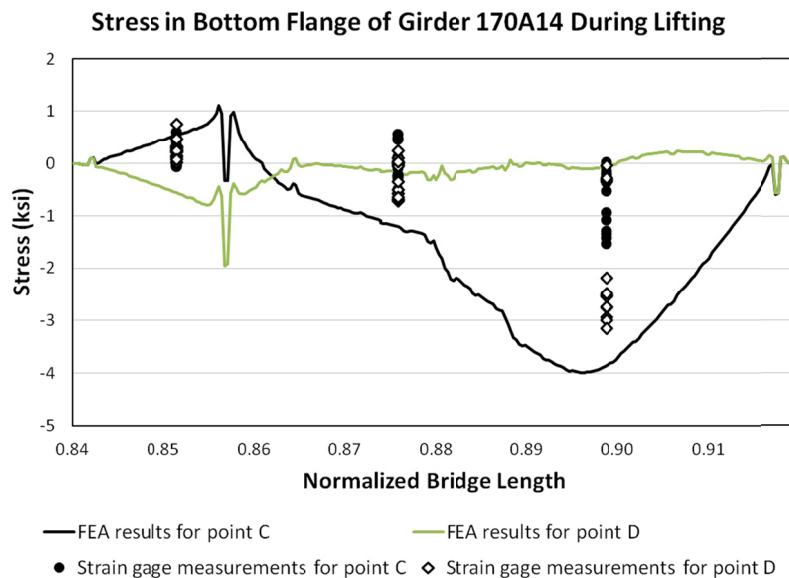


Figure 89: Stress in bottom flange of girder 170A14 during lifting

Figure 90 shows similar information for the top flange of the girder. With the exception of the center instrumentation line for the bottom flange, the maximum measured stresses are within 0.25ksi of the predicted values.

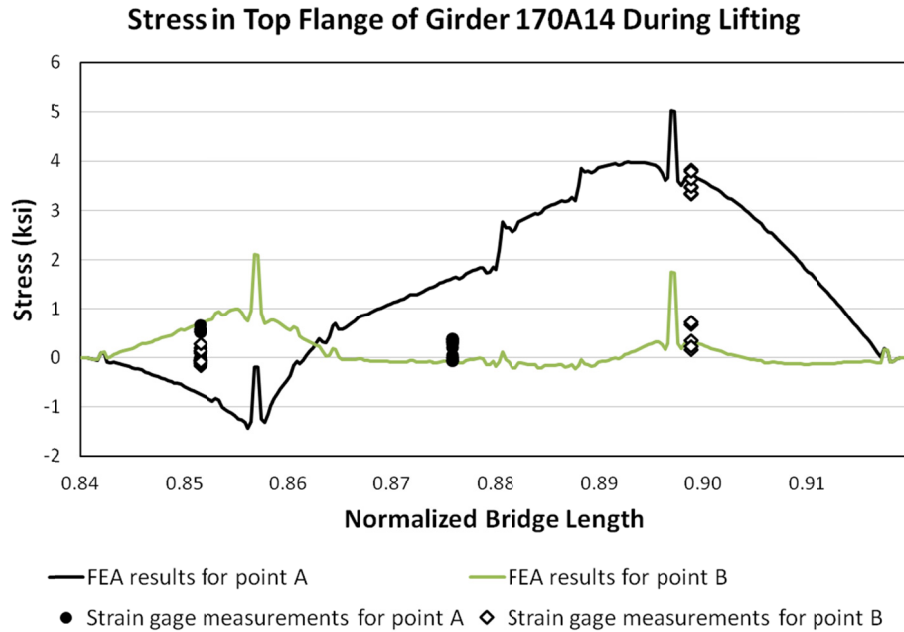


Figure 90: Stress in top flange of girder 170A14 during lifting

6.2.2 Before Connection of Cross Frames

The next set of comparisons is for the condition that occurred after girder 170A14 was lifted and connected to girder 165A13, but before the cross frames were attached to connect it to girder 169B14. Strain readings were taken every three minutes from 12:15pm to 1:00pm. Figure 91 shows the comparison of stresses in the bottom flange and Figure 92 shows the comparison of stresses for the top flange. For the bottom flange, the measured stresses are larger than the predicted stresses for point D at both IL20 and IL21. At IL22, the FEA model predicts larger stresses than were measured for point C and smaller stresses than were measured for point D. For the top flange, the signs of the stress for IL20 and IL22 is reversed from what was predicted and the magnitude is 4-6 ksi higher than expected for IL22. Overall, the correlation between the expected and actual stress is worse for the girders before connecting the cross frames than it is during lifting. Two important points need to be made with respect to these

results. First, the actual magnitudes are relatively small (about 5% of yield). Second, the holding cranes were still in place on girders 165A13 and 170A14 until after the cross frames had been connected. The presence of the cranes introduces additional redundancy into the system and makes it more complicated to accurately determine the load distribution in the bridge. The FEA model assumed that the girders were held at an ideal elevation by the cranes and perfect alignment between girders 165A13 and 170A14 at the splice.

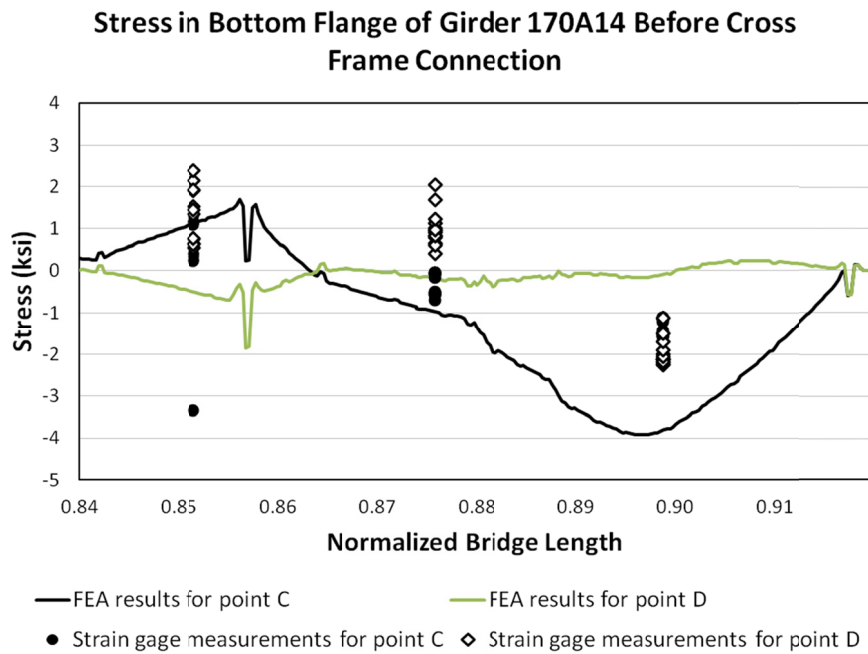


Figure 91: Comparison of stress in bottom flange of girder 170A14 before cross frames

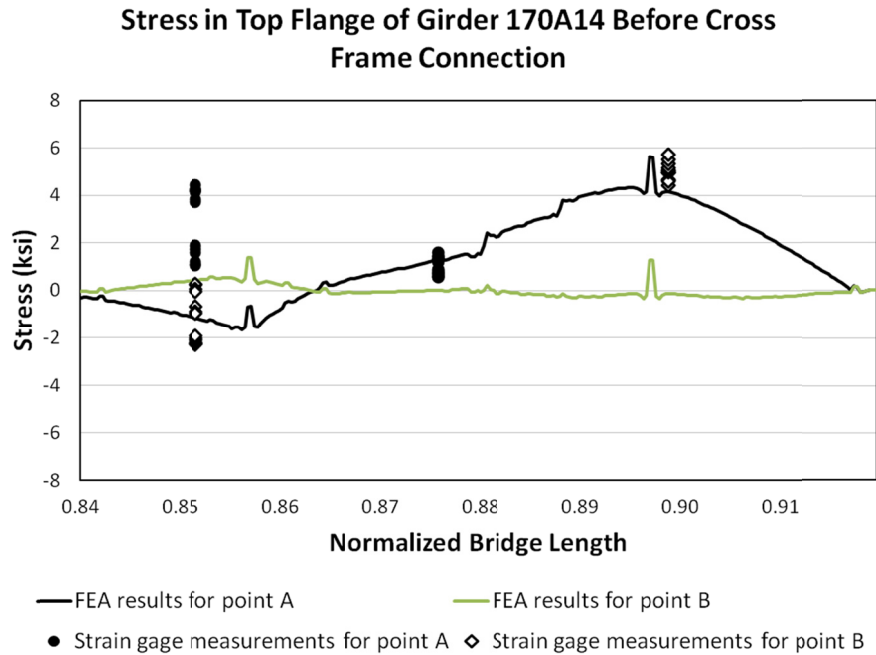


Figure 92: Comparison of stress in top flange of girder 170A14 before cross frames

6.2.3 After Connection of Cross Frames

The final set of comparisons for girder 170A14 contains the stress comparison for the time after the cross frames have been installed to fully connect it to girder 169B14. Strain readings were taken every hour from 6pm to 12am. Figure 93 shows the stress comparison for the bottom flange, and Figure 94 shows the stress comparison for the top flange. Here, again, large local differences can be seen between the predicted and measured stresses for the top and bottom flanges. It is likely that fit-up forces from the cross frames installed close to IL20 and IL22 factored into the discrepancy. The fit-up forces can be influenced by several factors including temperature differences throughout the structure.

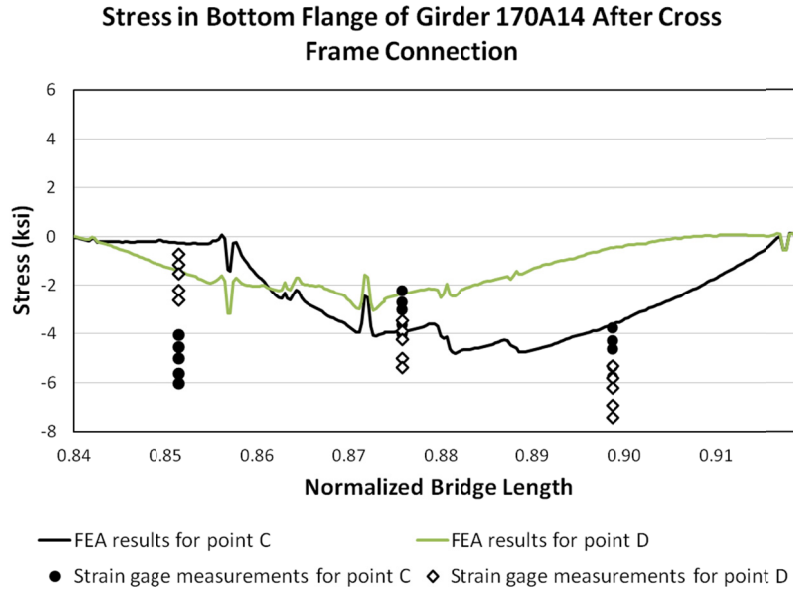


Figure 93: Comparison of Stress in Bottom Flange of Girder 170A14 after cross frames

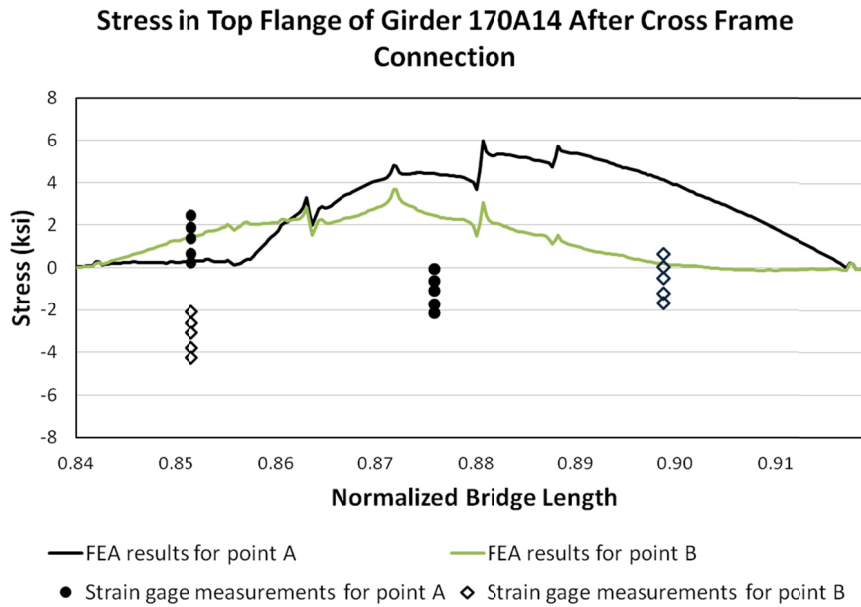


Figure 94: Comparison of Stress in Top Flange of Girder 170A14 After Cross Frames

6.3 Live Load

Stresses and deflections were compared for three of the live load stages. Each figure has the position along the bridge as the x-axis with the stress or displacement along the y-axis. Stresses are measured as a change in stress from an unloaded

condition on the day of the live load test to the specified load case. Several iterations of the FEA model were used for the comparisons, including one model without the parapets included and the trucks in their designated configuration, one model with the parapets included and the trucks in their designated configuration, and one model with the parapets included and the trucks two feet away from their designated location. The bridge was modeled with and without parapets because while the parapets were in place during the live load test, it was unknown whether or not they had reached their full strength and to what degree they would contribute to the stiffness of the bridge. The change in truck position was to account for potential error in aligning the trucks on the bridge during the test. On the day of the live load test, there were large fluctuations in temperature in Nashville. The morning started off cold and rainy, with temperatures in the mid sixties. The sun came out in the afternoon, and temperatures rose to the mid seventies.

6.3.1 Loading Condition B8

The first loading condition that was chosen for the comparison is B8, in which the trucks were arranged in two lines on the eighth and final span of the bridge. (Figure 80) One line of trucks was placed along the centerline of the span, while the other was as close to the outside curve as possible. Several FEA models were developed for this stage. The comparisons shown below were generated using a model that included the parapets.

6.3.1.1 Stress Comparisons

Figure 95 shows a comparison between the measured and predicted stresses in the outside girder (Line A) over the length of the bridge during loading B8. For the portion of the bridge nearest the applied load, the measured stresses are somewhat

smaller than the predicted stresses. At distances farther from the applied loads, the predicted and actual stresses are coincident.

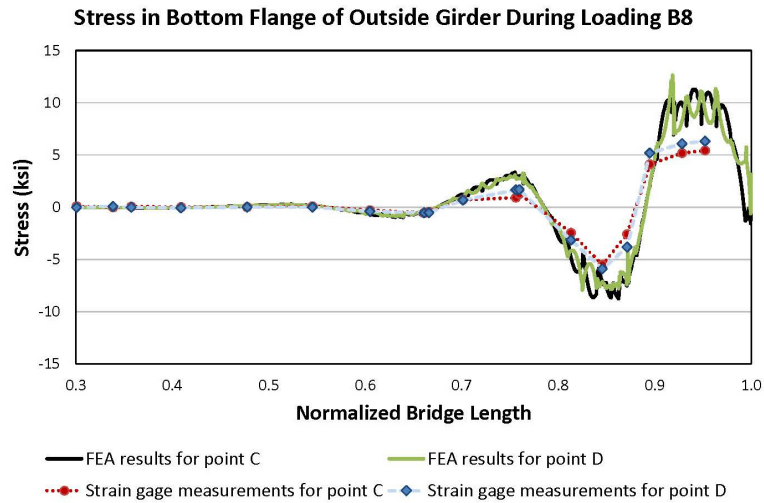


Figure 95: Comparison of Stress in Bottom Flange of Outside Girder During Loading Condition B8

Figure 96 shows a comparison between the predicted and measured stresses on the inside girder (Line E) for loading B8. As shown in the graph, most of the gages are reading values that are indistinguishable from the predicted values. The gages located in the near vicinity to the applied loading are experiencing a measured stress that is greater in magnitude than the value predicted by the FEA model by about 1.5ksi. This may indicate that the parapets had not yet reached their full strength and were not fully contributing to the stiffness. However, with only two data points near the loading for each point being monitored, it is difficult to discern the stress distribution for the inside girder.

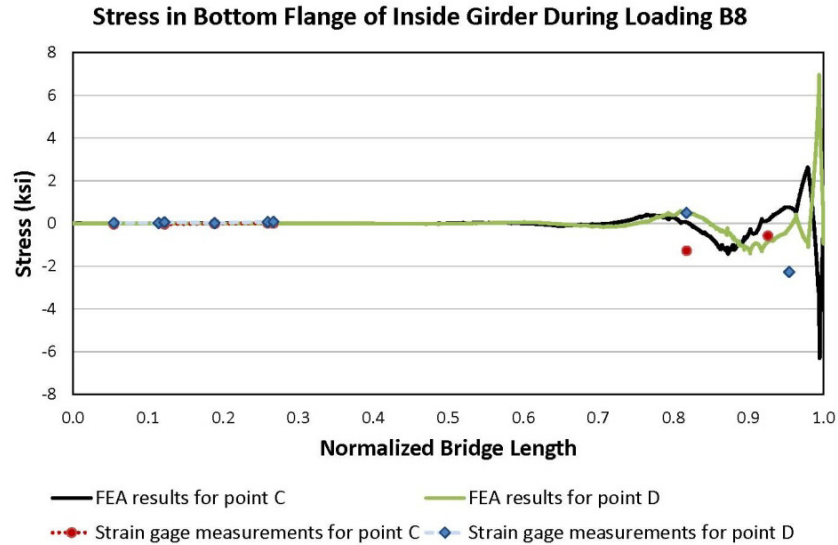


Figure 96: Comparison of stress in bottom flange of inside girder during loading condition B8

6.3.1.2 Displacement Comparisons

Figure 97 shows a comparison between the predicted and measured values for the vertical displacement in the inside girder during loading condition B8. Three lines are included for the predicted values generated using the FEA models. One model includes the trucks in their target locations without the inclusion of the parapets, one includes the trucks in their target locations with the inclusion of the parapets, and one includes the trucks moved two feet from their target location with the inclusion of the parapets. The most extreme behavior was predicted by the model without the inclusion of parapets and the least extreme behavior was predicted by the model with the trucks moved two feet from their target location. As the graph indicates, the measured values were closest to behavior of the models with parapets with the exception for the two targets that were closest to the location of the loading. Those targets deflected farther than would be expected with the parapets included, but were within the expected range if the parapets are neglected.

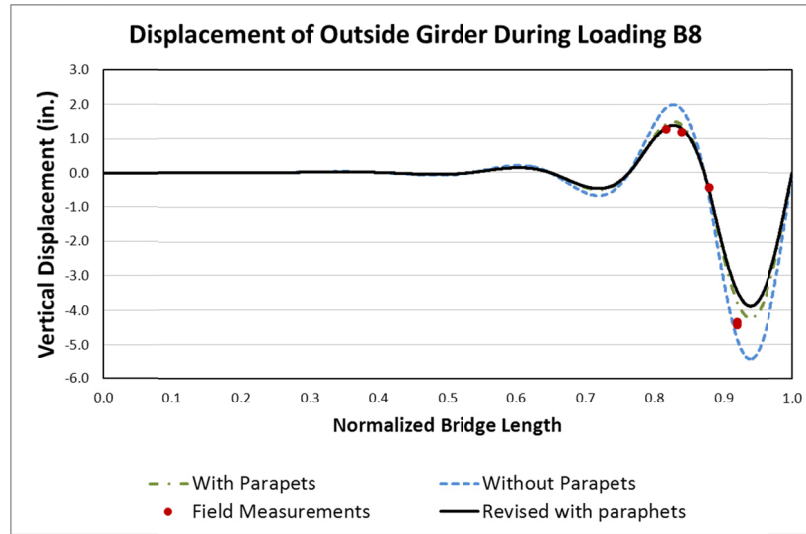


Figure 97: Comparison of deflection in outside girder during loading condition B8

Figure 98 shows a similar comparison for the inside girder during loading condition B8. As shown in the graph, some of the deflections are about twice as great as the highest deflection predicted by any of the three FEA models for that location. However, the differences are small if one looks at their magnitudes and compares the vertical scales in Figure 97 and Figure 98. The other points taken by the robotic total station experienced vertical deflections similar to those predicted by the FEA model without parapets.

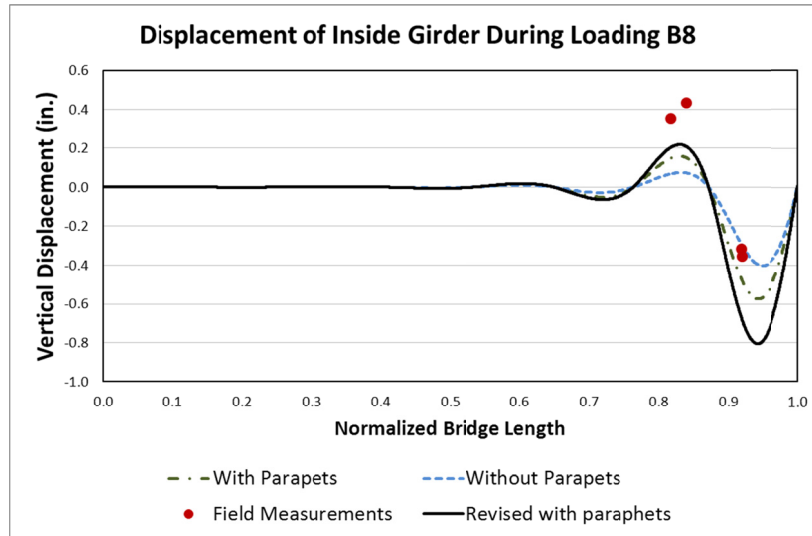


Figure 98: Comparison of deflection in inside girder during loading condition B8

6.3.2 Loading Condition C8

The next set of comparisons were done for loading condition C8, in which the trucks were placed on span 8 with one line as close to the inside curve of the bridge as possible and the second line of trucks centered on the bridge. (Figure 81)

6.3.2.1 Stress Comparisons

Two sets of zero readings were utilized for the measured stresses in these comparisons. The first zero readings were taken very early in the morning before the start of the live load test. The second zero readings were taken when the trucks were removed from the bridge during the lunch break. The comparisons below were generated using the second zeroing point as this was considered more representative of the bridge at a steady-state temperature. Even using the more accurate zeroing point, there was a difference in temperature of about 1-2° Fahrenheit between the zero reading and loading C8, which may have produced additional thermally induced stresses.

Figure 99 shows a stress comparison for the bottom flange of the outside girder during loading C8. The curve for the measured stresses fits the shape of analytical curve

very well, but the measured values are all slightly higher than predicted for most of the length of the bridge. This is likely due in part to the thermally induced stresses referred to in the above.

Figure 100 shows a stress comparison for the inside girder during loading C8. The measured stresses do not seem to have a consistent relation to the predicted values for this loading condition, though the sparse distribution of the strain gages on this girder again makes it more difficult to make a comparison.

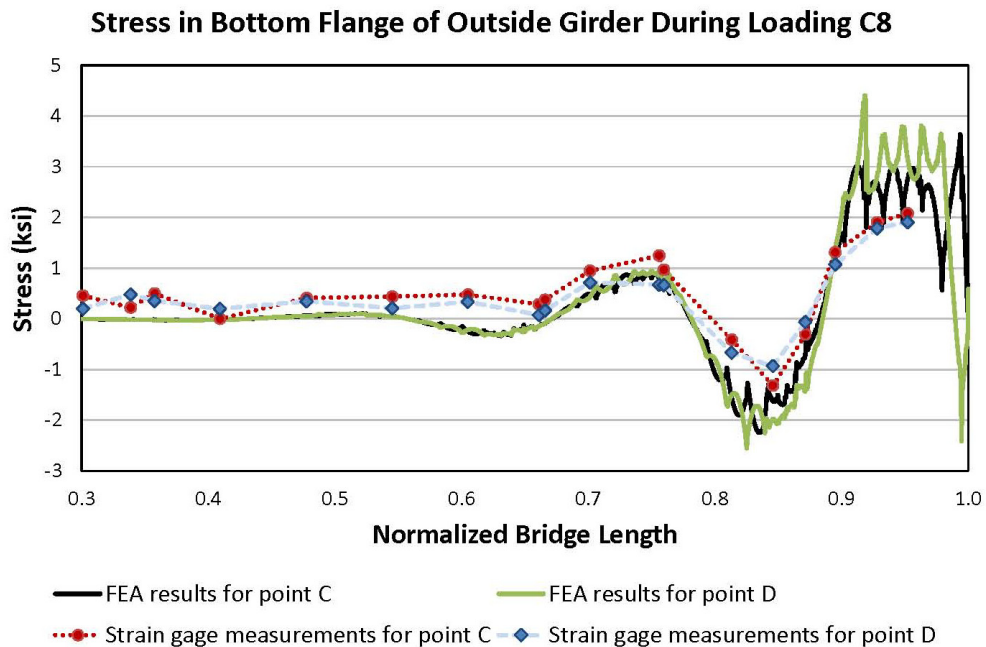


Figure 99: Comparison of stress in bottom flange of outside girder during loading C8

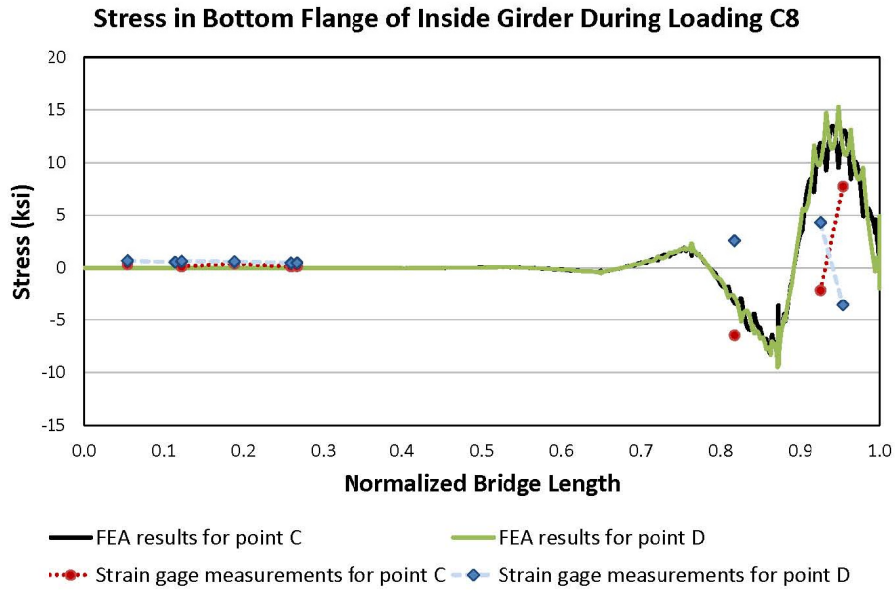


Figure 100: Comparison of stress in bottom flange of inside girder during loading C8

6.3.2.2 Displacement Comparisons

Figure 101 shows the predicted and measured vertical displacement of the bottom flange of the outside girder during loading condition C8. The measured values fit the shape of the analytical curve very closely, though the magnitudes are slightly higher.

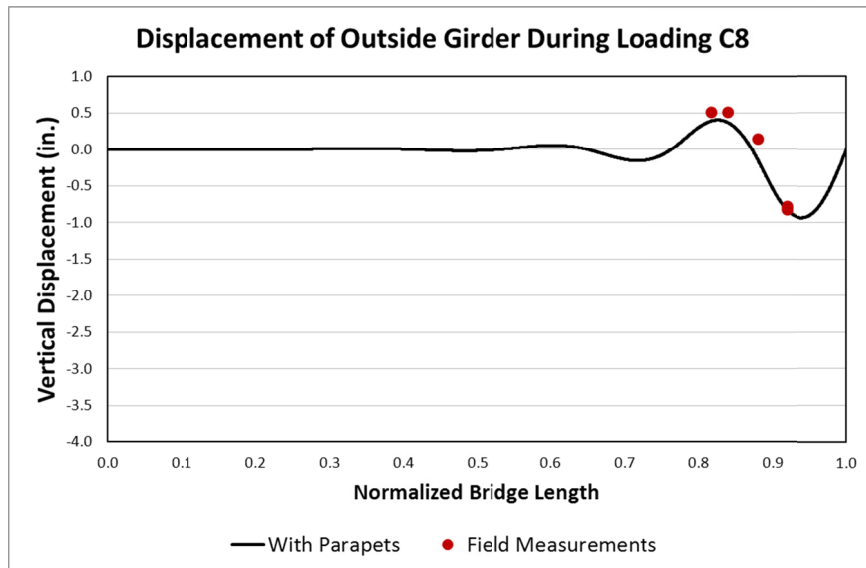


Figure 101: Comparison of deflections in bottom flange of outside girder during loading C8

Figure 102 shows a similar comparison for the inside girder. The measured values for this girder are slightly lower for the upward deflections and somewhat larger in magnitude for the downward displacements.

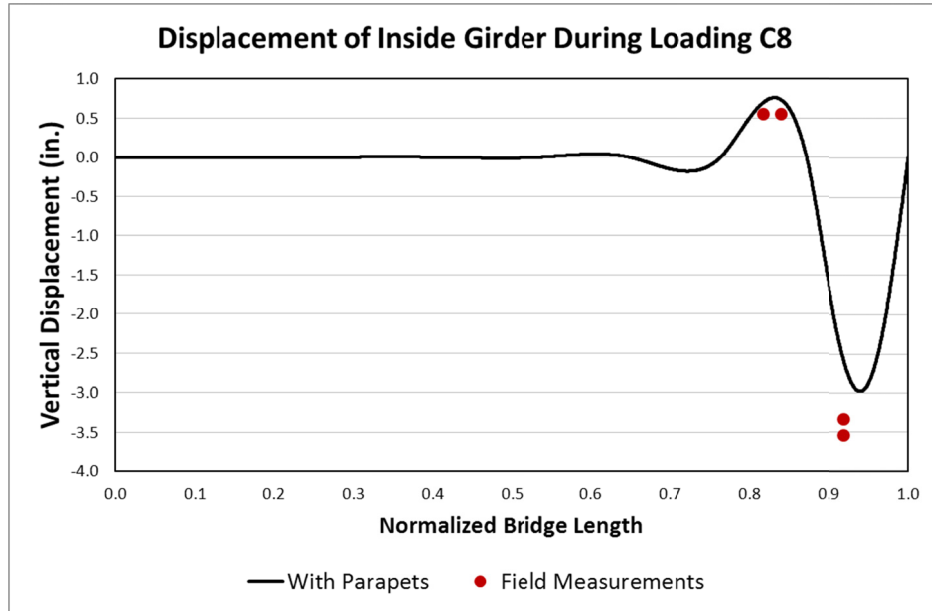


Figure 102: Comparison of deflections in bottom flange of inside girder during loading C8

6.3.3 Loading Condition D7

The final set of live load comparisons were generated for loading condition D7, in which one line of trucks was placed on span seven as close to the inside curve of the bridge as possible. The second line of trucks was placed on span eight as close to the outside curve of the bridge as possible. (Figure 82)

6.3.3.1 Stress Comparisons

The measured stress values were calculated using two different zeroing points, in the same way that they were calculated for loading condition C8. The comparisons shown below use the second set of zero readings.

Figure 103 shows the stress comparison for the bottom flange of the outside girder during loading D7. The measured stresses fit the shape of the predicted curve reasonably well, though the magnitudes of the measured stresses are lower.

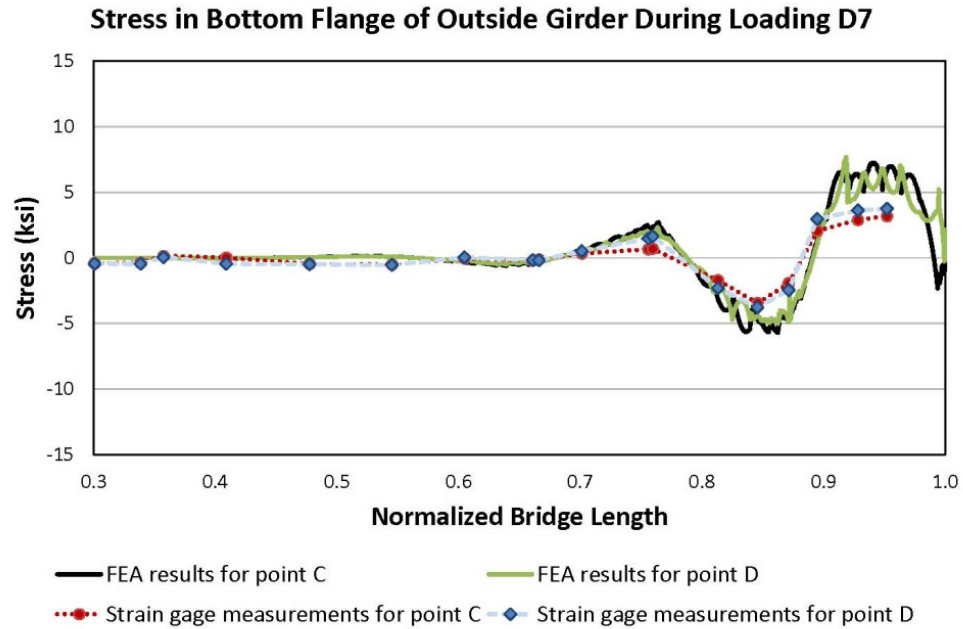


Figure 103: Comparison of stress in bottom flange of outside girder during loading D7

Figure 104 shows the stress comparison for the bottom flange of the inside girder during loading D7. The sparse distribution of strain gages on the inside girder again make it difficult to compare the predicted and measured stress values.

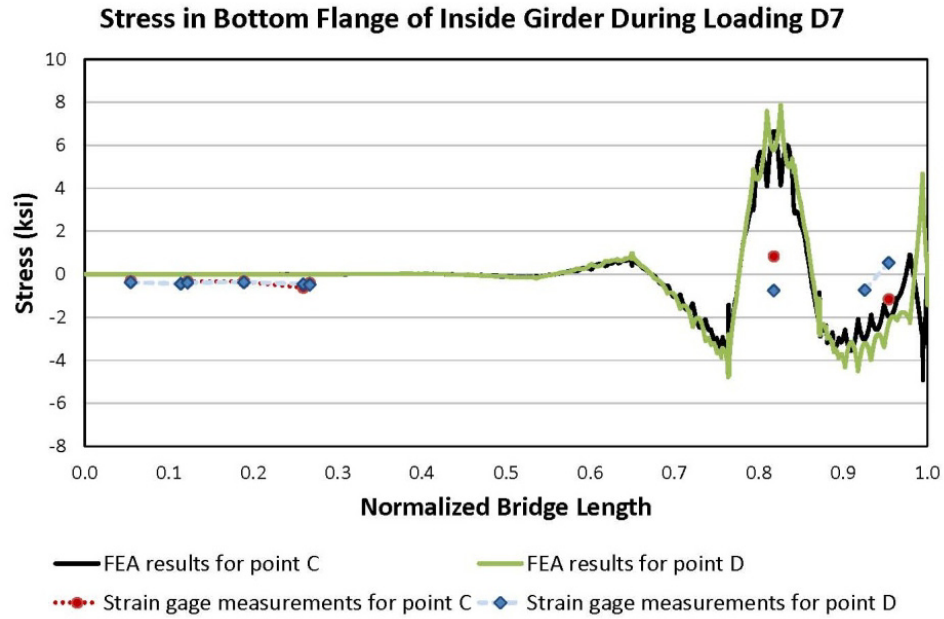


Figure 104: Comparison of stress in bottom flange of inside girder during loading D7

6.3.3.2 Displacement Comparisons

Figure 105 and Figure 106 show the comparison of the predicted and measured vertical displacement of the outside and inside girder respectively. On both graphs the measured displacements are very close to the predicted values, but slightly higher in magnitude. The FEA model included parapets for these comparisons, which may contribute to the discrepancy.

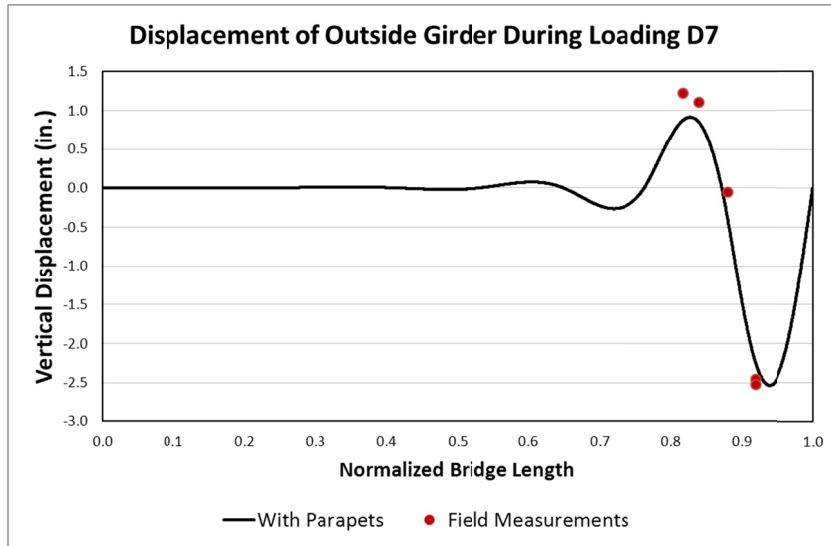


Figure 105: Comparison of deflections in bottom flange of outside girder during loading D7

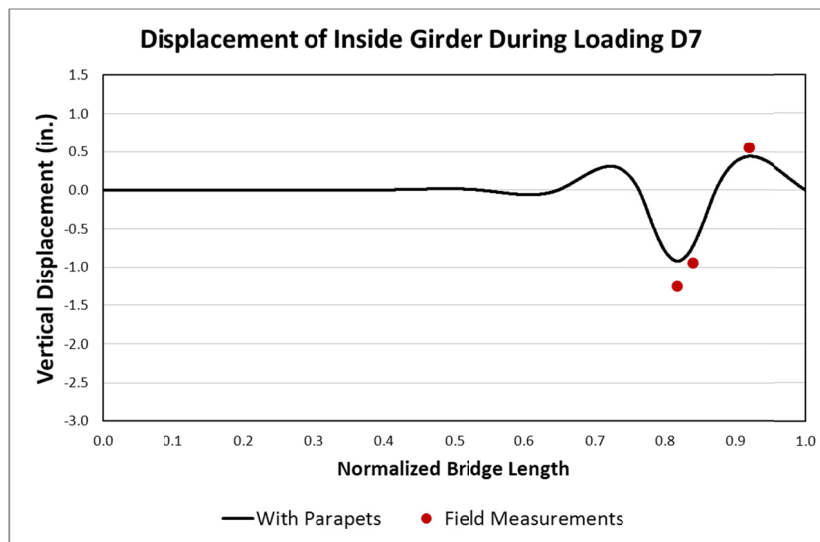


Figure 106: Comparison of deflections in bottom flange of inside girder during loading D7

CHAPTER 7: CONCLUSIONS

This report outlines the changes in stresses and displacements during the construction of Ramp B -- a highly curved steel I-girder bridge. The results reported include the stresses and deflections measured during several stages of construction, the stresses and deflections measured during a static live load test and a comparison between the measured data and the predicted values generated using a 3D finite element model.

7.1 Measured Responses during Construction

A wealth of high quality data were obtained during the construction process. Ideally, the girders would have been instrumented before being brought to the construction site and the erection would have been done in pairs of girders, like the original plan called for. This would have involved many fewer cable splices and would have allowed the strain gages to collect data for more of the girders during the lifting process. However, the trends in the data that were collected from adjacent girders are clear and consistent with the analytical models. Comparing the stress curves and the temperature curves for a particular set of data made it very evident when a change in stress was due to temperature loadings and when it was due to construction loadings. The thermal stresses were caused by axial expansion of the girders which was restrained by the fixed piers. This resulted in corresponding changes in stress for all measured points on the girder cross section. The construction loadings, on the other hand, induced bending and torsional stresses.

