Timber Bridge Competition

E90 Project Proposal

12/6/06

Abstract

The goal of this project is to design and build a timber bridge to win the 2007 National Timber Bridge Design Competition (NTBDC). Once the bridge and timber type have been determined, we will use FEMLAB to analyze and finalize our design which will follow the NTBDC rules. Design and construction documents will be created using AutoCAD and the bridge will be assembled and tested on campus. All timber should be provided by one of the competition's sponsors, the Pennsylvania Forest Products Association (PFPA), and the cost of additional building and loading components is estimated to be between $400, with full timber sponsorship, and $1500 without any sponsorship. Entering this competition places our team in direct contact with industry and fosters an appreciation of wood as a building material. It also provides positive publicity for Swarthmore College, as one of the main objectives of the competition is to promote the use of renewable resources such as timber.

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Jaime Cardenas

John Charles

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Fall 2006

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Introduction

For our senior design project we propose to compete in, and win, the 2007 National Timber Bridge Design Competition. In this competition, open to student chapters of the American Society of Civil Engineers (ASCE) and the Forest Products Society (FPS), each team is required to design, build, and test a bridge constructed from wood structural members. The competition has three main objectives: first, to promote interest in the use of wood as a competitive bridge construction material; second, to generate innovative and cost-effective timber bridge design techniques; and third is to develop an appreciation of the engineering capabilities of wood.

This competition was originally developed with rural America in mind. In rural America, there are thousands of deficient bridges that limit the movement of cattle and/or grain from fields to mills or barns. These same bridges also limit those in rural America easy access to goods and services. The U.S. Department of Agriculture (USDA) sees modern timber bridges as a partial solution to these problems. In addition to being economical, aesthetic, and easy to install, the USDA believes that a timber bridge can boost a local economy in that the timber bridge is built and used in the same community. Beyond this, wood is a renewable natural resource that is safe for use in agriculture applications.

This project proposal is divided in to several sections. In the technical discussion, we will present all of the competition rules and regulations regarding the bridge dimensions and minimum performance specifications. Some preliminary considerations for design methodology will also be presented in the technical discussion. The project plan section will discuss how we plan to complete the design, construction, and testing of the bridge. This will include a CPM flow chart and GANTT chart for our entire project. The project qualifications section will explain how we are qualified to undertake such a project. The division of responsibility section will detail how we plan to divide responsibility for the main tasks of our project. Finally, this proposal will have a detailed list of expected project costs. These costs will include all materials that are going to be not supplied by a sponsor.

Technical Discussion

The design constraints for this project have already been determined, in the form of the NTBDC rules. The design span of this bridge must be 3.8 meters from center line to center line of the supports. The maximum length of an individual member can not exceed 2.1 meters. However, there is no limitation on built-up and laminated members as long as the pieces of wood making up these members are less than 2.1 meters in length. The maximum width of the supporting base plates is 60 mm. There are no length constraints on cables, straps, rods or other tensioning devices. The horizontal clearance must be 1.4 meters from inside curb to inside curb. The vertical clearance must be 2.5 meters from the deck surface. The depth of the understructure is a maximum of 500 mm at the center-span and 1000 mm at the support bases measured from the top surface of the deck to the lowest point of the support structure. All the required bridge dimensions can be seen in cross-section in figure 1 and in plan in figure 2.

