

## **ABSTRACT**

### **FATIGUE PERFORMANCE OF UNCOATED AND GALVANIZED COMPOSITE PRESS-BRAKE-FORMED TUB GIRDERS**

The Short Span Steel Bridge Alliance (SSSBA) is a group of bridge and culvert industry leaders (including steel manufacturers, fabricators, service centers, coaters, researchers, and representatives of related associations and government organizations) who have joined together to provide educational information on the design and construction of short span steel bridges in installations up to 140 feet in length. Within the SSSBA technical working group, a modular, shallow press-brake-formed steel tub girder was developed. This new technology consists of cold-bending standard mill plate width and thicknesses to form a trapezoidal box girder. The steel plate can be uncoated or galvanized steel, as each is an economical option. Once the plate has been press-brake-formed, shear studs are welded to the top flanges. A reinforced concrete deck is cast on the girder in the fabrication shop and allowed to cure, forming a composite modular unit. The composite tub girder is shipped to the bridge site, expediting construction and reducing traffic interruptions.

The increased use of the press-brake-formed tub girders has led to the recognition that long-term service life testing of different steel types in this system have not been investigated. The cold-bending of the steel plate into the desired tub-girder shape creates residual stresses in the bends of the girder. At this time, the majority of prefabricated bridge elements undergoing fatigue testing are of traditional structural shapes. It is currently unknown if the high heat of galvanization affects the residual stresses in the bends of the tub girder.

The scope of this project is to determine if hot-dip galvanization affects the fatigue performance of a cold-bent shallow press-brake-formed steel tub girder. Two composite steel tub girders were constructed, one composed of an uncoated steel tub and the second composed of a galvanized steel tub. The composite system was fatigue loaded simulating a 75-year life in a rural environment. At a predetermined number of load cycles, a Service II load was applied to the system to observe the performance of the specimen. Strain gages were applied to the webs and bottom flange of each section to determine the actual moments induced in the system. Experimental results were used to evaluate any difference in the performance of the different steels used in the composite tub girder system. Results from this project show the type of steel does not have an influence on the fatigue performance of press-brake-formed tub girders.

# TABLE OF CONTENTS

ABSTRACT	II
TABLE OF CONTENTS .....	III
LIST OF TABLES.....	VII
LIST OF FIGURES.....	IX
CHAPTER 1: INTRODUCTION .....	1
1.1 BACKGROUND / OVERVIEW .....	1
1.2 PROJECT SCOPE & OBJECTIVES.....	1
1.3 REPORT ORGANIZATION.....	2
CHAPTER 2: LITERATURE REVIEW .....	3
2.1 INTRODUCTION .....	3
2.2 ACCELERATED BRIDGE CONSTRUCTION.....	3
2.2.1 Geosynthetic Reinforced Soil-Integration Bridge System.....	4
2.2.2 Slide-In Bridge Construction .....	5
2.2.3 Prefabricated Bridge Elements and Systems .....	6
2.3 PREVIOUS APPLICATIONS OF COLD-BENT STEEL GIRDERS.....	7
2.3.1 Prefabricated Press-Formed Steel T-Box Girder Bridge System (Taly & Gangarao, 1979) .....	7
2.3.2 Composite Girders with cold Formed Steel U-sections (Nakamura, 2002) .....	9
2.3.3 Folded Plate Girders (Developed at the University of Nebraska).....	10
2.3.4 Texas Department of Transportation Rapid Economical Bridge Replacement.....	11
2.3.5 MDOT Prefabricated Composite Steel Box-Girder Systems for Rapid Bridge Construction.....	12
2.3.6 Con-Struct Prefabricated Bridge System.....	13
2.4 PREVIOUS RESEARCH AT WVU ON PRESS-BRAKE-FORMED STEEL TUB GIRDERS .....	14
2.4.1 Development and Feasibility Assessment of Shallow Press-Brake-Formed Steel Tub Girders for Short-Span Bridge Applications (Michaelson 2014) .....	14

