Laboratory Exercise -- Week 12
The Truss

In Class Session: Tuesday 11/18/08
Laboratory Work: Wednesday-Friday, 11/19-21/08
Laboratory Report Due: In Class, Wednesday 11/26/08

Overview

A three-dimensional truss is tested under transverse loading and the load-deflection characteristics and the internal bar/member strains are measured. From the latter, the internal bar/member loads are determined. These latter derived results are compared to results obtained from analysis using a two-dimensional model of the truss. Thus, comparison can be made between the model of the truss and the performance of an actual truss, and therefore some examination of the validity of some of the assumptions made in forming the model can be examined.

In performing the laboratory, each student is introduced to a number of types of instrumentation and associated concepts. These are strain gages and the measurement of strain; deflection meters; loads cells; load-displacement relations; and the use of experimental/empirical calibration to obtain indirect measurements of one parameter via the direct measurement of another parameter (in this case, member loads via member strains).

The performance of the laboratory requires three parts: work before coming to the laboratory ("Pre-Lab Preparation"); work during the laboratory ("In-Lab Work"); and work to be done after leaving the laboratory ("Post-Lab Work").

Background

As was discussed in lecture, trusses are used for a number of different structures. They are structurally very efficient (i.e. they can carry high loads for a given mass of structure), so they are widely used for bridges, general building structures, and space structures, and also were used for early airframes. In the context of Unified Engineering, trusses are also useful to us in introducing you to structural analysis, as they are relatively simple structures to analyze. However, it is important to realize that for trusses, and for any other structure that we design or analyze, the analysis is performed on an idealization of the actual, physical structure. In conducting any structural analysis, it is crucial at some point to assess whether the modeling assumptions required to perform the analysis are justified. This laboratory exercise will give you a chance to explore the assumptions we have made in order to analyze trusses.

In this laboratory exercise, you will test the performance of a truss with dimensions as shown in Figure 1 by placing loads of different magnitudes in the middle of the truss. This Howe truss configuration is two identical two-dimensional trusses, connected by intervening members. This particular truss consists of four bays of the same length. The height of each bay is equal to its length. The intervening members have the same length as the length of each bay. The overall span is 2 meters.

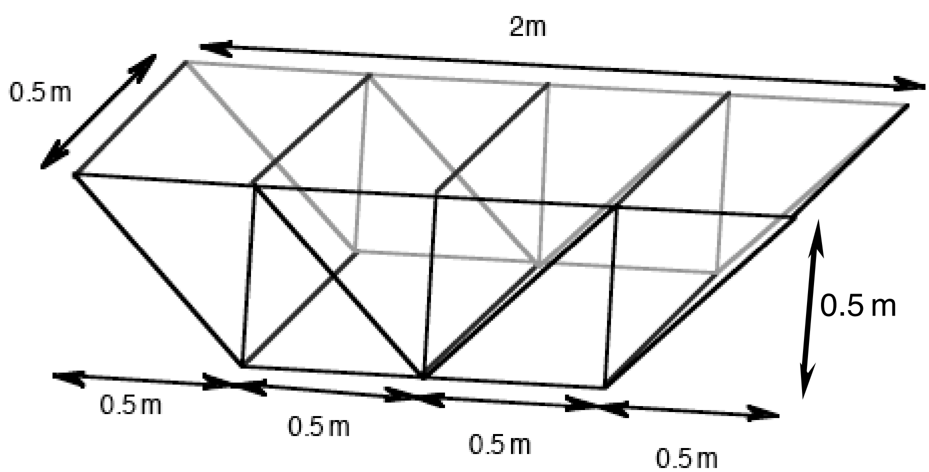

Figure 1. Illustration of truss configuration (two two-dimensional Howe trusses connected by intervening members) used in the lab.

You will then compare your experimental results to results from an analytical model for this configuration.

Truss Model

In order to perform an analysis, the real physical device must be modeled such that the *analytical model* can be relatively simply analyzed. However, the model must also capture the essential physics of the situation. In this case, it is assumed that the three-dimensional connections are such that the two two-dimensional trusses are loaded evenly. Thus, the full three-dimensional configuration is represented by a two-dimensional Howe truss having the same dimensions as the experimental model.

The connections at the end of the trusses are assumed to be statically-determinate. Thus, one connection is pinned and the other is a roller. Additional assumptions are:

a) The truss members and joints have no mass.

b) The load that the structure must support is distributed across the intervening member connecting the joints between the second and third bays in the two-dimensional trusses so that this load is assumed to be evenly distributed between each of the two two-dimensional trusses. Thus, for each two-dimensional truss, the applied load is modeled as a point load, equal to half the total load, concentrated at the joint between the second and third bays and the midspan of the truss. This results in a load as noted in the accompanying illustration of the analytical model contained in Figure 2.

c) The normal assumptions associated with "idealized planar (two-dimensional) trusses" of:

1. All bars are straight,
2. Bar joints are frictionless pins,
3. Bars are massless and perfectly rigid for loading analysis,
4. All loads and reactions are applied at the joints,
5. Loads in members are colinear, and
6. Thus, bars carry only axial forces.