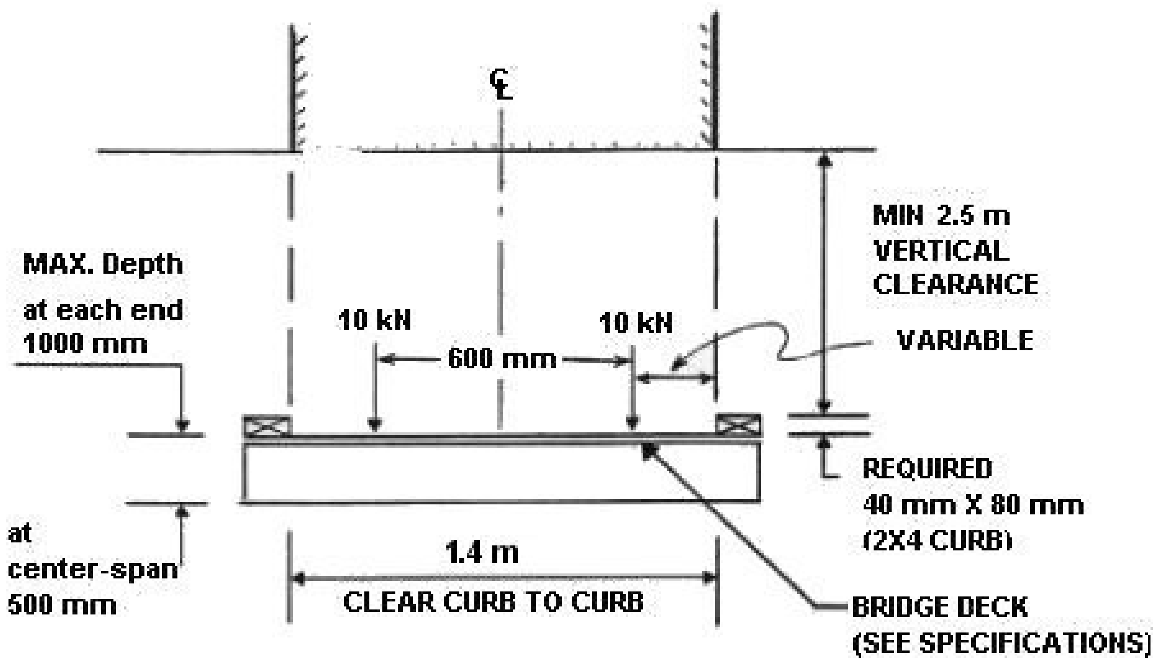


Figure 1: Cross-Sectional view of Bridge Dimensions

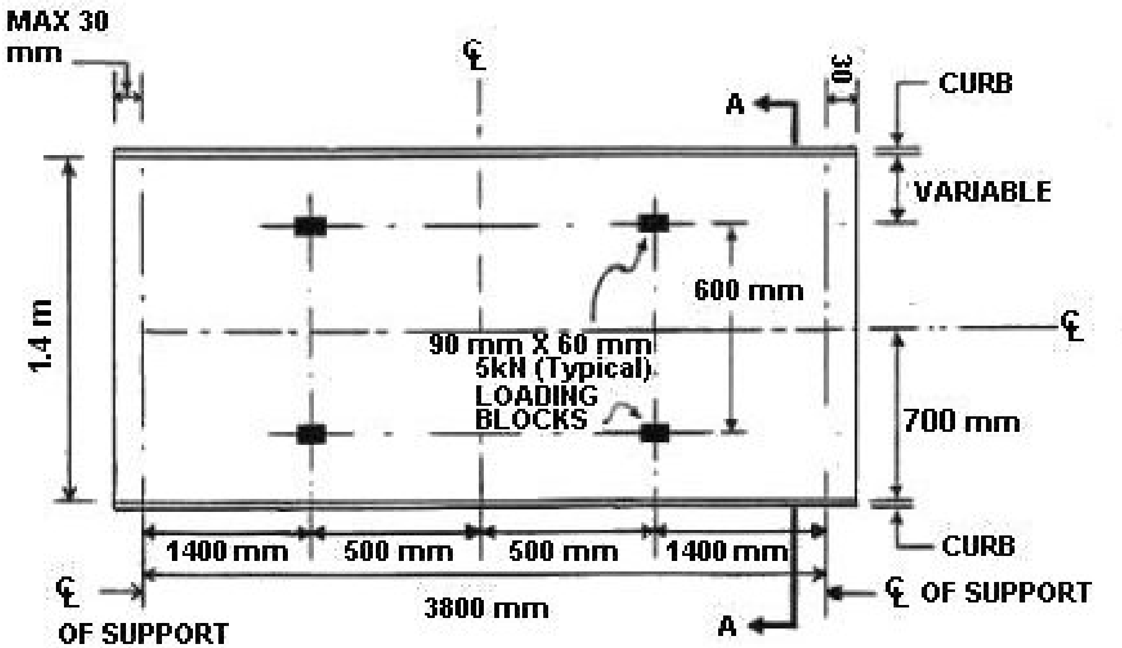


Figure 2: Plan View of Bridge Dimensions with Loading Setup

The bridge deck must be of uniform width and material, though not necessarily of wood. Any material can be used as long as it meets the following conditions. The material must be able to effectively transfer loads at all locations on its surface to the support structure. It must also not be an open grid and must be able to withstand repetitive loading and wear, thereby ensuring that the deck could withstand real-life applications. The curb does not need to resist a force, but it must be connected to the bridge. The total bridge weight is the weight before testing. It includes all parts of the bridge which form a part of the bridge as a structural system. All non-wood components of the bridge cannot exceed 25% of the total bridge weight. The test load for the testing is 20 kN for 1 hour. The load will be applied in four equal increments of 5 kN. The full 20 kN load can not be achieved in less than 5 minutes or more than 20 minutes. The deflection will be read by gauges after each 5 kN loading. In addition to this, there will be four deflection readings made every 15 minutes while under the one hour full loading condition. For a more detailed explanation of how the deflection will be measured, see the competition description in Appendix A. The loading points are four 90 mm x 60 mm loading blocks whose location on the deck of the bridge was predetermined by the competition rules. The exact dimensions required for the loading setup can be seen above in figure 2.

In order to perform the loading, we plan to place two steel I beams spanning the length of the bridge, each supported on two loading blocks. On top of these beams, we will place a wooden pallet, which we will load with cinder blocks, steel plates, and other dense materials in the increments described above. This loading scheme was used by the United States Military Academy Team in the 2005 competition, as shown below in figure 3.

Figure 3: Loading Setup Used by United States Military Academy Team in 2005 Competition

The competition will be judged largely based on deflection. Because of this, we will design the bridge by first ensuring that it meets these deflection requirements. Once the bridge has been designed to meet deflection requirements, checks can be made to ensure that stresses stay within acceptable levels. We anticipate that if the bridge is designed to minimize deflection at a specified load, then there will be sufficient reserve strength to guard against failure. If this is not the case, and the stresses developed are greater than the strength of the chosen material and factor of safety, then the member will be redesigned to keep stress at acceptable levels. Thus, the method of design used will most likely be a version of allowable stress design.

