

# Freshman Engineering Clinic I

## Civil Engineering Measurements

### Truss Bridge Deflection and Design Exercise

#### Purpose of the Module:

This module is designed to introduce you to some of the concepts that are further explored in two of the sophomore-level engineering mechanics courses – Statics and Solid Mechanics. You will measure the deflections of an aluminum truss bridge and you will use your data to demonstrate important concepts in engineering mechanics. During the last part of the period, you will use a design program developed at the United States Military Academy at West Point to explore the relationship between strength and cost in the design of a truss bridge.

#### Engineering Definitions:

**Tension** is caused when a force is applied along the axis of a structural member and the length of the member increases.

**Compression** is caused when a force is applied along the axis of a structural member and the length of the member decreases.

A **Truss** is a structure composed entirely of tension and compression members with members connected by pins at the ends and arranged in rigid triangles.

A **Warren Truss** is a specific type of truss that is characterized by inverted-V pairs of diagonal members as shown in Figures 1, 2, and 3. The vertical members shown in Figures 2 and 3 help to distribute the actual vehicle loads to the other members in the truss.

A **Beam** is an individual structural member that is designed to resist lateral (usually vertical) loads. A beam that is supported at each end and is load vertically in the middle will experience compression in the top fibers of the beam and tension in the bottom fibers of the beam in direct proportion to the distance from the center of the beam.

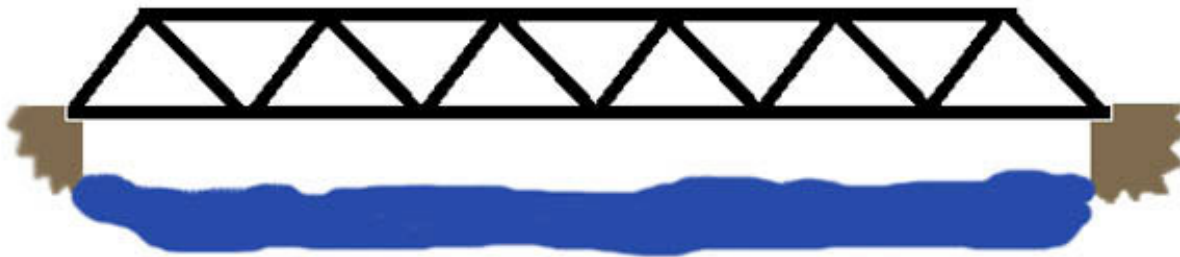


Figure 1 – Typical Warren Truss without Vertical Members



Figure 2 – Foxburg Bridge in Pennsylvania (Two Warren Trusses with Vertical Members)



Figure 3 – Scale Model of a Warren Truss with Vertical Members

**Strain** (typically given the symbol  $\varepsilon$ ) is a measure of how much a material stretches when a force is applied to it. It is defined as the change in length of the material divided by the original length,  $\Delta L / L_o$ . For example, if a one-inch rubber band is stretched until it is two inches long, the strain in the rubber band is  $1.0 = (2'' - 1'') / 1''$ . Strain is a dimensionless measurement.

When a Warren Truss, such as the ones shown in Figures 1, 2, and 3, has a vertical load applied downward at midspan, the members across the top of the truss (the top chord members) are all subjected to compression and are shortened, while the members across the bottom of the truss (the bottom chord members) are all subjected to tension and are elongated.

**Stress** (typically given the symbol  $\sigma$ ) is a measure of load intensity. It has units of force/unit area. Stress is directly related to strain through the relationship  $\sigma = E \varepsilon$ . The constant E represents a material property known as the modulus of elasticity.

**Strength** is a measure of the load that causes a structure or component to fail. The American Society for Testing Materials (ASTM) produces standards for material testing to ensure consistency in reported material properties. A standard test for the strength of metals is to pull a bar in tension until failure.

**Deflection** is the measure of the vertical displacement of a point on a truss or beam. Deflection is usually denoted by the Greek symbol delta ( $\delta$ ).

**Stiffness** is the measure of the ability of a truss or beam to resist vertical deflection. For a solid rectangular beam, the measure of stiffness is the moment of inertia  $I = \frac{b h^3}{12}$  where  $b$  = the width of the beam cross-section and  $h$  = the height of the beam cross-section.

**Levels** are field instruments that are used to project a level plane (a plane of constant elevation) in surveying (Figure 4). Levels are used to determine the difference in elevation (vertical distance) between two points on the surface of the Earth. Levels consist of a scope that magnifies the image of the target and a set of crosshairs that are used to determine the reading on the target. The target is either a graduated rod or ruler. Each level has a vial that is filled with fluid and a single bubble that is used to level the instrument and establish the level plane.