The same comparisons could be made for the vertical deflection measured in a total station target and the temperature data pulled from the nearest strain gage. The vertical deflections were clearly influenced by temperature, in that the targets tended to move upward as the temperature increased, and downward as the temperature

decreased. It is difficult to distinguish thermally induced deflections when there are additional load changes on the bridge, however, because the deflections due to changes in temperature are much smaller than those induced by the construction loads. For example, during the 48 hour deflection test a change in temperature of 20°F resulted in about 0.5in. of displacement. A similar temperature change was experienced during the concrete placement, but the deflections were 4-6 in (primarily due to the addition of concrete weight).

7.2 Measured Responses during Live Load Test

The live load test initially included thirty-two loading conditions, but due to time and equipment constraints only nineteen were collected. The stress plots generated from the live load test show the changes in loading very clearly, and the change in stress between the zero loading condition and each load case is a useful measure when comparing to expected values. The total station was used to generate vertical deflection data for each target.

7.3 Comparison of Predicted Vs. Measured Bridge Responses

When comparing the stresses measured during the erection of girder 170A14 to the values predicted by the FEA model, values correlated reasonably well in some cases and not very well in others. During lifting, the changes in loading occurred gradually once the girder was removed from the truck, and the difference between the maximum measured and predicted stresses was typically less than 1ksi. Modeling the system for the lifting stage was fairly straight forward as the girder was essentially simply supported. Once girder 170A14 had been spliced to girder 165A13, however, the system was indeterminate. The measured stresses were typically several times higher than expected. Some of the factors that may have caused the differences were slight misalignment of girder 170A14 at the connection to girder 165A13, the restraint of the

holding cranes, and thermal stresses induced by temperature differences throughout all the bridge components.

When comparing the stresses during the static live load test, there was a good correlation between the measured and predicted stresses in the outside girder. The measured stresses followed the shape of the predicted curve very closely. In all three loadings, the measured stress was slightly lower than the predicted stress for the portion of the bridge being loaded. For the inside girder the correlation between the measured and predicted stress values is poor. However, the number of data points is not sufficient to understand the discrepancy.

The measured deflections fit well with the predicted deflected shape for all three loadings. The measured deflections were typically somewhat larger than the predicted values. The largest discrepancy occurred on the inside girder during loading C8, where the actual deflection was 0.5 in. (17%) higher than expected.

APPENDIX A: INSTRUMENTATION

Appendix A includes additional information regarding the strain gages, clinometers, and data acquisition system.

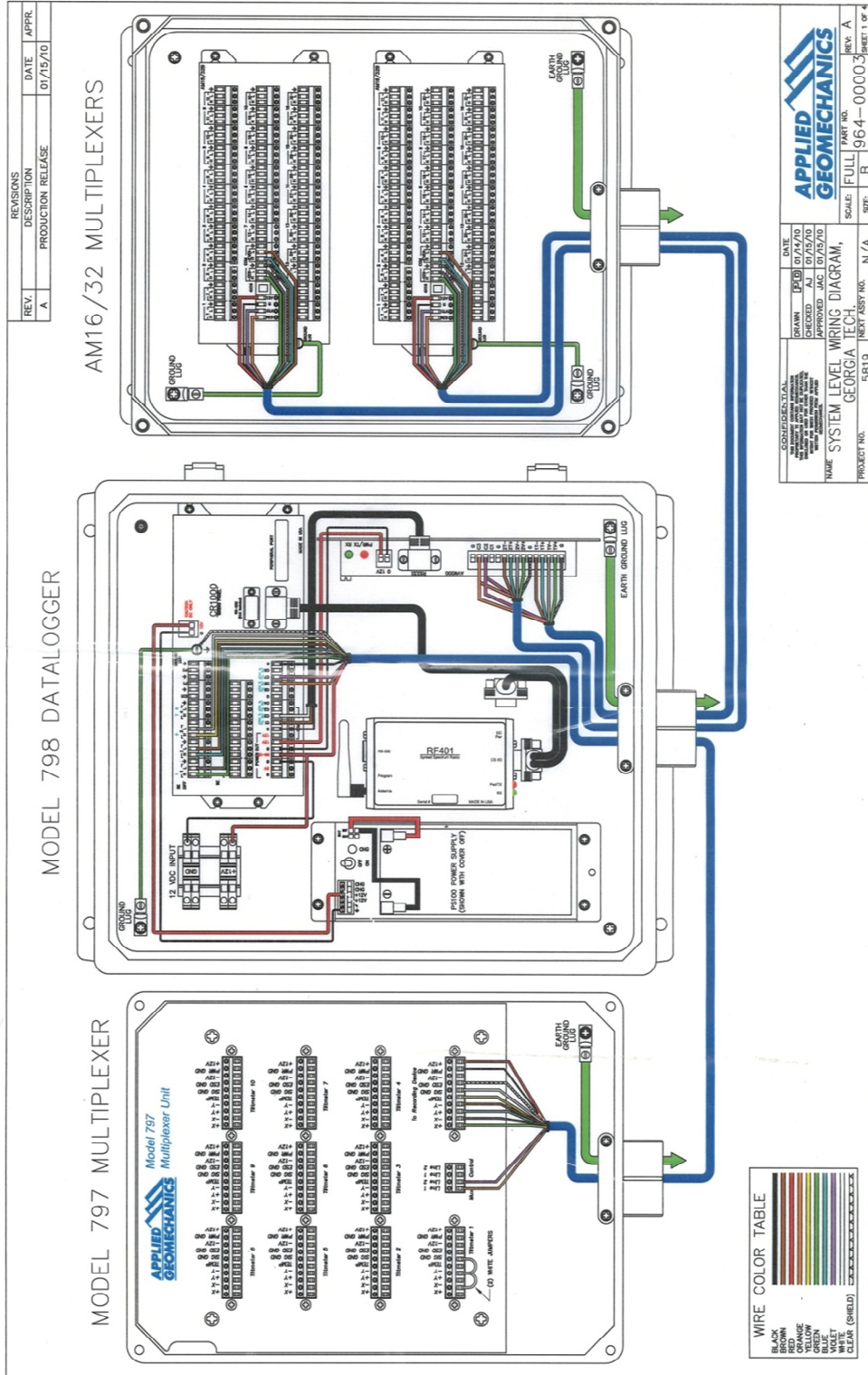


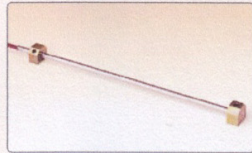
Figure 107: Wiring diagram for data acquisition system

Arc Weldable Strain Gage

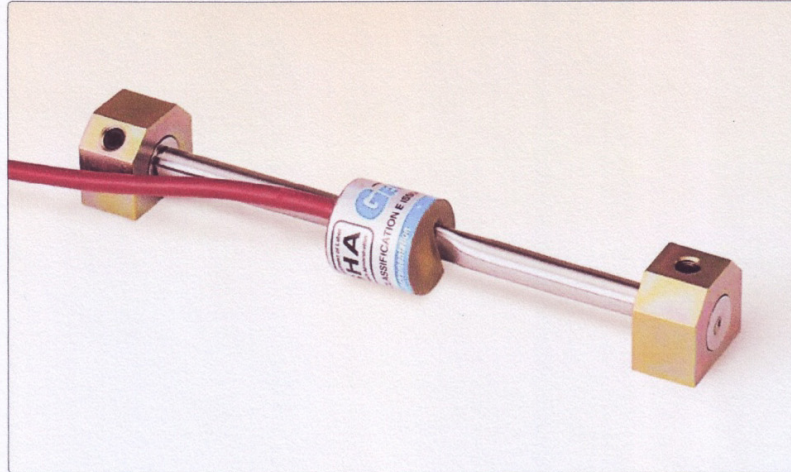
Applications

The Model 4000 Vibrating Wire Strain Gage is designed primarily for long-term strain measurements of steel structures including...

- Tunnel linings
- Excavation bracing
- Arches
- Struts
- Sheet piling
- Piles
- Bridges



• The Model 4050 with a 12 inch active gage length.



• Model 4000 Vibrating Wire Strain Gage.

Operating Principle

The Model 4000 basically consists of a length of steel wire tensioned between two mounting blocks that are arc welded to the surface of a structural steel member. Deformation of the structure under load produces relative movement between the two mounting blocks causing a change in the wire tension and a corresponding change in its frequency of vibration.

The resonant frequency is measured by plucking the wire using an electromagnetic coil connected through a signal cable to a readout box, which also measures the frequency and displays the strain in the wire directly in microstrain.

The Model 4000 can also be used on other materials such as wood, rock or concrete. Standard mounting blocks can be epoxy bonded to the surface or special concrete mounting blocks can be used in which short rebar studs are grouted into boreholes.

The Model 4050 is a modified version of the Model 4000 designed for measuring strains over a longer base length.

Advantages & Limitations

The Model 4000 is the most popular vibrating wire strain gage in the world on account of its elegant, robust design combined with all the usual advantages of vibrating wire technology, i.e. long-term stability, high resistance to water intrusion and lightning damage and the ability to be used with long signal cables.

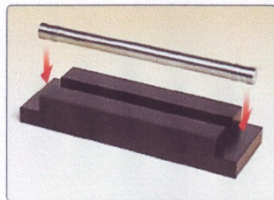
The electronic coil can be detached from the rest of the gage at any time without disturbing the gage reading. This provides a degree of flexibility in the event of cable damage. Gages and coils are re-usable.

Temperature effects are automatically compensated for when the gages are welded to steel. The thermistor permits real thermal induced strain to be distinguished from load induced strains.

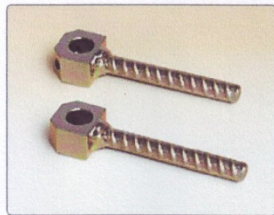
The gage is not suitable for dynamic applications, although auto-resonant versions can follow low frequency (less than 100 Hz) oscillations.

Figure 108: Geokon vibrating wire strain gage

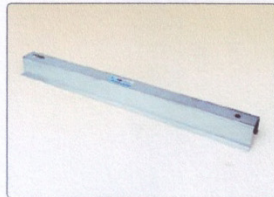
(<http://www.geokon.com/products/datasheets/4000.pdf>)



• A spacer bar and welding jig (Model 4000-8) can be used during strain gage installation.



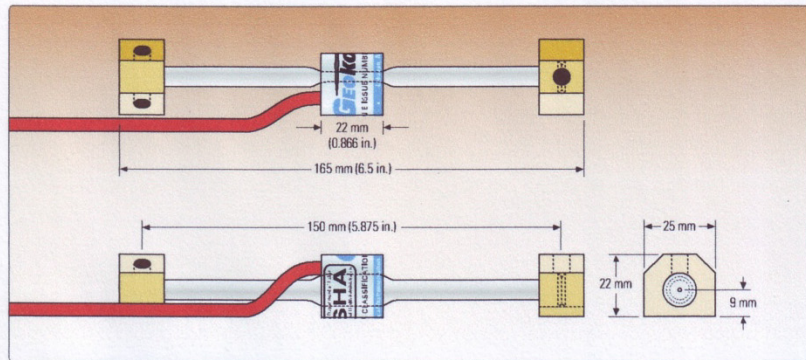
• Concrete mounting blocks (optional).



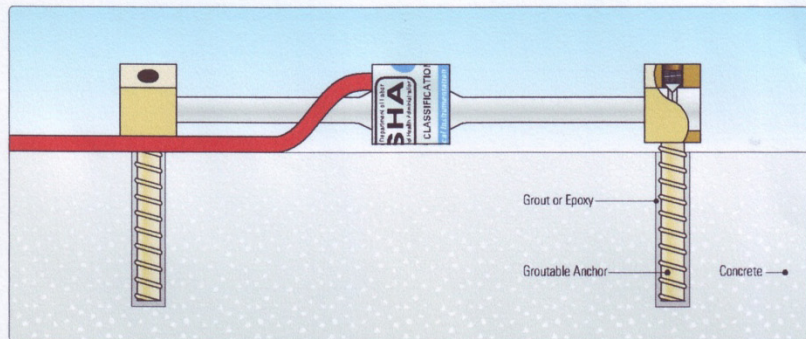
• Cover plate (optional).



• Geokon Model GK-403 Readout Box for use with the Model 4000 and 4050 Strain Gages.



• Dimensions of the Model 4000.



• Illustration shows the Model 4000 attached to concrete via grouted concrete mounting blocks.

System Components

The vibrating wire is protected inside a stainless steel tube with 'O' ring seals at both ends for complete water-proofing. The electronic coil clips over the center of the tube and a thermistor is encapsulated with the coil to permit the measurement of temperature.

The Model 4000-8 spacer bar and welding jig is used to correctly space the mounting blocks during welding. Cover plates (Model 4000-6) can be used to protect the gage from accidental damage.

Readout is accomplished using the Geokon Model GK-401, GK-403 or GK-404 Readout Boxes or the Micro-10 Datalogger.

Technical Specifications

	4000	4050
Standard Range	3000 $\mu\epsilon$	3000 $\mu\epsilon$
Resolution	1.0 $\mu\epsilon$	1.0 $\mu\epsilon$
Accuracy ¹	$\pm 0.1\%$ to $\pm 0.5\%$ F.S.	$\pm 0.1\%$ to $\pm 0.5\%$ F.S.
Nonlinearity	< 0.5% F.S.	< 0.5% F.S.
Temperature Range	-20°C to +80°C	-20°C to +80°C
Active Gage Length ²	150 mm (5.875 in.)	300 mm (12 in.)

¹ $\pm 0.1\%$ F.S. with individual calibration, $\pm 0.5\%$ F.S. with standard batch calibration.
²Other lengths available on request.



The World Leader in Vibrating Wire Technology™

Geokon, Incorporated
 48 Spencer Street
 Lebanon, NH 03766
 USA

Geokon maintains an ongoing policy of design review and reserves the right to amend products and specifications without notice.

1 • 603 • 448 • 1562
 1 • 603 • 448 • 3216
 geokon@geokon.com
 www.geokon.com

©2007 Geokon, Incorporated. All Rights Reserved | Doc. Rev. E, 03/07

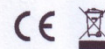


Figure 109: Description of vibrating wire

(<http://www.geokon.com/products/datasheets/4000.pdf>)

APPENDIX A - SPECIFICATIONS

	Model 4000	Model 4050
Range (FS), (nominal):	3000 $\mu\epsilon$	3000 $\mu\epsilon$
Resolution:	1.0 $\mu\epsilon$	1.0 $\mu\epsilon$
Accuracy ¹ :	Batch Calibration... +/- 0.5% FS Individual Calibration... +/- 0.1% FS	Batch Calibration... +/- 0.5% FS Individual Calibration... +/- 0.1% FS
Zero Stability:	0.02% FS/yr	0.02% FS/yr
Linearity:	+/- 0.5% FS	+/- 0.5% FS
Thermal Coefficient:	12.2 $\mu\epsilon/^\circ\text{C}$	12.2 $\mu\epsilon/^\circ\text{C}$
Dimensions (gage):	6.125 x 0.750"	12.625" x 0.750"
(Length x Diameter)	155 x 19 mm	645 x 19 mm
Dimensions (coil):	0.875 x 0.875" 22 x 22 mm	Internal
Frequency Range:	450 – 1250 Hz	1400 – 3200 Hz
Coil Resistance:	180 Ω	50 Ω
Temperature Range:	-20 to +80° C	-20 to +80° C

Notes:

¹ Using curve fitting techniques, (second order polynomial).

A.2 Thermistor (see Appendix C also)

Range: -80 to +150° C

Accuracy: $\pm 0.5^\circ\text{C}$

Figure 110: Vibrating wire specification

(http://www.geokon.com/products/manuals/4000_Strain_Gage.pdf)

APPENDIX B - THEORY OF OPERATION

A vibrating wire attached to the surface of a deforming body will deform in a like manner. The deformations alter the tension of the wire and hence also its natural frequency of vibration (resonance). The relationship between frequency (period) and deformation (strain) is described as follows;

1. The fundamental frequency (resonant frequency) of vibration of a wire is related to its tension, length and mass by the equation:

$$f = \frac{1}{2L_w} \sqrt{\frac{F}{m}}$$

Where;

L_w is the length of the wire in inches.

F is the wire tension in pounds.

m is the mass of the wire per unit length (pounds, sec.²/in.²).

2. Note that:

$$m = \frac{W}{L_w g}$$

Where;

W is the weight of L_w inches of wire (pounds).

g is the acceleration of gravity (386 in./sec.²).

3. and:

$$W = \rho a L_w$$

Where;

ρ is the wire material density (0.283 lb./in.³).

a is the cross sectional area of the wire (in.²).

4. Combining equations 1, 2 and 3 gives:

$$f = \frac{1}{2L_w} \sqrt{\frac{Fg}{\rho a}}$$

5. Note that the tension (F) can be expressed in terms of strain, e.g.:

$$F = \epsilon_w E a$$

Where;

ϵ_w is the wire strain (in./in.).

E is the Young's Modulus of the wire (30 x 10⁶ Psi).

Figure 111: Theory of operation for vibrating wire strain gages

(from http://www.geokon.com/products/manuals/4000_Strain_Gage.pdf)

APPENDIX E - MEASUREMENT OF, AND CORRECTION FOR, TEMPERATURE EFFECTS

If the ends of the structural member were free to expand or contract without restraint then strain changes would take place without any change in stress. And in these situations the strain gage would indeed show no change in reading. Conversely, if the ends of a steel structural member were restrained by some semi-rigid medium, then any increase in temperature of the structural member would result in a build-up of compressive strain in the member. (Even though the actual strain would be tensile!) The magnitude of this temperature-induced compressive stress increase would be measured accurately by the strain gage. (Because, while the member is restrained from expansion, the vibrating wire is not restrained and the expansion of the wire would cause a reduction in wire tension and a resulting decrease in the vibrational frequency. This would be indicated by a decrease in strain reading on the readout box, corresponding to an apparent increase in compressive stress, which is, mirabile dictu, exactly equal to the temperature-induced increase in compressive stress in the member.)

The temperature-induced stresses can be separated from the load-induced stresses by reading both the strain and temperature of the strain gages at frequent intervals over a period of time in which the external loading from construction activity can be assumed to be constant. When these strain changes are plotted against the corresponding temperature changes, the resulting graph shows a straight-line relationship the slope of which yields a factor K_T . This factor can be used to calculate the temperature-induced stress

$$\sigma_{thermal} = K_T (T_1 - T_0)E \dots \dots \dots E1$$

Which if desired can be subtracted from the observed apparent stress change

$$\sigma_{apparent} = (R_1 - R_0)BE \dots \dots \dots E2$$

to give that part of the stress change due to construction activity loads only

$$\sigma_{load} = [(R_1 - R_0)B - K_T (T_1 - T_0)]E \dots \dots \dots E3$$

Note that the correction factor, K_T , may change with time and with construction activity due to the fact that the rigidity of the restraint may change. It would then be a good idea to repeat the above procedure in order to calculate a new temperature correction factor.

If, for whatever reason, the actual strain of the steel member is required, that is, the change of unit length that would be measured by, say, a dial gage attached to the surface, this is given by the equation

$$\mu\epsilon_{actual} = (R_1 - R_0)B + (T_1 - T_0) \times CF_1 \dots \dots \dots E4$$

Where CF_1 represents the coefficient of expansion of steel = +12.2 microstrain/°C.

Figure 112: Temperature correction for vibrating wire strain gages

(http://www.geokon.com/products/manuals/4000_Strain_Gage.pdf)

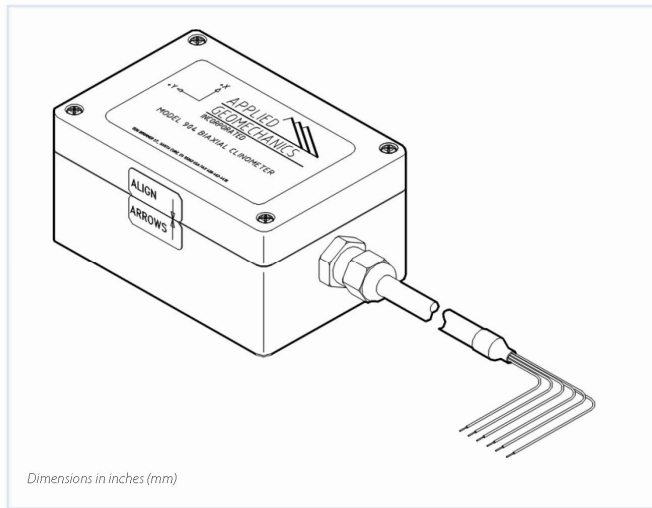
Model 904-T Clinometer Pak

The Clinometer Pak is a low-cost, analog output, biaxial clinometer for a wide variety of test and measurement applications. A liquid-filled electrolytic transducer comprises the sensing element. The transducer is excited and read by stable, low-noise electronics.

The clinometer is housed in a weatherproof NEMA 4X (IP65) enclosure and provides analog voltage signals for X tilt, Y tilt and temperature. Each "Clinometer Pak" comes standard with a 10 ft (3m) cable. Cable lengths to 1650 ft (500 m) are available.



Dual-Axis Clinometer Pak



Dimensions in inches (mm)

Model 904 Clinometer

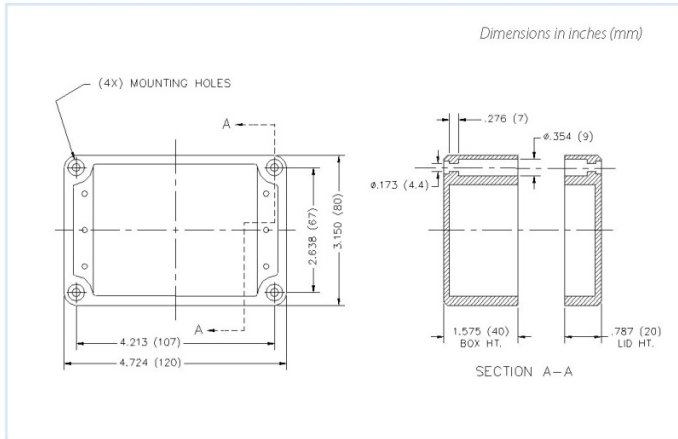
WIRE COLOR	FUNCTION
Red	Power
Black	Power Ground
Green	X Tilt
Blue	Y Tilt
Yellow	Temperature
White	Signal Ground



1-415-364-3200 • Geomechanics.com

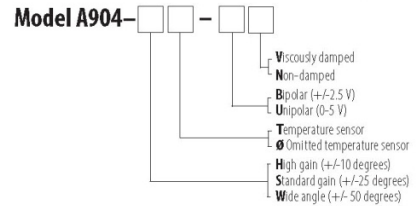
Figure 113: Description of Applied Geomechanics Model 904-T clinometer
 (http://www.carboceramics.com/attachments/files/201/904_Clinometer_Pak.pdf)

	MODEL 904-TH HIGH-GAIN VERSION	MODEL 904-TS STANDARD VERSION	MODEL 904-TW WIDE-ANGLE VERSION
ANGULAR RANGE	±10 degrees	±25 degrees	±50 degrees
SCALE FACTOR	4°/ volt typical	10°/ volt typical	25°/ volt typical
RESOLUTION	0.005 degree of angle	0.01 degree of angle	0.02 degree of angle
REPEATABILITY	0.01 degree	0.02 degree	0.04 degree
HYSTERESIS	0.01 degree	< 0.02 degree	< 0.04 degree
LINEARITY	1% of full span typical	2.5% of full span typical	7.5% of full span typical (1.2% of half span)
TIME CONSTANT, T	0.01 degree		
TILT OUTPUT	1% of full span typical		
TEMPERATURE OUTPUT	0.1°C/mV, ±0.75°C accuracy; 0°C = 0 mV (bipolar output version), 0°C = 2.5 V (0-5 V output version)		
OUTPUT IMPEDANCE	270 Ohms		
NATURAL FREQUENCY	10 Hz; available with viscous sensor to damp vibrations		
TEMPERATURE COEF.	Span: +0.03%/ °C, Zero: ±10 arc sec/ °C typical		
POWER REQUIREMENTS	+8 to +24 VDC (bipolar output version) or +10.5 to +26.5 VDC (0-5 V output version) @ 7 mA, 250 mV ripple max., reverse polarity protected		
ENVIRONMENTAL	10 to +70 degrees C operating and storage, 100% humidity		
ENCLOSURE & MOUNTING	Painted, NEMA 4X (IP65) aluminum box, 120 x 80 x 60 mm. Four 4.4 mm dia. mounting holes.		
CABLE	10 ft (3 m) multiconductor cable with PVC jacket and tinned ends, greater lengths on request		
WEIGHT	1 lb (0.4 kg)		



Model 904 Clinometer Pak

ORDER CODES:



USEFUL ACCESSORIES:

- 0-5VUP** 0-5 volt output
- VISCDAMP** Critically damped viscous sensor
- P/N 70369** Additional cable, specify length
- P/N 62204** 6-pin male receptacle (connector) for tiltmeter cable
- P/N 62202** 6-socket in-line plug (mates to P/N 62204)
- Model 870** Readout module (requires purchase of P/N 62204)
- RMS225** Digital multimeter display unit (used with Model 870)
- 81439** Mounting bracket for vertical surfaces
- 84051** Mounting plate for horizontal surfaces

APPLIED GEOMECHANICS

140 Chestnut St.
San Francisco CA, 94111
T: 1+415-364-3200
F: 1+415-861-1448
Geomechanics.com

A CARBO Company

©2011 Applied Geomechanics, Inc. All Rights Reserved. 02.11/A



Figure 114: Description of Applied Geomechanics Model 904-T clinometer

(http://www.carboceramics.com/attachments/files/201/904_Clinometer_Pak.pdf)

APPENDIX B: CONSTRUCTION DATA

Appendix B contains data collected in the field during the steel erection stages. This includes stress, displacement, and rotation data.

Construction of Span 1

Stress in Girder 104B1 Instrumentation Line 1 During Construction of Span 1

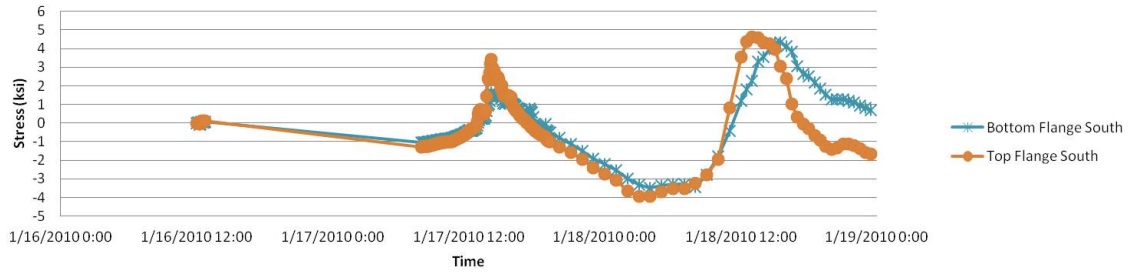


Figure 115: Stress in girder 104B1, instrumentation line 1 during construction of span 1

Temp. in Girder 104B1 Instrumentation Line 1 During Construction of Span 1

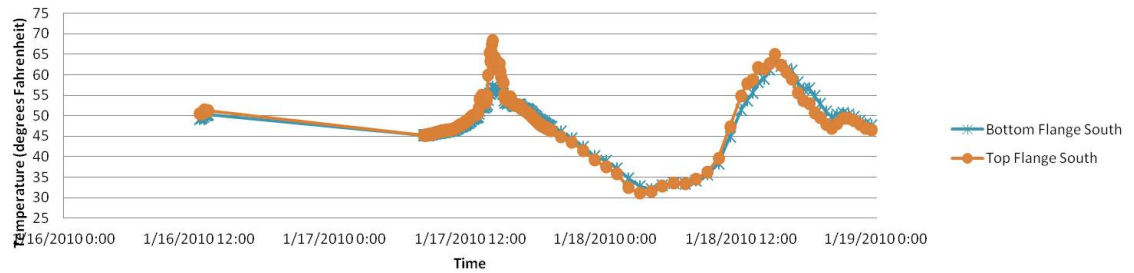


Figure 116: Temperature in girder 104B1, instrumentation line 1 during construction of span 1

Angle of Girder 104B1, Instrumentation Line 1 During Construction of Span 1

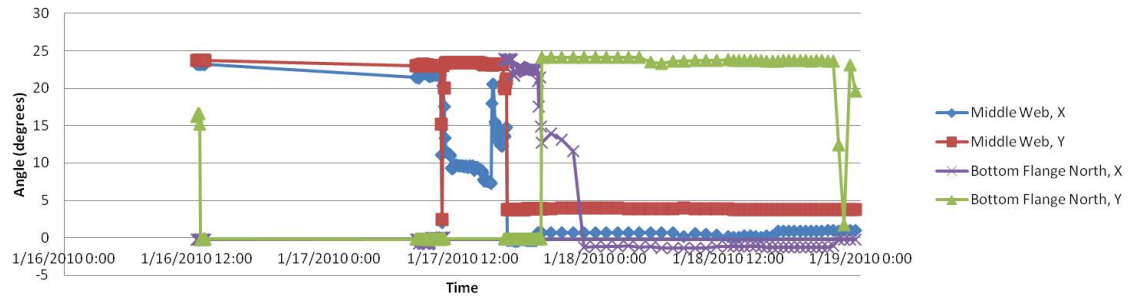


Figure 117: Rotation in girder 104B1, instrumentation line 1 during construction of span 1

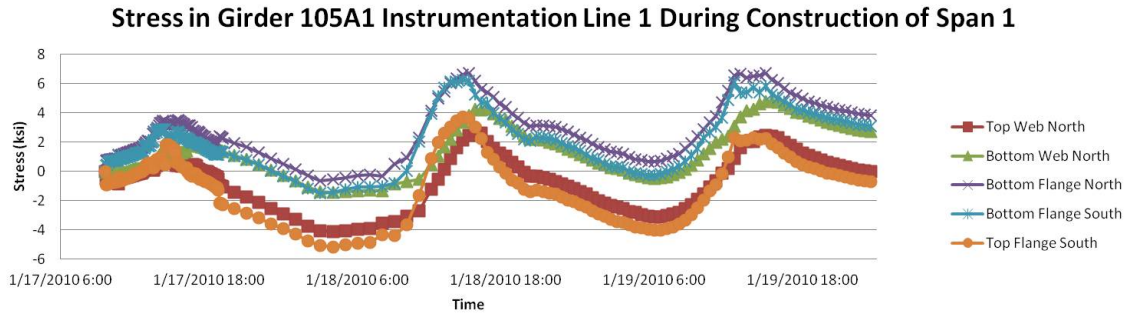


Figure 118: Stress in girder 105A1, instrumentation line 1 during construction of span 1

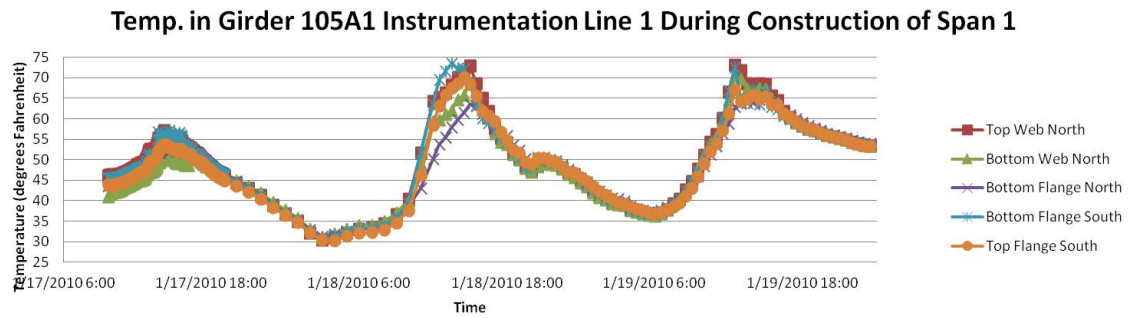


Figure 119: Temperature in girder 105A1, instrumentation line 1 during construction of span 1

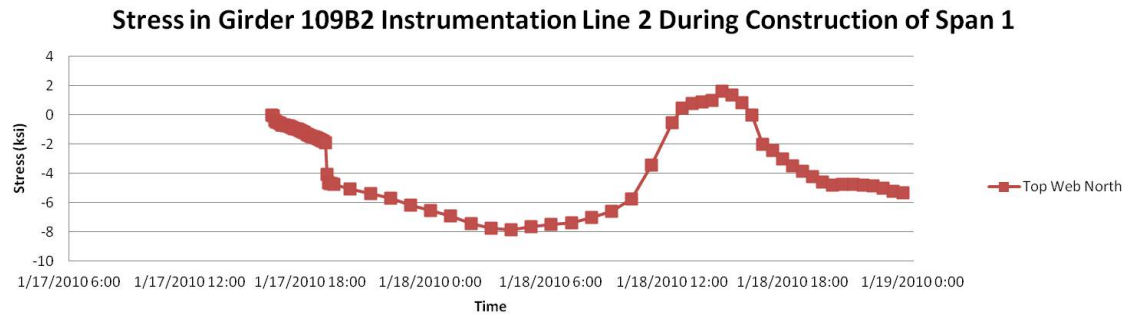


Figure 120: Stress in girder 109B2, instrumentation line 2 during construction of span 1

Temp. in Girder 109B2 Instrumentation Line 2 During Construction of Span 1

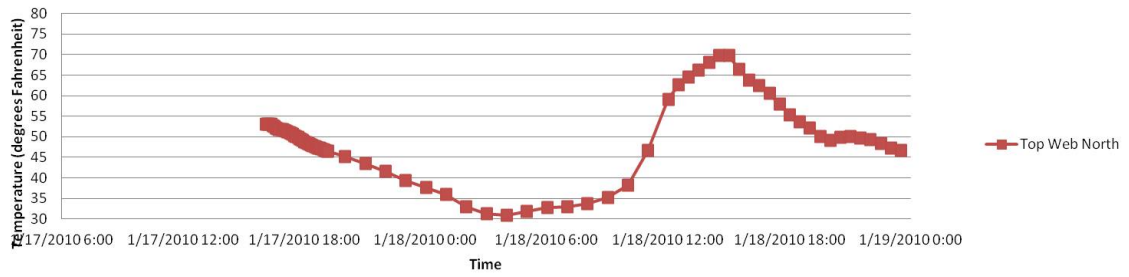


Figure 121: Temperature in girder 109B2, instrumentation line 2 during construction of span 1

Angle of Girder 109B2 Instrumentation Line 3 During Construction of Span 1

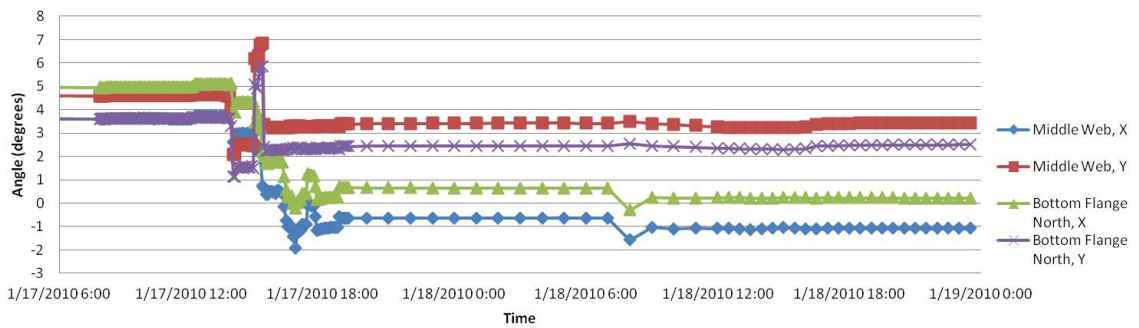


Figure 122: Rotation in girder 109B2, instrumentation line 3 during construction of span 1

Stress in Girder 110A2 Instrumentation Line 2 During Construction of Span 1

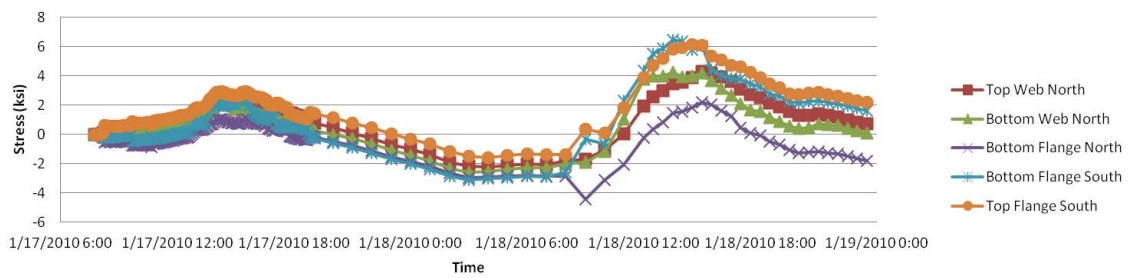


Figure 123: Stress in girder 110A2, instrumentation line 2 during construction of span 1

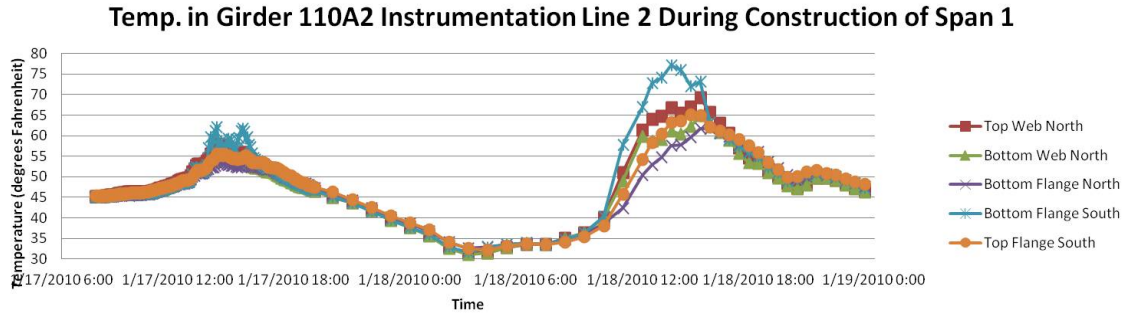


Figure 124: Temperature in girder 110A2, instrumentation line 2 during construction of span 1

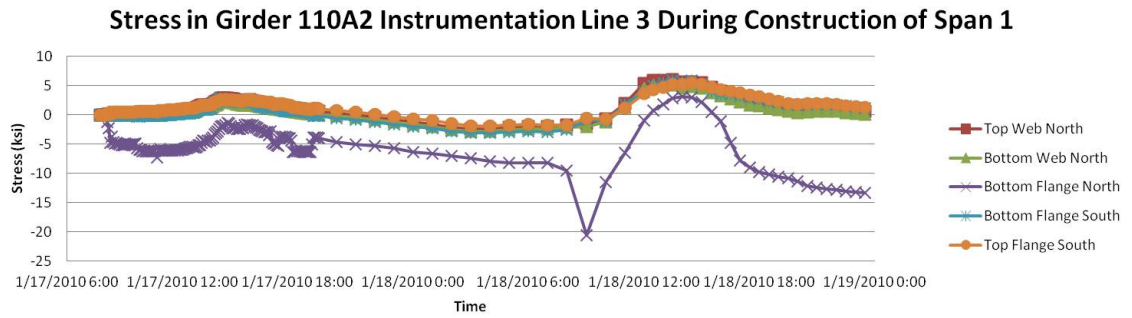


Figure 125: Stress in girder 110A2, instrumentation line 3 during construction of span 1

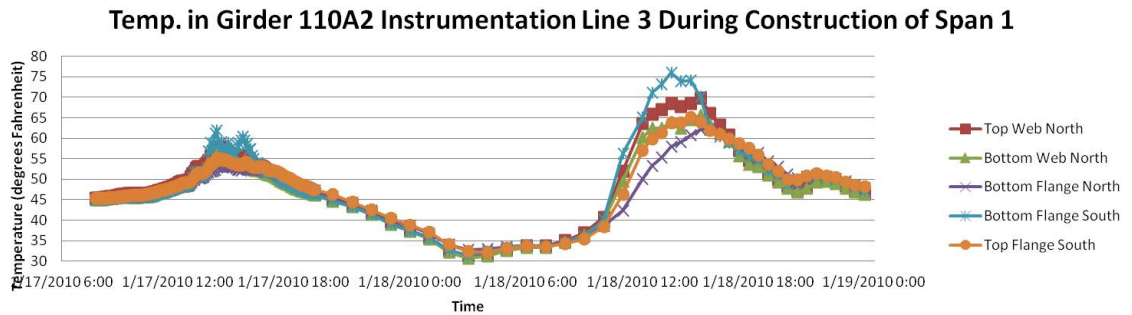


Figure 126: Temperature in girder 110A2, instrumentation line 3 during construction of span 1