The type of timber selected will depend primarily on its availability and mechanical properties. Typical mechanical properties of interest for bridge applications are ultimate strength, density, and modulus of elasticity. Since limiting deflection is a primary design goal, a high modulus of elasticity would be desirable. Ultimate strength, though also important, is expected to be of less significance because the bridge is being designed to maintain a minimum deflection, not simply hold together. Density is not a particularly important design consideration since the weight of the bridge will be low compared to the load it carries. That being said, the weight of the bridge is considered in judgment, so a relatively light timber would be ideal. Other concerns include machinability and resistance to weathering. Although the bridge will not be used in the long term, it should be designed with long term use and life-cycle analysis in mind. Ideal species we are currently considering include white ash, sweet birch, rock elm and black locust. These species are all hardwoods, because our sponsor only deals in hardwoods.

Project Plan

The planning for this project began with a general brainstorming to develop a complete list of necessary tasks and contingencies. A detailed task list with established dependences and estimates of duration and effort is attached in Appendix B. These tasks are arranged in a Critical Path diagram in Appendix C. Finally, the entire project is visualized on a GANNT Chart in Appendix D. We believe that the conceptual scope of any given task in the project is well within our grasp, the challenge being consistent and efficient completion of the work. The GANNT Chart, therefore, will be indispensable to the bi-monthly project manager, who will use it to plan the work schedule for his work period. While the chart is a valuable starting point for planning and visualizing the course of the project, its true value will come as a constantly updated progress report.

Project Qualifications

All members of our group are senior engineering majors with a variety of experience relevant to the project. Relevant coursework includes Mechanics and Dynamics (E6), during which miniature wooden bridges were built and tested until failure, and Structural Theory and Design I (E 60). Two of the team members, Edward Goldstein and Peter Brennan, have also completed Engineering Materials (E82) and Mechanics of Solids (E59), where they learned about the engineering properties of wood and steel, and conducted a project on the structural properties of burned wood. In addition, each team member has significant experience in their major component of the project (see above).