This results in the analytical model configuration shown in Figure 2.

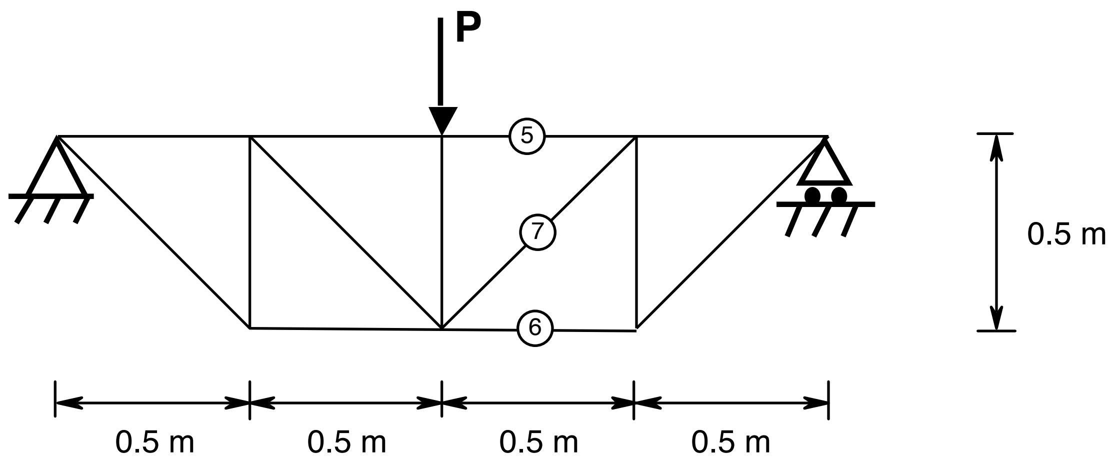

Figure 2. Illustration of two-dimensional model to be utilized for analysis.

Experimental Apparatus and Setup

Loading Setup

The experimental model of the full-scale truss is supported on a pair of unistrut supports with a horizontal separation of 2 meters as shown in Figure 3.

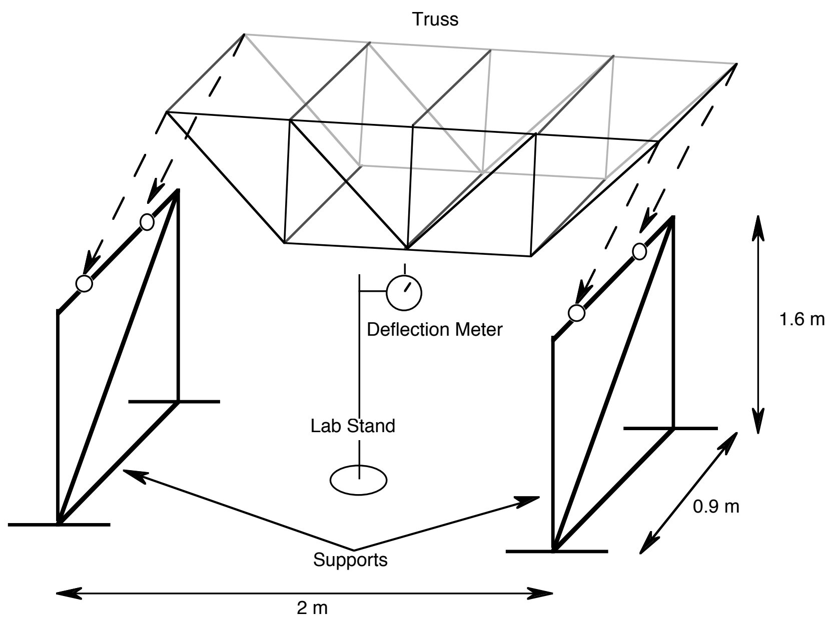

Figure 3. Illustration of experimental supports and truss configuration. Note that the dashed arrows indicate where the truss will actually rest on the supports.

The truss is loaded using the jack and pulley set-up shown in Figure 4. This set-up is placed at the joints between the second and third bays so that the load is applied at the same point as shown in Figure 2.

Load Cells and Instrumented Bars

In this work, we wish to measure the load applied to the overall structural configuration as well as load in specific members of the truss. This is done via an *indirect measurement and calibration technique*.

