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Spaghetti Bridges: Build, Load and Repeat

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Abstract

The construction and subsequent loading of a bridge made out of spaghetti has proven to be an effective instructional tool in combining elements of materials science, mechanics (statics) and manufacturing. This paper reports the advantages of requiring the students to repeat their design layout with slightly different manufacturing criteria instead of just completing one design. The use of spaghetti bridges in introduction to engineering courses has been done before; however, only one bridge is typically done per student team. Requiring the students to design more than one bridge and loading each to failure has a greater impact on student learning by forcing the students to understand the consequences of the differences between their bridges. A description of the design project and the results from implementing the project in improving the impact on student learning and the appreciation of engineering are reported.

Introduction

The construction and subsequent loading to failure of a spaghetti bridge is detailed in Karweit¹. In this seminal work, the benefit of a “virtual lab” (www.jhu.edu/virtlab/bridge/truss.htm)² was used to dramatically improve the overall performance of the final designs, at least in two dimensional space, i.e. the maximum capacity was significantly increased by conducting virtual loading of the design.

Construction is a critical component of these spaghetti bridge projects. Construction clearly demonstrates the third dimension pitfalls¹. The bridge design criterion is detailed in the Materials and Methods section below. The use of spaghetti bridges in introduction to engineering courses has been done before; however, only one bridge is typically done per student team³. Construction of these bridges is labor-intensive, and as a result, rarely are prototypes constructed and tested. However, if the three to four person teams work efficiently, at least two full scale bridges can be constructed in an appropriate predetermined timeframe (typically five hours per bridge).

This paper will focus on the advantages of having the students repeat their design layout with slightly different manufacturing criteria versus just completing one design. As a result, each team will test two bridges to failure. A description of the design project and the results from implementing the project in improving the impact on student learning and the appreciation of engineering are reported.

Materials and Methods

Project Description:

Each team is to build two bridges made solely from spaghetti and epoxy. The objective is to construct a design that will carry the heaviest load while meeting the specifications summarized on the following page. Completed bridges are loaded until failure.

Rules and Specifications:

1. The bridge is to be built solely from spaghetti and five minute epoxy. Per three or four person team, the two bridges are to be as identical as possible with the **ONLY** exception being that one bridge can have epoxy at any location and the other bridge can only have epoxy up to 1.5 cm in any direction from the node. Disqualification will result if this is violated.
2. The bridge shall be free-standing and must span two level surfaces which are one-half meter (50 cm) apart (Figure 1).
3. Support for the bridge shall be from the *top* of the level surfaces only. The *edges* of the level surfaces cannot be used in any way for support.
4. The bridge must include a decking of spaghetti to provide a suitable “road surface” at least 5 cm wide across the full span of the bridge. Three conditions must be met:
 - a) gaps in the bridge deck are not to exceed 2 mm.
 - b) a block of wood (5 cm x 5 cm x 10 cm), representing a car, must be able to move the entire length of the span unobstructed.
 - c) the deck of the bridge must not be more than 5 cm above or below the ends of the bridge at any point along its length.
5. A “loading platform” consists of a piece of plywood (.7 cm x 5 cm x 10 cm) and an eye-bolt. This platform is to be attached at the center of the bridge such that the bottom of the eye-bolt is no more than 5 cm from the top of the bridge decking. All loads will be suspended from this eye-bolt, and there must be a clear space directly below the eye-bolt to allow loads to be attached. Loads will be attached using an S-hook (Figure 1).
6. The maximum vertical height of the bridge cannot exceed 25 cm.
7. The maximum mass of the bridge including the loading platform cannot exceed 200 grams (Figure 2).