Edward Goldstein has completed the machine shop course and will be enrolled in Structural Theory and Design II next semester. He has specialized in civil engineering through his coursework and spends spare time doodling bridge designs. Jaime Cardenas-Navia has used FEMLAB with MATLAB to analyze plates for summer research and has considerable programming experience in a variety of languages. He also has tested an assortment of materials for various properties through his coursework at home in Swarthmore College and abroad at the University of Auckland in New Zealand.

John Charles has extensive experience with AutoCAD through his summer work with Vollmer Associates where he made revisions to engineering and architectural design plans. While studying abroad at Edinburgh University in Scotland, he completed an AutoCAD design course that included 2-D truss bridge design. In addition, he has industry experience in designing timber beams for load-bearing applications. Peter Brennan spent this past summer working with the Pennsylvania Department of Transportation (PennDOT) inspecting and supervising construction projects. He has also completed Swarthmore College's machine shop course and will be enrolled in Structural Theory and Design II next semester.

Two of the tasks in detailed in Appendix B are reserved for research: one for wood design, and one for construction. This research is intended to familiarize each team member with suitable techniques for design and construction of timber structures, motivated by a desire to streamline our design and construction processes. While two team members have some experience with wood as an engineering material, having taken engineering materials, we are allowing time for all team members to refresh and expand their knowledge of wood and bridge design. The NTBDC website offers links to handbooks to this end in downloadable pdf format, which we have already begun to take advantage of. All team members have been assigned to read one handbook in particular, the USDA Forest Service Timber Bridge Handbook, over the winter break.

Division of Responsibility

While all team members will undoubtedly end up working on all aspects of the project, each member has been assigned a major component of the project based on their skills and interests. The goal is that each team member will become an expert in some facet of the project and serve as the principal engineer for all relevant tasks. It should be noted that the principal engineer is separate from the rotating bi-monthly project manager, whose responsibility is mainly scheduling of work to ensure task completion. Below is a summary of the major project activities and the team member or members responsible for that activity.

Phase I: Planning

- Peter Brennan, Edward Goldstein
  - Project Planning, CPM Diagram and GANNT Chart (and its upkeep)
- All Team Members
  - Contact supplier, determine sponsorship, ultimately arrange delivery
  - Research wood as a building material
  - Choose 2-3 timbers
  - Research competition rules, guidelines

Phase II: Preliminary Design

- All Team Members
  - Choose bridge type

    - Finalize timber selection
- Edward Goldstein
    - Complete bridge design

Phase III: Analysis and Final Design

- Jaime Cardenas-Navia
    - Comprehensive FEMLAB Analysis
    - Isolated joint testing
- John Charles
    - Draft AutoCAD portfolio
    - Order timber and other supplies

Phase IV: Construction

- Peter Brennan
    - Research construction methods
    - Create (refine) Critical Path for construction
- All Team Members
    - Member fabrication
    - Joint fabrication
    - Main assembly

Phase V: Load Setup Design and Testing

- John Charles
    - Design loading setup and procedure
    - Load bridge and record

Phase VI: Analysis and Report

- All Team Members
    - Write report
    - Prepare and practice presentation

Project Cost

Based on previous NTBDC entrance designs, we estimate that costs beyond the donated timber to be somewhere in the range of $400 to $800. This includes the cost of materials such as metal rods, brackets, hangers, screws, washers, bolts, nails, cable clamps, plates, and glue, in addition to the cost of materials for loading. We will be unable to accurately estimate our non-timber costs until all aspects of our bridge design and construction have been finalized. We have, however, been in contact with the Pennsylvania Forestry Products Association (PFPA) and are in the process of acquiring their support. Hopefully, they will agree to donate all wood materials for the project. Should we be unable to secure sponsorship, from the PFPA or others, we anticipate spending an additional $500 to $700 to purchase wood from a lumber yard. These estimates are based on the cost summaries of past teams that have purchased wood from lumber yards.

In addition to funding, this bridge will require a space reserved for its assembly. We propose to assemble, and most likely test, the bridge in the wet lab cage, in the basement of Hicks. This is, of course, dependent on departmental approval.

References

"Bridge Design and Test Setup." National Timber Bridge Design Competition. Southwest Mississippi Resource Conservation and Development (RC&D), Inc. 5 Dec 2006 <http://www.msrcd.org/bridge.htm>.