Construction of Span 2

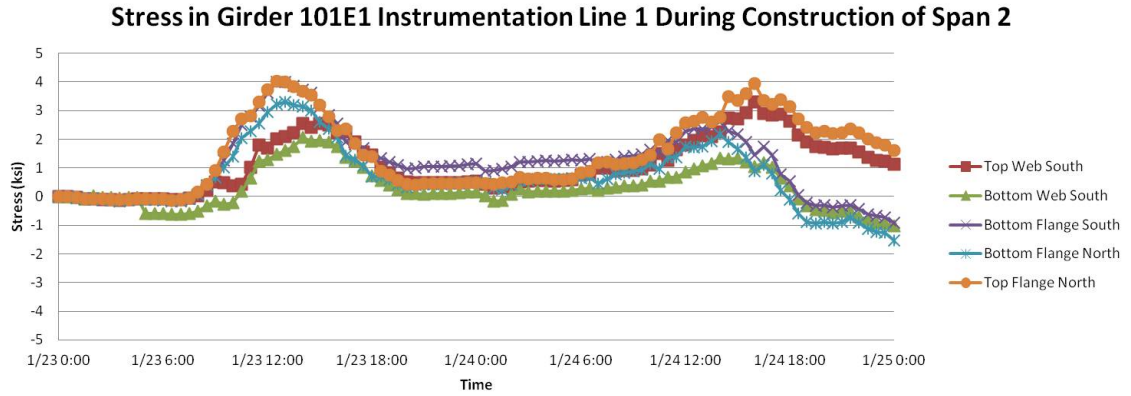


Figure 127: Stress in girder 101E1, instrumentation line 1 during construction of span 2

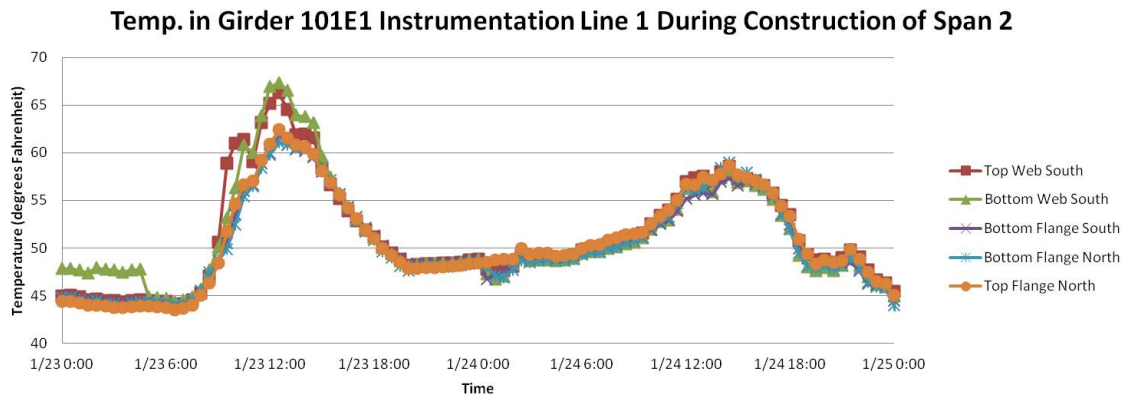


Figure 128: Temperature in girder 101E1, instrumentation line 1 during construction of span 2

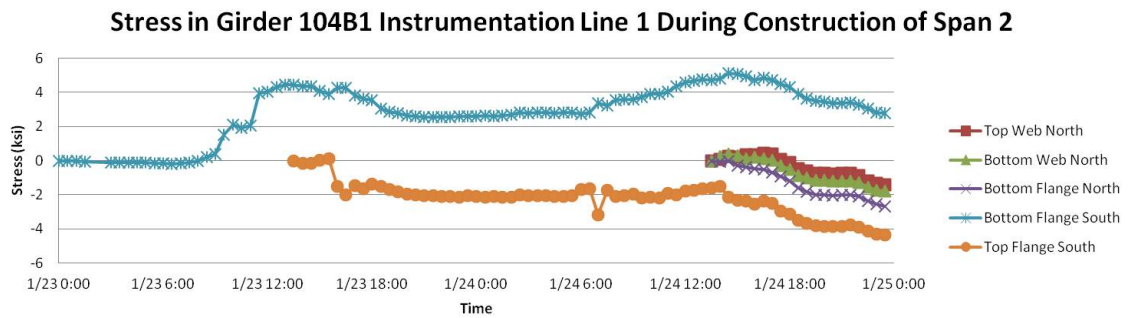


Figure 129: Stress in girder 104B1, instrumentation line 1 during construction of span 2

Temp. in Girder 104B1 Instrumentation Line 1 During Construction of Span 2

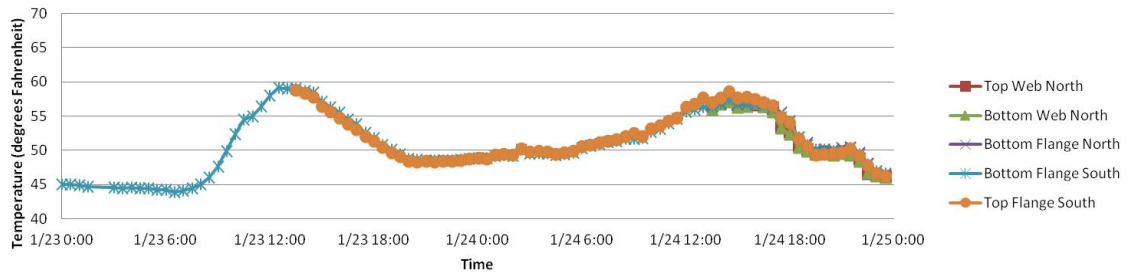


Figure 130: Temperature in girder 104B1, instrumentation line 1 during construction of span 2

Angle of Girder 104B1 Instrumentation Line 1 During Construction of Span 2

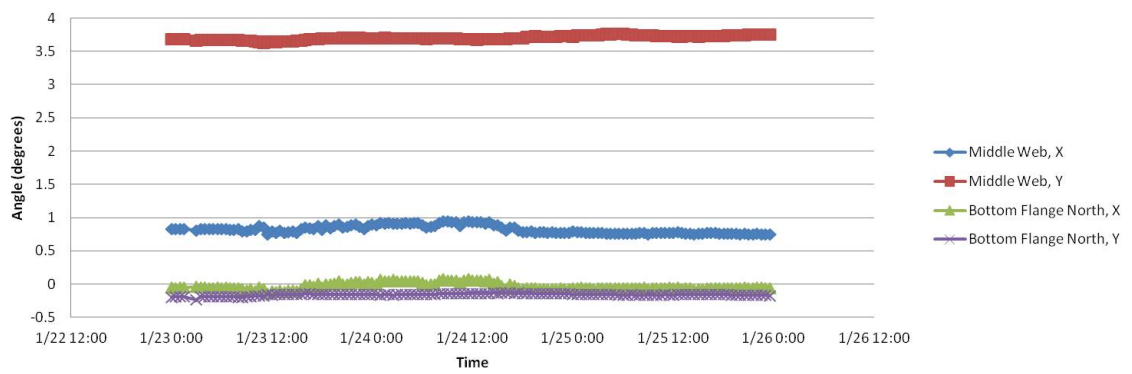


Figure 131: Rotation in girder 104B1, instrumentation line 1 during construction of span 2

Stress in Girder 105A1 Instrumentation Line 1 During Construction of Span 2

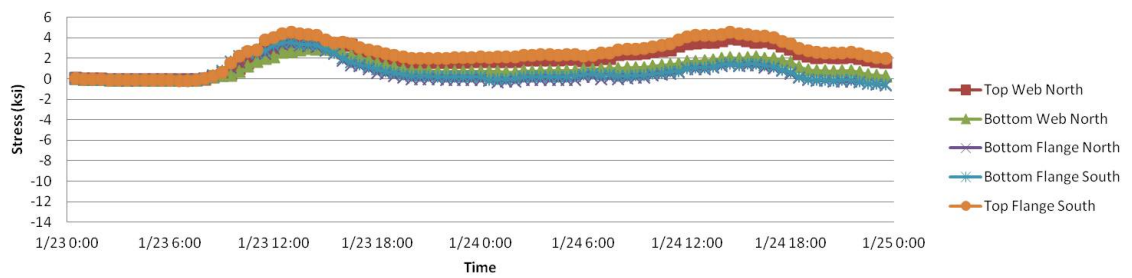


Figure 132: Stress in girder 105A1, instrumentation line 1 during construction of span 2

Temp. in Girder 105A1 Instrumentation Line 1 During Construction of Span 2

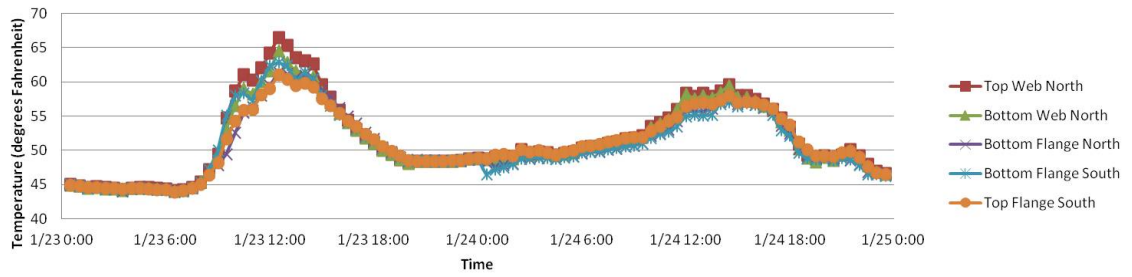


Figure 133: Temperature in girder 105A1, instrumentation line 1 during construction of span 2

Stress in Girder 109B2 Instrumentation Line 2 During Construction of Span 2

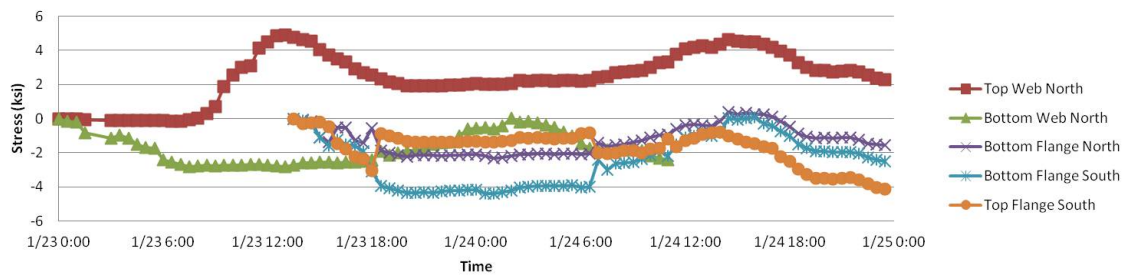


Figure 134: Stress in girder 109B2, instrumentation line 2 during construction of span 2

Temp. in Girder 109B2 Instrumentation Line 2 During Construction of Span 2

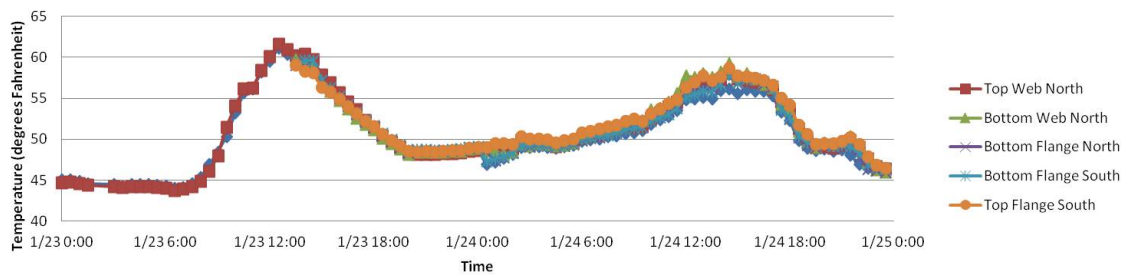


Figure 135: Temperature in girder 109B2, instrumentation line 2 during construction of span 2

Stress in Girder 110A2 Instrumentation Line 2 During Construction of Span 2

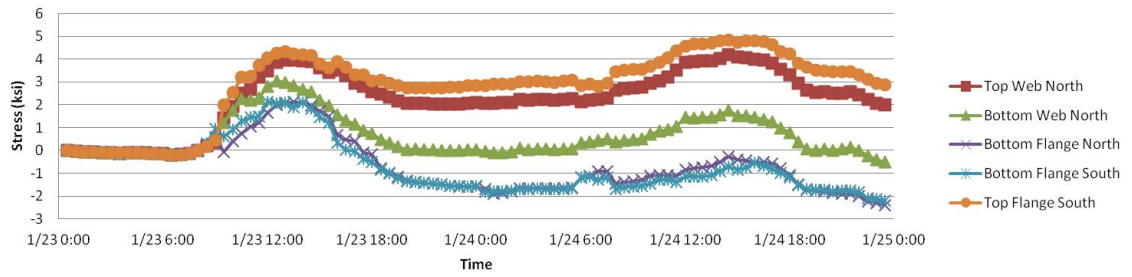


Figure 136: Stress in girder 110A2, instrumentation line 2 during construction of span 2

Temp. in Girder 110A2 Instrumentation Line 2 During Construction of Span 2

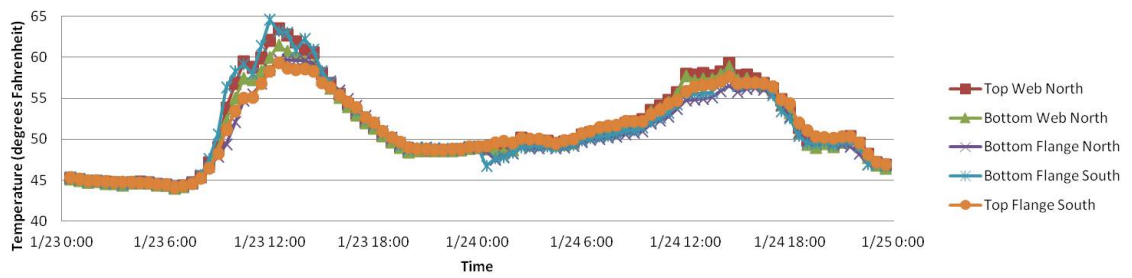


Figure 137: Temperature in girder 110A2, instrumentation line 2 during construction of span 2

Stress in Girder 110A2 Instrumentation Line 3 During Construction of Span 2

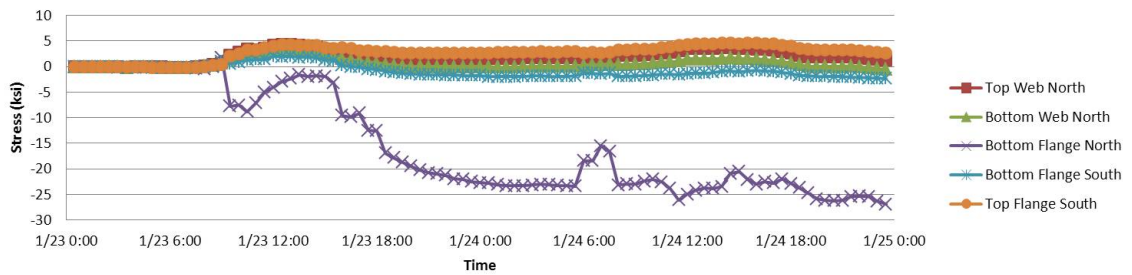


Figure 138: Stress in girder 110A2, instrumentation line 3 during construction of span 2

Temp. in Girder 110A2 Instrumentation Line 3 During Construction of Span 2

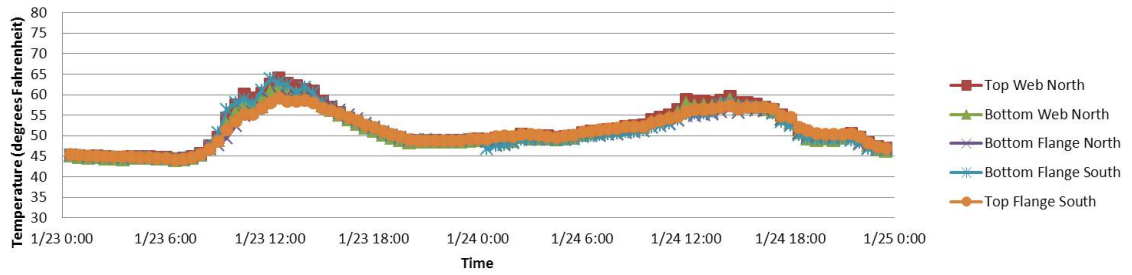


Figure 139: Temperature in girder 110A2, instrumentation line 3 during construction of span 2

Stress in Girder 114B3 Instrumentation Line 4 During Construction of Span 2

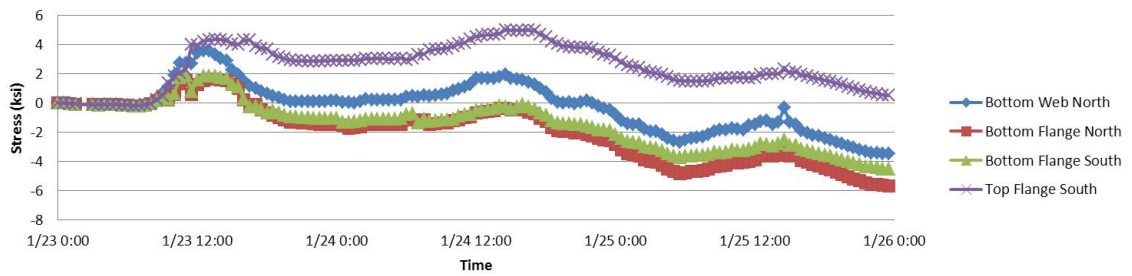


Figure 140: Stress in girder 114B3, instrumentation line 4 during construction of span 2

Temp. in Girder 114B3 Instrumentation Line 4 During Construction of Span 2

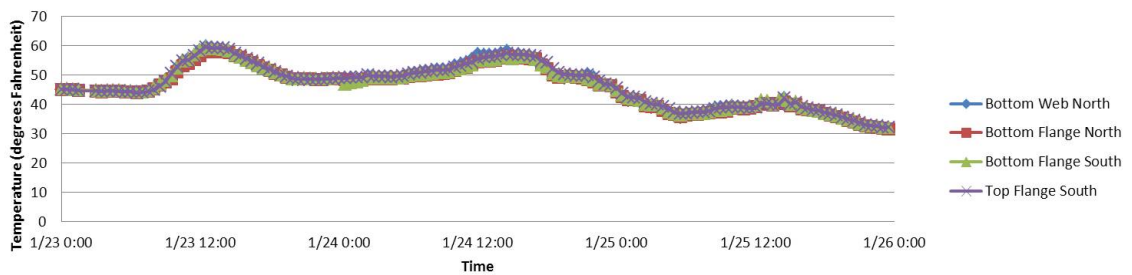


Figure 141: Temperature in girder 114B3, instrumentation line 4 during construction of span 2

Angle of Girder 114B3 Instrumentation Line 4 During Construction of Span 2

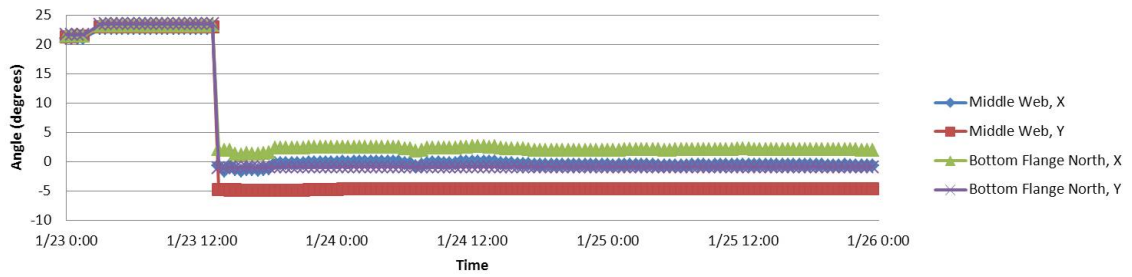


Figure 142: Rotation in girder 114B3, instrumentation line 4 during construction of span 2

Stress in Girder 116E4 Instrumentation Line 5 During Construction of Span 2

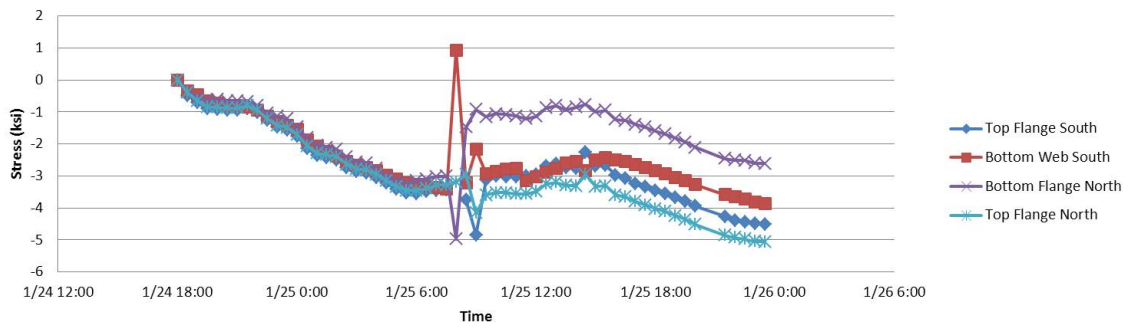


Figure 143: Stress in girder 116E4, instrumentation line 5 during construction of span 2

Temp. in Girder 116E4 Instrumentation Line 5 During Construction of Span 2

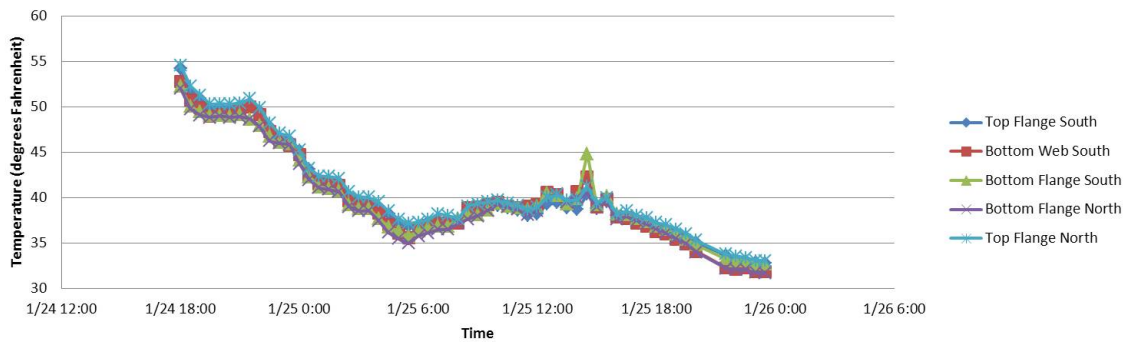


Figure 144: Temperature in girder 116E4, instrumentation line 5 during construction of span 2

Stress in Girder 116E4 Instrumentation Line 6 During Construction of Span 2

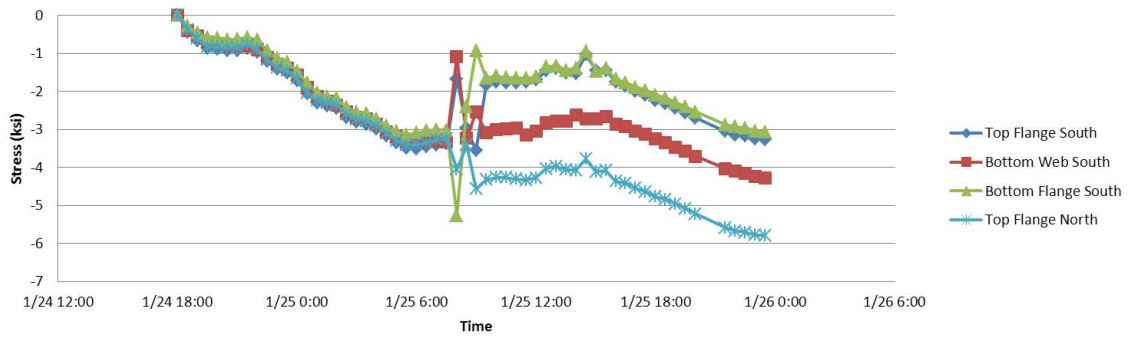


Figure 145: Stress in girder 116E4, instrumentation line 6 during construction of span 2

Temp. in Girder 116E4 Instrumentation Line 6 During Construction of Span 2

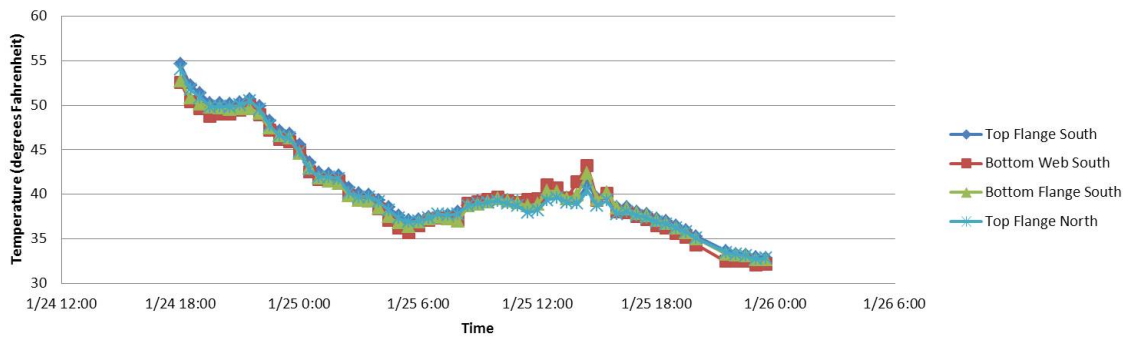


Figure 146: Temperature in girder 116E4, instrumentation line 6 during construction of span 2

Stress in Girder 119B4 Instrumentation Line 5 During Construction of Span 2

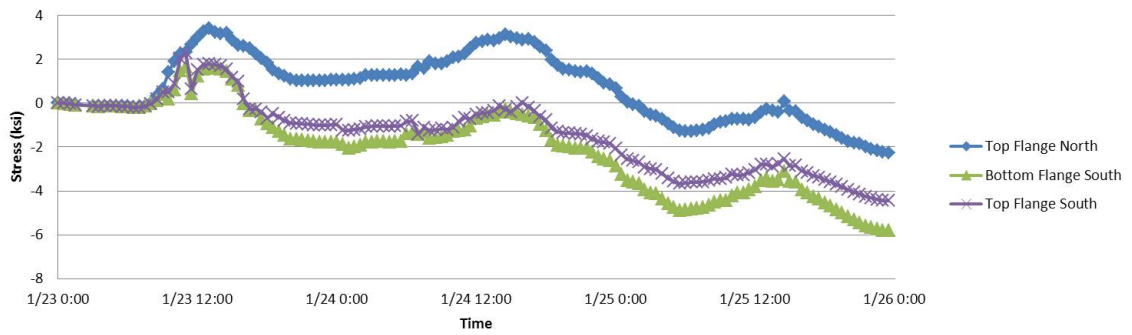


Figure 147: Stress in girder 119B4, instrumentation line 5 during construction of span 2

Temp. in Girder 119B4 Instrumentation Line 5 During Construction of Span 2

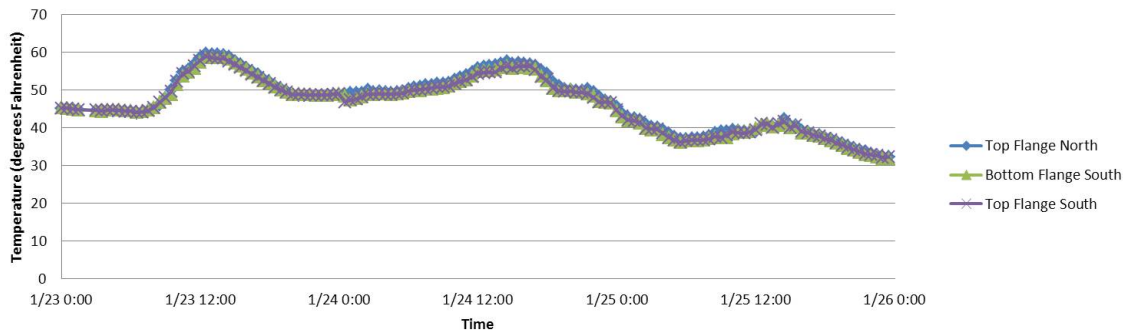


Figure 148: Temperature in girder 119B4, instrumentation line 5 during construction of span 2

Stress in Girder 119B4 Instrumentation Line 6 During Construction of Span 2

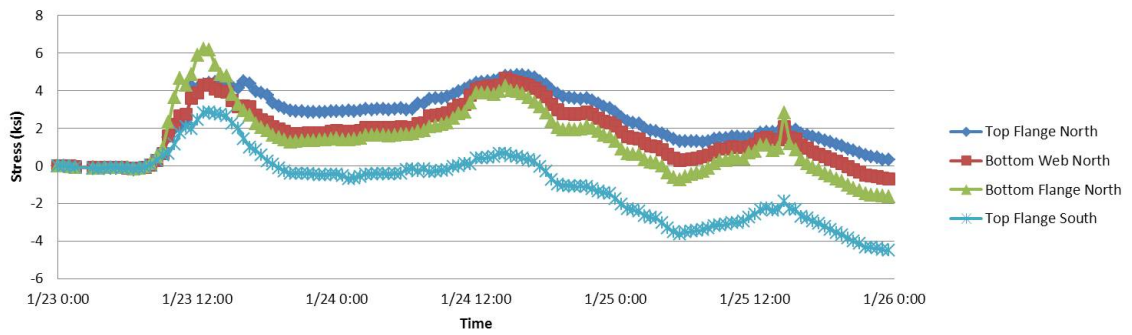


Figure 149: Stress in girder 119B4, instrumentation line 6 during construction of span 2

Temp. in Girder 119B4 Instrumentation Line 6 During Construction of Span 2

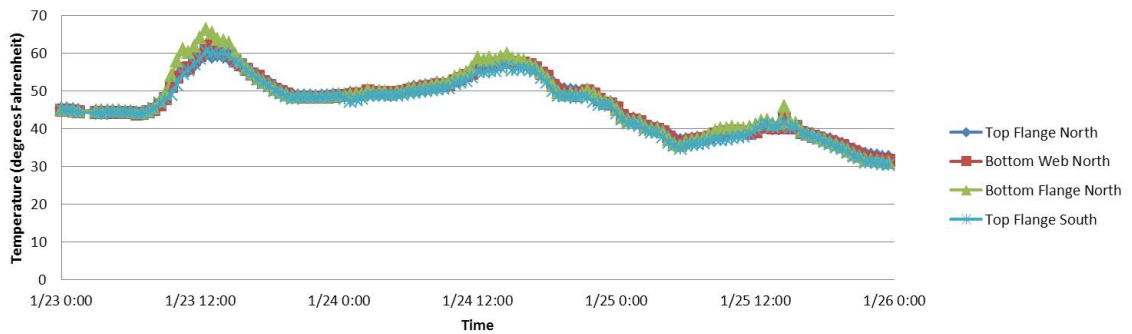


Figure 150: Temperature in girder 119B4, instrumentation line 6 during construction of span 2

Construction of Span 3

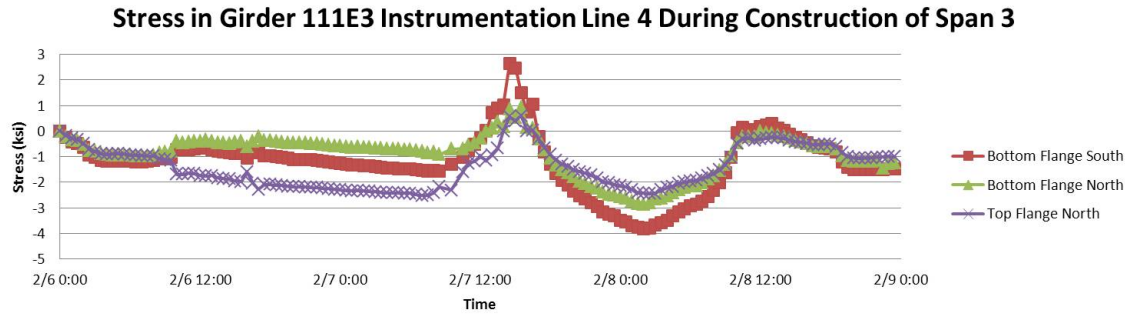


Figure 151: Stress in girder 111E3, instrumentation line 4 during construction of span 3

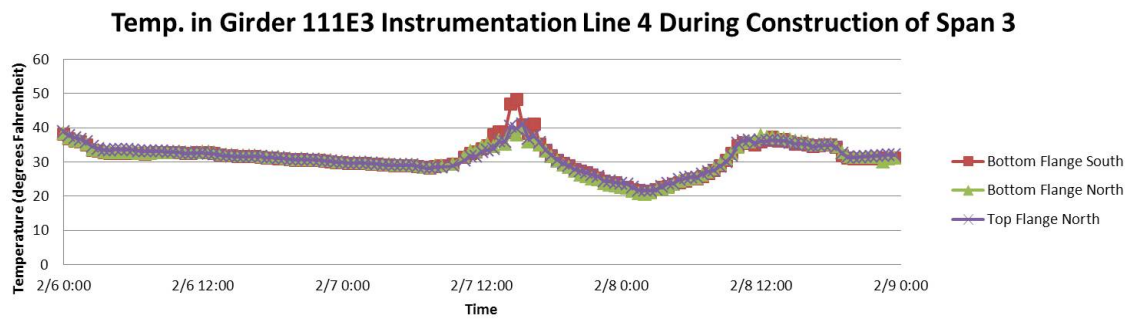


Figure 152: Temperature in girder 111E3, instrumentation line 4 during construction of span 3

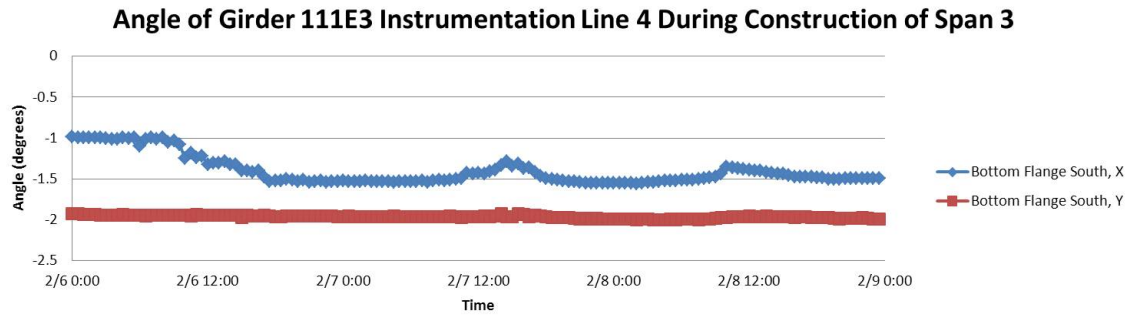


Figure 153: Rotation in girder 111E3, instrumentation line 4 during construction of span 3

Stress in Girder 116E4 Instrumentation Line 5 During Construction of Span 3

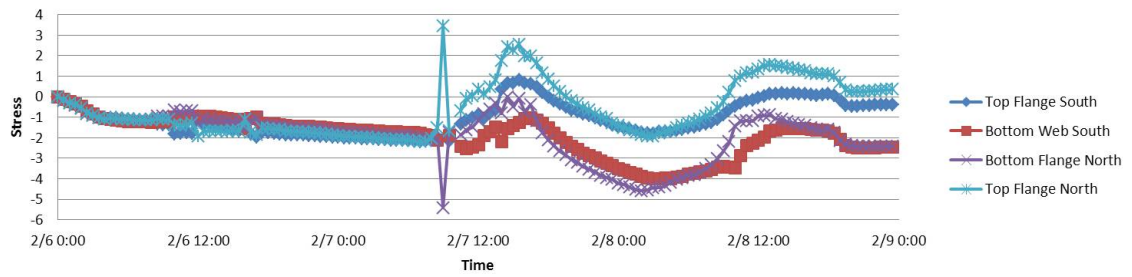


Figure 154: Stress in girder 116E4, instrumentation line 5 during construction of span 3

Temp. in Girder 116E4 Instrumentation Line 5 During Construction of Span 3

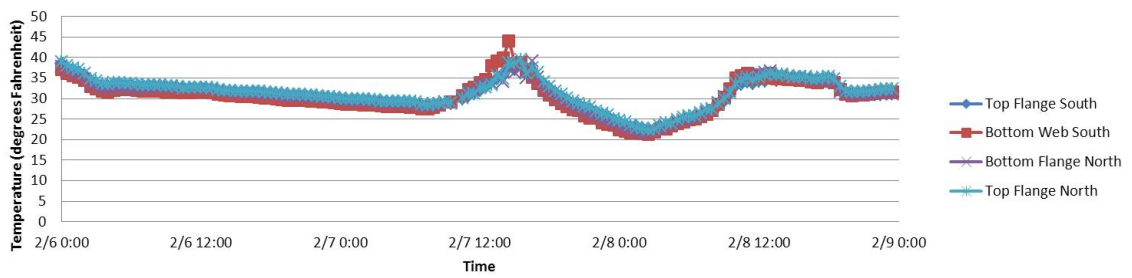


Figure 155: Temperature in girder 116E4, instrumentation line 5 during construction of span 3

Stress in Girder 116E4 Instrumentation Line 6 During Construction of Span 3

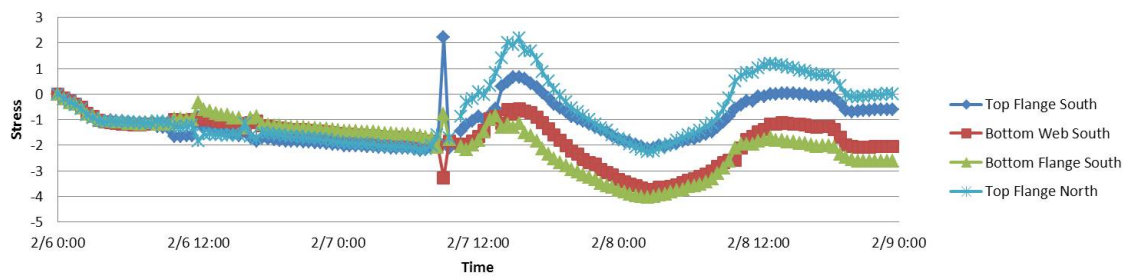


Figure 156: Stress in girder 116E4, instrumentation line 6 during construction of span 3

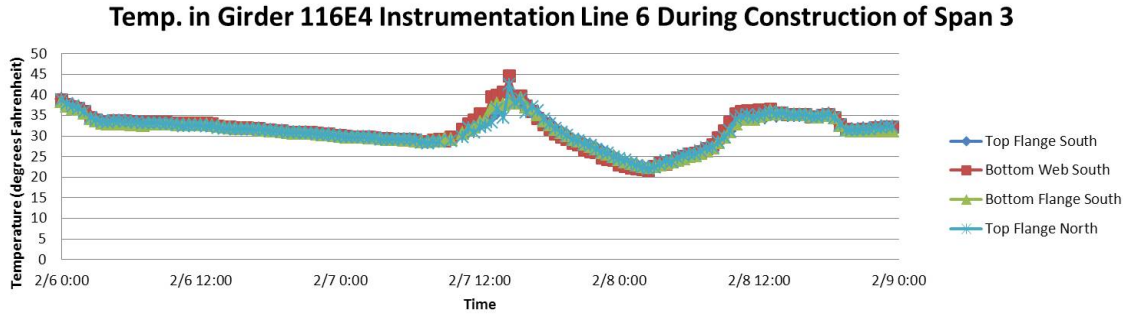


Figure 157: Temperature in girder 116E4, instrumentation line 6 during construction of span 3
Construction of Span 5