Figure 4 – Typical Surveying Level

### **Historic Background:**

In 1638, Galileo Galilei published *Dialogues Concerning Two New Sciences* while he was under house arrest for his previous publications supporting the Copernican theory of the solar system. His 1638 publication dealt with the resistance of solid bodies to fracture and with the motion of solid bodies. These are topics covered in statics, solid mechanics, and dynamics. This work was based upon experiments he conducted throughout his life.

In *Dialogues Concerning Two New Sciences*, Galileo presents a series of propositions relating breaking strength to the geometry of prisms and cylinders. These propositions were developed based upon experimentation and geometry. For the most part, Galileo's propositions were correct. Two of his propositions (with paraphrased versions in parenthesis) are as follows:

1. The resistance to breaking is proportional to the cube of the height of the element (the deflection of a beam is a function of the inverse of the cube of the height of the beam).
2. If a hollow element and a solid element (Figure 5) are constructed to the same length and have the same cross-sectional area, the hollow section's resistance to fracture will be greater than the solid element's by the proportion of their diameters (the hollow element will have greater resistance to lateral deflection and buckling compared with the solid element in proportion to the relative diameters of the two elements).

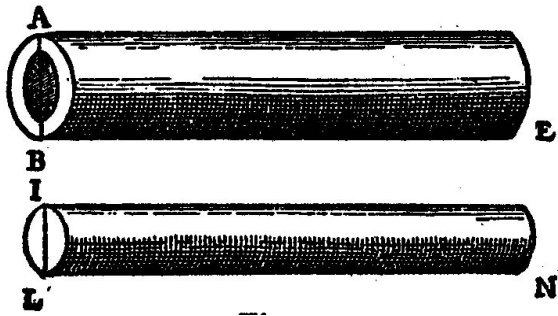


Figure 5 – Galileo's Hollow and Solid Cylinders

### **Laboratory Procedure:**

For the laboratory portion of this module, a 96-inch aluminum Warren truss has been set up in Room 302. This truss has a height of 14 inches and has rulers that are graduated in tenths and hundredths of an inch attached to the top. Loads of 0, 25, 50, 75, and 100 pounds will be applied to the truss and the vertical deflections of the truss under each load will be measured.

To measure the deflection, each group will use a level to determine the reading on the ruler when the truss is unloaded. Using the level, readings at loads of 0, 25, 50, 75, and 100 pounds will also be taken. By subtracting the readings under each load from the reading under 0 load, the vertical deflection can be determined. Each group will repeat these measurements twice using different levels. Because there are only 4 levels and 5 groups, the truss will be loaded and unloaded a total of 3 times.

**At the end of the laboratory measurements today, your team should turn in a copy of all of the raw lab data that you collected for the aluminum Warren truss and your calculated deflections. This data sheet should have the names of all of your team members on it.**

### **Laboratory Report:**

#### **Required Exercises:**

1. Calculate the average deflections under each load case (0, 25, 50, 75, and 100 pounds) and then plot the deflections versus the applied loads.

**Based on the measurements you made and your plot of deflection versus load, what is the relationship between applied load and deflection? Using the**

**data supplied by the professor, how well do your measurements compare with the calculated deflections? What could have caused the differences?**

2. If the height H of the truss were increased from 14 inches to 16, 18, 20, 22, or 24 inches, the truss would become stiffer and the deflections would be reduced. Using the deflections calculated by the professor for aluminum trusses with heights of 14 to 24 inches, plot the truss deflection versus truss height.

**What is the relationship between truss deflection and truss height? Is Galileo's first proposition applicable to trusses? Explain your answer.**

3. The strength of truss members that are under compression (the top chord members in a Warren Truss) is a function of the member's ability to resist buckling, which is a sudden catastrophic failure. The theoretical force P that will cause a compression member to buckle is calculated using the following formula which was derived by Euler:

$$P = \frac{\pi^2 E I}{L^2}$$

Where: E = Modulus of Elasticity of the material =  $29 \times 10^6$  psi for steel

I = moment of inertia

L = length of the member, inches

**Two steel compression members have lengths of 240 inches and cross-sectional areas of  $14.6 \text{ in}^2$ . If the first compression member is a solid round steel rod with a diameter  $D = 4 \frac{3}{16}$  inches and a moment of inertia  $I = 17 \text{ in}^4$ , while the second compression member is a hollow round steel tube with a diameter  $D = 12$  inches and a moment of inertia  $I = 279 \text{ in}^4$ , what will be the critical compression load P for each of these compression members? How do these results compare with Galileo's second proposition, i.e. was Galileo correct, partially correct, or wrong, and why?**

### **Final Lab Report:**

When your team meets next week for the third civil engineering module, you will need to turn in a typed team lab report for the second civil engineering module following the team report format previously distributed.

Your team's answers to the questions listed above should include justification for the answers provided. That will usually require more than just one or two words. Your team's answers should include enough justification such that a technically trained individual would be convinced you were not just guessing.