Ritter, Michael A. Timber Bridges: Design, Construction, Inspection, and Maintenance. Washington, DC: USDA Forest Service, FPL, 1992.

Seely, Oliver. "Physical Properties of Common Woods." CSU Dominguez Hills. 5 Dec 2006 <http://www.csudh.edu/oliver/chemdata/woods.htm>.

Appendix A

Maximum Vertical Bridge Deflection: Maximum allowed bridge deflection is 9.5 mm as recorded at midspan of the longitudinal beam receiving the greatest loading. Subtraction from deflection due to compression of supports will not be allowed. If two or more longitudinal beams are predicted to receive equal loading, select only one to monitor, or monitor all such beams and submit average deflection (contestant's choice).

Maximum Vertical Net Deck Deflection: Maximum allowed net deck deflection is deck span divided by 100, with deck span being measured as the shortest side of the largest "deck panel" formed by 2 longitudinal members and 2 transverse members, if applicable. "Deck panel" is defined as any area of clear-span deck bordered (i.e. defined) by the 2 nearest longitudinal bridge support members and the 2 nearest transverse support members, if applicable. In other words, deck span is the distance between points monitored by the 2 gauges at points 3 and 4 below. However, note that deck span is actually measured from inside structural member to inside structural member.

Gross deck deflection shall be measured under the centroid of the loading point placed where the deck is calculated to experience maximum deflection under full loading if the 4-point was moved anywhere on the deck. This point should be the same as the center of the largest "deck panel" described above. The selected loading point must be at the deck's weakest point. It must be halfway between any transverse members such as floor beams, deck stiffeners, cross-bracings, diaphragms, etc. that make contact with the deck's underneath surface. It must also be halfway between any adjacent longitudinal support members.

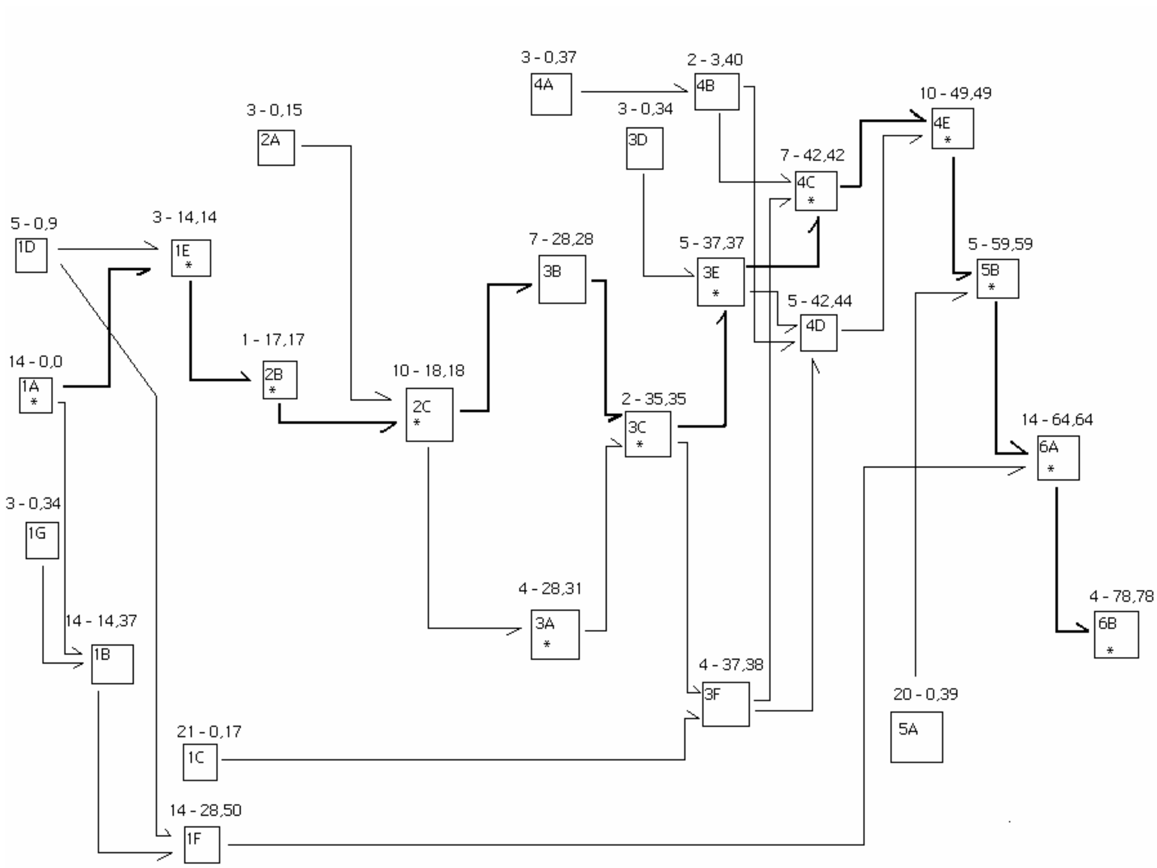
Net deck deflection shall be determined by subtracting the average of the deflections recorded in the 2 bridge structural members forming the longer side of the largest bridge "deck panel" as recorded at midpoint of the longest sides of the "deck panel" and as measured by gauges at points 3 and 4 below. See "Test Setup" sketch below for details on placement of the 4 loading points, size of bearing plates, etc.

