Creating Computational Tools for Industry- A Capstone Design Project Experience

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Abstract

Engineers at STUPP Bridge Company in Bowling Green, Kentucky are continually seeking ways to improve the heat curving process of girders to create a higher quality product while maintaining affordability and improving safety. A team of senior students in the mechanical engineering program at Western Kentucky University researched and provided computational tools on the development of improved design specifications for horizontally curved steel girder highway bridges. The study started in January 2015 with a literature review of available references. Although this work was focused primarily on available information and technology, portions of the research were also devoted to improving on the current state-of-the-art technology.

The recommended specifications and developed tools were based on the sound structural engineering principles. The recommended specifications were divided into two divisions: Division I – Design and Division II – Construction. The recommendations by the team and the computational tool generated in MS Excel were developed according to Division II - Construction of the AASHTO Standard Specifications.

The company provided technical support towards the completion of the project. The resources of the company were also available to the project team to clarify research/design requirements, to offer guidance for the heat curving, and to obtain components. The entire work was completed prior to May 1, 2015.

The developed tool was received well by the industry partner and they plan on testing and using the tool and recommendations in their future heat curving of girders. This capstone project experience proved that engineering students are capable of developing tools which can be very useful for industry partners. Both industry and university benefited from the project. The industry had a new tool to be implemented in their heat curving process and the university had graduates with some experience from working on a real engineering problem.

Keywords

Senior Design, Mechanical Engineering, Engineering Education

Introduction

The engineering programs mission statement at Western Kentucky University is:

> *…to produce, as its graduates, competent engineering practitioners. An engineering practitioner is one who has a foundation of basic science,*

> *mathematics, and engineering knowledge, combined with practical knowledge and experience in applying existing technology to contemporary problems. … Program curricula will be project-based. Students will have sufficient opportunity to engage in project activities to support development of a clear understanding of engineering practice. … Projects that provide opportunity to accomplish design, development, and implementation should be available.*

To achieve this outcome, Western Kentucky University ME students experience a curriculum where they can acquire design tools and skills, as well as competency in mathematical and technical analysis, and communication.[1-2] The curriculum is consistent with the Criterion 5 requirements EAC of ABET: "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints." [3]

Stupp Bridge, a company that fabricates steel I-Beams for bridges, presented the challenge to Western Kentucky University to research and create documents to aid in the process of heat curving steel girders being built for highway bridges. The company mainly relied on the experience of their workers and technicians in heat curving of girders. The sponsors at Stupp were interested in finding ways to standardize their process by which steel girders were heat curved. Affordability, safety, and improved repeatability were key components to this project. A team of WKU Mechanical Engineering students who used the moniker of Team Scoober was assigned to complete the task. Starting with a general project outline and scope from the sponsor, the team researched and created documents to standardize and aid technicians with the heat curving for horizontally curved steel girder highway bridges. The team approach was guided by the standards and parameters from American Association of State Highway and Transportation Officials (AASHTO). Once the gathered information was assessed a detailed spreadsheet guideline of heat curving of girders was prepared. The spreadsheets are used as an aid for the heat curving process from the beginning, design phase all the way to the final portion where the heat curving actually takes place. The guideline created was divided into two portions; Division I – Design and Division II – Construction adhering to the AASHTO standards and specifications. The final deliverables by from the project met the requirements and expectations of the Stupp Bridge Company.

Heat curving of girders

In the early days of curved bridge design and construction, bridge superstructures supporting curved roadway alignment was comprised of short straight girders linked together at the supports. This resulted in inefficient use of very short spans between support piers. As the technology for designing and fabricating curved girders became available, it became possible to design curved bridges with much greater distances between supports.

Nowadays, curved girders are widely used in bridge superstructures. The past four decades have resulted in advances in optimizing curved bridge design, as well as innovative, and aesthetically pleasing structures.[4-5] However, the design and construction of bridges becomes complicated due to the addition of curvature. Straight bridges, the girders, stringers, and floor beams can be designed by systematically isolating each member and applying standard loads, while the system-wide behavior should be taken in consideration for designing of the curved bridges.[6-7] In other words, the addition of curvature will add torsion to the system that results in extra warping and distortional stresses within the beam cross-sections. Figure 1 shows schematically the heat curving process where multiple spots on I-beam are warmed out with a certain distance from each other.