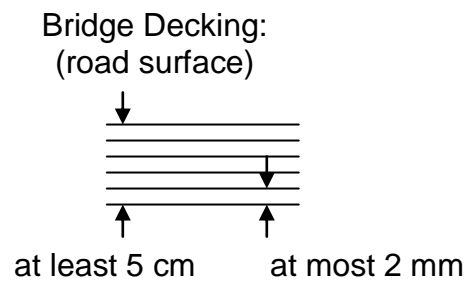
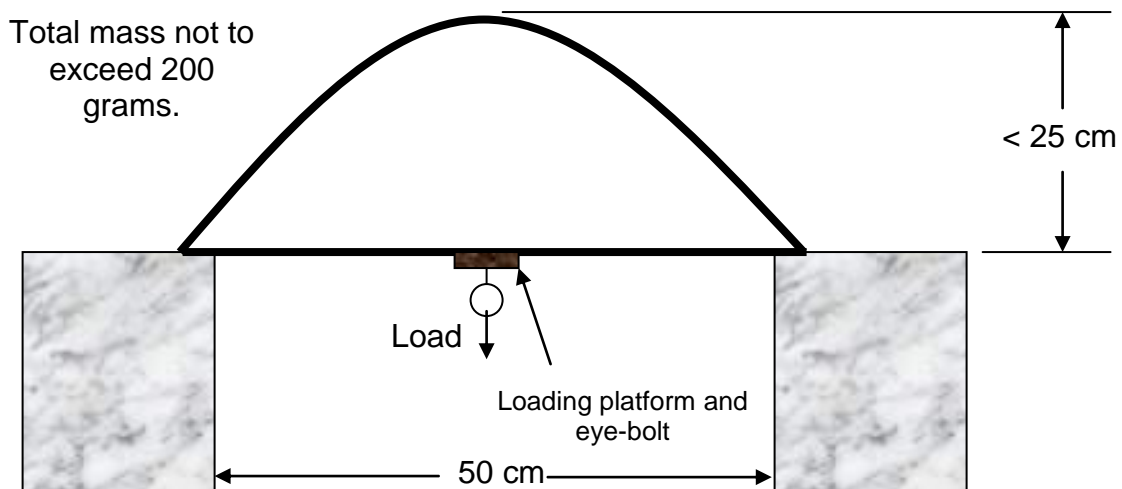