Note that more than one loading setup may be required to properly measure both bridge deflection and deck deflection at their weakest points, i.e. at points of expected maximum deflection. Some designs may, however, allow for one loading setup to monitor both defections. If needed, the 4-point loading setup may be moved as a unit transversely <u>only</u> to monitor Maximum Vertical Bridge Deflection, but it may be moved as a unit both transversely and longitudinally to monitor Maximum Vertical Deck Deflection, thus placing any one of the four loading points over the center of the largest "deck panel".

Appendix B: Project Task List

Action	Activity	Duration (days)	Effort (hours)	Needs	Feeds
Phase 1: Planning (140-160 hours)					
Brainstorm for Project Plan	1-A	4	32		1-B
Write Draft Proposal	1-B	14	24	1-A, 1-G	1-F
Contact Supplier, Determine Sponsorship	1-C	21	8		3-F
Research Wood as building material	1-D	5	32		2-A, 1-E
Choose 2-3 timbers	1-E	3	8	1-D,1-A	2-A, 2-B
Write Final Proposal	1-F	4	20	1-D, 1-B	5-B
Research Competition Rules/Guidelines	1-G	3	12		1-B
			136		
Phase 2: Preliminary Design					
Choose Bridge type	2-A	3	24	1-D	2-B, 2-C
Finalize Timber Selection	2-B	1	12	1-E, 2-A	2-C
Design	2-C	10	120	2-A,2-B	3-B
			156		
Phase 3: Analysis and Final Design					
Isolated Material Testing	3-A	4	100	2-G	3-C
Comprehensive ANSYS Analysis	3-B	7	80	2-C	3-C
Finalize Changes to Design	3-C	2	28	3-A, 3-B	3-E, 3-F
Learn AutoCAD	3-D	3	32		3-E, 3-F
Draft AutoCAD Portfolio	3-E	5	44	3-C, 3-D	4-C, 4-D
Order timber and other supplies	3-F	4	20	1-C, 3-C	4-C, 4-D
			304		
Phase 4: Construction					
Research Construction Methods	4-A	3	32		4-B,
Create (Refine) Critical Path for Construction	4-B	2	20	4-A	4-C, 4-D
Member Fabrication	4-C	7	60	3-E, 3-F, 4-B	4-E
Joint Fabrication	4-D	5	44	3-E, 3-F	4-E
Main Assembly	4-E	10	100	4-B,4-C,4-D	5-B
			256		
Phase 5: Load Setup Design and Testing					
Design Loading Setup and Procedure	5-A	20	100		5-B
Load Bridge and Record	5-B	5	60	4-E, 5-A	6-A
			160		
Phase 6: Analysis and Report					
Write Report	6-A	14	100	5-B, 1-F	6-B
Compile and Practice Presentation	6-B	4	60	6-A	
			160		
TOTAL			**1172**		

Appendix C: Critical Path Diagram



Appendix D: GANNT Chart

Due to the difficult nature of this document for formatting, it has been emailed separately as an excel spreadsheet.