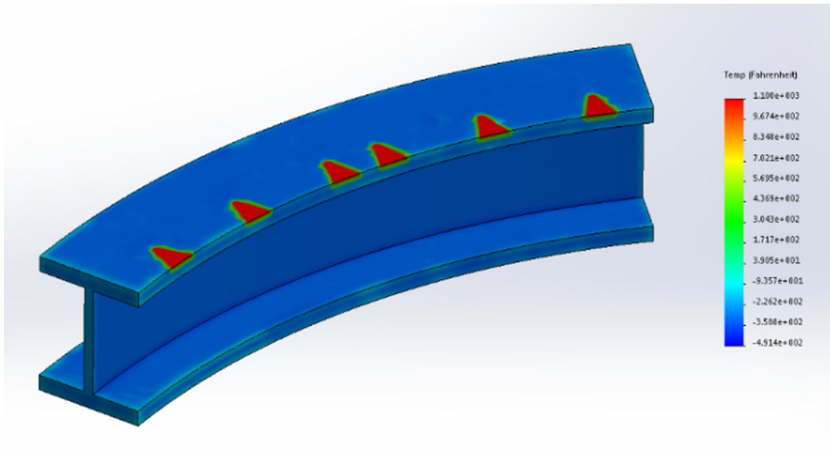

Figure 1. I-Beam under the heat conditions during the heat curving process. The color indicates temperature zones created by heating

Results

The student team developed a spreadsheet to determine if the suggested design parameters of a beam would allow that beam to be heat curved. This spreadsheet would require the geometry and material data of a beam to be entered and would return a minimum radius of curvature allowed through heat curving. A sample of this spreadsheet entry screen is shown in Figure 2.

The AASHTO Beam Guidance Spreadsheet was created to aid in the design and quoting stage of the curved bridge building process. This document defines the parameters and guidelines that must be adhered to in order to curve a steel highway beam using a heating process. This set of parameters is designed to insure that the structural integrity of a curved beam is not risked by heat curving. If the heat curving process would decrease the strength of the beam an alternative curving process (cutting a curved beam as opposed to taking a straight beam and curving it with heat) would have to be used. The problem with this alternative method of creating a curved beam is that it generates a lot of wasted steel scrap and is, therfore, the far more expensive and less desirable method for making a curved girder.

Upon opening the AASHTO Beam Guidance Spreadsheet the user should first select which profile best fits the beam in question. This is done by clicking on the appropriate tab at the bottom of the page from the three choices: Doubly Symmetric, Singly Symmetric, and Hybrid.

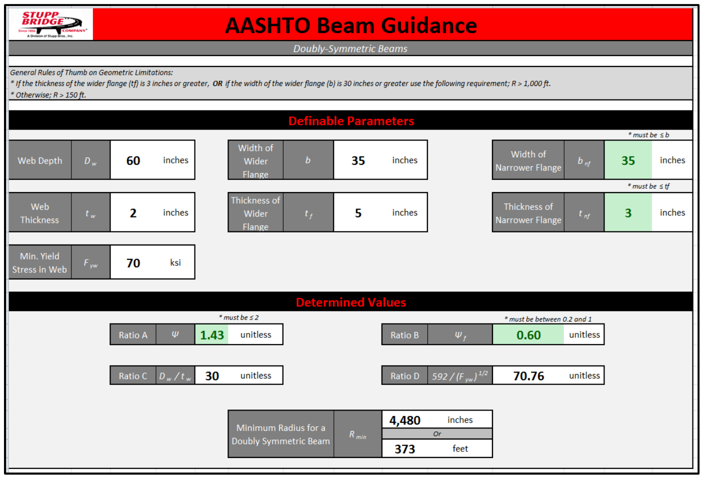

Figure 2. Sample image from the AASHTO Beam Guidance Spreadsheet

After the correct sheet has been selected, some general rules of thumb can be seen at the top of the page. These are preliminary critera that must be met and can quickly help the user determine whether or not the beam in question is eligible for heat curving. If these criteria are satisfied the next step is to input the geometric and material properties of the beam that are prompted for in the definable parameters section of the sheet. Some of the cells in this section have logical statements above them which inform the user of which values are acceptable. If the cells appear green when a value is entered the entry is acceptable. If the cell appears red the value is not acceptable and must be changed to satisfy the logical statement. If none of the cells are red the correct minimum radius is displayed in the determined values section of the sheet. If this radius is smaller than that called for in the design the girder can be safely heat curved. Otherwise, the girder must be cut-curved.