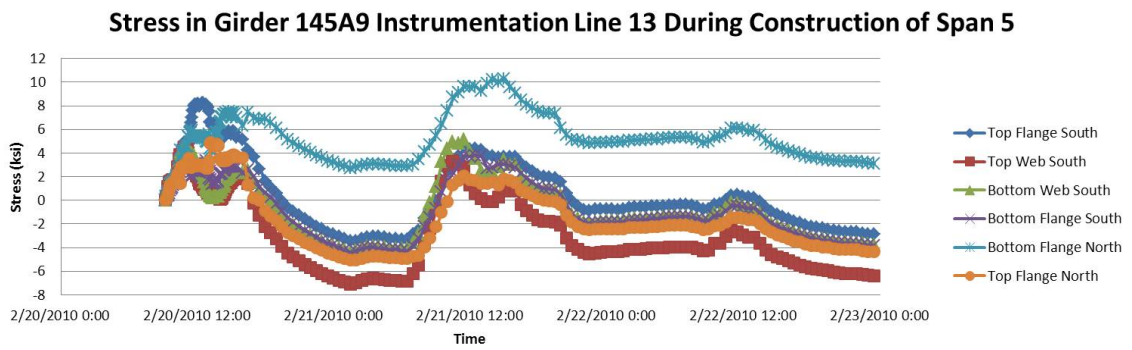


Figure 158: Stress in girder 145A9, instrumentation line 13 during construction of span 5

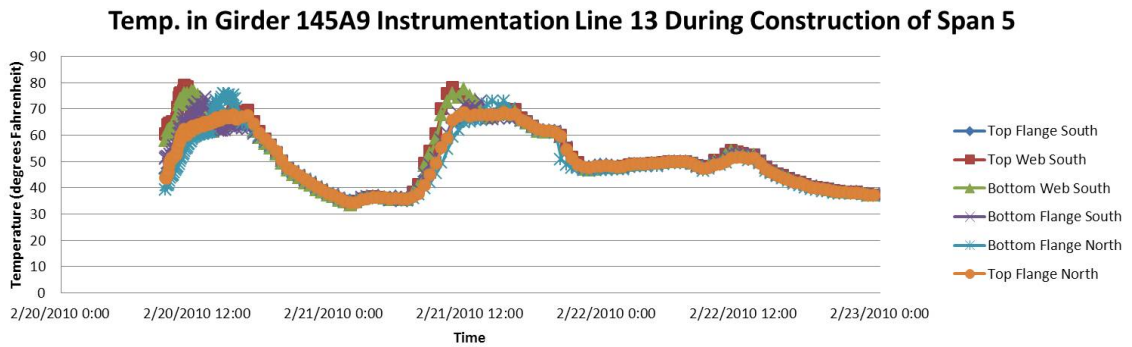


Figure 159: Temperature in girder 145A9, instrumentation line 13 during construction of span 5

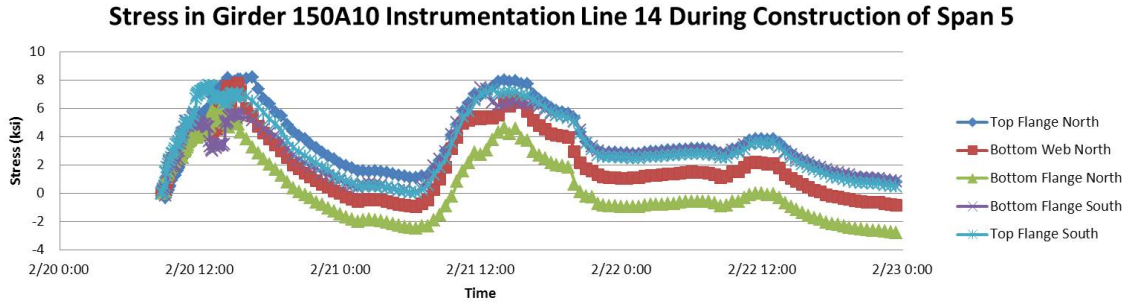


Figure 160: Stress in girder 150A10, instrumentation line 14 during construction of span 5

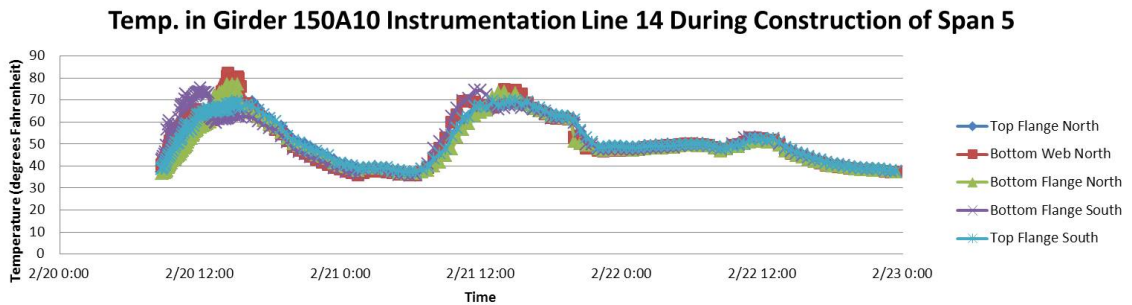


Figure 161: Temperature in girder 150A10, instrumentation line 14 during construction of span 5

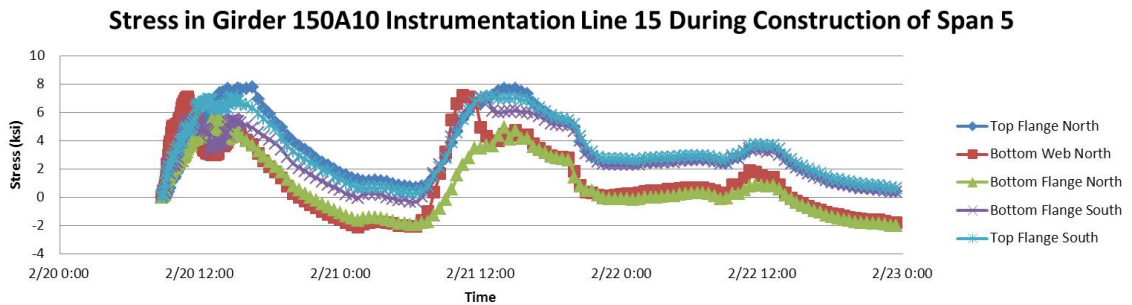


Figure 162: Stress in girder 150A10, instrumentation line 15 during construction of span 5

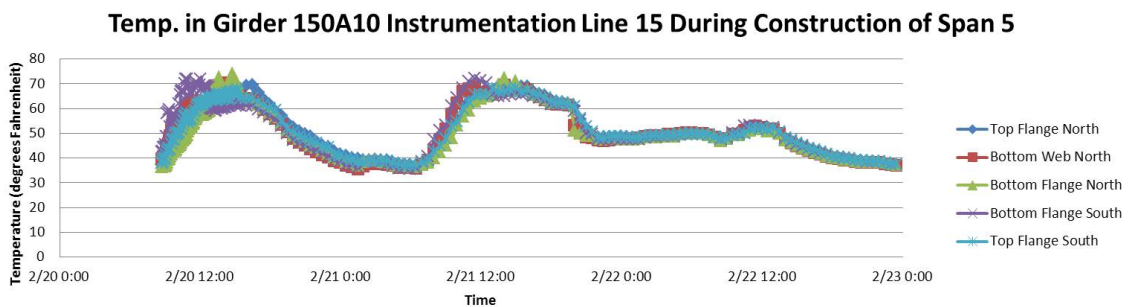


Figure 163: Temperature in girder 150A10, instrumentation line 15 during construction of span 5

Construction of Span 6

Stress in Girder 145A9 Instrumentation Line 13 During Construction of Span 6

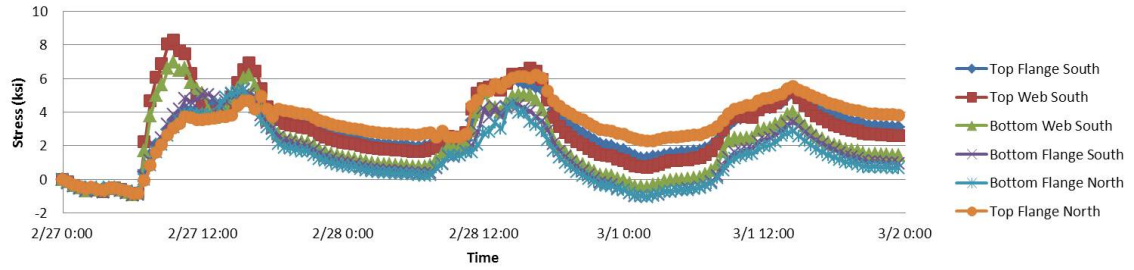


Figure 164: Stress in girder 145A9, instrumentation line 13 during construction of span 6

Temp. in Girder 145A9 Instrumentation Line 13 During Construction of Span 6

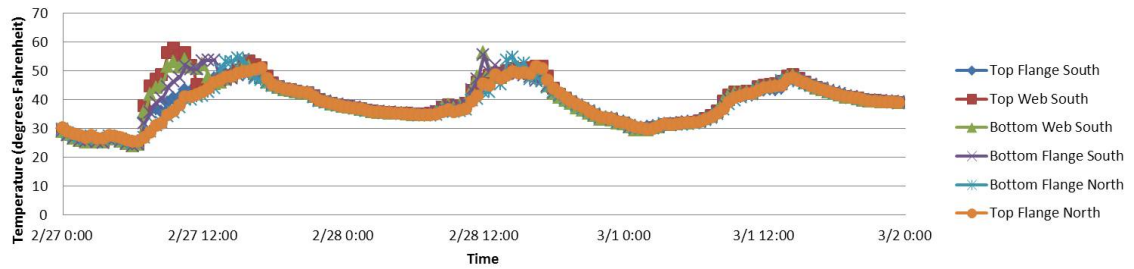


Figure 165: Temperature in girder 145A9, instrumentation line 13 during construction of span 6

Stress in Girder 150A10 Instrumentation Line 14 During Construction of Span 6

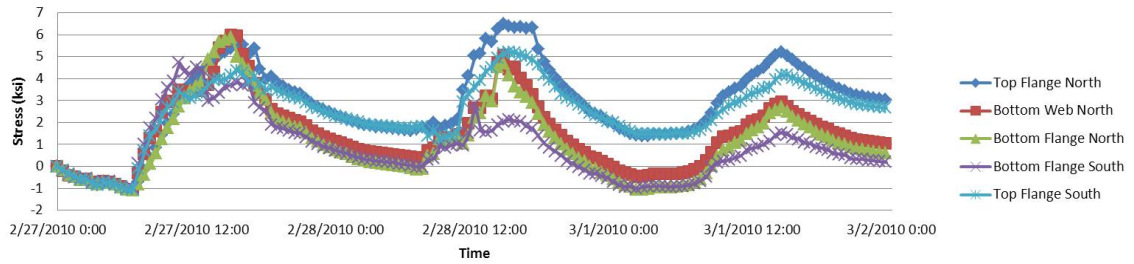


Figure 166: Stress in girder 150A10, instrumentation line 14 during construction of span 6

Temp. in Girder 150A10 Instrumentation Line 14 During Construction of Span 6

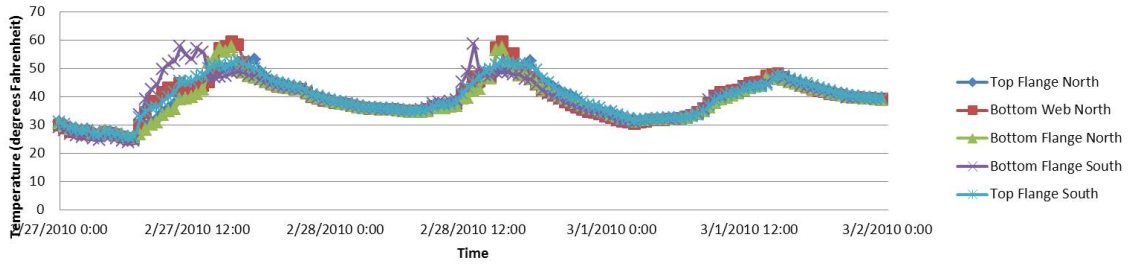


Figure 167: Temperature in girder 150A10, instrumentation line 14 during construction of span 6

Stress in Girder 150A10 Instrumentation Line 15 During Construction of Span 6

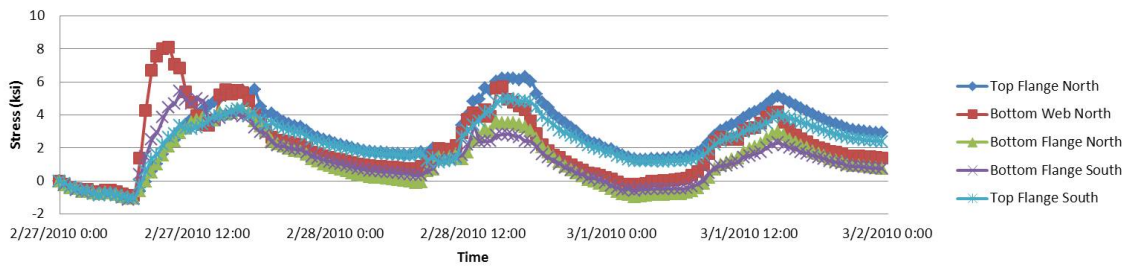


Figure 168: Stress in girder 150A10, instrumentation line 15 during construction of span 6

Temp. in Girder 150A10 Instrumentation Line 15 During Construction of Span 6

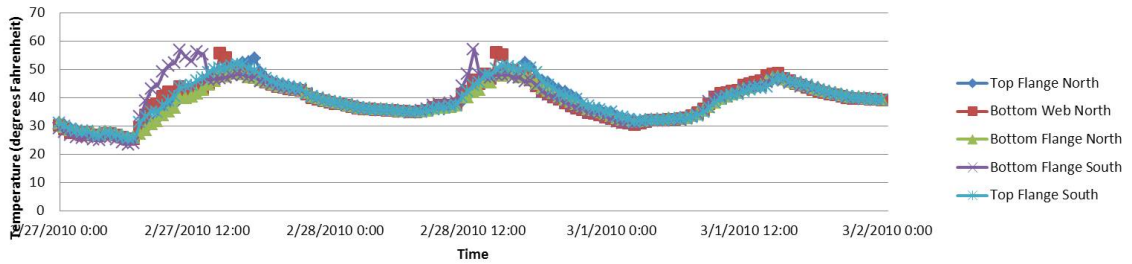


Figure 169: Temperature in girder 150A10, instrumentation line 15 during construction of span 6

Construction of Span 7

Stress in Girder 165A13 Instrumentation Line 19 During Construction of Span 7

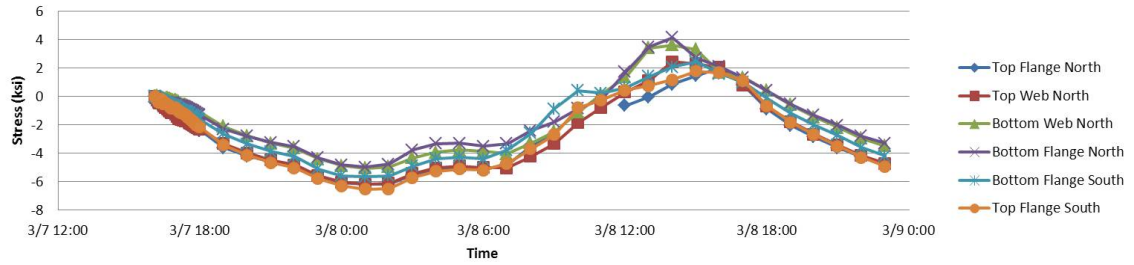


Figure 170: Stress in girder 165A13, instrumentation line 19 during construction of span 7

Temp. in Girder 165A13 Instrumentation Line 19 During Construction of Span 7

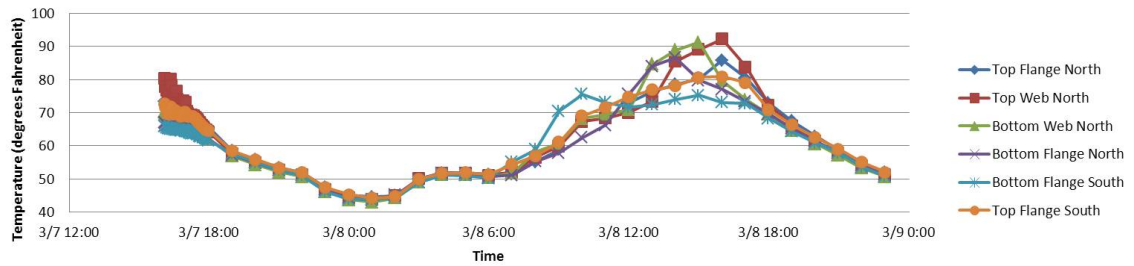


Figure 171: Temperature in girder 165A13, instrumentation line 19 during construction of span 7

Construction of Span 8

Stress in Girder 155A11 Instrumentation Line 16 During Construction of Span 8

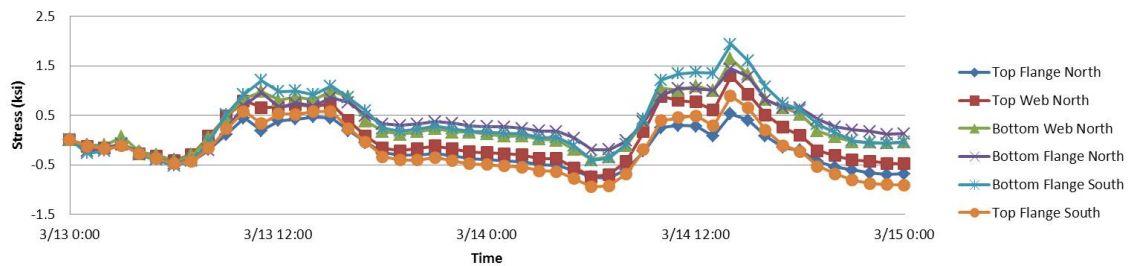


Figure 172: Stress in girder 155A11, instrumentation line 16 during construction of span 8

Temp. in Girder 155A11 Instrumentation Line 16 During Construction of Span 8

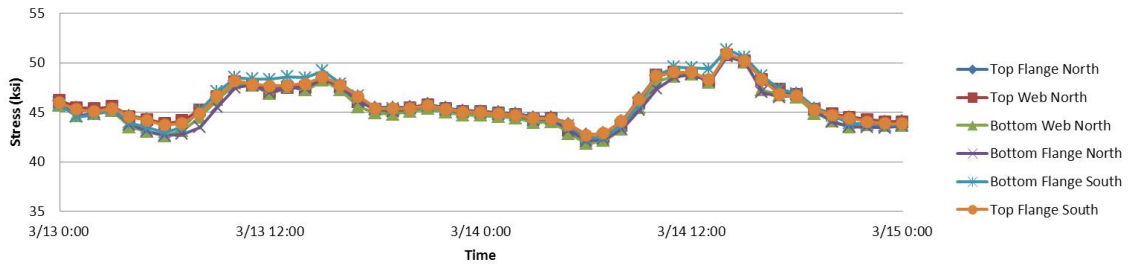


Figure 173: Temperature in girder 155A11, instrumentation line 16 during construction of span 8

Stress in Girder 160A12 Instrumentation Line 17 During Construction of Span 8

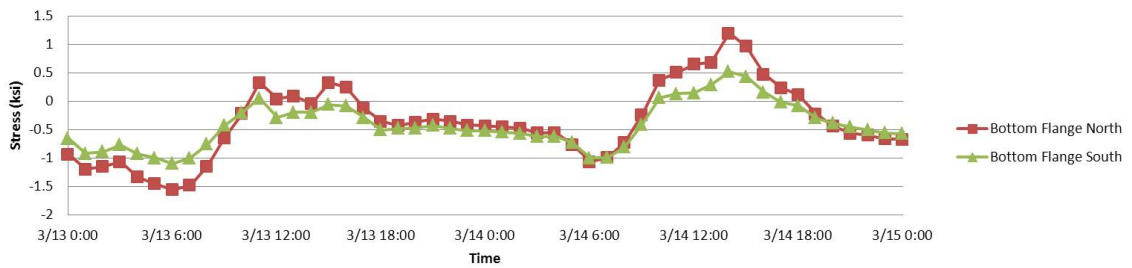


Figure 174: Stress in girder 160A12, instrumentation line 17 during construction of span 8

Temp. in Girder 160A12 Instrumentation Line 17 During Construction of Span 8

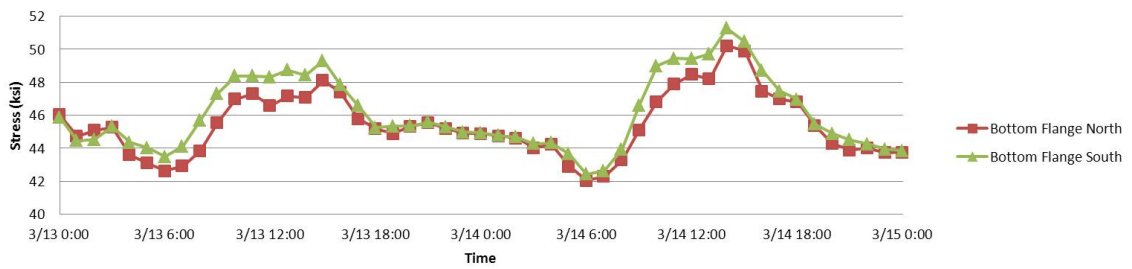


Figure 175: Temperature in girder 160A12, instrumentation line 17 during construction of span 8

Stress in Girder 160A12 Instrumentation Line 18 During Construction of Span 8

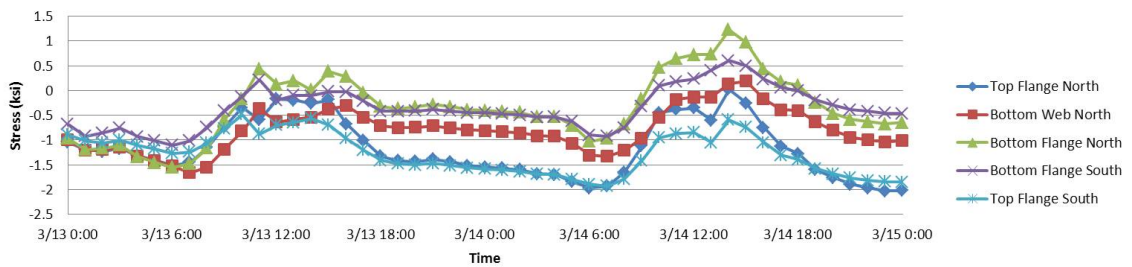


Figure 176: Stress in girder 160A12, instrumentation line 18 during construction of span 8

Temp. in Girder 160A12 Instrumentation Line 18 During Construction of Span 8

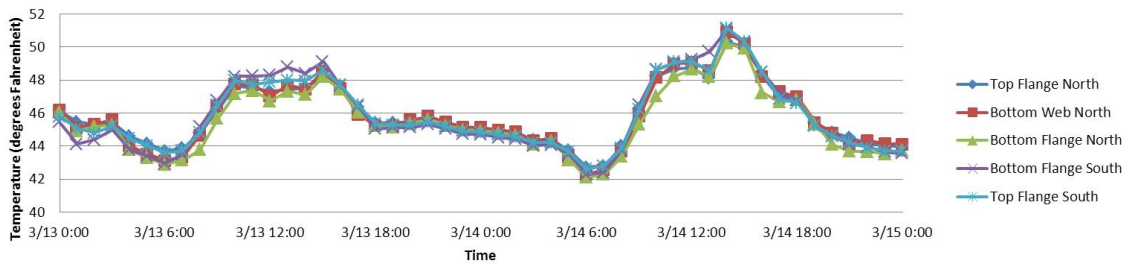


Figure 177: Temperature in girder 160A12, instrumentation line 18 during construction of span 8

Stress in Girder 170A14 Instrumentation Line 20 During Construction of Span 8

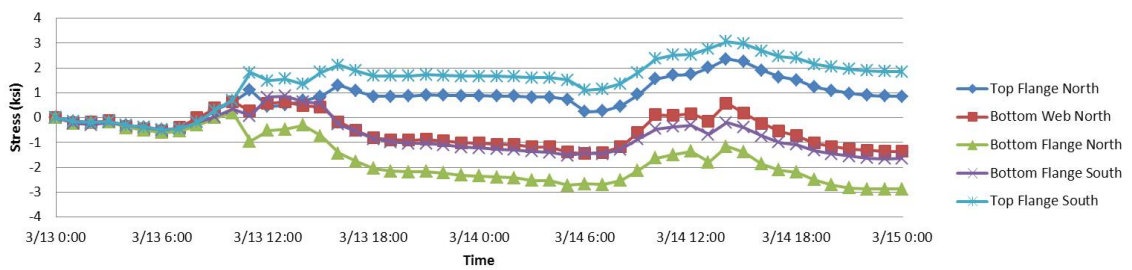


Figure 178: Stress in girder 170A14, instrumentation line 20 during construction of span 8

Temp. in Girder 170A14 Instrumentation Line 20 During Construction of Span 8

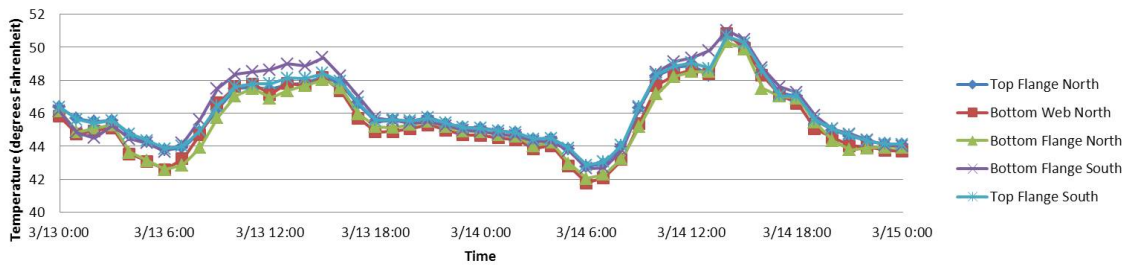


Figure 179: Temperature in girder 170A14, instrumentation line 20 during construction of span 8

Stress in Girder 170A14 Instrumentation Line 21 During Construction of Span 8

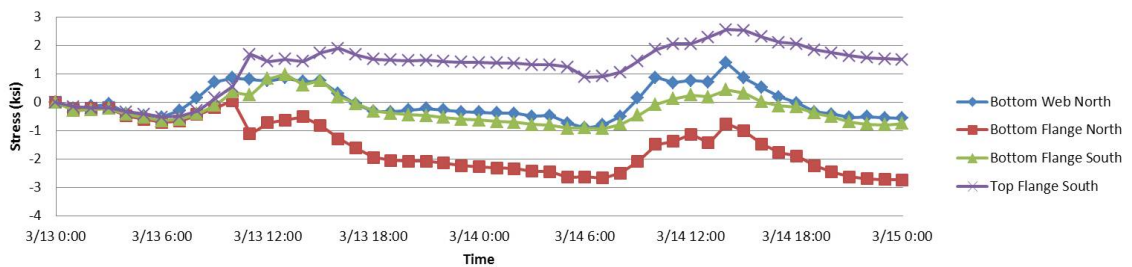


Figure 180: Stress in girder 170A14, instrumentation line 21 during construction of span 8

Temp. in Girder 170A14 Instrumentation Line 21 During Construction of Span 8

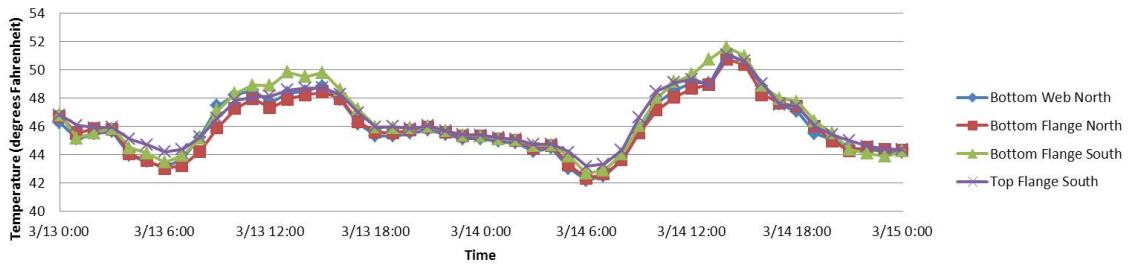


Figure 181: Temperature in girder 170A14, instrumentation line 21 during construction of span 8

Stress in Girder 170A14 Instrumentation Line 22 During Construction of Span 8

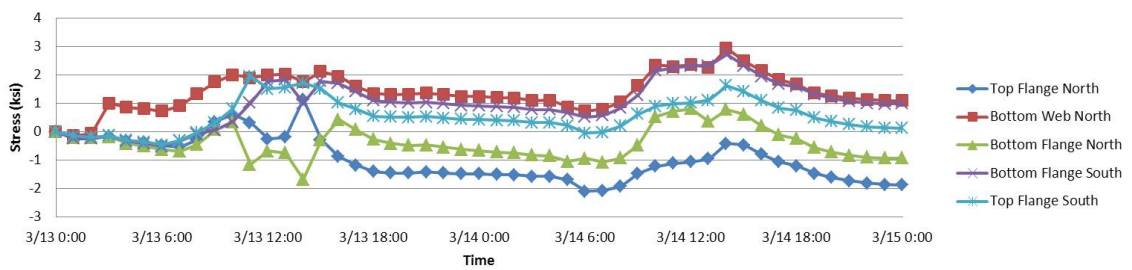


Figure 182: Stress in girder 170A14, instrumentation line 22 during construction of span 8

Temp. in Girder 170A14 Instrumentation Line 22 During Construction of Span 8

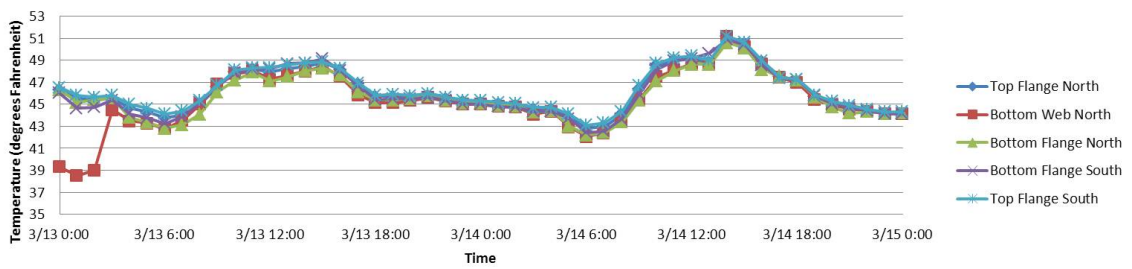


Figure 183: Temperature in girder 170A14, instrumentation line 22 during construction of span 8

Stress in Girder 175A15 Instrumentation Line 24 During Construction of Span 8

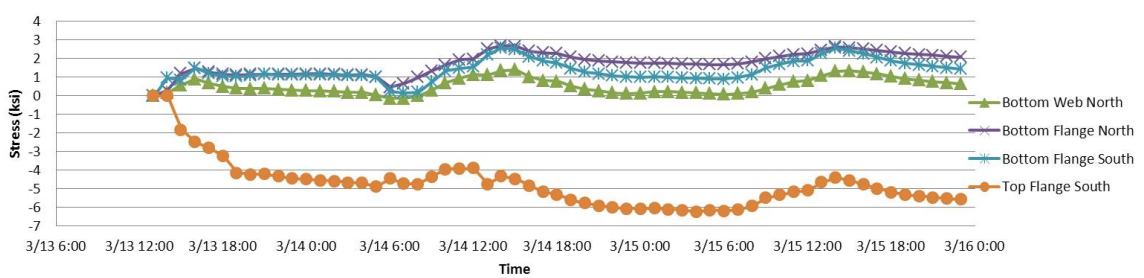


Figure 184: Stress in girder 175A15, instrumentation line 24 during construction of span 8

Temp. in Girder 175A15 Instrumentation Line 24 During Construction of Span 8

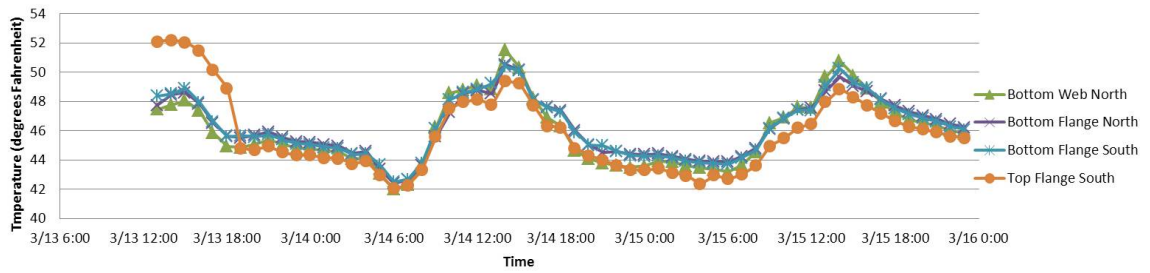


Figure 185: Temperature in girder 175A15, instrumentation line 24 during construction of span 8

Angle of Girder 175A15, Instrumentation Line 24 During Construction of Span 8

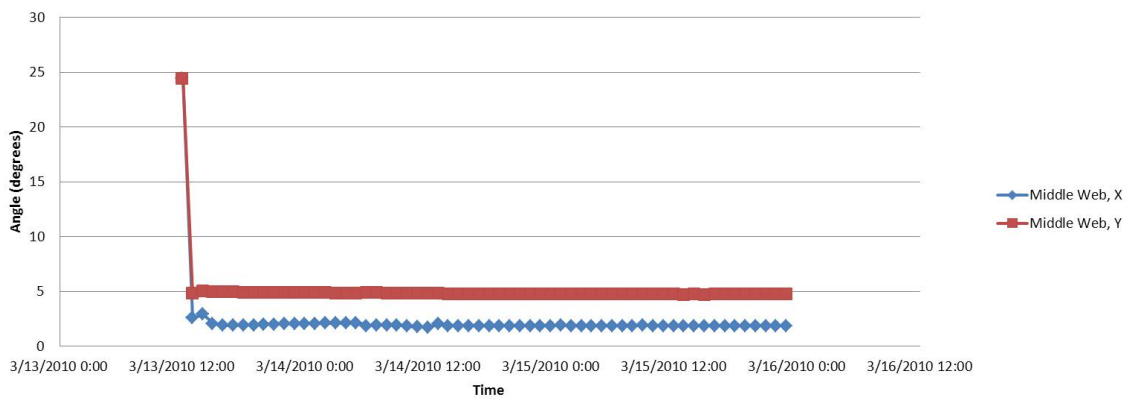


Figure 186: Rotation in girder 175A15, instrumentation line 24 during construction of span 8

APPENDIX C: CONCRETE PLACEMENT DATA

Appendix C contains data collected in the field during the concrete placement stages. This includes stress, rotation, and displacement data.