2.4.2 Experimental Evaluation of Non-Composite Shallow Press-Brake-Formed Steel Tub Girders (Kelly 2014) .....	17
2.4.3 Evaluation of Modular Press-Brake-Formed Tub Girders with UHPC Joints (Kozhokin, 2016).....	18
<b>2.5 CURRENT IMPLEMENTATIONS OF PRESS-BRAKE-FORMED STEEL TUB GIRDERS.....</b>	<b>21</b>
2.5.1 Amish Sawmill Bridge in Buchanan County, Iowa .....	21
2.5.2 Cannelville Road Bridge in Muskingum County, Ohio.....	23
<b>2.6 CORROSION PROTECTION SYSTEMS.....</b>	<b>24</b>
2.6.1 Corrosion Process.....	24
2.6.2 Painting Systems .....	27
2.6.3 Weathering Steel .....	29
2.6.4 Hot-Dip Galvanization.....	30
<b>CHAPTER 3: TUB GIRDER DESIGN EXAMPLE .....</b>	<b>33</b>
<b>3.1 INTRODUCTION .....</b>	<b>33</b>
<b>3.2 BRIDGE LAYOUT.....</b>	<b>33</b>
<b>3.3 GIRDER GEOMETRY .....</b>	<b>34</b>
<b>3.4 LOADS &amp; LOAD COMBINATIONS.....</b>	<b>37</b>
3.4.1 Component and Attachment Dead Load (DC).....	38
<b>3.5 MULTIPLE PRESENCE FACTORS &amp; LIVE LOAD DISTRIBUTION.....</b>	<b>40</b>
<b>3.6 STRUCTURAL ANALYSIS.....</b>	<b>41</b>
<b>3.7 LIMIT STATE EVALUATIONS .....</b>	<b>47</b>
3.7.1 Cross Section Proportion Limits (AASHTO Article 6.11.2) .....	47
3.7.2 Constructability.....	49
3.7.3 Service Limit State.....	49
3.7.3.1 Permanent Deformations .....	49
3.7.3.2 Elastic Deformations.....	51
3.7.4 Fatigue Limit State.....	52
3.7.5 Strength Limit State.....	55
3.7.5.1 Flexure .....	55
3.7.5.2 Shear .....	61

3.7.5.3 Ductility .....	63
3.7.6 Shear Connectors .....	63
<b>3.8 PERFORMANCE SUMMARY .....</b>	<b>67</b>
<b>3.9 AASHTO EQUATION REFERENCES .....</b>	<b>67</b>
<b>CHAPTER 4: EXPERIMENTAL TESTING .....</b>	<b>69</b>
<b>4.1 INTRODUCTION .....</b>	<b>69</b>
<b>4.2 OVERVIEW OF TESTING PROGRAM .....</b>	<b>69</b>
<b>4.3 SPECIMEN DESCRIPTIONS .....</b>	<b>72</b>
<b>4.4 INSTRUMENTATION .....</b>	<b>74</b>
4.4.1 Instruments .....	74
4.4.2 Layout of Strain Gages .....	74
4.4.3 Layout of LVDTs .....	76
<b>4.5 TEST SPECIMEN ASSEMBLY .....</b>	<b>76</b>
4.5.1 Concrete Formwork .....	76
4.5.2 Reinforcing Bars .....	78
4.5.3 Concrete Deck Pour .....	79
<b>4.6 LOAD CONFIGURATION .....</b>	<b>81</b>
<b>4.7 LOAD MAGNITUDE DETERMINATION .....</b>	<b>82</b>
4.7.1 Load Determination Overview .....	82
4.7.2 Magnitude of Applied Loads .....	83
4.7.3 Number of Cycles .....	83
<b>4.8 TESTING PROCEDURE .....</b>	<b>84</b>
4.8.1 Procedure for Fatigue Testing .....	84
4.8.2 Procedure for Test to Ultimate Failure .....	85
<b>4.9 SUMMARY .....</b>	<b>85</b>
<b>CHAPTER 5: EXPERIMENTAL TESTING RESULTS .....</b>	<b>86</b>
<b>5.1 INTRODUCTION .....</b>	<b>86</b>
<b>5.2 CONCRETE STRENGTH .....</b>	<b>86</b>
<b>5.3 MOMENT CALCULATION .....</b>	<b>87</b>

5.3.1 Gage Configuration .....	87
5.3.2 Gage Data Selection .....	88
5.3.3 Linear Regression .....	90
5.3.4 Calculation of Induced Moment.....	91
<b>5.4 DEFLECTIONS .....</b>	<b>129</b>
<b>5.5 TEST TO FAILURE RESULTS .....</b>	<b>130</b>
<b>5.6 SUMMARY .....</b>	<b>133</b>
<b>CHAPTER 6: PROJECT SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK.....</b>	<b>134</b>
<b>6.1 PROJECT SUMMARY .....</b>	<b>134</b>
<b>6.2 RECOMMENDATIONS FOR CONTINUED RESEARCH.....</b>	<b>134</b>
<b>REFERENCES</b>	<b>136</b>
<b>APPENDIX A: LOADING CALCULATIONS .....</b>	<b>139</b>
<b>APPENDIX B: GAGE DATA.....</b>	<b>145</b>
<b>B.1 ORIGINAL RAW DATA FROM UNCOATED STEEL SPECIMEN .....</b>	<b>145</b>
<b>B.2 ORIGINAL RAW DATA FROM GALVANIZED STEEL SPECIMEN .....</b>	<b>154</b>