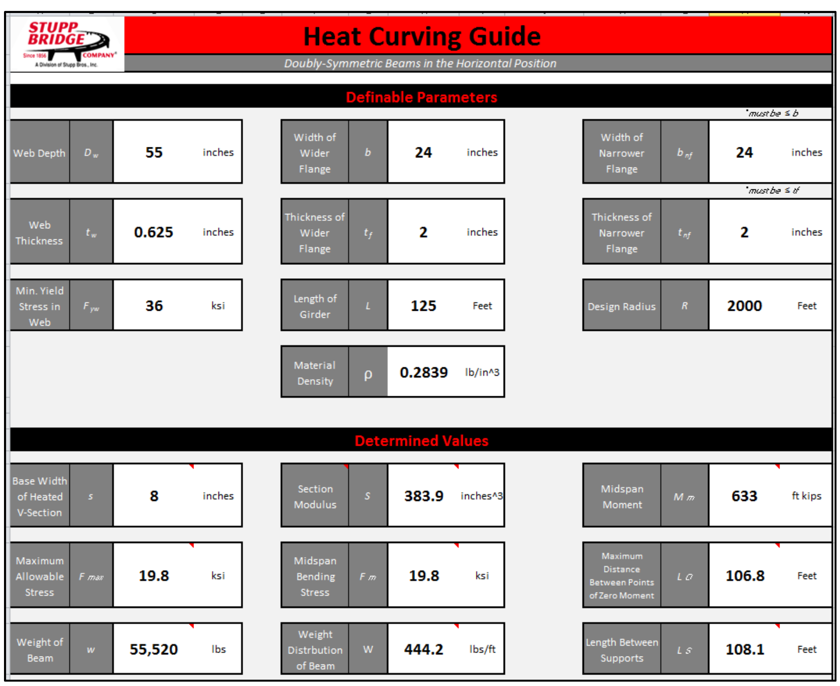

Figure 3. Sample image from the Heat Curving Guide showing input variables as well as calculated values

The team developed the second spreadsheet to be used to determine the proper spacing between heat zones during the heat curving process and was determined using the U.S. Steel Heat Curving document given to the team by Stupp.[8] A sample of this spreadsheet is shown in Figure 3. Where the AASHTO Beam Guidance Spreadsheet is meant to be used during the design phase the Heat Curving Guide was made to assist in the physical curving process. The calculations in this spreadsheet are based on the "U.S. Steel Fabrication Aids for Girders Curved with V-Heats" which is used by the Stupp team as a method of estimating the correct heating pattern for a particular girder. Students created this spreadsheet as a reliable guide to assist in the curving of standard doubly symmetric girders having no steps in the flange thickness.

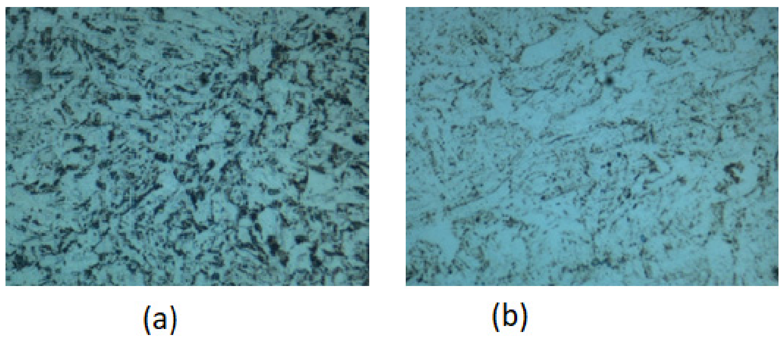

Figure 4. (a) Steel at 1000x magnification before heating, and (b) at 1000x magnification after heating