Concrete Placement Stage 1

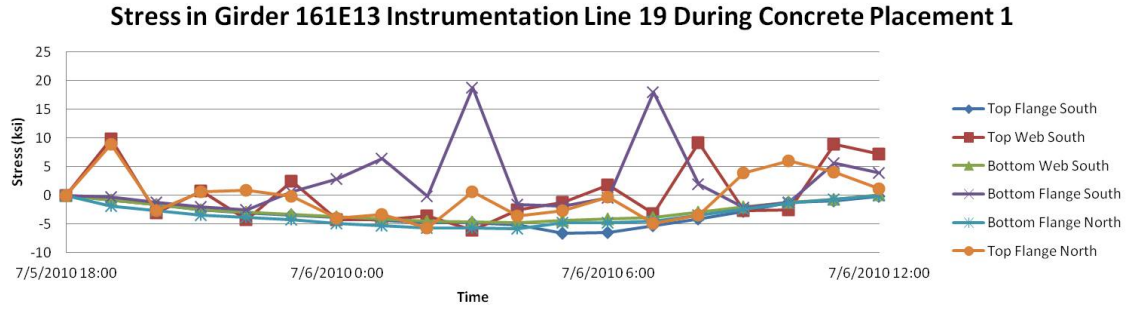


Figure 187: Stress in girder 161E13, instrumentation line 19 during concrete placement 1

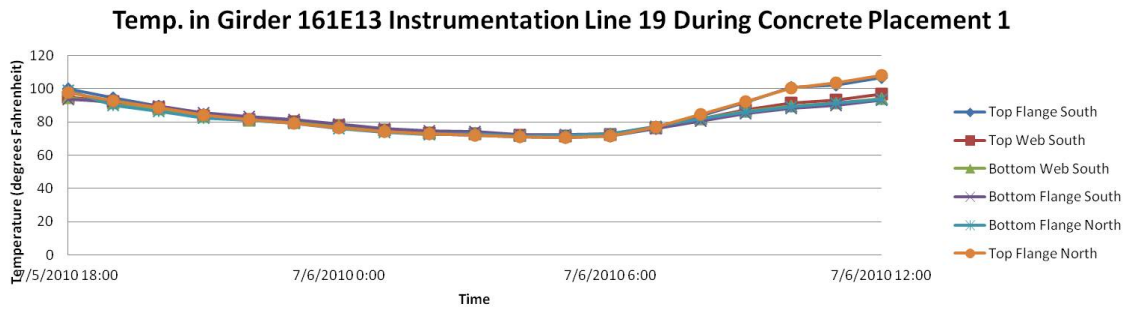


Figure 188: Temperature in girder 161E13, instrumentation line 19 during concrete placement 1

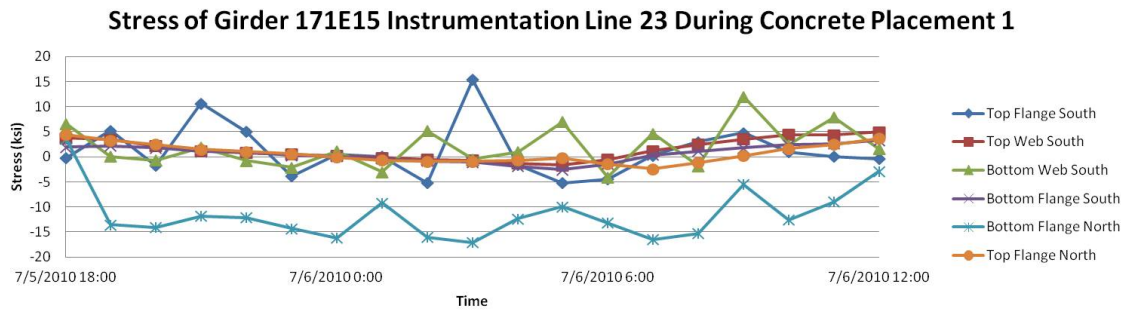


Figure 189: Stress in girder 171E15, instrumentation line 2319 during concrete placement 1

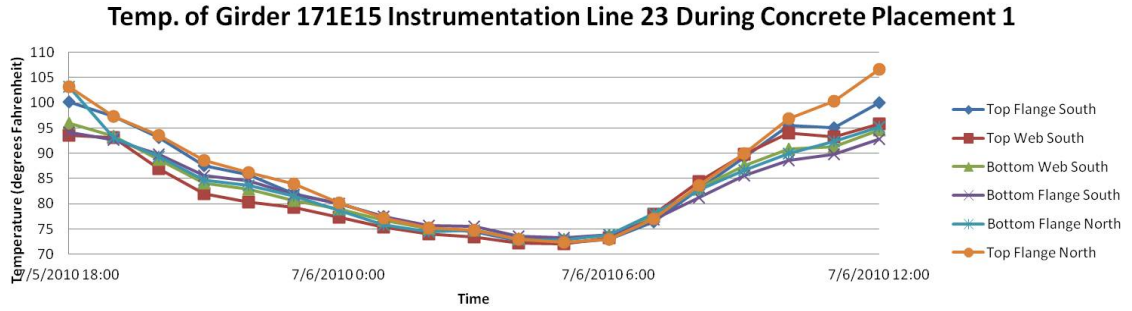


Figure 190: Temperature in girder 171E15, instrumentation line 23 during concrete placement 1

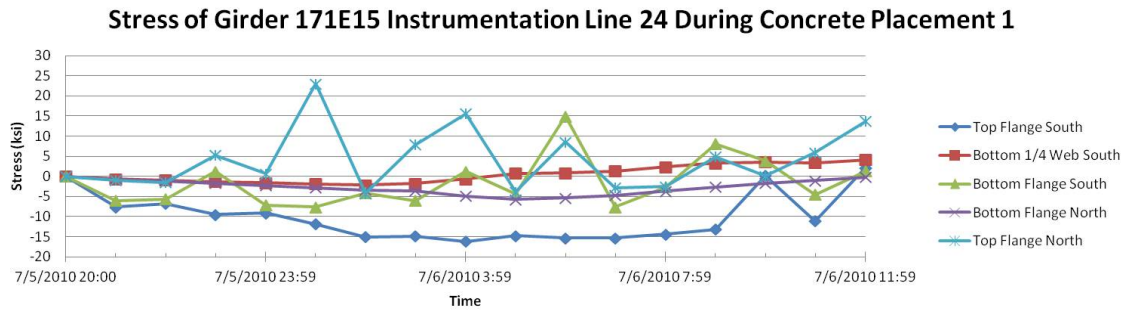


Figure 191: Stress in girder 171E15, instrumentation line 24 during concrete placement 1

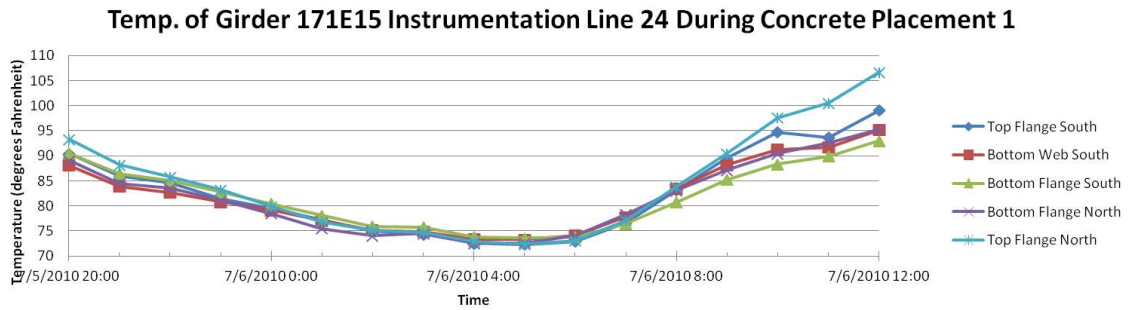


Figure 192: Temperature in girder 171E15, instrumentation line 24 during concrete placement 1

Vert. Displacement of Girders 171E15-175A15 at Connection to 166E14-170A14 During Concrete Placement 1

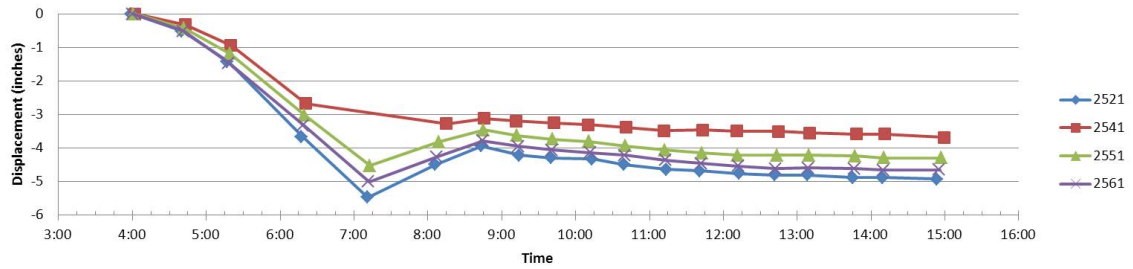


Figure 193: Displacement in girders 171E15-175A15 near connection to 166E14-170A14 during concrete placement 1

Vert. Displacement of Girders 171E15-175A15 at Mid Span During Concrete Placement 1

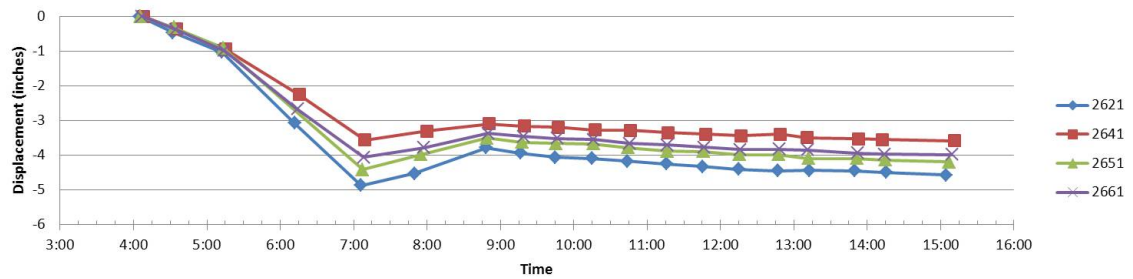


Figure 194: Displacement in girders 171E15-175A15 at mid span during concrete placement 1

Vertical Displacement of Inside Girder During Concrete Placement 1

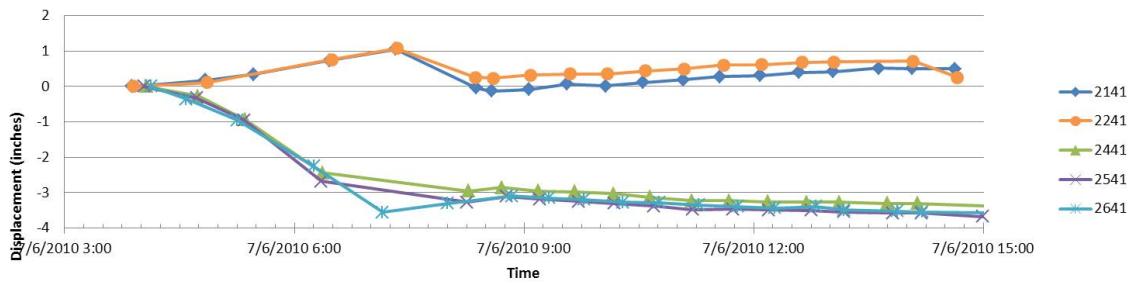


Figure 195: Displacement of inside girder during concrete placement 1

Concrete Placement Stage 2

Temp. in Girder 104B1 Instrumentation Line 1 During Concrete Placement 2

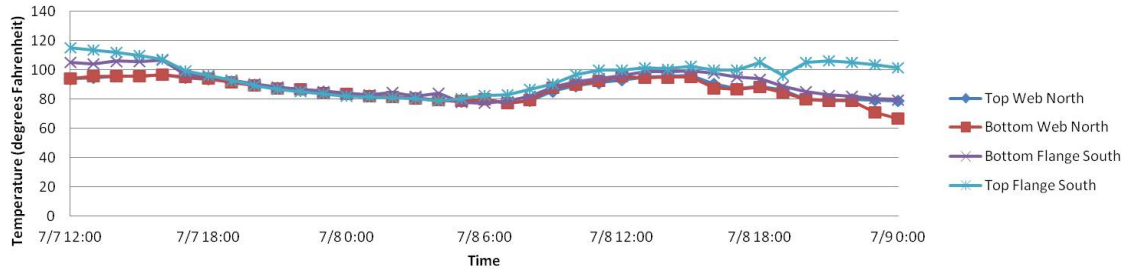


Figure 196: Temperature in girder 104B1, instrumentation line 1 during concrete placement 2

Stress in Girder 101E1 Instrumentation Line 1 During Concrete Placement 2

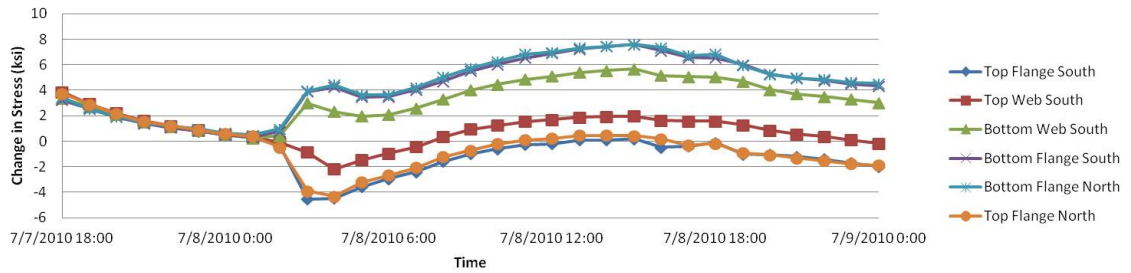


Figure 197: Stress in girder 101E1, instrumentation line 1 during concrete placement 2

Temp. in Girder 101E1 Instrumentation Line 1 During Concrete Placement 2

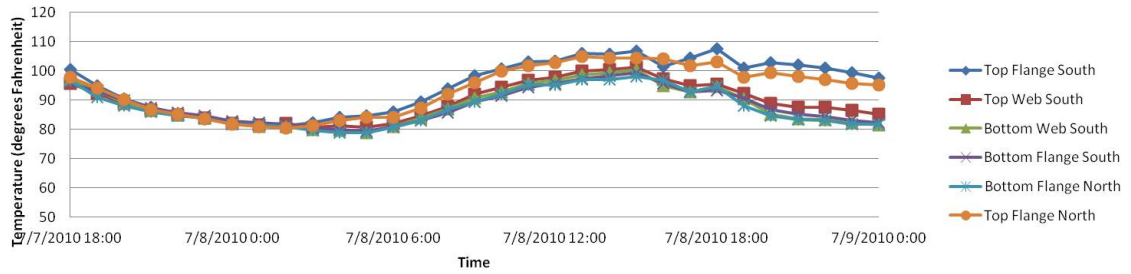


Figure 198: Temperature in girder 101E1, instrumentation line 1 during concrete placement 2

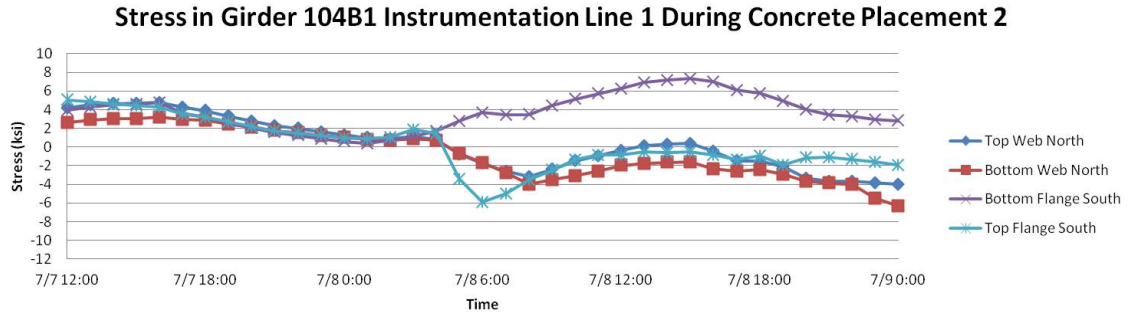


Figure 199: Stress in girder 104B1, instrumentation line 1 during concrete placement 2

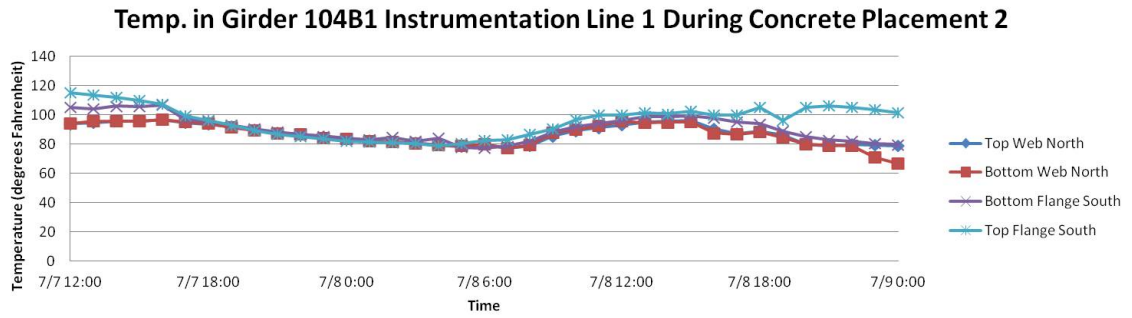


Figure 200: Temperature in girder 104B1, instrumentation line 1 during concrete placement 2

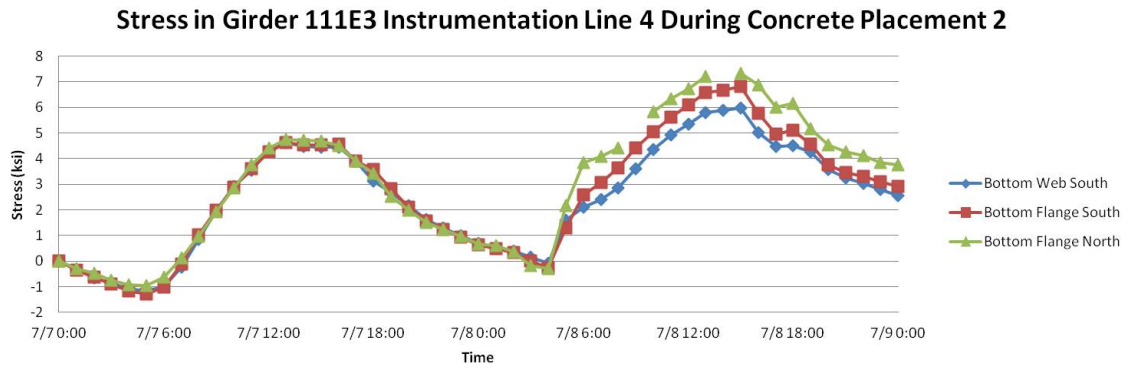


Figure 201: Stress in girder 111E3, instrumentation line 4 during concrete placement 2

Temp. in Girder 111E3 Instrumentation Line 4 During Concrete Placement 2

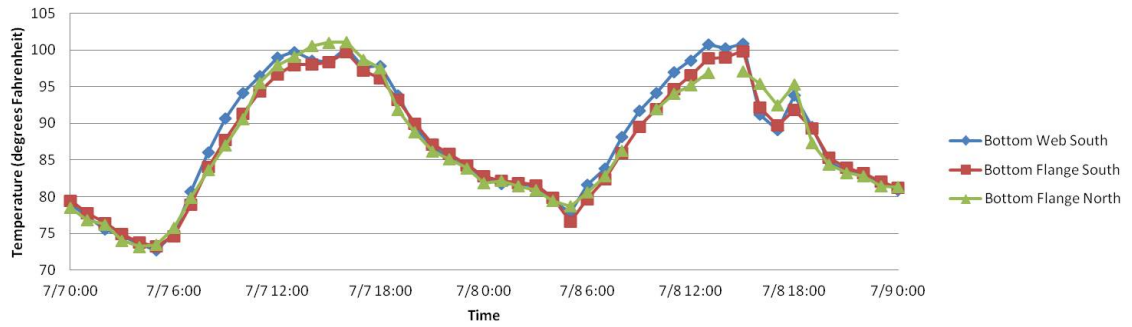


Figure 202: Temperature in girder 111E13, instrumentation line 4 during concrete placement 2

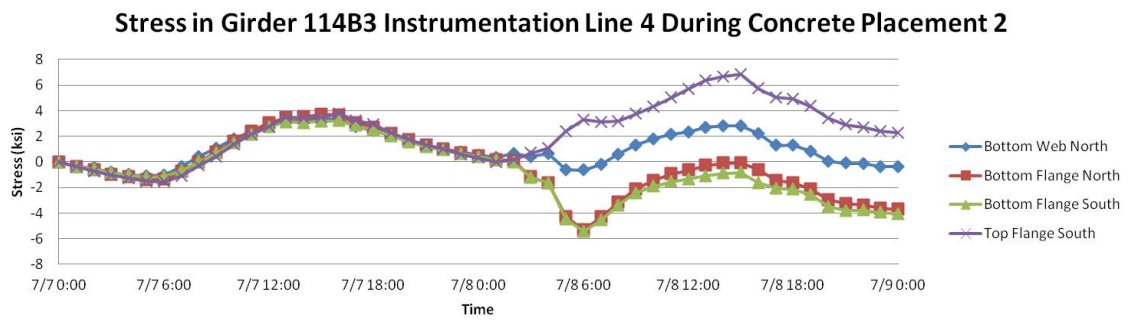


Figure 203: Stress in girder 114B3, instrumentation line 4 during concrete placement 2

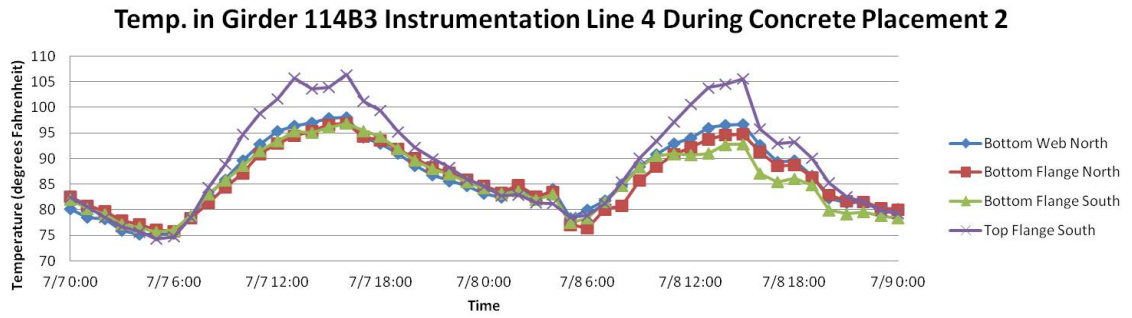


Figure 204: Temperature in girder 114B3, instrumentation line 4 during concrete placement 2

Concrete Placement Stage 3

Stress in Girder 167D14 Instrumentation Line 22 During Concrete Placement 3

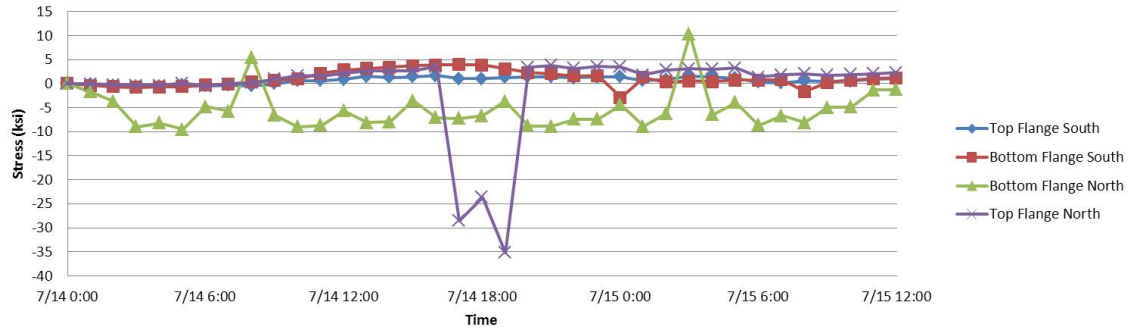


Figure 205: Stress in girder 167D14, instrumentation line 22 during concrete placement 3

Temp. in Girder 167D14 Instrumentation Line 22 During Concrete Placement 3

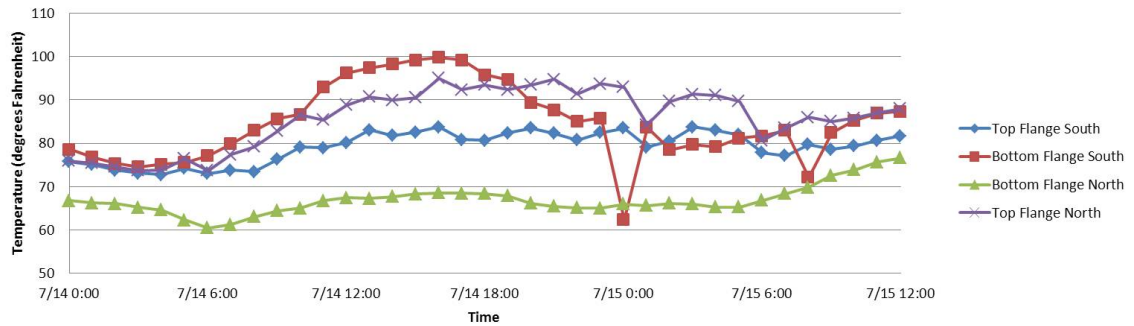


Figure 206: Temperature in girder 167D14, instrumentation line 22 during concrete placement 3

Stress in Girder 170A14 Instrumentation Line 22 During Concrete Placement 3

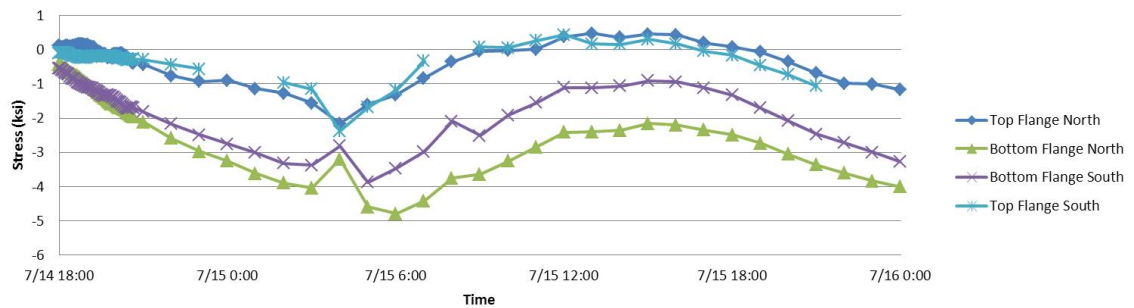


Figure 207: Stress in girder 170A14, instrumentation line 22 during concrete placement 3

Temp. in Girder 170A14 Instrumentation Line 22 During Concrete Placement 3

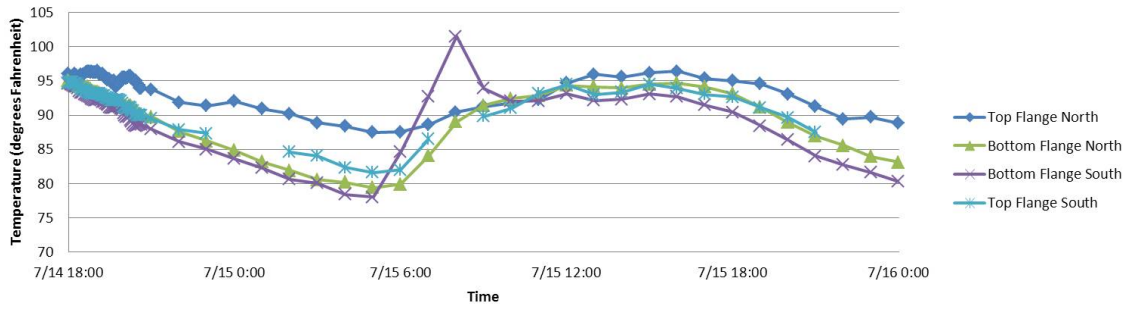


Figure 208: Temperature in girder 170A14, instrumentation line 22 during concrete placement 3

Vert. Displacement of Girders 171E15-175A15 at Connection to 166E14-170A14 During Concrete Placement 3

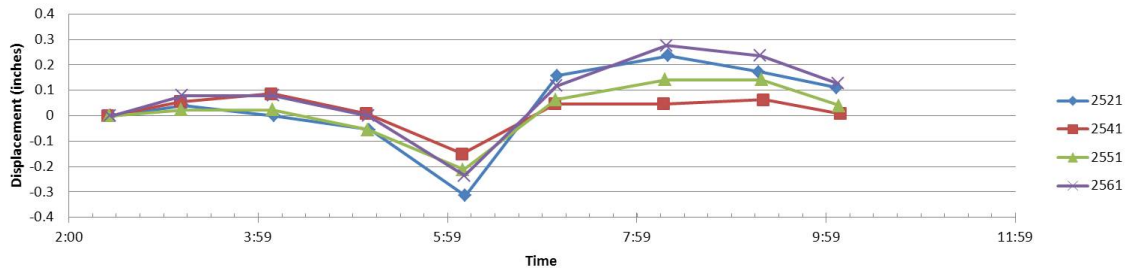


Figure 209: Displacement in girders 171E15-175A15 at connection to girders 166E14-170A14 during concrete placement 3

Vert. Displacement of Girders 171E15-175A15 at Mid Span During Concrete Placement 3

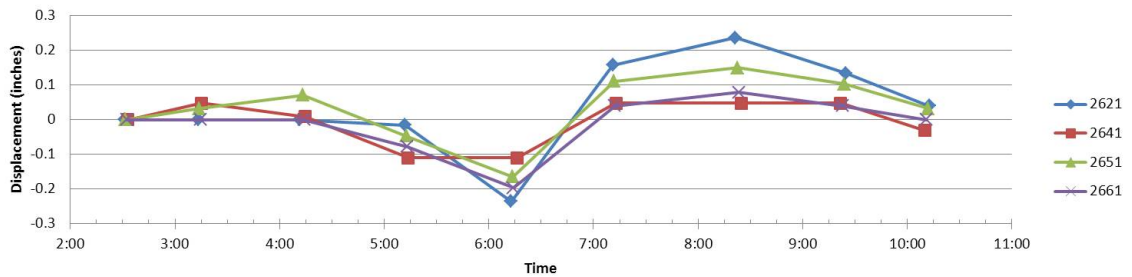


Figure 210: Displacement in girders 171E15-175A15 at mid span during concrete placement 3

APPENDIX D: LIVE LOAD DATA

Appendix D contains data collected in the field during the live load test. This includes stress, rotation, and displacement data. Table 1 lists the start time of each load case in chronological order.

Table 1: Start times of live load cases

Time	Loading
7:33	B4
7:51	C4
8:03	D4
8:12	B5
8:45	C5
8:57	D5
9:12	B6
9:33	C6
9:45	D6
10:00	B7
10:21	C7
10:45	D7
12:45	B8
13:21	C8
14:09	B1
14:21	B2
14:30	B3
14:45	C1
14:54	C2

Stress During Live Load Test

Stress in Girder 101E1, Instrumentation Line 1 During Live Load Test

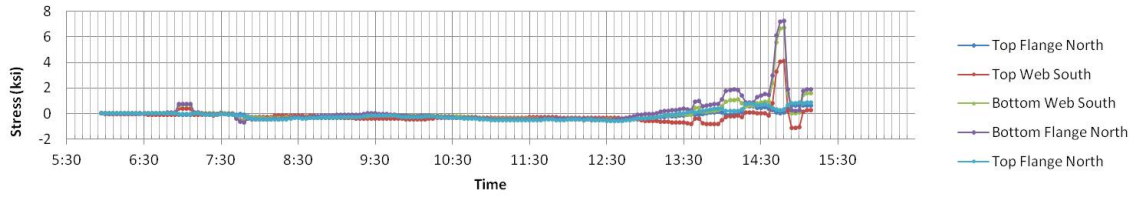


Figure 211: Stress in girder 101E1, instrumentation line 1 during live load test

Stress in Girder 104B1, Instrumentation Line 1 During Live Load Test

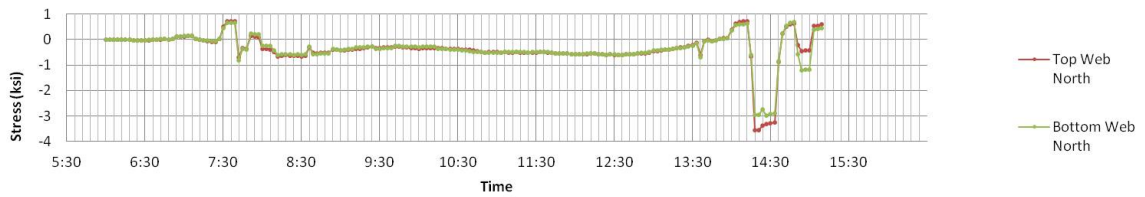


Figure 212: Stress in girder 104B1, instrumentation line 1 during live load test

Stress in Girder 106E2, Instrumentation Line 2 During Live Load Test

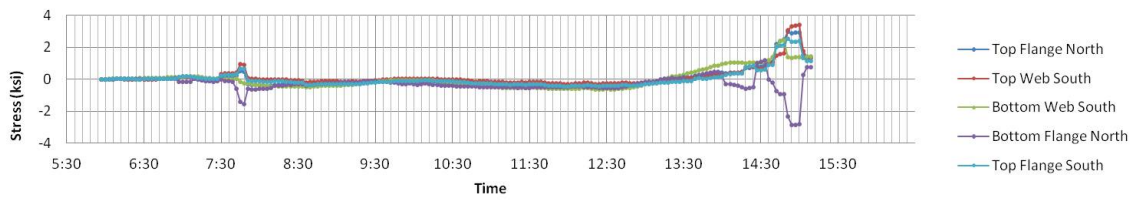


Figure 213: Stress in girder 106E2, instrumentation line 2 during live load test

Stress in Girder 109B2, Instrumentation Line 3 During Live Load Test

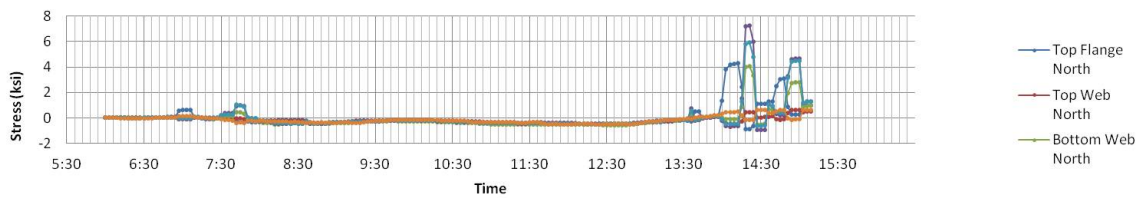


Figure 214: Stress in girder 109B2, instrumentation line 3 during live load test

Stress in Girder 111E3, Instrumentation Line 4 During Live Load Test

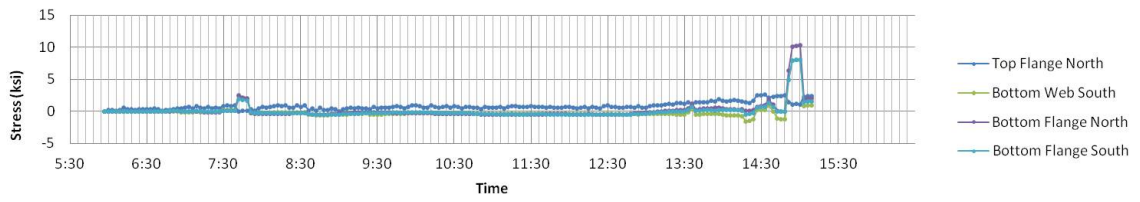


Figure 215: Stress in girder 111E3, instrumentation line 4 during live load test

Stress in Girder 114B3, Instrumentation Line 4 During Live Load Test

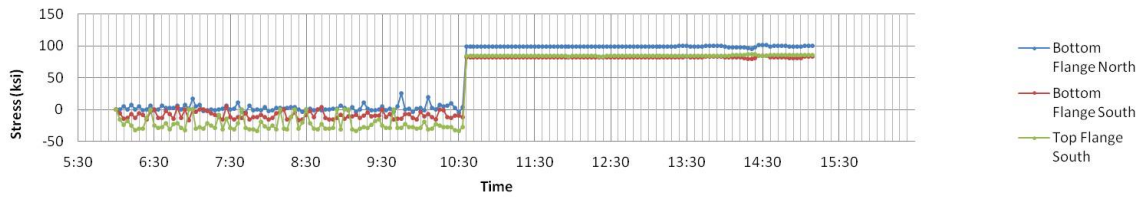


Figure 216: Stress in girder 114B3, instrumentation line 4 during live load test

Stress in Girder 116E4, Instrumentation Line 6 During Live Load Test

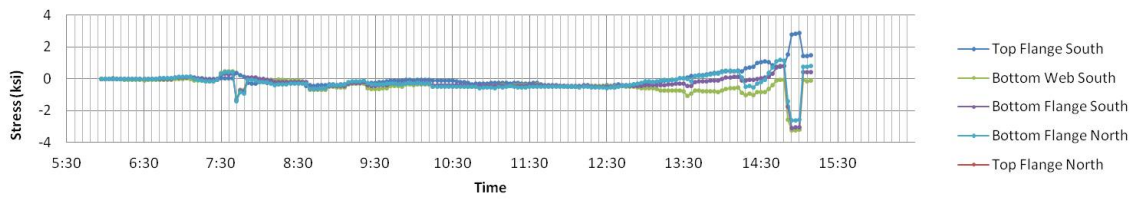


Figure 217: Stress in girder 116E4, instrumentation line 6 during live load test

Stress in Girder 119B4, Instrumentation Line 5 During Live Load Test

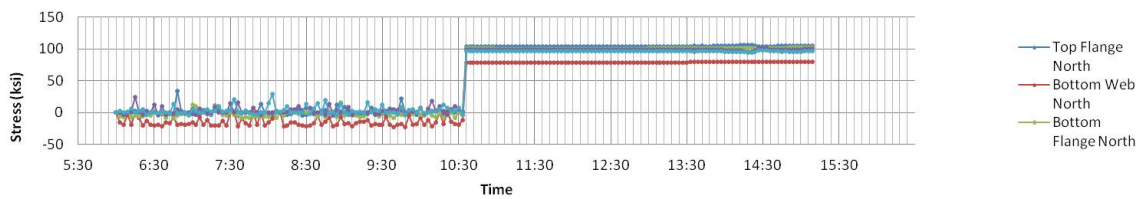


Figure 218: Stress in girder 119B4, instrumentation line 5 during live load test

Stress in Girder 119B4, Instrumentation Line 6 During Live Load Test

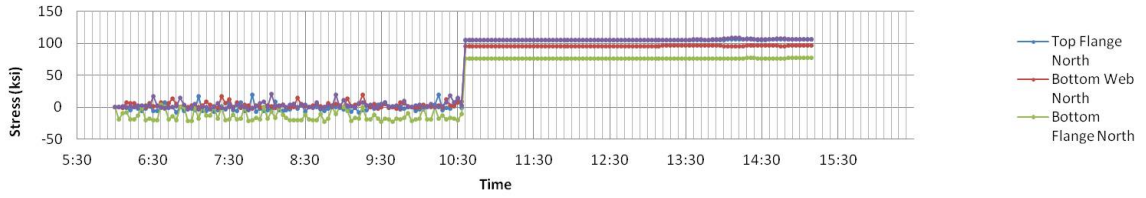


Figure 219: Stress in girder 119B4, instrumentation line 6 during live load test

Stress in Girder 125A5, Instrumentation Line 7 During Live Load Test

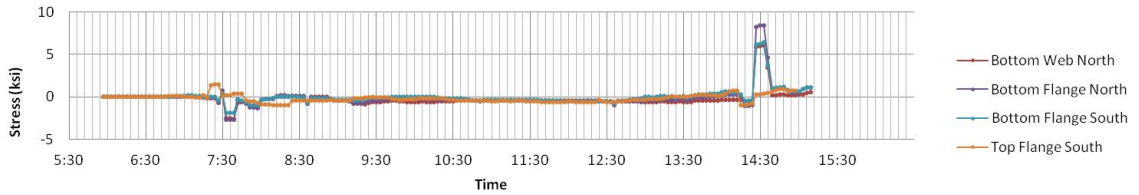


Figure 220: Stress in girder 125A5, instrumentation line 7 during live load test

Stress in Girder 125A5, Instrumentation Line 8 During Live Load Test

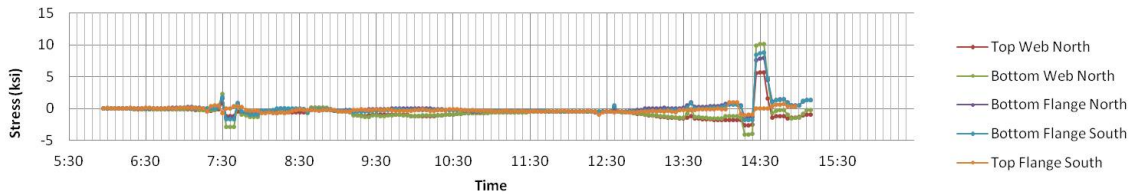


Figure 221: Stress in girder 125A5, instrumentation line 8 during live load test

Stress in Girder 125A5, Instrumentation Line 9 During Live Load Test

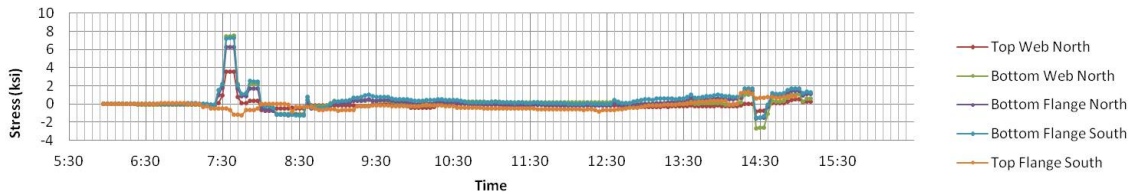


Figure 222: Stress in girder 125A5, instrumentation line 9 during live load test

Stress in Girder 130A6, Instrumentation Line 10 During Live Load Test

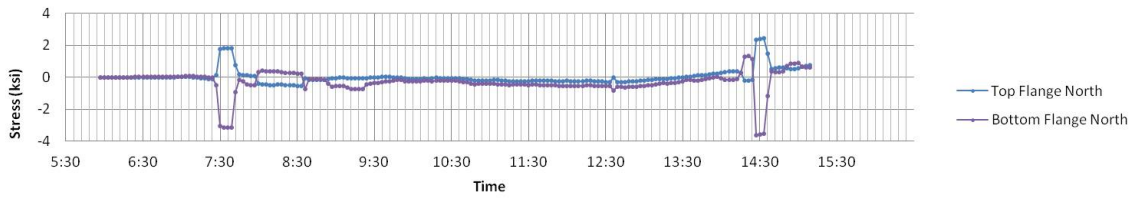


Figure 223: Stress in girder 130A6, instrumentation line 10 during live load test

Stress in Girder 135A7, Instrumentation Line 11 During Live Load Test

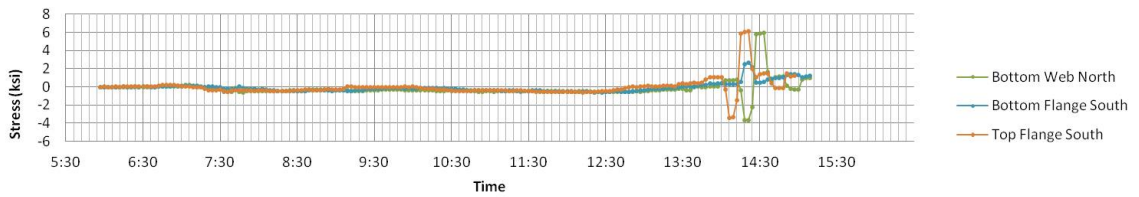


Figure 224: Stress in girder 135A7, instrumentation line 11 during live load test

Stress in Girder 140A8, Instrumentation Line 12 During Live Load Test

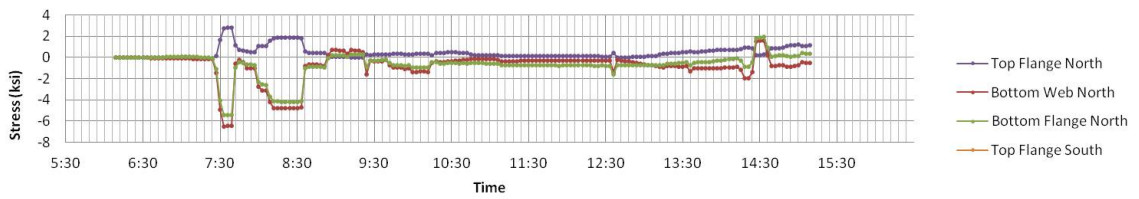


Figure 225: Stress in girder 140A8, instrumentation line 12 during live load test