Figure 1: Bridge specifications. Note: not drawn to scale

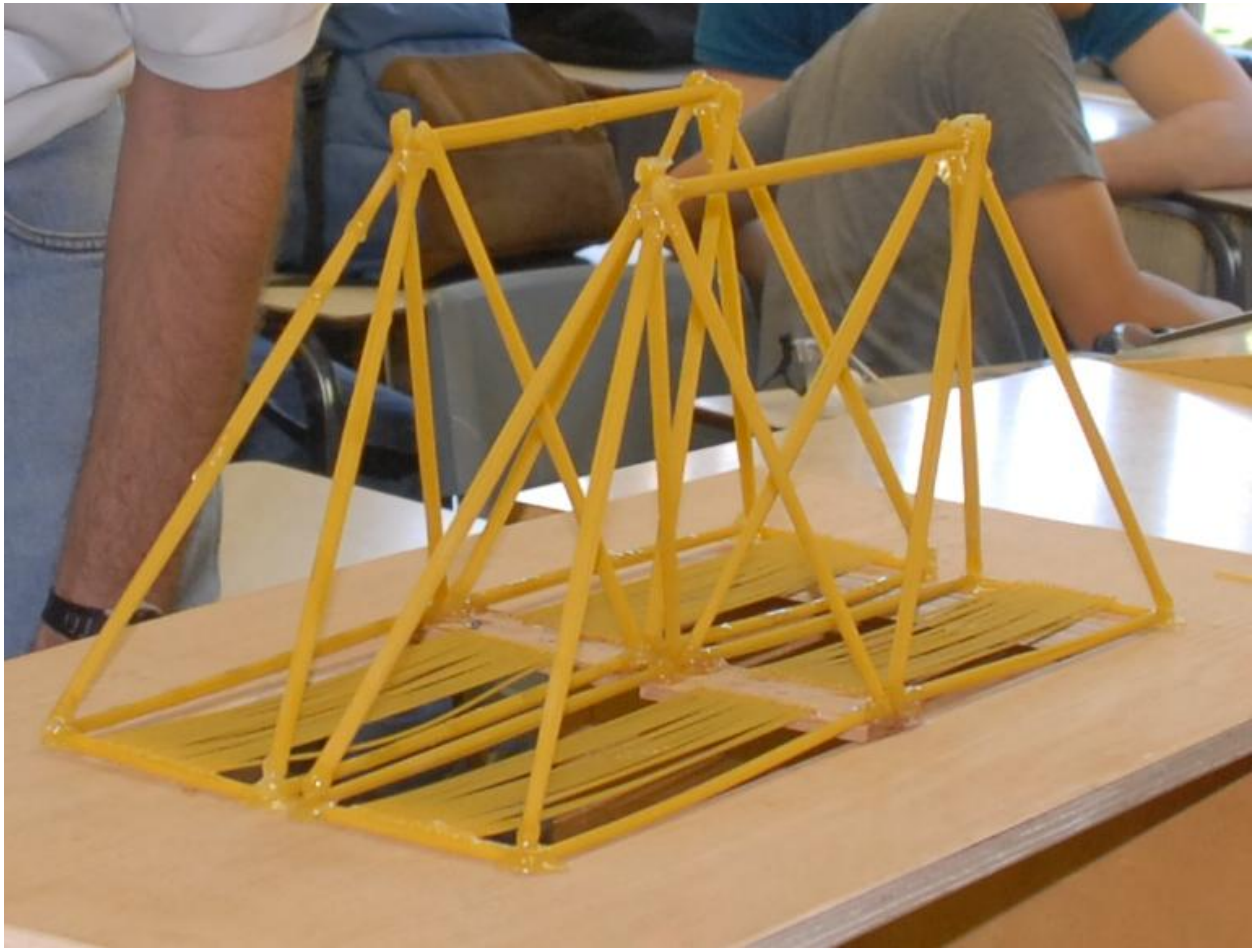


Figure 2: Spaghetti bridge testing.

Results and Discussion

Three or four person student teams were tasked with building two bridges using the criteria previously described. This preliminary study is summarized in Table 1: the load to failure for eight undergraduate teams in a second year materials science class. The “1.5 cm Epoxy Bridge” column refers to the bridge that only had epoxy up to 1.5 cm in any direction from a node. The “Unlimited Epoxy Bridge” permitted a liberal use of epoxy, but all bridges had to be less than or equal to 200 g.

Table 1: Load capacity per team for each bridge.

Team	1.5 cm Epoxy Bridge Load [kg]	Unlimited Epoxy Bridge Load [kg]
A	5	10
B	3	10
C	4	7.5
D	2	4.5
E	4	3
F	3	2
G	2	2
H	2	2

The liberal use of epoxy produced stronger bridges (e.g., teams A-D). However, when the design was fundamentally flawed as in teams E-H, an increase in load was not achieved and indeed the loads appear to plateau at a two kilogram load. This plateau which indicates little, if any, improvement in load capacity with added epoxy justifies the effort of manufacturing two bridges by serving as a learning tool for the students.

With only one bridge required in previous attempts at this project, teams would often dismiss poor performance as either a material and/or manufacturing defect. Their body language often suggested that their design would have been just fine if it were not for errors that could be fixed with improved materials and/or manufacturing skills. For teams E-H in Table 1, the data suggests that they had two attempts to improve their manufacturing skills, and despite the composite nature of a liberal use of epoxy, their bridge design did not perform well. In contrast, teams A-D in Table 1 increased their load capacity with epoxy/spaghetti composite thereby validating their design, and in the process serving as a means of emphasizing the difference in the material properties of spaghetti and epoxy.

From the instructors' perspective, there is always that fine line as to how much assistance one should provide. When an excessive amount of spaghetti and epoxy are devoted to the horizontal “road surface,” one can only ask the students how much load that portion of the bridge can possibly carry? In point of fact, if the students do not recognize that the roadway surface is not the best use of material, the actual loading of their bridge definitely highlights this point. The authors feel this is a valuable lesson to learn and witness by loading their bridges to catastrophic failure.

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