A third deliverable for this project was a brief metallographic analysis of the steel I-Beams and assessing the effects of the heating during the heat curving process. Sample results are shown in Figure 4. The metallographic analysis was completed using two samples of 70WT2 Steel which is one of the most common steel types used. The before and after micrographs reveal that there are changes from the heating process in the microstructure, however these changes are not enough to be detrimental to the beam. The heating temperature and time creates insignificant changes in the grain size or morphology. The curve that is achieved through heating results from a mechanical mechanism due to the geometry of the beam rather than from microscopic alterations.

Senior Design course

The course (ME 412) which housed this project is a continuation of ME 400 and provides students with a capstone engineering design experience. The grading in ME 412 is 2/3 team based and 1/3 individual. The expected course outcomes for ME 412 are: 1) Use structured problem-solving techniques, appraise the needs of clients, produce product/project definition documents, and propose appropriate engineering solutions; 2) Execute a design from inception through completion, and convey/document solutions in a wide variety of formats – including effective oral business presentations, and clear, concise project documentation that flows from general to specific; 3) Successfully manage projects using management tools such as timelines, responsibility charts, etc; and 4) Participate effectively in multi-disciplinary teams, demonstrating that they are effective team members and evaluating the performance of team members.

The student performance is assessed via their scores on intermediate activities related to their final projects (design reviews, update presentations) and final project results (reports, presentations, demonstration). In general, students are proving themselves to be effective team members, are capable of demonstrating structured problem solving and are successfully managing projects from; inception to completion.

Conclusions

Overall this project provided the experiences necessary to achieve the desired outcomes of our ME Program. In particular, this project was very suitable to the two-course sequence for our capstone senior project, ME400 – Mechanical Engineering Design and ME 412 – Mechanical Engineering Senior Project. The work done by team Scoober in the Spring of 2016 is the ground work for a future project that could span multiple semesters by WKU engineering student teams. The accomplishments include; initial metallographic work and analysis, the creation of the AASHTO Beam Guidance spreadsheet which is used to determine the minimum radius of curvature for a given beam design, and the creation of the Heat Curving Guide – Doubly Symmetric Beams spreadsheet which is used to determine the proper spacing between heating zones.

The team drafted both the interim and final project status reports to address the specific guidelines of the sponsor. This project was presented at the 46th WKU Annual Student Research Conference where their work was favorably reviewed by peers and other faculty within the university community. It was also presented to the Mechanical Engineering Advisory Board.

The Western Kentucky University ME curriculum assures that program graduates have experienced the engineering profession and demonstrated the ability to perform in a professional manner. The team project demonstrated student competence in the areas of Engineering Design, Professional Communications, Professional Tools, and Ethics.

The industry sponsored design projects in the Senior Design course serve as an effective means to begin the practice of engineering. The project provided an excellent activity for the students to develop and demonstrate their Engineering Design proficiency. It is an appropriate senior-level project because the technical and organizational requirements are sufficient for this stage of the educational process. The introduction of a partially defined problem and an external customer prepares the teams for expectations after the senior year.

Acknowledgments

The authors acknowledge the contributions of the student team: Johnathon Keith, Jackson Massengale, Duc Nuygen, and Brandon Hanna. The authors would like to acknowledge the support of STUPP Bridge Company and Mechanical Engineering Advisory Board member, Derek Clemons, who has generously sponsored this project.

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Prior to joining WKU, Morteza Nurcheshmeh worked two years as postdoctoral fellow at University of Windsor. He possesses five years industrial experience in energy auditing, metal cutting and power generation fields. His teaching specialties are in engineering mechanics, mechanical vibrations, materials science, design and manufacturing processes. Research areas include metal forming processes, forming limits prediction in sheet metals, and formability testing.

Christopher Byrne

Christopher Byrne has been teaching in Mechanical Engineering at WKU for over 16 years. This includes engineering science and design courses from the freshman to senior year of the program. He is active in research and industry outreach, with specialization in materials science, friction and wear mechanisms, non-destructive evaluation and failure analysis.