Stress in Girder 145A9, Instrumentation Line 13 During Live Load Test

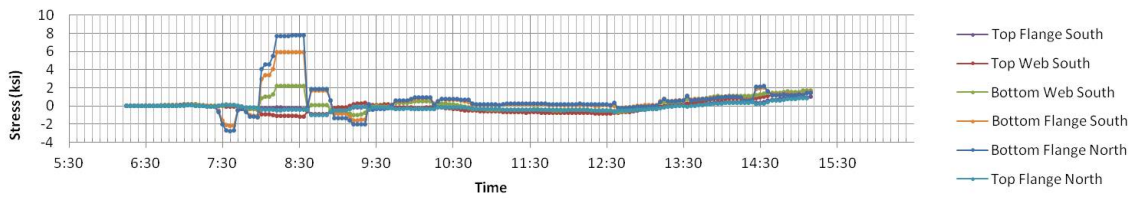


Figure 226: Stress in girder 145A9, instrumentation line 13 during live load test

Stress in Girder 150A10, Instrumentation Line 15 During Live Load Test

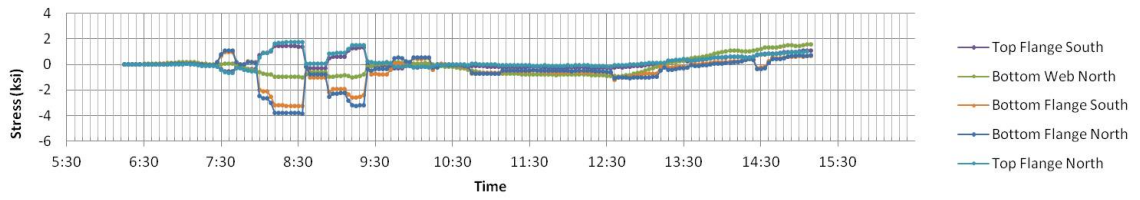


Figure 227: Stress in girder 150A10, instrumentation line 15 during live load test

Stress in Girder 155A11, Instrumentation Line 16 During Live Load Test

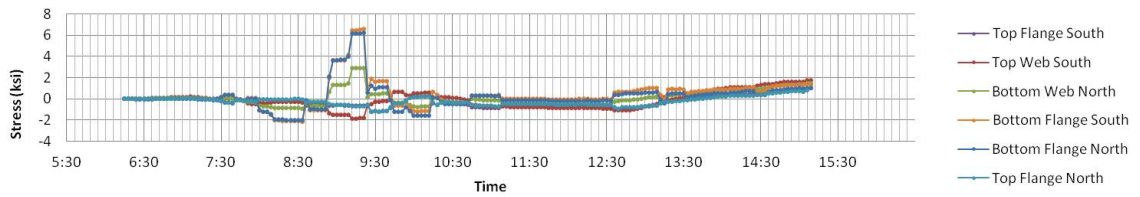


Figure 228: Stress in girder 155A11, instrumentation line 16 during live load test

Stress in Girder 160A12, Instrumentation Line 17 During Live Load Test

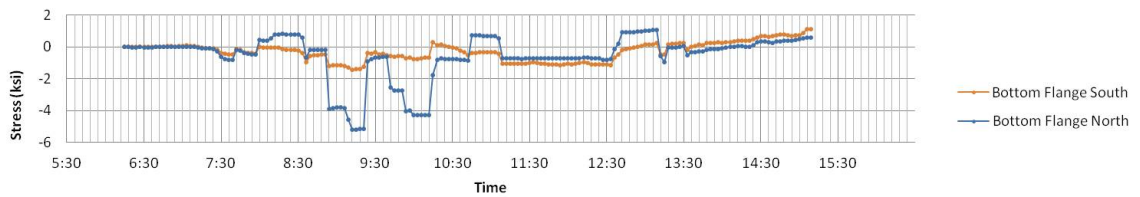


Figure 229: Stress in girder 160A12, instrumentation line 17 during live load test

Stress in Girder 160A12, Instrumentation Line 18 During Live Load Test

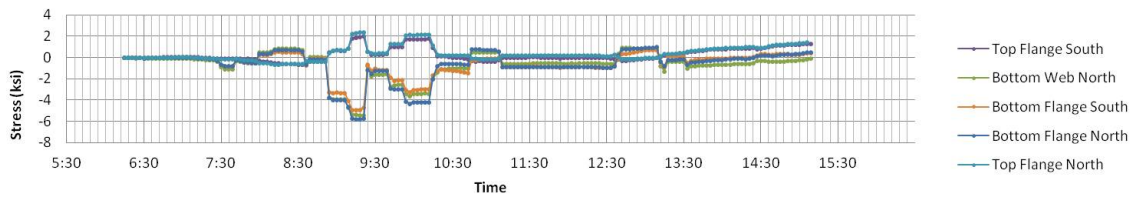


Figure 230: Stress in girder 160A12, instrumentation line 18 during live load test

Stress in Girder 161E13, Instrumentation Line 19 During Live Load Test

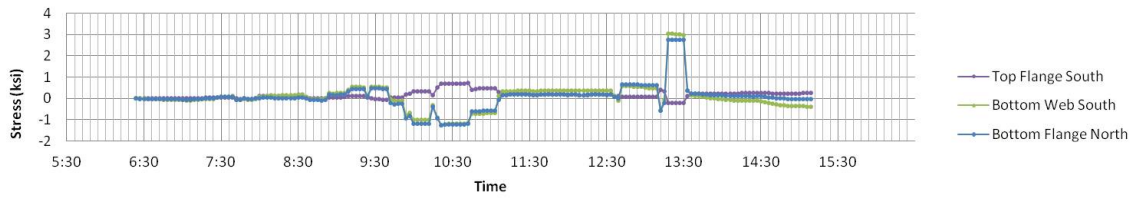


Figure 231: Stress in girder 161E13, instrumentation line 19 during live load test

Stress in Girder 165A13, Instrumentation Line 19 During Live Load Test

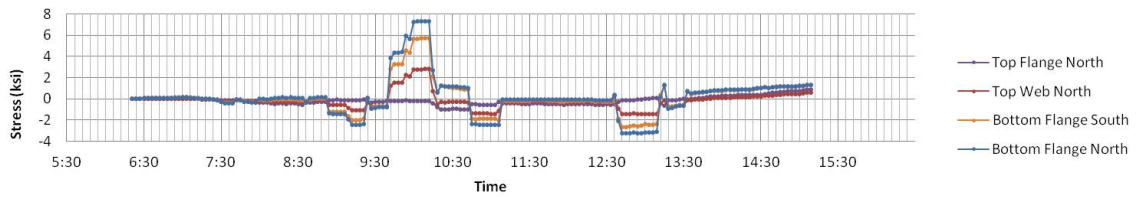


Figure 232: Stress in girder 165A13, instrumentation line 19 during live load test

Stress in Girder 167D14, Instrumentation Line 20 During Live Load Test

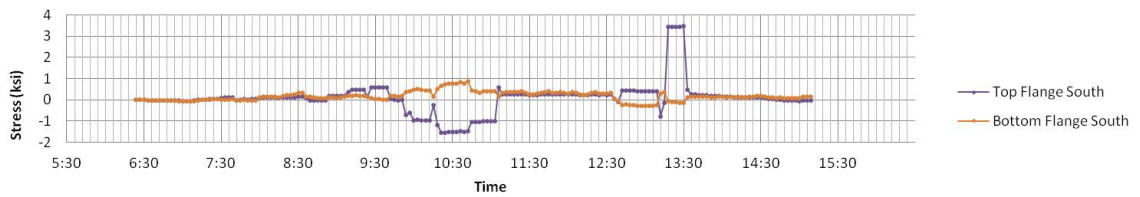


Figure 233: Stress in girder 167D14, instrumentation line 20 during live load test

Stress in Girder 170A14, Instrumentation Line 20 During Live Load Test

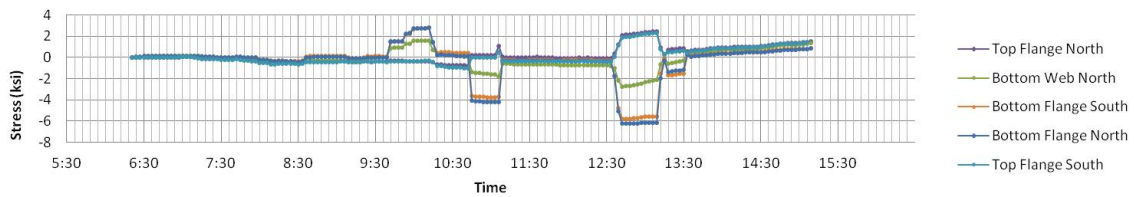


Figure 234: Stress in girder 170A14, instrumentation line 20 during live load test

Stress in Girder 171E15, Instrumentation Line 23 During Live Load Test

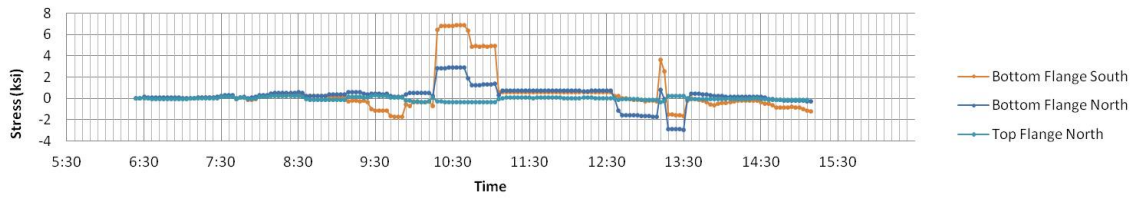


Figure 235: Stress in girder 171E15, instrumentation line 23 during live load test

Stress in Girder 171E15, Instrumentation Line 24 During Live Load Test

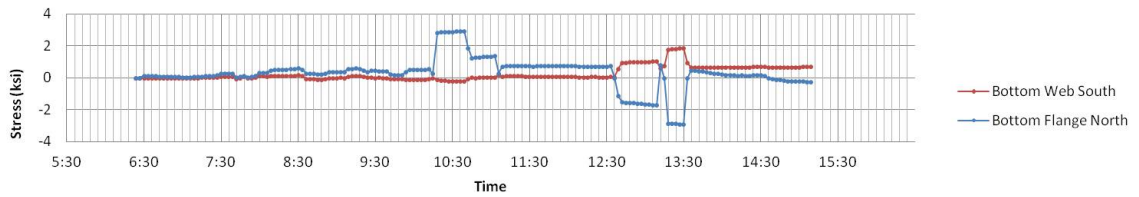


Figure 236: Stress in girder 171E15, instrumentation line 24 during live load test

Stress in Girder 175A15, Instrumentation Line 23 During Live Load Test

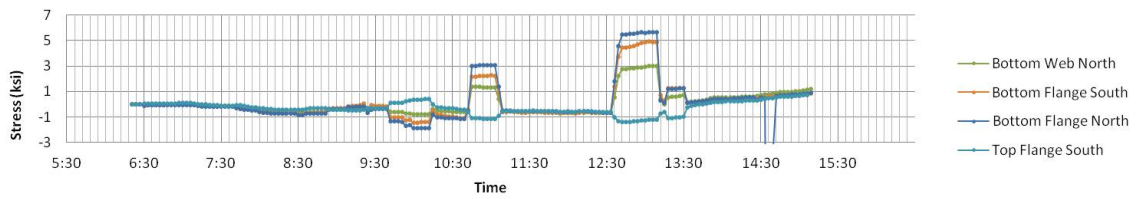


Figure 237: Stress in girder 175A15, instrumentation line 23 during live load test

Stress in Girder 175A15, Instrumentation Line 24 During Live Load Test

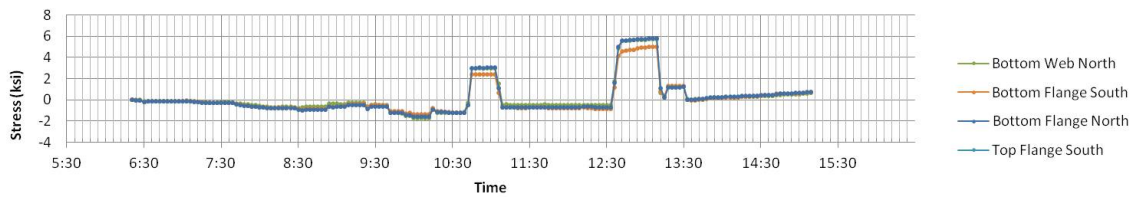


Figure 238: Stress in girder 175A15, instrumentation line 24 during live load test

Displacement During Live Load Test

Vertical Displacement of Target 1 During Live Load Test

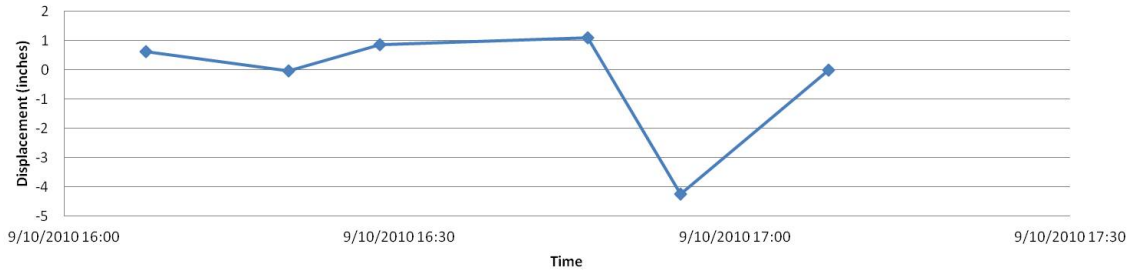


Figure 239: Displacement of target 1 during live load test

Vertical Displacement of Target 2 During Live Load Test

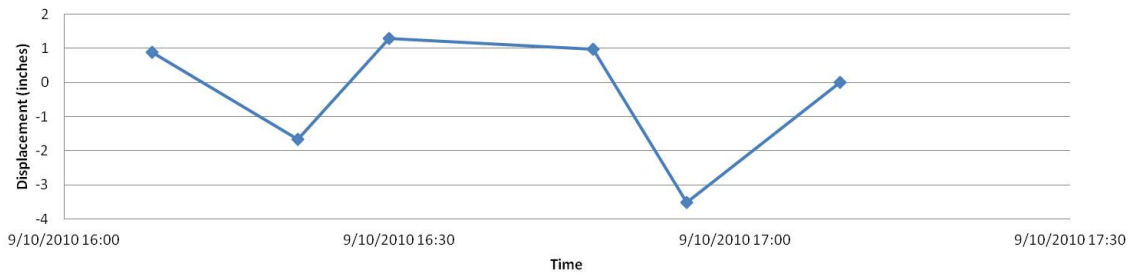


Figure 240: Displacement of target 2 during live load test

Vertical Displacement of Target 3 During Live Load Test

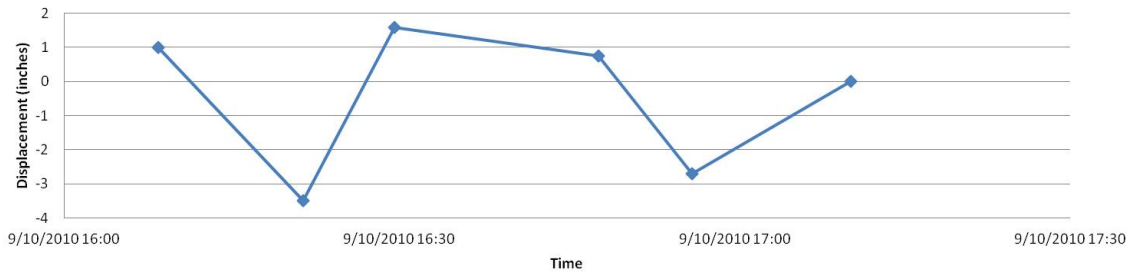


Figure 241: Displacement of target 3 during live load test

Vertical Displacement of Target 4 During Live Load Test

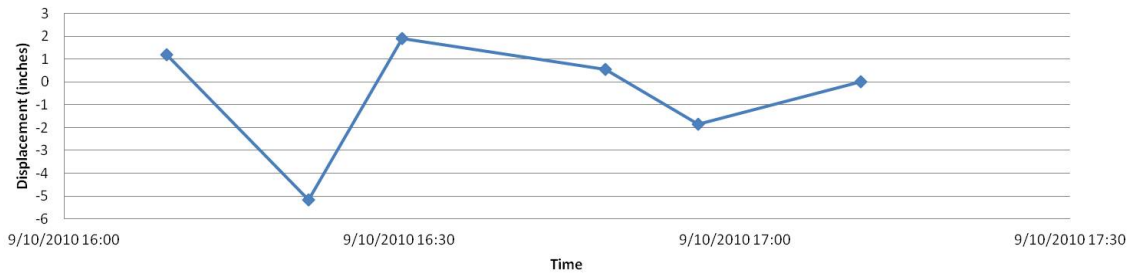


Figure 242: Displacement of target 4 during live load test

Vertical Displacement of Target 5 During Live Load Test

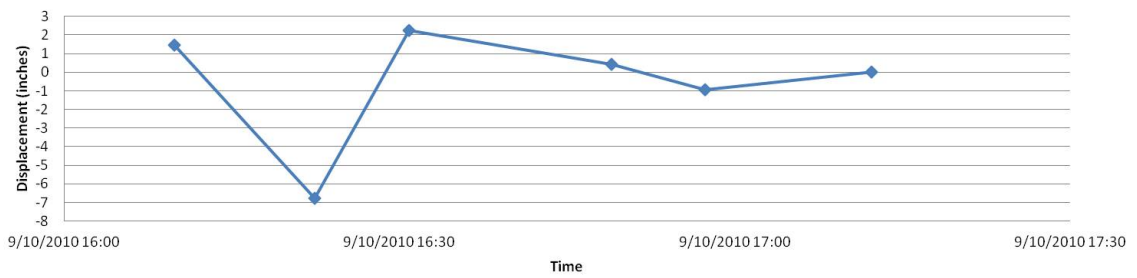


Figure 243: Displacement of target 5 during live load test

Vertical Displacement of Target 2111 During Live Load Test

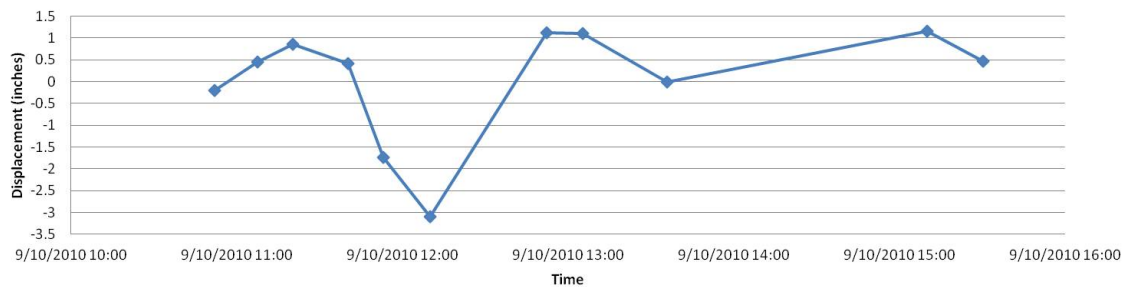


Figure 244: Displacement of target 2111 during live load test

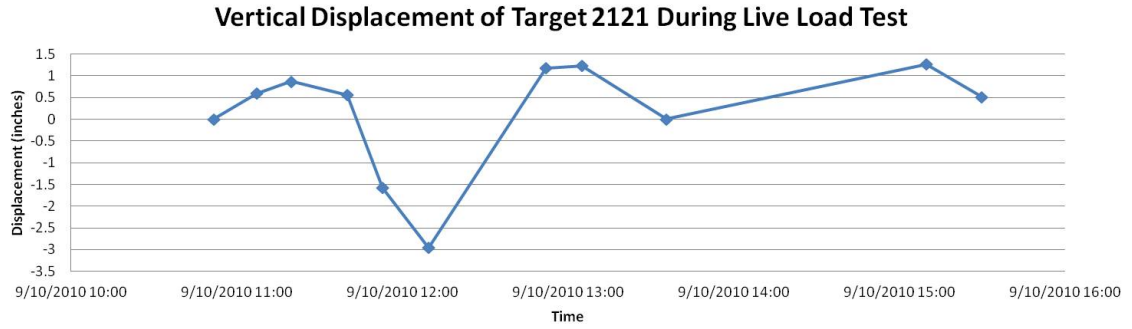


Figure 245: Displacement of target 2121 during live load test

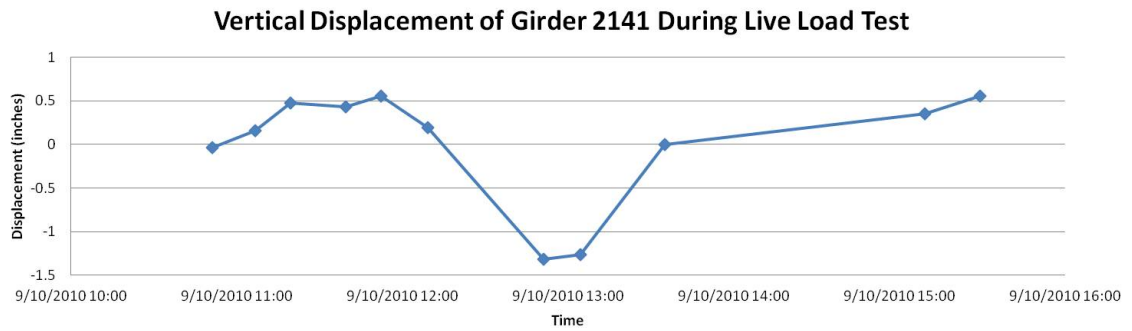


Figure 246: Displacement of target 2141 during live load test

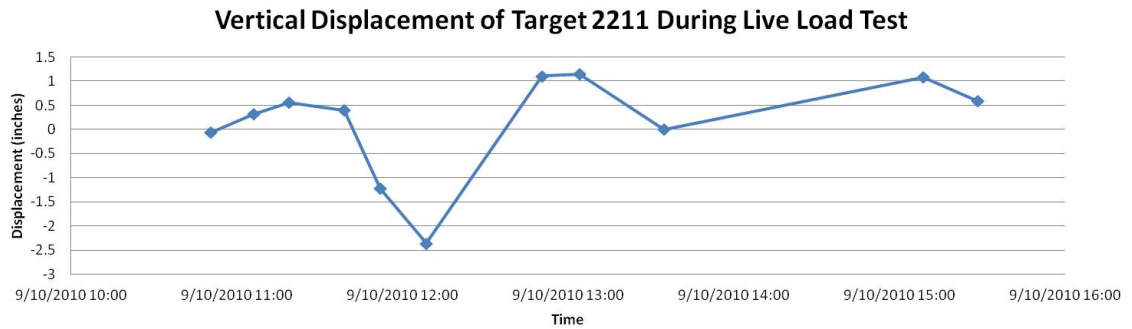


Figure 247: Displacement of target 2211 during live load test

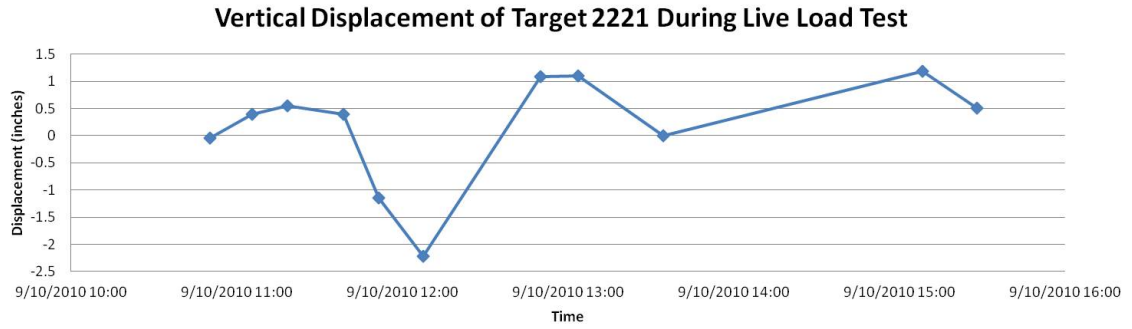


Figure 248: Displacement of target 2221 during live load test

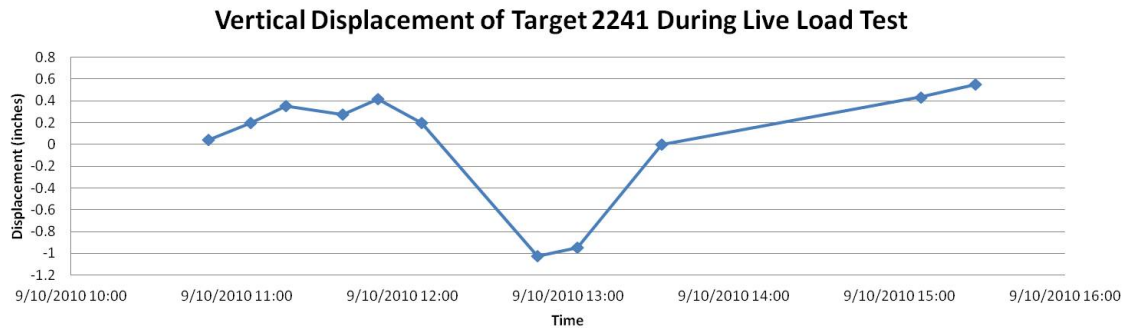


Figure 249: Displacement of target 2241 during live load test

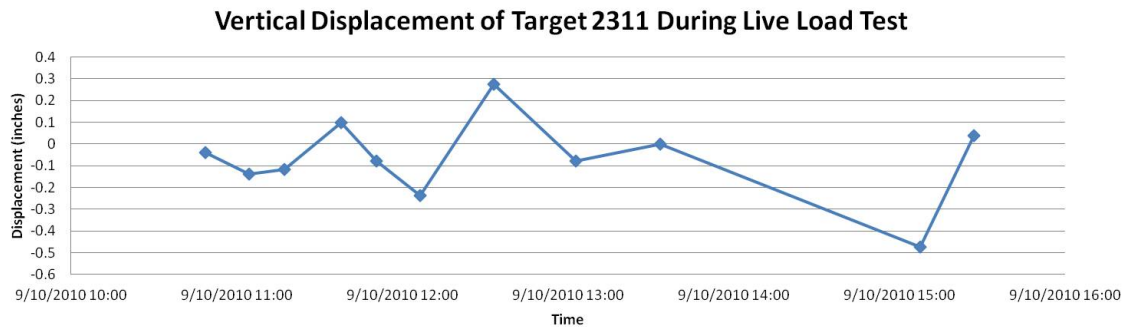


Figure 250: Displacement of target 2231 during live load test

Vertical Displacement of Target 2321 During Live Load Test

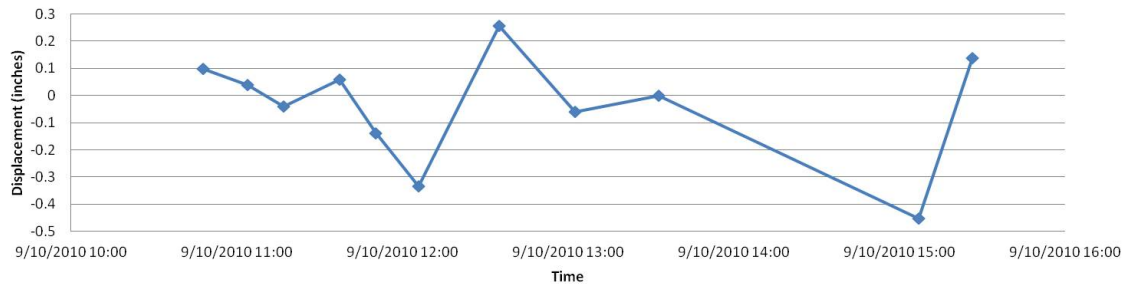


Figure 251: Displacement of target 2321 during live load test

Vertical Displacement of Target 2411 During Live Load Test

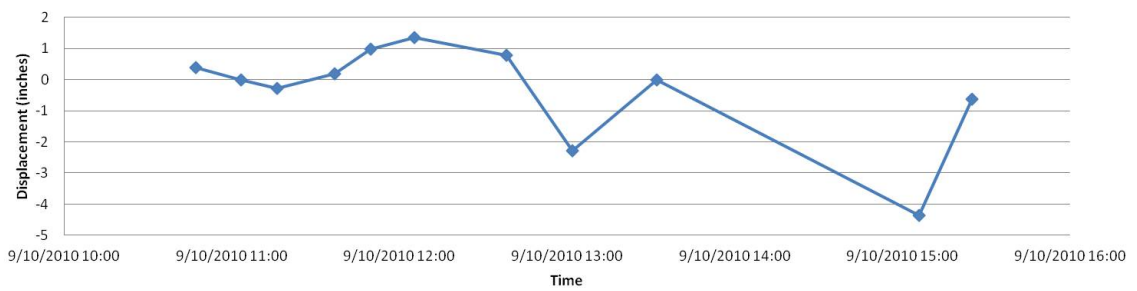


Figure 252: Displacement of target 2411 during live load test

Vertical Displacement of Target 2421 During Live Load Test

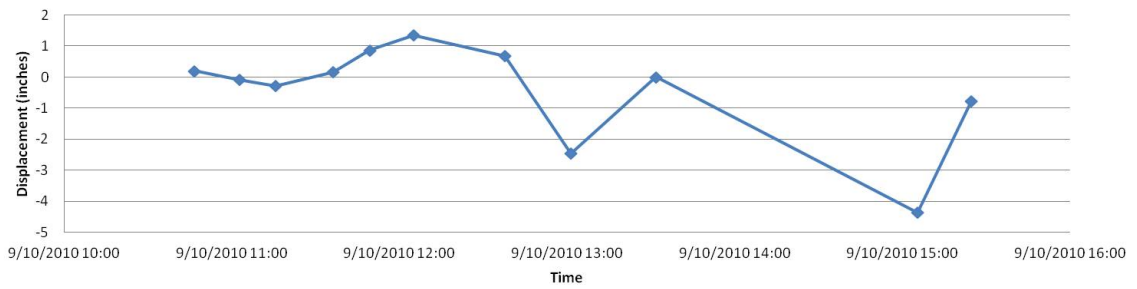


Figure 253: Displacement of target 2421 during live load test

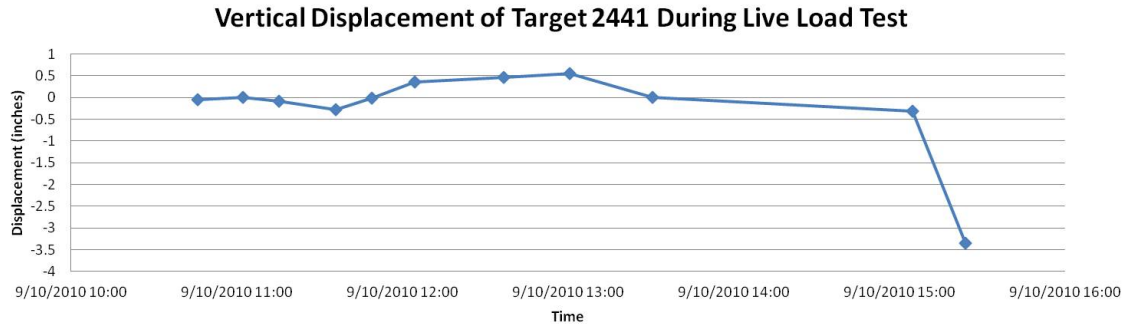


Figure 254: Displacement of target 2441 during live load test

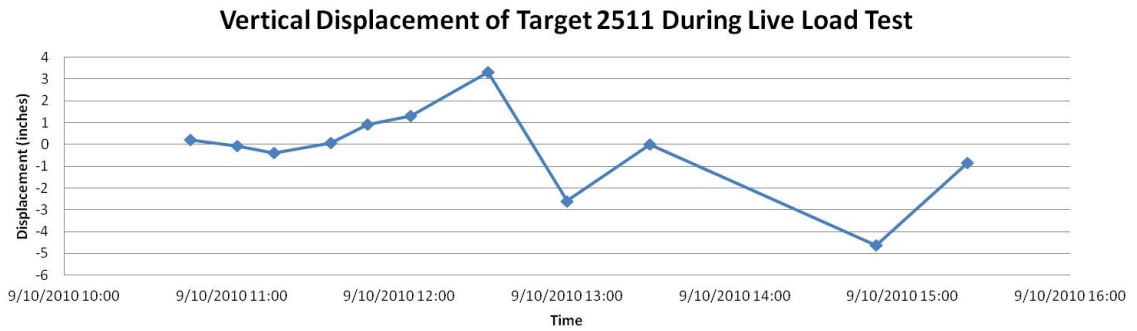


Figure 255: Displacement of target 2511 during live load test

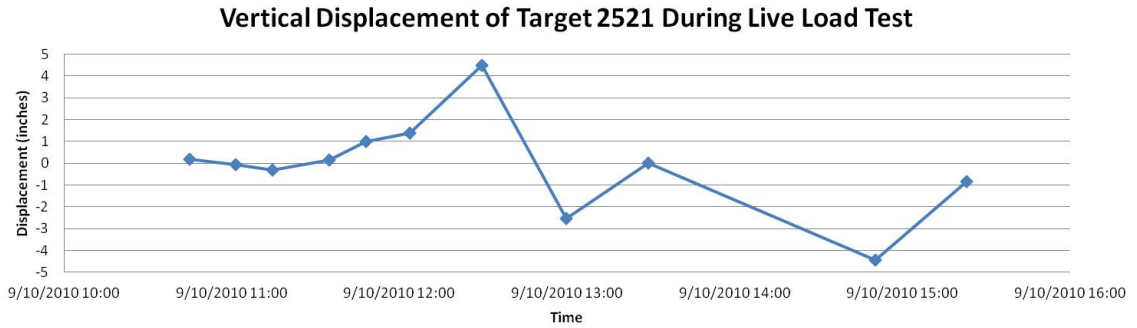


Figure 256: Displacement of target 2521 during live load test

Vertical Displacement of Target 2541 During Live Load Test

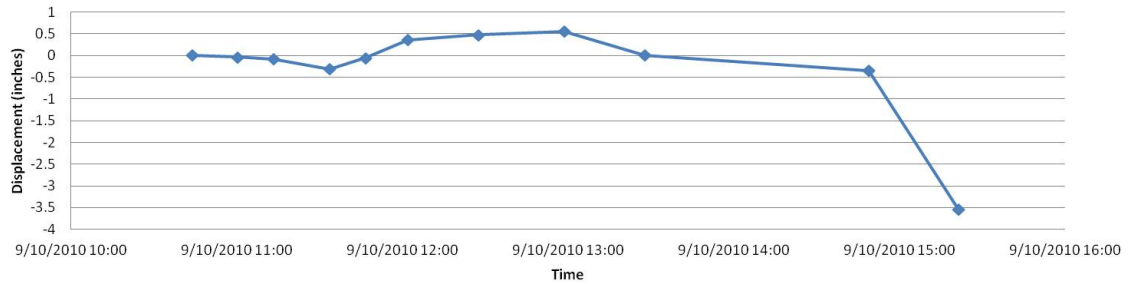


Figure 257: Displacement of target 2541 during live load test

Vertical Displacement of Target 2551 During Live Load Test

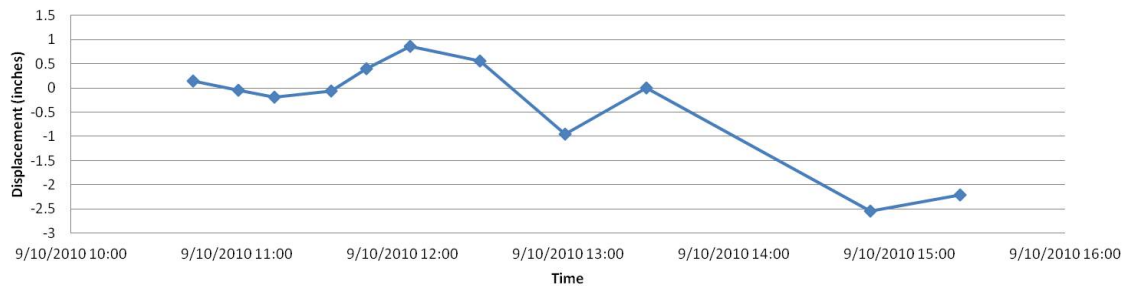


Figure 258: Displacement of target 2551 during live load test

Vertical Displacement of Target 2561 During Live Load Test

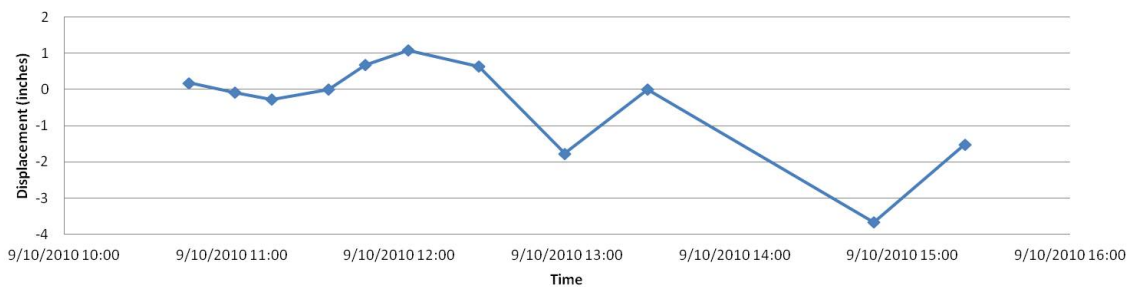


Figure 259: Displacement of target 2561 during live load test

Vertical Displacement of Target 2611 During Live Load Test

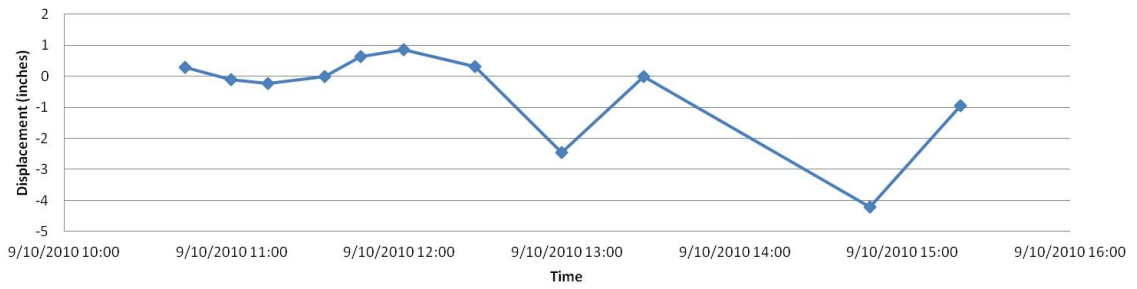


Figure 260: Displacement of target 2611 during live load test

Vertical Displacement of Target 2621 During Live Load Test

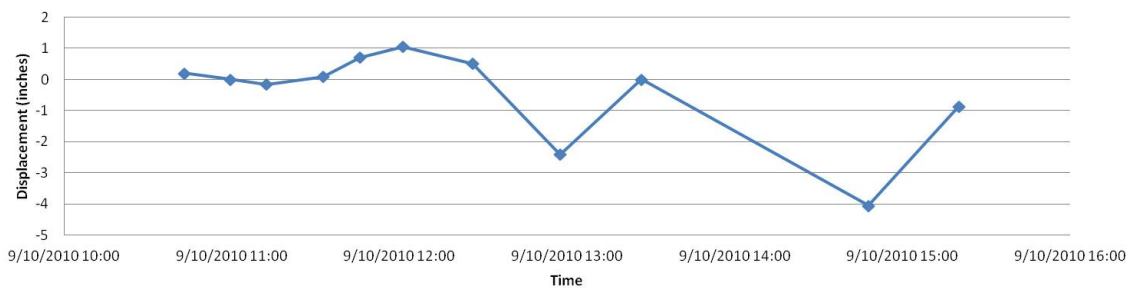


Figure 261: Displacement of target 2621 during live load test

Vertical Displacement of Target 2641 During Live Load Test

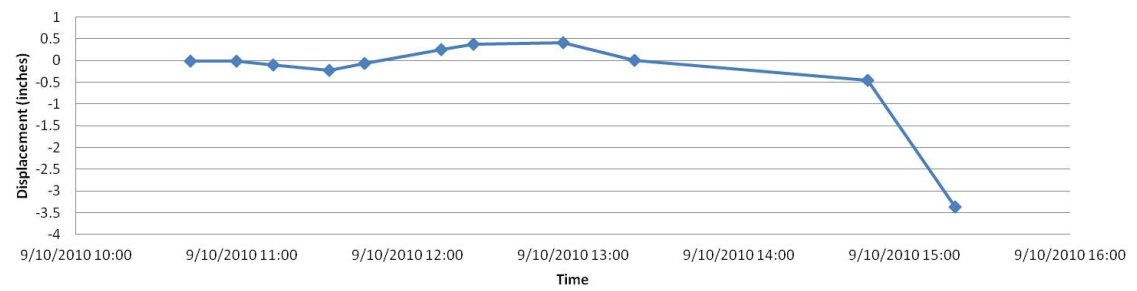


Figure 262: Displacement of target 2641 during live load test

Vertical Displacement of Target 2651 During Live Load Test

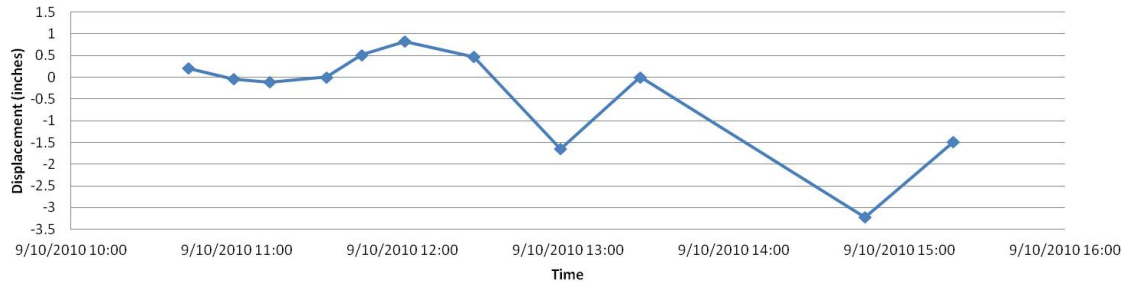


Figure 263: Displacement of target 2651 during live load test

Vertical Displacement of Target 2661 During Live Load Test

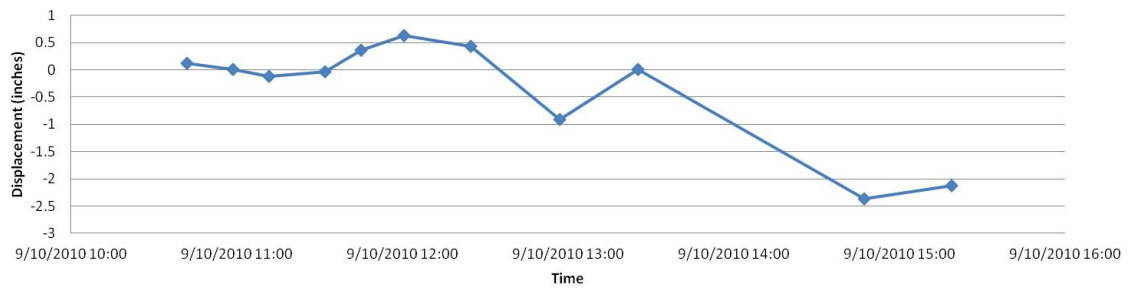


Figure 264: Displacement of target 2661 during live load test

Vertical Displacement in Span 2 During Live Load Test

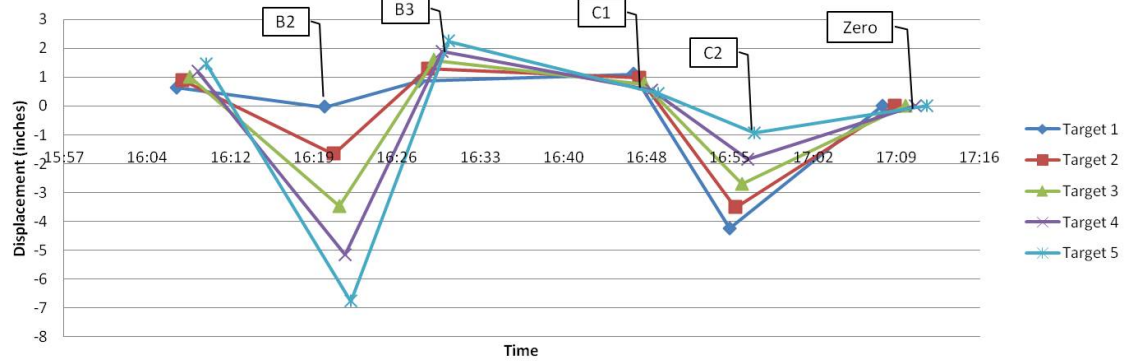


Figure 265: Displacement span 2 during live load test

APPENDIX E: ORIGINAL ERECTION PLAN

Appendix E contains the original steel erection plans provided by Powell Construction Company, Inc., changes to which have been noted in section 3.2.1. Included in the erection plans are rigging configurations, crane locations for each span, and more detailed information regarding the capacities and limitations of the cranes used during erection.

12/18/2009

Powell Construction Company, Inc.
Robertson Road Erection Plan

Project Name: CNH635

Job #: 00209925
Jobsite Address: Davidson County, TN

Controlling Contractor: Bell & Associates, Nashville, TN
Project Manager: Jeremy Mitchell
Phone: (615) 373-4343 - Mobile: (615) 405-8857

Project Superintendent: Dennis Howell
Phone: (615) 351-5176
Fax: (615) 866-9245

Structural Steel Fabricator: PDM Bridge, LLC, Palatka, FL
Contact: Jerry Martin
Phone: (386) 328-4683 Ext. 4006

PCC Personnel Assigned

Division Manager: Butler Hudgins
Phone: (865) 546-0245 - Mobile: (423) 202-8356

Division Superintendent: Mike Trent
Phone: (865) 546-0245 - Mobile: (865) 389-0416

Project Manager: David Horton
Phone: (423) 282-0111 - Mobile: (423) 647-1740

Project Foreman: Harold West
Mobile: (865) 389-2467

Qualified and Competent Persons Assigned to Project:
TBD - Qualified Rigger and Competent Person
TBD - Qualified Crane Operators
Certified Welders-See attached list

Cranes Selected for Project: See attached charts.
KRUPP KMK 5175 175 Ton Hydraulic
P&H 9150 Truck Crane 150 Ton Conventional
Grove TMS 300B 40 Ton Hydraulic

General Scope: To unload and erect one lot of girders, splices and cross frames.

Sequence of Erection:

Using appropriate capacity cranes, lifting beams, rigging, and Crosby Clamp-Co. Model NS-25 25-ton capacity beam clamps, we shall start erection activities at Abutment No. 1 on the west end of the bridge. Crane placement will be per drawing 00209925-003. Girders shall be set in place using the two larger cranes and the 40-ton crane shall provide girder stabilization so that field splices may be connected and erection cross braces installed. Bolt up and tensioning of bolts shall follow consecutively.

12/18/2009

ERECTION PROCEDURE:

The following procedure shall commence by using two large cranes as aforementioned making the splices in the air at the bent elevations. The cranes shall be set up for the heaviest lift at a lifting radius of 45' for the 150-ton crane and 50' for the 175-ton crane. Please see crane placement drawings and charts attached.

SPAN 1:

Girder 105A1 shall be the first piece hoisted into place by the 175-ton crane located on northwest side of Ramp with girder 110A2 hoisted with the 150-ton crane also on northwest side of Ramp making the splice, see drawing 00209925-003. The 40-ton crane will then be rigged to stabilize the girder assembly permitting the two larger cranes to be cut loose to start the next girder line, Girder Line 2.

The 175-ton crane shall hoist girder 104B1 with the 150-ton hoisting girder 109B2 into place over Bent No.1 and making the splice between the girders. Using a forklift, erection cross braces shall then be installed to offer stability to Girder Lines 1 and 2 over Bent No.1. Erection bolts and pins shall then be installed, permitting the cranes to be disengaged and free to start Girder Line 3.

Starting Girder Line 3, the 175-ton crane shall hoist girder 103C1 and the 150-ton crane shall hoist girder 108C2 with the 40-ton crane or forklift hoisting erection cross braces with erection bolts and pins installed, permitting the cranes to be disengaged in order to start the erection of Girder Lines 4 and 5. Girder 102D1 along with girder 107D2 shall be the next girders erected in the same manner. Girders 101E1 and 106E2 shall complete Span 1 in like manner.

SPAN 2:

Using the same procedures as in Span 1, Girder Line 1 with the cranes relocated north of Ramp B as indicated by drawing shall be set with girders 115A3 and 120A4 erected over Bent 1A. Girder Line 2 shall be set next with girders 114B3 and 119B4 erected over Bent 1A with erection procedures as in Span 1. Girder Lines 3, 4, and 5 shall be similarly erected in order with girders 113C3 - 118C4, 112D3 - 117D4, and 111E3 with 116E4 being the last of Span 2.

SPAN 3:

Span 3 over Briley Parkway shall be the next span to be erected starting with Girder Line 5. Girder 121E5 shall be hoisted with the 150-ton crane located in left two lanes of Robertson Rd. and the 175-ton crane located east of Briley Parkway shall hoist girder 126E6 over Bent No.2. Then Girder Line 5 of Span 3 shall be stabilized and spliced with procedures similar to Span 1. Girder Line 4 shall be erected next with girders 122D5 and 127D6 with splices and erection cross braces installed. Girder Lines 3, 2, and 1 shall be similarly erected likewise and in order with girders 123C5 - 128C6, 124B5 - 129B6, and 125A5 - 130A6 being the last girder of Span 3.

SPAN 4:

The cranes shall be positioned with the 175-ton crane being on the south side of I-40, adjacent to east bound lane, and the 150-ton crane on the north side, adjacent to west bound lane. A 200-ton capacity shoring tower shall be installed on the south side of the interstate along Girder Line 5. Traffic shall be controlled during erection with rolling road blocks.

12/18/2009

Girder Line 5 of Span 4 shall start with 131E7 and 136E8 over bent 3 and shall be stabilized with the shoring tower and Bent 3. Girder Line 4 shall be next with girders 132D7 and 137D8 installing field splices and erection cross braces. Girder Lines 3, 2, and 1 shall be similarly erected and in order with girders 133C7 – 138C8, 134B7 – 139B8, and 135A7 – 140A8 being the last of Span 4.

SPAN 5:

Traffic control shall be similar to Span 3 over east bound lane of I-40. The 175-ton crane shall be relocated to the west side of Bent 4 on the south side of Ramp E. The 150-ton crane shall be relocated to the right of the west bound lane west of Ramp B. A 200-ton capacity shoring tower shall be installed adjacent to the west bound lane of the interstate under Girder Line No. 1.

Girder Line 1 shall be continued over the shoring tower with girder 145A9 from a truck on emergency lane of I-40 west bound, hoisted by the 150-ton crane and stabilized on the tower with the 175-ton crane hoisting girder 150A10 from its position at Bent 4 off a truck on Ramp E. The 40-ton crane shall be rigged to this girder line so that the two larger cranes may be disengaged and commence with Girder Line 4. The 150-ton crane shall hoist girder 144B9 with the 175-ton crane hoisting girder 149B10 with splices made and erection cross braces installed. Girder Lines 3, 2, and 1 shall be erected, spliced, and erection cross braces installed in a like manner with girders 143C9 – 148C10, 142D9 – 147D10, and 141E9 – 146E10 completing Span 5.

SPAN 6:

The 175-ton crane shall be relocated to the north side of Ramp E east of Ramp B with the 150-ton crane on the north side of Bent 5.

Starting with Girder Line 5, girder 151E11 shall be hoisted with the 175-ton crane and girder 156E12 with the 150-ton crane, using similar procedures as in Span 1 with field splices and erection cross braces installed. Girder Line 4 shall be next with girders 152D11 and 157D12 spliced and erection cross braces installed. Girder Lines 3, 2, and 1 shall be erected as previous and in that order. Girders 153C11 – 158C12, 154B11 – 159B12, and 155A11 – 160A12 shall be erected, spliced, and erection cross braces installed completing Span 6 over Bent 5.

SPAN 7:

The 175-ton crane shall be relocated to the north of Bent 5 and near the middle of the span with 150-ton crane relocated just south of Bent 6.

Girder Line 5 with girders 161E13 and 166E14 shall be erected and bear on Bent 6, spliced and stabilized, as in Span 1. Girder Line 4 with girders 162D13 and 167D14 shall be erected, spliced, and erection cross braces installed. Girder Lines 3, 2, and 1 with girders 163C13-168C14, 164B13-169B14, and 165A13-170A14, respectively, shall be erected, spliced and erection cross braces installed, completing Span 7.

SPAN 8

The 150-ton crane shall be relocated to the north side of Urbandale Avenue and on the west side of Ramp G with the 175-ton crane just north of the 150-ton crane on the same side of Ramp B. Both cranes shall be involved in making dual lifts on this last span.

12/18/2009

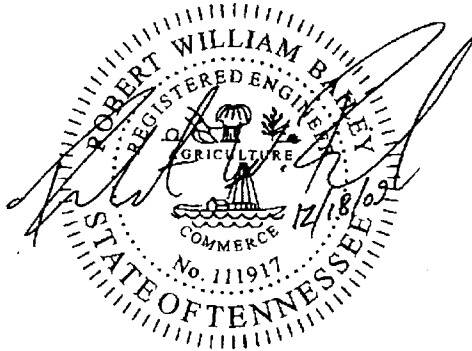
The first girder to be erected shall be on Girder Line 1 with girder 175A15 spliced and stabilized as in previous spans with girder 174B15 erected, spliced, and erection cross braces installed. Girder Lines 3, 4, and 5 shall be erected in that order with girders 173C15, 172D15, and 171E15. The erection splices and cross braces shall be installed with each line until Span 8 is completed.

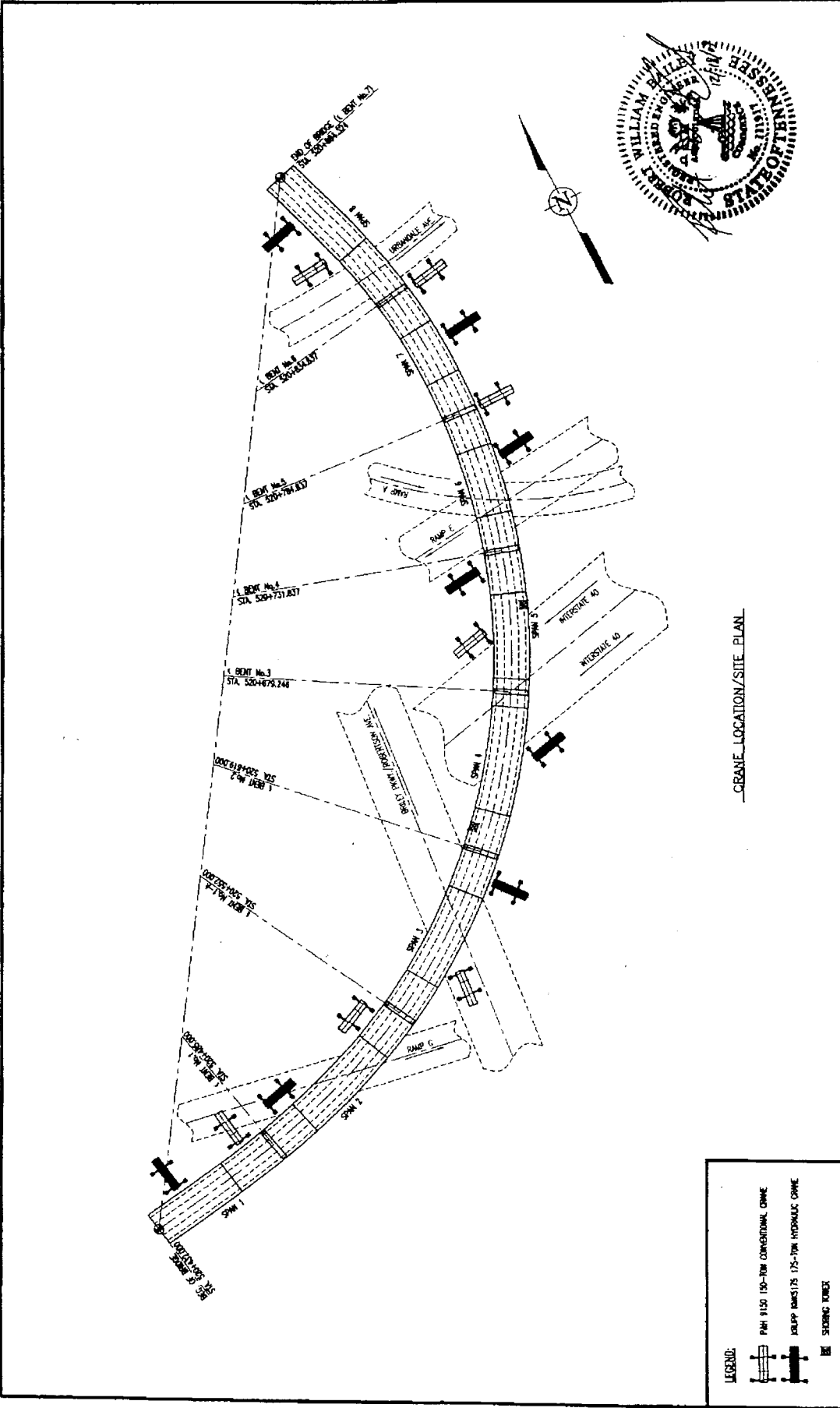
Detail crews shall work following behind the erection crew completing the spans and tensioning the bolts as they move toward Bent No.7. At this stage or as required, either shoring towers or erection hardware shall be removed from the bridge to permit other trades to follow up with their work activities.

Please see Drawings Nos. 00209925-001 and 002 for rigging configurations, 00209925-003 for crane location plan, and 00209925-004 for optional temporary plate girder bracing.

David Horton
Project Manager
Powell Construction Company

Robert W. Bailey, P.E.
Powell Construction Company
TN#: 111917





CRANE LOCATION/SITE PLAN



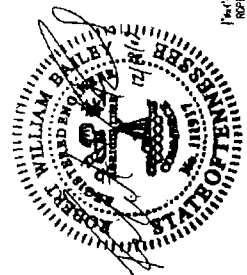
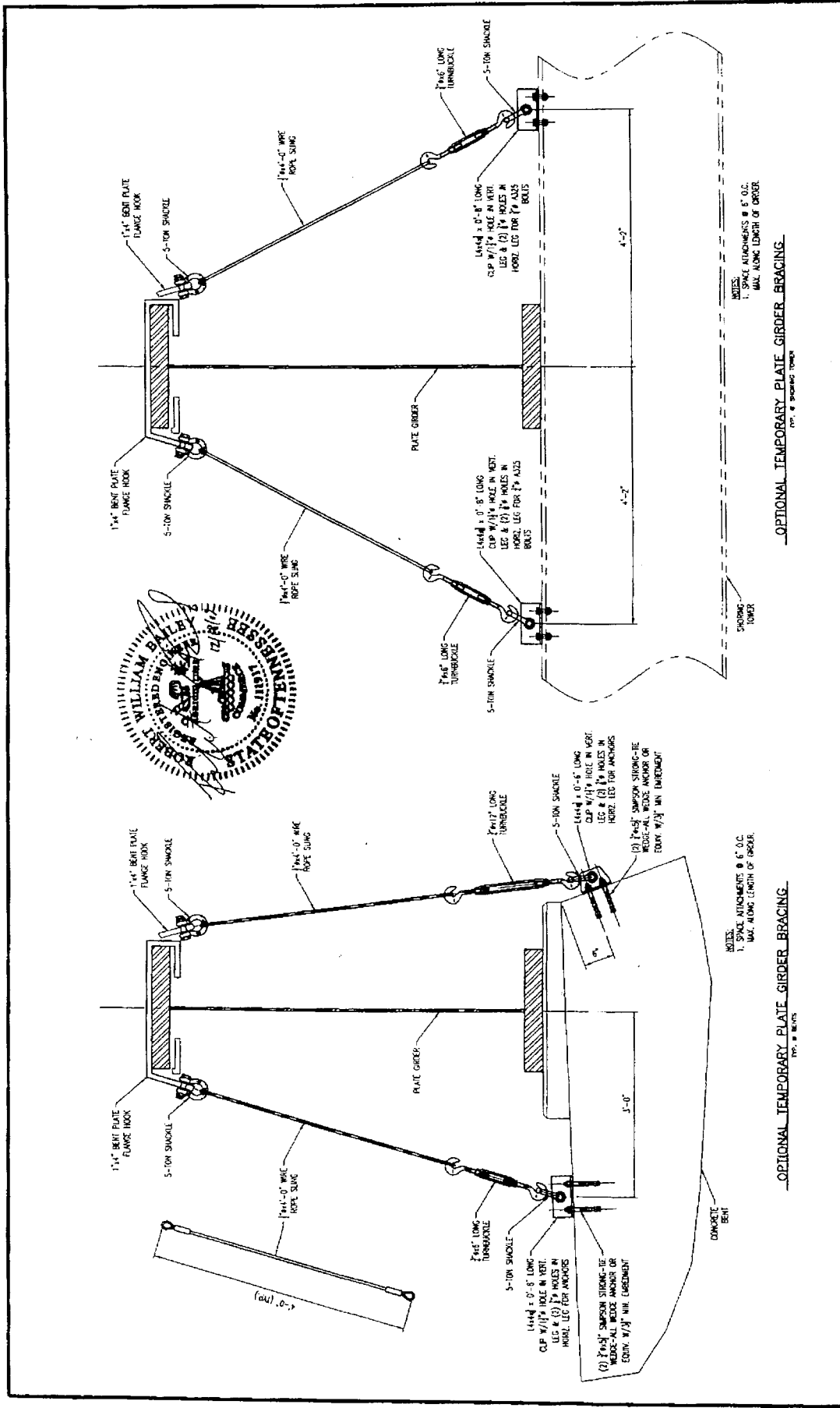
OHM BUS ROBERTSON ROAD BRIDGE
 DAVIDSON COUNTY, TENNESSEE
 CRANE LOCATION/SITE PLAN
 BELL & ASSOCIATES
 NASHVILLE, TENNESSEE

PROJECT NO.	00209925 - 003
DATE	12/17/09
BY	N. BELL
CHECKED BY	
APPROVED BY	

Powell Construction Company
 JOHNSON CITY
 TENNESSEE

NO.	1	DATE	12/17/09	BY	N. BELL	DESCRIPTION	ORIGINAL SITE
NO.	2	DATE		BY		DESCRIPTION	
NO.	3	DATE		BY		DESCRIPTION	

LEGEND:
 150-TON CONVENTIONAL CRANE
 175-TON HYDRAULIC CRANE
 STAGING KURVE



OPTIONAL TEMPORARY PLATE GIRDER BRACING

OPTIONAL TEMPORARY PLATE GIRDER BRACING

		CHH ELS ROBERTSON ROAD BRIDGE DAVIDSON COUNTY, TENNESSEE OPTIONAL TEMPORARY PLATE GIRDER BRACING BELL & ASSOCIATES NASHVILLE, TENNESSEE		Project Number: 00209825 - 004
Date: 12/18/08 Drawn by: S. BULLY Checked by:	Date:	Date:	Date:	Date:
Powell Construction Company JOHNSON CITY TENNESSEE		Scale:		
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100	

Crosby Clamp-Co Beam Clamps

BEAM CLAMPS

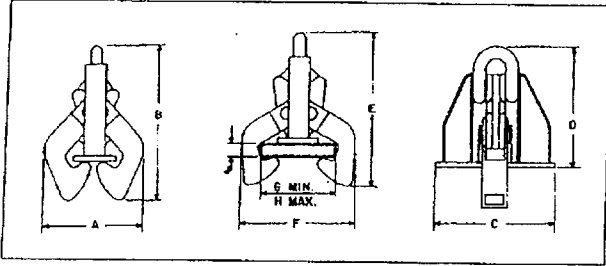


Crosby Clamp-Co Beam Clamps provide an efficient method for handling wide flange beam sections and plate girders. When lifting, these beam clamps grip the beam at three points, and when properly balanced and safely guided, the beam can be handled even if the clamp is slightly off center lengthwise.

- Capacities: 5 Tons to 35 Tons
- Eliminates the need for slings, chokers, and spreader bars.
- When applied to load, the tongs automatically open and slide under the flange of the beam.
- Center plate and gripping tongs work together - the heavier the beam, the greater the clamping pressure.
- Model "NS" clamps have a recessed base to accept studs welded to the beam surface.
- Individually Proof Tested to 2 times the Working Load Limit with certification.
- Finish - Red Paint
- All sizes are RFID EQUIPPED.



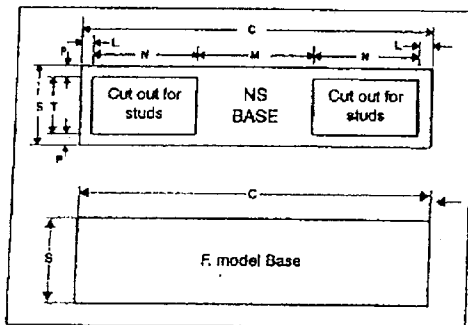
NOTE: Control the beam at all times. Beams should be gripped as near the center as possible. Snubbing lines at each end must be used to control excessive twisting or swinging, and to guide the beam to its proper place. Each lifting situation may have a specific demand which should be addressed before lifting.



Beam Clamps

Model	Part No.	Capacity (Tons)	Beam Height (in)	Beam Flange (in)	Beam Web (in)	Beam Depth (in)	Beam Weight (lb)	Beam Weight (kg)	Beam Weight (kN)	Beam Weight (kN)	Beam Weight (kN)	Beam Weight (kN)	Beam Weight (kN)	Beam Weight (kN)	Beam Weight (kN)	Beam Weight (kN)
F-5	2732000	5	4 - 10	.5 - 1	70.0	9.50	26.00	12.00	20.00	25.50	16.00	.75	4.00	1.00		
F-15	2732009	15	7 - 17	.5 - 2	153	15.50	34.00	17.00	27.00	34.50	25.00	7.00	17.00	2.00		
NS-15	2732018	15	7 - 17	.5 - 2	153	15.50	34.00	17.00	27.00	34.50	25.00	7.00	17.00	2.00		
F-25	2732027	25	16 - 24	1 - 3	290	23.00	48.00	22.25	36.00	53.00	37.25	16.00	24.00	3.00		
	2732036		16 - 24	1 - 3	290	23.00	48.00	22.25	36.00	53.00	37.25	16.00	24.00	3.00		
F-35	2732045	35	16 - 36	1.63 - 4	519	30.00	64.00	27.50	48.00	58.00	53.00	16.00	38.00	4.00		
NS-35	2732054	35	16 - 36	1.63 - 4	519	30.00	64.00	27.50	48.00	58.00	53.00	16.00	38.00	4.00		

* Maximum Proof Load is 2 times the Working Load Limit.



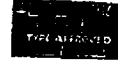
Model	Capacity (Tons)	Beam Height (in)	Beam Flange (in)	Beam Web (in)	Beam Depth (in)	Beam Weight (lb)	Beam Weight (kg)	Beam Weight (kN)
F-5	13.50	-	-	-	-	3.00	-	-
F-15	17.00	-	-	-	-	4.00	-	-
NS-15	17.00	.50	6.50	4.50	.75	4.00	2.50	-
F-25	22.25	-	-	-	-	5.50	-	-
NS-25	22.25	.75	7.75	6.50	.75	5.50	4.00	-
F-35	27.50	-	-	-	-	6.00	-	-
NS-35	27.50	.75	9.00	8.50	.75	6.00	4.50	-

Crosby® Bolt Type Shackles

Load Rated Fatigue Rated



MAXTOUGH®



BOLT TYPE ANCHOR SHACKLES



G-2130 S-2130

Bolt Type Anchor shackles with thin head bolt - nut with cotter pin. Meets the performance requirements of Federal Specification RR-C-271D Type IVA, Grade A, Class 3, except for those provisions required of the contractor. For additional information, see page 391.

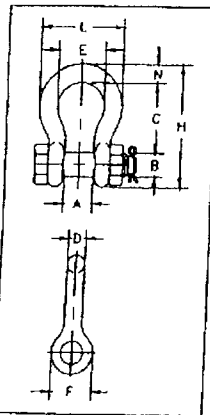
BOLT TYPE CHAIN SHACKLES



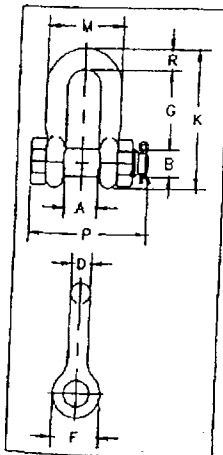
G-2150 S-2150

Bolt Type Chain shackles. Thin hex head bolt - nut with cotter pin. Meets the performance requirements of Federal Specification RR-C-271D Type IVB, Grade A, Class 3, except for those provisions required of the contractors. For additional information, see page 391.

- Capacities 1/3 thru 150 metric tons.
- Working Load Limit permanently shown on every shackle.
- Forged — Quenched and Tempered, with alloy pins.
- Hot Dip galvanized or Self Colored.
- Fatigue rated (1/3t - 55t).
- Shackles 25t and larger are RFID EQUIPPED.
- Crosby products meet or exceed all requirements of ASME B30.26 including identification, ductility, design factor, proof load and temperature requirements. Importantly, Crosby products meet other critical performance requirements including fatigue life, impact properties and material traceability, not addressed by ASME B30.26.
- Shackles 55 metric tons and smaller can be furnished proof tested with certificates to designated standards, such as ABS, DNV, Lloyd's, or other certification when requested at time of order.
- Shackles 85 metric tons and larger can be provided as follows.
 - Non Destructive Tested
 - Serialized Pin and Bow
 - Material Certification (Chemical) Certification must be requested at time of order.
- Look for the Red Pin®... the mark of genuine Crosby quality.
- Type Approval and certification in accordance with ABS 2006 Steel Vessel additional information, see page 391. Rules 1-I-17.7, and ABS Guide for Certification of Cranes.



G-2130 S-2130



G-2150 S-2150

Shackle Size	Pin Size	Part No.	Capacity (Metric Tons)	Capacity (U.S. Tons)	Working Load Limit (Metric Tons)	Working Load Limit (U.S. Tons)	Proof Load (Metric Tons)	Proof Load (U.S. Tons)	Min. Ultimate Strength (Metric Tons)	Min. Ultimate Strength (U.S. Tons)
3/16	1/32	1019464	.06	.38	.25	.88	.19	.60	.56	1.47
1/4	1/2	1019466	.11	.47	.31	1.13	.25	.78	.61	1.84
5/16	3/4	1019468	.22	.53	.38	1.22	.31	.84	.75	2.09
3/8	1	1019470	.33	.66	.44	1.44	.38	1.03	.91	2.49
7/16	1-1/2	1019471	.49	.75	.50	1.69	.44	1.16	1.06	2.91
1/2	2	1019472	.79	.81	.64	1.88	.50	1.31	1.19	3.28
5/8	3-1/4	1018490	1.68	1.06	.77	2.38	.63	1.69	1.50	4.19
3/4	4-3/4	1019515	2.72	1.25	.89	2.81	.75	2.00	1.81	4.97
7/8	6-1/2	1019533	3.95	1.44	1.02	3.31	.88	2.28	2.09	5.83
1	8-1/2	1019551	5.66	1.69	1.15	3.75	1.00	2.69	2.38	6.56
1-1/8	9-1/2	1019579	8.27	1.81	1.25	4.25	1.13	2.91	2.69	7.47
1-1/4	12	1019597	11.71	2.03	1.40	4.69	1.29	3.25	3.00	8.25
1-3/8	13-1/2	1019613	15.83	2.25	1.53	5.25	1.42	3.63	3.31	9.16
1-1/2	17	1019631	19.00	2.38	1.66	5.75	1.53	3.88	3.63	10.00
1-3/4	25	1019659	33.91	2.88	2.04	7.00	1.84	5.00	4.19	12.34
2	35	1019677	52.25	3.25	2.30	7.75	2.08	5.75	4.81	13.68
2-1/2	55	1019695	98.25	4.13	2.80	10.50	2.71	7.25	5.69	17.90
3	† 85	1019711	154.00	5.00	3.30	13.00	3.12	7.88	6.50	21.50
3-1/2	† 120 ‡	1019739	265.00	5.25	3.76	14.63	3.62	9.00	8.00	24.88
4	† 150 ‡	1019757	338.00	5.50	4.28	14.50	4.00	10.00	9.00	25.68

Shackle Size	Pin Size	Part No.	Capacity (Metric Tons)	Capacity (U.S. Tons)	Working Load Limit (Metric Tons)	Working Load Limit (U.S. Tons)	Proof Load (Metric Tons)	Proof Load (U.S. Tons)	Min. Ultimate Strength (Metric Tons)	Min. Ultimate Strength (U.S. Tons)
1/4	1/2	1019768	.13	.47	.31	.25	.62	.91	1.59	.97
5/16	3/4	1019770	.23	.53	.38	.31	.75	1.07	1.91	1.15
3/8	1	1019772	.33	.66	.44	.38	.92	1.28	2.31	1.42
7/16	1-1/2	1019774	.49	.75	.50	.44	1.06	1.48	2.67	1.63
1/2	2	1019775	.75	.81	.64	.50	1.18	1.66	3.03	1.81
5/8	3-1/4	1019793	1.47	1.06	.77	.63	1.50	2.04	3.76	2.32
3/4	4-3/4	1019819	2.52	1.25	.89	.75	1.81	2.40	4.53	2.75
7/8	6-1/2	1019837	3.85	1.44	1.02	.88	2.10	2.86	5.33	3.20
1	8-1/2	1019855	5.55	1.69	1.15	1.00	2.38	3.24	5.94	3.69
1-1/8	9-1/2	1019873	7.60	1.81	1.25	1.13	2.68	3.61	6.78	4.07
1-1/4	12	1019891	10.81	2.03	1.40	1.25	3.00	3.97	7.50	4.53
1-3/8	13-1/2	1019917	13.75	2.25	1.53	1.38	3.31	4.43	8.28	5.01
1-1/2	17	1019935	18.50	2.38	1.66	1.50	3.62	4.87	9.05	5.38
1-3/4	25	1019953	31.40	2.88	2.04	1.75	4.19	5.82	10.97	6.38
2	35	1019971	46.75	3.25	2.30	2.10	5.00	6.82	12.74	7.25
2-1/2	55	1019999	85.00	4.12	2.80	2.63	5.68	8.07	14.85	9.38
3	† 85	1020013	124.25	5.00	3.25	3.00	6.50	8.56	16.87	11.00

* NOTE: Maximum Proof Load is 2.0 times the Working Load Limit. Minimum Ultimate Strength is 6 times the Working Load Limit. For Working Load Limit reduction due to side loading applications, see page 74.
 † Individually Proof Tested with certification.
 ‡ Furnished in Anchor style only and furnished with Round Head Bolts with welded handles.

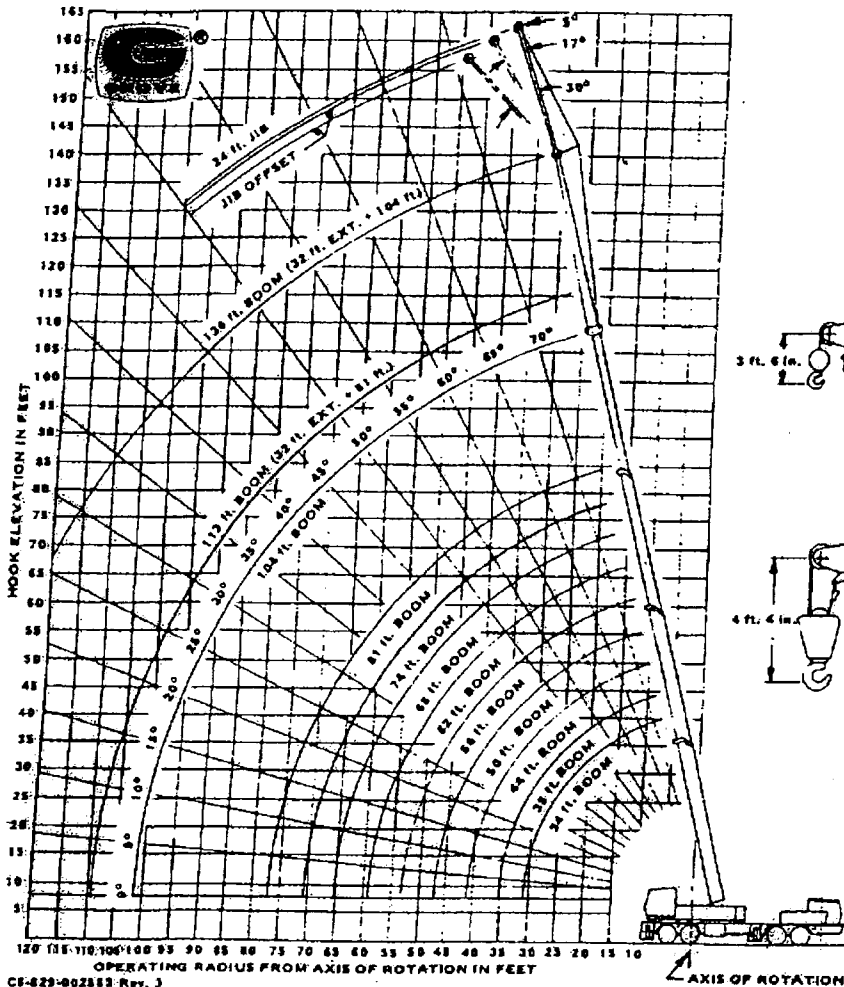
Inc. ved

Copyright © 2008 The Crosby Group, Inc. All Rights Reserved

GROVE® TMS300

40 TON Capacity

RANGE DIAGRAM



NOTES FOR LIFTING CAPACI

- Do not exceed any rated lifting ca. Rated lifting capacities are based on suspended loads with the machine standing on a firm supporting surface. Ratings with outriggers are base outriggers being extended to maximum position and tires raised to crane weight before extending the bo lifting loads.
- Practical working loads for each job shall be established by the depending on operating conditio include: the supporting surface, win other factors affecting stability, haza surroundings, experience of persi handling of load, etc. No attempt m made to move a load horizontally o ground in any direction.
- Operating radius is the horizontal dis from the axis of rotation before loadi the centerline of the vertical hoist i tackle with loads applied.
- "On Rubber" lifting (if permitted) det on proper tire inflation, capacity condition. "On Rubber" loads ma transported at a maximum vehicle spe 2.5 m/hr (4 Km/hr) on a firm and surface under conditions specified.
- Jibs may be used for lifting crane se only. Jib capacities are based on struc strength of jib or main boom and on boom angle.
- Operation is not intended or approve any conditions outside of those st hereon. Handling of personnel from boom is not authorized except equipment furnished and installed by G Manufacturing Company.
- For clamshell or concrete bucket opera weight of bucket and load must not ex 80% of rated lifting capacities.
- Power-telescoping boom sections mus extended equally at all times. I cantilever booms can create a tip condition when in extended and low position.
- The maximum load which may telescoped is limited by hydraulic press boom angle, boom lubrication, etc. It is attempt to lift any load within limits of rated lifting capacity chart.
- With certain boom and hoist ta combinations, maximum capacities may be obtainable with standard cable leng
- With certain boom and load combinatio raising of load with boom lift cylinders r not be possible. Operational safety is affected by this condition.
- Keep load handling devices a minimum 12 inches (30 cm) below boom head w lowering or extending boom.
- If actual boom length and/or radius between values listed, use lifting capai for the next longer rated length and radius.
- All load handling devices and bo attachments are considered part of the i and suitable allowances must be made their combined weights.
- Operation of this equipment in excess rating charts or disregard of the instructi is hazardous and voids the warranty manufacturer's liability.

WEIGHT REDUCTION FOR LOAD HANDLING DEVICES

32 ft. BOOM EXTENSION	
UNMOVED	430 lbs.
ERECTED	2,385 lbs.
28 ft. JIB & 32 ft. EXT. COMB.	
UNMOVED	478 lbs.
ERECTED	7,210 lbs.
ERECTED	1,739 lbs.

†Reduction of main boom capacities.
††Reduction of 32-ft. Ext. capacities.

HOOK BLOCK	
40 Ton, 3 Sheave	640 lbs.
15 Ton, 1 Sheave	310 lbs.
Auxiliary Boom Head	190 lbs.
5 Ton Headache Ball	130 lbs.
7 1/2 Ton Headache Ball	300 lbs.
10 Ton Headache Ball	500 lbs.

NOTE: All Load Handling Devices and Boom Attachments are Considered Part of the Load and Suitable Allowances MUST BE MADE for Their Combined Weights. Weights are for Grove furnished equipment.

When lifting over swingaway and/or jib combination, deduct total weight of all load handling devices reeved over main boom nose directly from swingaway or jib capacity.



GROVE MANUFACTURING COMPANY

Division of Kiewit, Inc.

Distributed by:
Sold & Serviced By
THE W. W. WILLIAMS CO.



TW

40

341

PC

RATED LIFTING

ON OUTRIGGERS FULLY EXTENDED - OVER SIDE

Radius in Feet	Main Boom Length in Feet (Power Pinned Fly Retracted)										Power Pin. Fly & 81 ft.	32 ft. Ext. & 81 ft.	32 ft. Ext. & 104 ft.
	34	38	44	50	56	62	68	74	81	88			
10	80,000 (69)	68,000 (71.5)	64,000 (74.5)	60,000 (78.5)							105	113	135
12	65,000 (65)	62,500 (68)	57,500 (71.5)	54,000 (74)	51,000 (76)	49,000 (77.5)							
15	57,000 (59.5)	55,000 (63)	50,000 (67.5)	46,500 (70.5)	43,500 (73)	41,980 (74.5)	40,000 (76.5)	38,500 (77.5)					
20	46,890 (48.5)	43,000 (54)	39,500 (60)	36,500 (64)	34,500 (67.5)	32,700 (70)	31,400 (72)	30,000 (73.5)	28,700 (75)				
25	29,450 (35.5)	29,450 (44)	29,450 (52)	29,450 (57.5)	28,100 (61.5)	26,508 (65)	25,300 (67.5)	24,200 (69.5)	23,100 (72)	20,000 (77)	17,300 (77.5)		
30	20,560 (14)	20,560 (31)	20,560 (43)	20,560 (50)	20,560 (55.5)	20,560 (59.5)	20,560 (62.5)	20,560 (65.5)	20,560 (68)	19,000 (74.5)	17,750 (75.5)		
35			15,450 (31.5)	15,450 (42)	13,450 (49)	13,450 (54)	13,450 (57.5)	13,450 (61)	13,450 (64.5)	13,450 (68)	13,608 (71.5)	13,700 (73)	9,600 (77.5)
40			11,410 (13.5)	11,410 (32)	11,410 (41.5)	11,410 (47.5)	11,410 (52.5)	11,410 (56.5)	11,410 (60)	13,108 (68.5)	12,200 (70.5)	10,800 (75.5)	7,500 (79)
45				8,450 (18)	8,450 (32.5)	8,450 (41)	8,450 (47)	8,450 (51.5)	8,450 (56)	10,390 (65.5)	10,200 (67.5)	7,500 (73)	7,050 (77)
50					6,630 (20.5)	6,630 (33)	6,630 (40.5)	6,630 (46)	6,630 (51.5)	8,750 (62)	8,750 (64.5)	7,050 (71)	
55						5,288 (22.5)	5,288 (33)	5,288 (40)	5,288 (46.5)	7,130 (59)	7,308 (61.5)	6,350 (68.5)	
60							4,090 (24)	4,090 (33.5)	4,090 (41)	5,650 (55.5)	5,890 (59.5)	5,800 (66)	
65								3,060 (3)	3,060 (25)	4,500 (52)	4,780 (55.5)	5,190 (63.5)	
70									2,150 (11.5)	3,600 (48)	3,780 (52.5)	4,740 (61.5)	
75										1,300 (17)	2,340 (44)	3,690 (58.5)	
80											2,150 (40)	2,340 (45)	2,950 (56)
85											1,550 (39)	1,740 (41)	2,370 (53.5)
90											1,020 (29.5)	1,170 (37)	1,330 (47.5)
95													1,130 (44.5)
100													1,130 (44.5)

NOTE: Boom angles are in degrees.

AG-829-004311 & -002137D

- NOTES FOR OPERATOR
1. Capacities appearing above the bold line are based on structural strength and tipping loads as determined by test in accordance with SAE recommended practices.
 2. Do not exceed any rated load when lifting regardless of whether it is based on structural strength or tipping loads.
 3. Boom angle is the included angle between horizontal and the boom.
 4. For boom lengths less than 100 feet, the boom angle is based on structural strength.

UUB

CAPACITY
 B. C. J. M.
 (LIFTING)
 0-114

GROVE®

FULL HYDRAULIC CARRIER-MOUNTED CRANE

CAPACITIES IN POUNDS

ON OUTRIGGERS FULLY EXTENDED - OVER REAR

Main Boom Length in Feet (Power Pinned Fly Retracted)	Main Boom Length in Feet (Power Pinned Fly Retracted)									104 See Warning Note 4	113 See Warning Note 5	136 See Warning Note 6
	34	38	44	50	56	62	68	74	81			
80,000 (69)	68,000 (71.5)	64,000 (74.5)	60,000 (76.5)									
65,000 (65)	62,500 (68)	57,500 (71.5)	54,000 (74)	51,000 (76)	49,000 (77.5)							
57,000 (59.5)	55,000 (63)	50,000 (67.5)	46,500 (70.5)	43,900 (73)	41,900 (74.5)	40,000 (76.5)	38,600 (77.5)					
47,000 (48.5)	43,000 (54)	39,500 (60)	36,500 (64)	34,500 (67.5)	32,700 (70)	31,400 (72)	30,000 (73.5)	28,700 (76)				
55,675 (39.5)	33,300 (44)	31,000 (52)	30,000 (57.5)	28,100 (61.5)	26,500 (65)	25,300 (67.5)	24,200 (69.5)	23,100 (72)	20,000 (77)	17,500 (77.5)		
25,200 (14)	25,200 (31)	23,200 (43)	23,200 (50)	23,500 (55.5)	22,100 (59.5)	21,000 (62.5)	20,000 (65.5)	19,000 (68)	17,750 (74.5)	15,400 (75.5)		
		19,340 (31.5)	19,340 (42)	19,340 (49)	18,700 (54)	17,700 (57.5)	16,800 (61)	16,000 (64.5)	15,600 (71.5)	13,700 (73)	9,600 (77.5)	
		15,190 (13.5)	15,190 (32)	15,190 (41.5)	15,190 (47.5)	15,190 (52.5)	14,400 (56.5)	13,600 (60)	13,100 (68.5)	12,200 (70.5)	8,750 (75.5)	
			12,310 (18)	12,310 (32.5)	12,310 (41)	12,310 (47)	12,310 (51.5)	11,700 (56)	11,300 (65.5)	10,800 (67.5)	7,900 (73)	
				10,000 (20.5)	10,000 (33)	10,000 (40.5)	10,000 (46)	10,000 (51.5)	9,930 (62)	9,410 (64.5)	7,050 (71)	
					8,180 (22.5)	8,180 (33)	8,180 (40)	8,180 (46.5)	8,710 (59)	8,230 (61.5)	6,350 (68.5)	
						6,650 (24)	6,650 (33.5)	6,650 (41)	7,680 (55.5)	7,240 (58.5)	5,800 (66)	
						5,280 (3)	5,280 (25)	5,280 (35)	6,800 (52)	6,380 (55.5)	5,200 (63.5)	
							4,140 (11.5)	4,140 (27.5)	5,990 (48)	5,640 (52.5)	4,750 (61.5)	
								3,320 (17)	5,000 (44)	4,910 (49)	4,350 (58.5)	
									4,060 (40)	4,690 (45)	4,050 (56)	
									3,290 (35)	3,420 (41)	3,700 (53.5)	
									2,730 (29.5)	2,830 (37)	3,280 (50.5)	
									2,210 (22.5)	2,330 (32)	2,870 (47.5)	
									1,680 (10.5)	1,890 (26.5)	2,470 (44.5)	
										1,470 (19)	2,080 (41)	
											1,700 (37.5)	
											1,340 (33.5)	
											1,010 (29)	

boom angles are in degrees.

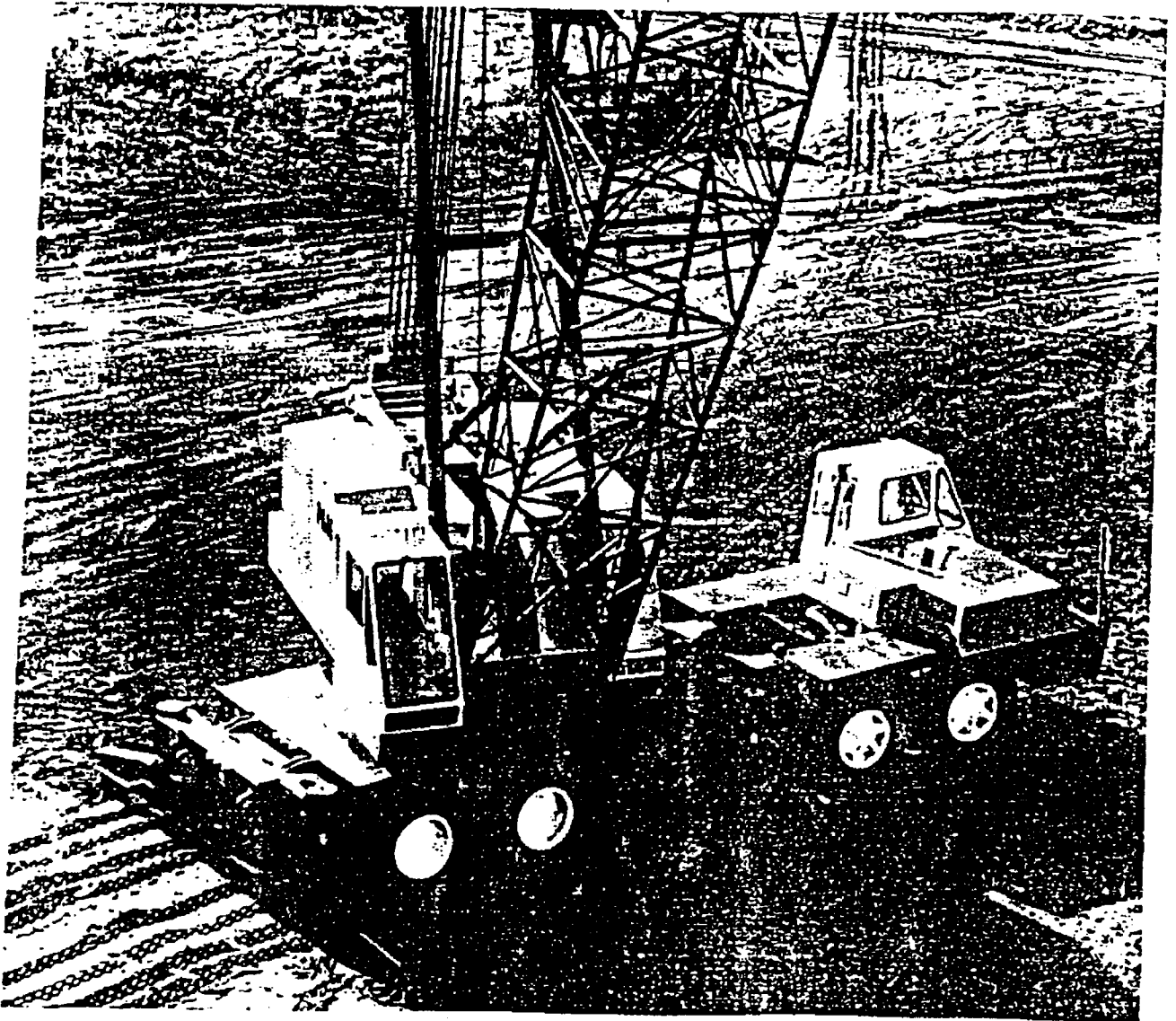
A6-829-006305A & -002137D

NOTES

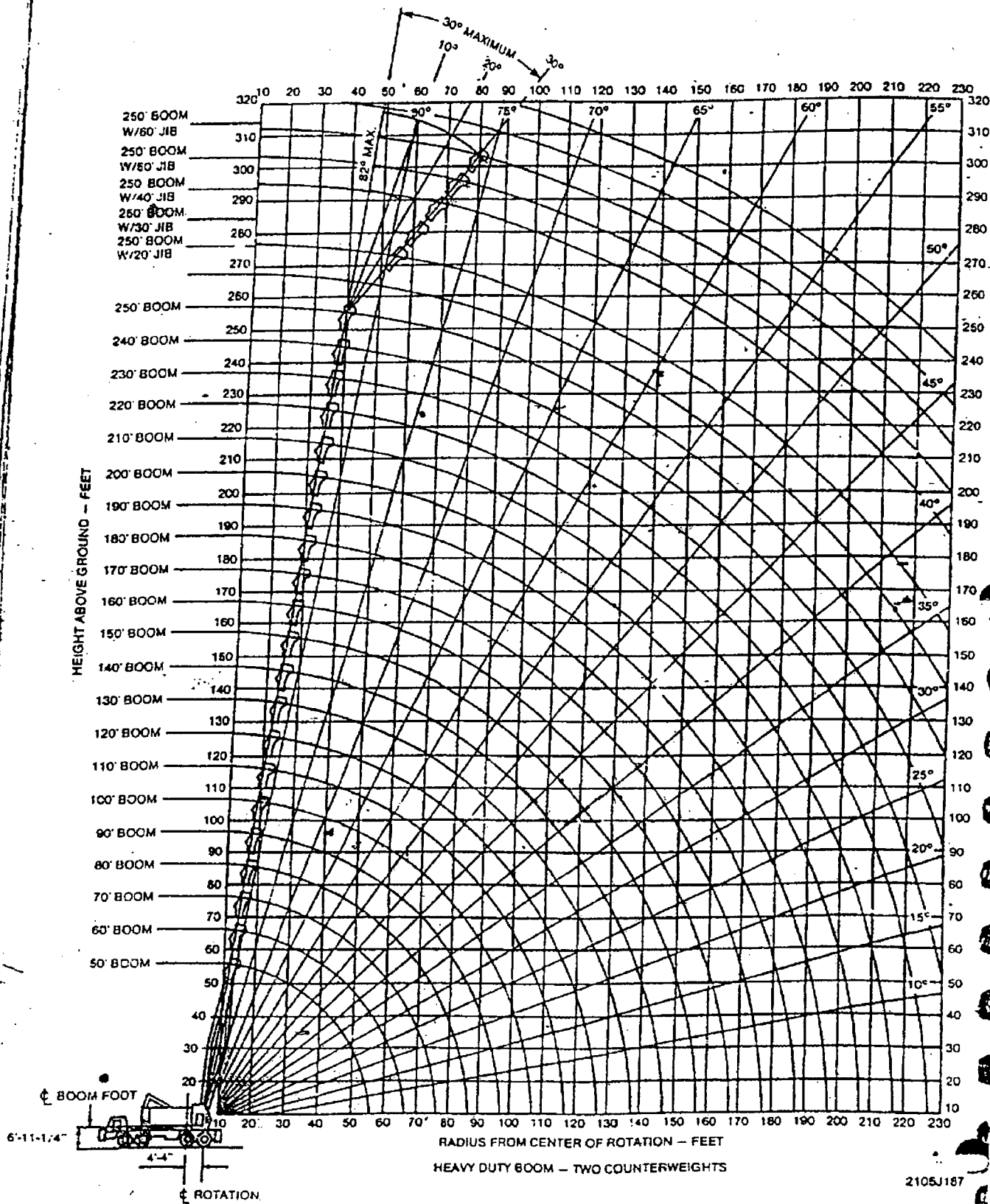
1. Not to be relied upon as a capacity limitation. Capacities do not exceed 85% of stability test code - SAE J-765.
 2. For stability.
 3. At rated load.
 4. Limited by boom angle only in the column headed by 104 ft. boom. For boom

P&H[®] 9150

150 ton Lattice Boom Truck Crane



- Travels under 100,000 lbs. — fast counterweight and outrigger stripdown.
- Torque Converter Transmission in upper.
- Longest Boom in Class — 330' maximum boom and jib.
- Short Lever Controls for operator comfort — powered by full flow hydraulics.
- Planetary Power Load Lowering.
- Super-Quiet Modular Cab.
- Sealed-in-steel crane gearing.





RATINGS LIFT CRANE SERVICE

two counterweights and
one bumper counterweight

69" x 69" boom
heavy duty tip (25')



outriggers extended and set

85% stability

rated boom loads in pounds

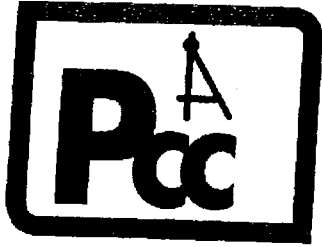
Boom Length (ft)	Load Radius (ft)	Boom Angle Δ°	Boom Point Elev. (ft)	Rated Load (lbs)		Boom Length (ft)	Load Radius (ft)	Boom Angle Δ°	Boom Point Elev. (ft)	Rated Load (lbs)	
				360°	Over Rear					360°	Over Rear
120	30	78.0	126.1	117,000	117,000	150	35	78.5	155.7	78,800	78,800
	35	75.6	124.9	93,300	99,700		40	76.5	154.6	76,000	77,500
	40	73.1	123.6	76,700	86,500		45	74.6	153.3	64,100	76,200
	45	70.5	121.9	64,800	77,000		50	72.6	151.9	55,100	65,800
	50	68.0	120.0	55,900	66,400		60	68.5	148.4	42,800	51,200
	60	62.7	115.5	43,500	52,000		70	64.3	144.0	34,300	41,400
	70	57.2	109.7	35,100	42,200		80	60.0	140.0	28,200	34,400
	80	51.3	102.5	29,100	35,200		90	55.9	138.7	24,300	29,100
	90	45.5	94.4	25,100	30,000		100	51.2	133.1	20,800	25,600
	100	38.3	83.1	21,500	26,400		110	46.0	125.7	17,800	22,300
	110	29.6	68.1	18,600	23,100		120	40.4	116.8	15,500	19,600
	120	17.5	44.6	16,200	—		130	34.1	92.8	13,600	17,300
130	35	76.7	135.2	92,100	92,100	140	26.4	75.4	11,900	15,300	
	40	74.4	134.0	76,500	84,400	150	15.6	48.9	10,500	—	
	45	72.1	132.5	64,600	76,700	160	40	77.4	164.9	69,400	69,400
	50	69.8	130.8	55,600	66,300		45	75.5	163.7	63,800	67,500
	60	65.0	126.6	43,300	51,800		50	73.7	162.3	54,800	65,500
	70	60.0	121.4	34,800	42,000		60	69.9	159.0	42,500	51,000
	80	54.7	115.0	28,800	34,300		70	66.0	155.0	34,000	41,100
	90	49.7	108.0	24,800	29,700		80	62.0	150.2	27,900	34,100
	100	43.6	98.5	21,200	26,200		90	58.3	145.0	24,100	28,800
	110	36.7	86.5	18,400	22,800		100	54.0	138.3	20,500	25,300
	120	28.4	70.6	16,000	20,100		110	49.4	130.3	17,600	22,000
	130	16.8	46.1	14,100	—		120	44.5	120.9	15,200	19,200
140	35	77.7	145.5	86,400	86,400		130	39.1	109.7	13,200	17,000
	40	75.5	144.3	76,300	81,500		140	33.0	95.8	11,500	15,000
	45	73.4	142.9	64,300	76,500	150	25.6	77.7	10,200	13,400	
	50	71.2	141.4	55,400	66,000	160	15.1	50.2	8,900	—	
	60	66.9	137.6	43,000	51,500						
	70	62.3	132.8	34,600	41,700						
	80	57.3	127.0	28,500	34,600						
	90	53.1	120.8	24,600	29,400						
	100	47.8	112.5	21,000	25,900						
	110	41.9	102.3	18,100	22,500						
	120	35.3	89.7	15,700	19,800						
	130	27.4	73.1	13,800	17,600						
140	16.2	47.5	12,100	—							

DEDUCTION FROM RATED BOOM LOADS WHEN
LIFTING OVER BOOM POINT WITH JIB ATTACHED

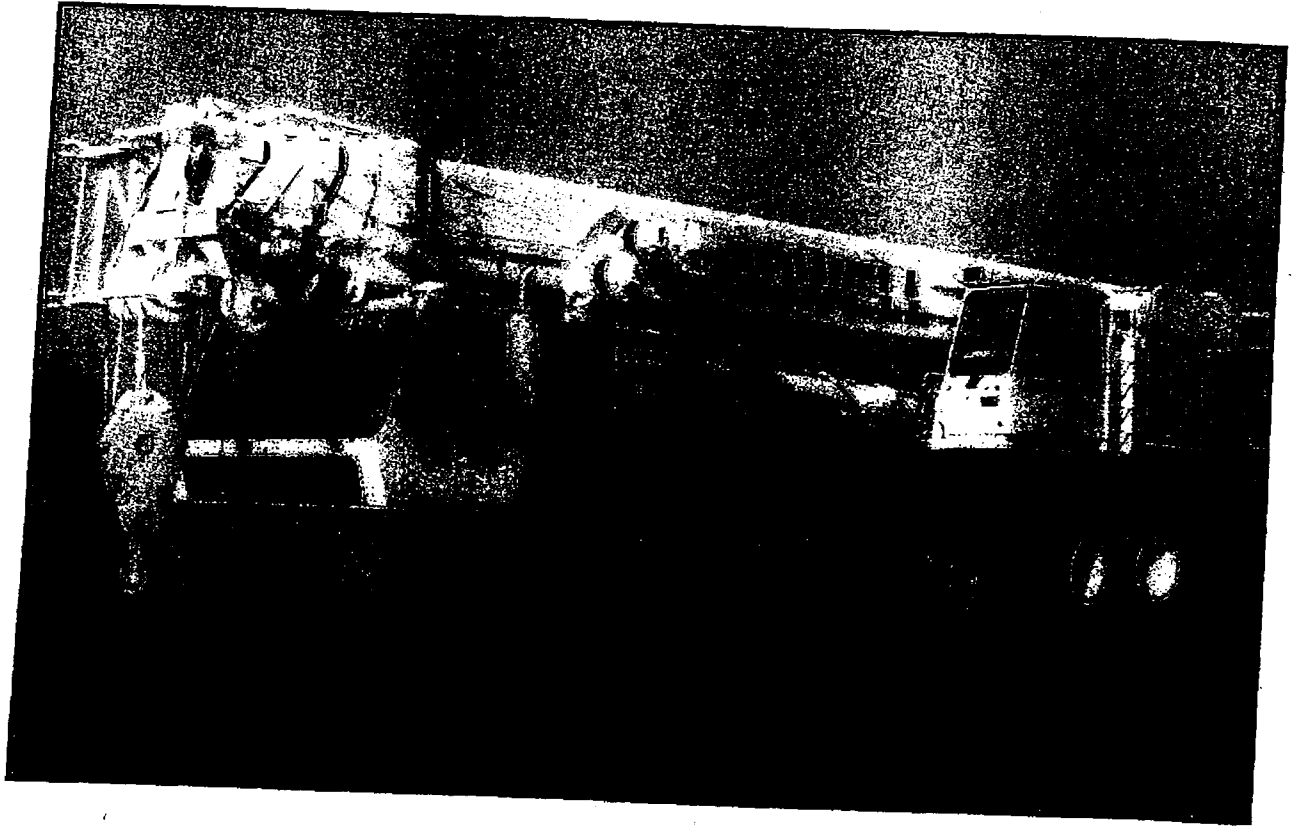
JIB LENGTH	20 FT.	30 FT.	40 FT.	50 FT.	60 FT.
DEDUCT — LBS.	1500	1500	2000	2500	3000

WARNING ⚠

Do not attempt to lift more than rated load at load radius shown, or lift where no radius or load is listed, as crane may tip or collapse.
Do not attempt to lift more than



Powell Construction Company



**KRUPP KMK 5175
175 TON CAPACITY
ALL TERRAIN CRANE**

Johnson City
(423) 282-0111

Knoxville
(423) 546-0245

Nashville
(615) 256-9600

Main Boom

Lifting Capacities in 1000 lbs

43 - 161 ft

360°

Counterweight **99,2*** lbs

Radius	Boom-length										Radius
ft	43 ft	43 ft	57 ft	72 ft	87 ft	102 ft	131 ft	146 ft	161 ft		ft
10	350,0	266,0	155,0	194,0	155,0	110,0					10
15	278,0	232,0	155,0	190,0	155,0	110,0	80,0				15
20	226,0	189,0	144,0	164,0	145,0	110,0	80,0	61,0	46,0		20
25	185,0	159,0	124,0	141,0	127,0	110,0	80,0	61,0	46,0		25
30	137,0	136,0	108,0	123,0	111,0	100,0	80,0	61,0	46,0		30
35			96,0	108,0	97,0	89,0	76,0	59,0	46,0		35
40			85,0	96,0	86,0	78,0	70,0	55,0	46,0		40
45			77,0	81,0	77,0	70,0	64,0	52,0	46,0		45
50				71,0	68,0	63,0	58,0	49,0	46,0		50
55				62,0	58,0	57,0	53,0	46,0	43,2		55
60					50,0	51,0	49,0	43,6	40,4		60
65					42,8	44,0	45,0	41,4	37,8		65
70					37,0	38,2	41,4	39,2	35,8		70
75					32,2	33,2	37,8	36,8	33,8		75
80						29,0	33,6	34,6	31,6		80
85						25,4	30,0	30,8	30,0		85
90						21,0	26,8	27,6	28,4		90
95							23,8	24,8	26,4		95
100							21,4	22,2	24,0		100
105							19,6	20,0	21,6		105
110							18,6	18,0	19,6		110
115							17,6	16,2	17,8		115
120							16,8	14,4	16,0		120
125								13,0	14,6		125
130									13,2		130
135									11,8		135
140									10,6		140
145									9,6		145

T1	T2	T3	T4	T1	T2	T3	T4
0	0	0	0	100	0	0	100
0	0	50	0	100	0	50	100
0	0	0	0	0	0	50	0
0	0	0	0	0	0	50	0

Counterweight **66,1*** lbs

Radius	Boom-length										Radius
ft	43 ft	43 ft	57 ft	72 ft	87 ft	102 ft	131 ft	146 ft	161 ft		ft
10	347,0	266,0	155,0	194,0	155,0	110,0					10
15	276,0	232,0	155,0	190,0	155,0	110,0	80,0				15
20	226,0	189,0	144,0	164,0	145,0	110,0	80,0	61,0	46,0		20
25	182,0	157,0	124,0	143,0	127,0	110,0	80,0	61,0	46,0		25
30	132,0	132,0	108,0	123,0	111,0	100,0	80,0	61,0	46,0		30
35			95,0	107,0	97,0	89,0	76,0	59,0	46,0		35
40			81,0	96,0	86,0	78,0	70,0	55,0	46,0		40
45			67,0	81,0	76,0	70,0	64,0	52,0	46,0		45
50				68,0	62,0	60,0	57,0	49,0	46,0		50
55				47,0	51,0	52,0	53,0	49,0	46,0		55
60					42,4	43,6	43,6	42,6	40,4		60
65					35,4	36,6	36,6	36,8	37,8		65
70					29,8	31,0	31,0	31,0	33,8		70
75					25,2	26,8	26,8	27,0	29,6		75
80					21,2	22,2	22,2	22,0	24,4		80
85						23,6	24,8	24,4	26,2		85
90						22,2	24,8	24,4	23,2		90
95						21,0	23,4	23,4	20,4		95
100							21,4	21,4	18,2		100
105							19,2	19,4	16,0		105
110							17,4	17,6	14,2		110
115							15,6	15,0	12,6		115
120							14,2	14,0	11,0		120
125							12,8	12,0	9,6		125
130								6,8	8,4		130
135								5,6	7,2		135
140									6,2		140
145									5,2		145

T1	T2	T3	T4	T1	T2	T3	T4
0	0	0	0	100	0	0	100
0	0	50	0	100	0	50	100
0	0	0	0	0	0	50	0
0	0	0	0	0	0	50	0

28' 2" x 26' 10" x 17' 9" ± 90° over rear

APPENDIX F: ORIGINAL PLATE GIRDER PRODUCTION SCHEDULE

Appendix F contains the tracking spreadsheet for the plate girder production.

Date 28-Dec-2009

PLATE GIRDER PRODUCTION TRACKER 409074A

PLATE GIRDER TRACKER 409074A						
		GIRDER	LENGTH	Tons	Bell Assoc Erection Date	Ship Date
1	3	103C1	108.56	19.78	16-Jan-10	
2	8	108C2	113.33	26.30	16-Jan-10	
16	4	104B1	108.82	22.21	16-Jan-10	
17	9	109B2	114.45	29.92	16-Jan-10	
31	5	105A1	109.09	25.56	16-Jan-10	
32	10	110A2	115.57	30.35	16-Jan-10	
46	1	101E1	108.04	18.88	17-Jan-10	
47	6	106E2	111.07	23.38	17-Jan-10	
61	2	102D1	108.30	19.20	17-Jan-10	
62	7	107D2	112.20	24.05	17-Jan-10	
3	13	113C3	118.01	20.00	23-Jan-10	
4	18	118C4	99.64	25.97	23-Jan-10	
18	14	114B3	119.12	21.70	23-Jan-10	
19	19	119B4	100.77	27.35	23-Jan-10	
33	15	115A3	120.21	24.63	23-Jan-10	
34	20	120A4	101.94	29.71	23-Jan-10	
48	11	111E3	115.84	19.41	24-Jan-10	
49	16	116E4	97.31	23.23	24-Jan-10	
63	12	112D3	116.93	19.81	24-Jan-10	
64	17	117D4	98.48	24.64	24-Jan-10	
5	21	121E5	114.98	19.23	30-Jan-10	
6	26	126E6	97.83	21.01	30-Jan-10	
20	22	122D5	116.35	20.60	30-Jan-10	
21	27	127D6	99.01	21.64	30-Jan-10	
35	23	123C5	117.71	20.83	30-Jan-10	
36	28	128C6	100.19	26.13	30-Jan-10	
50	24	124B5	119.12	21.07	31-Jan-10	
51	29	129B6	101.34	27.46	31-Jan-10	
65	25	125A5	120.48	26.06	31-Jan-10	
66	30	130A6	102.50	26.85	31-Jan-10	

PLATE GIRDER PRODUCTION TRACKER 409074A

PLATE GIRDER TRACKER 409074A					
		LENGTH	Tons	Bell Assoc Erection Date	Ship Date
	GIRDER				
7	31	131E7	125.73	21.16	6-Feb-10
8	36	136E8	31.76	6.95	6-Feb-10
22	32	132D7	127.21	21.70	6-Feb-10
23	37	137D8	32.14	7.12	6-Feb-10
37	33	133C7	128.70	22.93	6-Feb-10
38	38	138C8	32.52	7.20	6-Feb-10
52	34	134B7	130.20	23.18	7-Feb-10
53	39	139B8	32.90	7.27	7-Feb-10
67	35	135A7	131.72	26.99	7-Feb-10
68	40	140A8	33.27	10.04	7-Feb-10
9	43	143C9	104.05	18.08	13-Feb-10
10	48	148C10	94.54	18.81	13-Feb-10
24	44	144B9	105.25	18.34	13-Feb-10
25	49	149B10	95.66	19.04	13-Feb-10
39	45	145A9	106.46	18.86	13-Feb-10
40	50	150A10	96.75	22.95	13-Feb-10
54	41	141E9	101.60	17.41	14-Feb-10
55	46	146E10	92.34	18.01	14-Feb-10
69	42	142D9	102.83	17.87	14-Feb-10
70	47	147D10	93.44	18.61	14-Feb-10
11	51	151E11	81.39	13.48	20-Feb-10
12	56	156E12	89.95	16.65	20-Feb-10
26	52	152D11	82.38	13.80	20-Feb-10
27	57	157D12	91.00	17.19	20-Feb-10
41	53	153C11	83.34	13.96	20-Feb-10
42	58	158C12	94.16	17.39	20-Feb-10
56	54	154B11	84.30	14.32	21-Feb-10
57	59	159B12	93.17	17.60	21-Feb-10
71	55	155A11	85.29	15.18	21-Feb-10
72	60	160A12	94.24	17.80	21-Feb-10

PLATE GIRDER PRODUCTION TRACKER 409074A

PLATE GIRDER TRACKER 409074A					
		LENGTH	Tons	Bell Assoc Erection Date	Ship Date
	GIRDER				
13	61	161E13	65.05	10.76	25-Feb-10
14	66	166E14	116.95	24.63	25-Feb-10
28	62	162D13	65.86	11.01	25-Feb-10
29	67	167D14	118.27	25.30	25-Feb-10
43	63	163C13	66.61	11.13	25-Feb-10
44	68	168C14	119.64	25.61	25-Feb-10
58	64	164B13	67.37	12.17	26-Feb-10
59	69	169B14	120.97	28.00	26-Feb-10
73	65	165A13	68.15	12.22	26-Feb-10
74	70	170A14	122.32	33.93	26-Feb-10
15	71	171E15	118.72	20.05	27-Feb-10
30	72	172D15	119.85	20.50	27-Feb-10
45	73	173C15	120.96	22.57	27-Feb-10
60	74	174B15	122.09	25.96	27-Feb-10
75	75	175A15	123.24	34.42	27-Feb-10

Cprice@pdmbridge.com
386 937 3815

Date 28-Dec-2009

PLATE GIRDER PRODUCTION TRACKER 409074A

PLATE GIRDER TRACKER 409074A						
		GIRDER	LENGTH	Tons	Bell Assoc Erection Date	Ship Date
1	3	103C1	108.56	19.78	16-Jan-10	
2	8	108C2	113.33	26.30	16-Jan-10	
16	4	104B1	108.82	22.21	16-Jan-10	
17	9	109B2	114.45	29.92	16-Jan-10	
31	5	105A1	109.09	25.56	16-Jan-10	
32	10	110A2	115.57	30.35	16-Jan-10	
46	1	101E1	108.04	18.88	17-Jan-10	
47	6	106E2	111.07	23.38	17-Jan-10	
61	2	102D1	108.30	19.20	17-Jan-10	
62	7	107D2	112.20	24.05	17-Jan-10	
3	13	113C3	118.01	20.00	23-Jan-10	
4	18	118C4	99.64	25.97	23-Jan-10	
18	14	114B3	119.12	21.70	23-Jan-10	
19	19	119B4	100.77	27.35	23-Jan-10	
33	15	115A3	120.21	24.63	23-Jan-10	
34	20	120A4	101.94	29.71	23-Jan-10	
48	11	111E3	115.84	19.41	24-Jan-10	
49	16	116E4	97.31	23.23	24-Jan-10	
63	12	112D3	116.93	19.81	24-Jan-10	
64	17	117D4	98.48	24.64	24-Jan-10	
5	21	121E5	114.98	19.23	30-Jan-10	
6	26	126E6	97.83	21.01	30-Jan-10	
20	22	122D5	116.35	20.60	30-Jan-10	
21	27	127D6	99.01	21.64	30-Jan-10	
35	23	123C5	117.71	20.83	30-Jan-10	
36	28	128C6	100.19	26.13	30-Jan-10	
50	24	124B5	119.12	21.07	31-Jan-10	
51	29	129B6	101.34	27.46	31-Jan-10	
65	25	125A5	120.48	26.06	31-Jan-10	
66	30	130A6	102.50	26.85	31-Jan-10	

PLATE GIRDER PRODUCTION TRACKER 409074A

PLATE GIRDER TRACKER 409074A					
		LENGTH	Tons	Bell Assoc Erection Date	Ship Date
	GIRDER				
7	31	131E7	125.73	21.16	6-Feb-10
8	36	136E8	31.76	6.95	6-Feb-10
22	32	132D7	127.21	21.70	6-Feb-10
23	37	137D8	32.14	7.12	6-Feb-10
37	33	133C7	128.70	22.93	6-Feb-10
38	38	138C8	32.52	7.20	6-Feb-10
52	34	134B7	130.20	23.18	7-Feb-10
53	39	139B8	32.90	7.27	7-Feb-10
67	35	135A7	131.72	26.99	7-Feb-10
68	40	140A8	33.27	10.04	7-Feb-10
9	43	143C9	104.05	18.08	13-Feb-10
10	48	148C10	94.54	18.81	13-Feb-10
24	44	144B9	105.25	18.34	13-Feb-10
25	49	149B10	95.66	19.04	13-Feb-10
39	45	145A9	106.46	18.86	13-Feb-10
40	50	150A10	96.75	22.95	13-Feb-10
54	41	141E9	101.60	17.41	14-Feb-10
55	46	146E10	92.34	18.01	14-Feb-10
69	42	142D9	102.83	17.87	14-Feb-10
70	47	147D10	93.44	18.61	14-Feb-10
11	51	151E11	81.39	13.48	20-Feb-10
12	56	156E12	89.95	16.65	20-Feb-10
26	52	152D11	82.38	13.80	20-Feb-10
27	57	157D12	91.00	17.19	20-Feb-10
41	53	153C11	83.34	13.96	20-Feb-10
42	58	158C12	94.16	17.39	20-Feb-10
56	54	154B11	84.30	14.32	21-Feb-10
57	59	159B12	93.17	17.60	21-Feb-10
71	55	155A11	85.29	15.18	21-Feb-10
72	60	160A12	94.24	17.80	21-Feb-10

PLATE GIRDER PRODUCTION TRACKER 409074A

PLATE GIRDER TRACKER 409074A					
		LENGTH	Tons	Bell Assoc Erection Date	Ship Date
	GIRDER				
13	61	161E13	65.05	10.76	25-Feb-10
14	66	166E14	116.95	24.63	25-Feb-10
28	62	162D13	65.86	11.01	25-Feb-10
29	67	167D14	118.27	25.30	25-Feb-10
43	63	163C13	66.61	11.13	25-Feb-10
44	68	168C14	119.64	25.61	25-Feb-10
58	64	164B13	67.37	12.17	26-Feb-10
59	69	169B14	120.97	28.00	26-Feb-10
73	65	165A13	68.15	12.22	26-Feb-10
74	70	170A14	122.32	33.93	26-Feb-10
15	71	171E15	118.72	20.05	27-Feb-10
30	72	172D15	119.85	20.50	27-Feb-10
45	73	173C15	120.96	22.57	27-Feb-10
60	74	174B15	122.09	25.96	27-Feb-10
75	75	175A15	123.24	34.42	27-Feb-10

WORKS CITED

- AASHTO (2002). "Standard Specifications for Highway Bridges." 17th edition
- AASHTO (2003). "Guide Specifications for Horizontally Curved Steel Girder Highway Bridges"
- Dassault Systèmes (2010). ABAQUS/Standard Version 6.10, Dassault Systèmes, Inc. Providence, RI, <http://www.simulia.com/>
- Helwig, T. A. (1994). "Lateral Bracing of Bridge Girders by Metal Deck Forms." Doctoral dissertation, University of Texas, Austin, TX.
- White, D., Coletti, D., Leon, R., and Yadlosky, J. (2008). "NCHRP 12-79: Guidelines for Analytical Methods and Erection Engineering of Curved and Skewed Steel-Deck Girder Bridges." Unpublished.