The two *load cells* are attached to the loading bar and to the loading cable and are thus in the line of load on each end. These bars are instrumented with *strain gages* and give a direct reading of the strain in the bars (see next subsection for further description). The load cells are basically aluminum bars instrumented with strain gages

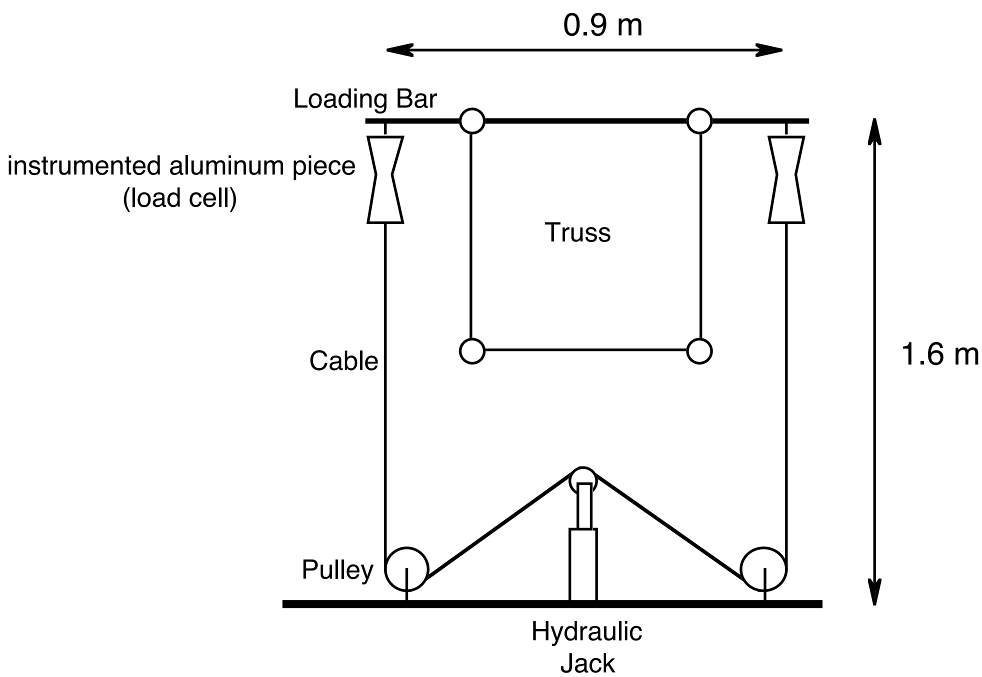

Figure 4. Cut-away side view, at loading point, of experimental loading configuration with jack and cable pulley set-up

giving a direct reading of the strain in these load cells. Prior to the assembly of the test setup, the load cells were *calibrated* by hanging known weights up to and beyond 360 pounds from them and reading the output from the strain gages. A *calibration curve* of load versus *microstrain* was thus established. In this way, readings of the strain can be taken and the load on the bar determined from the calibration curve. This, thereby, gives the load on that side of the truss. This is the *indirect measurement and calibration technique*.

It is important in using such a technique to occasionally check that the calibration is still valid. This will be done in each case for the load cells.

Three of the truss members (labeled 5, 6, and 7 in Figure 2) have also been instrumented to allow you to read the strain that each member experiences when the truss is loaded. These instrumented members were also calibrated in the same way. Once again, strain will be directly measured and load in the members determined from the calibration curves, one for each instrumented member. In this case, since the truss is already assembled, calibration will not be able to be checked.

The calibration curves obtained from this operation are quite linear -- generally to within less than 1% of a linear fit. Thus, it is not necessary to hand out calibration curves and have output values used to determine the desired variable by finding the corresponding value on the calibration curve. In the case of such linear relationships, gains can be set on various electrical equipment used in the measurement of the strain (see next section for further description). In the case of the loads cells, the gains of the electrical equipment were able to be set such that the readout of the (milli)voltage in that circuit is directly converted to the load, measured in pounds, applied to that load cell. These readings will therefore directly be read in pounds. It is important to note that calibration curves should generally not be used beyond the regime where the calibration took place. However, due to the linearity of the calibration curves shown in this case, some *extrapolation* of the calibration curves is permitted as is necessary here as the loading goes beyond the maximum calibration load of 300 pounds per load cell for some cases.

For the cases of the strain gages on the truss members, gains are set so that readings will be taken directly in millivolts as a calibration factor to go from microstrain to millivolts has been directly applied. A further calibration factor of 2.5 pounds/millivolt will need to be applied (via multiplication) to convert this reading to load in pounds. (This effectively yields one calibration factor of pounds/microstrain.) These are noted within the sections on “Experimental Procedure” and “Overall Work”.

Strain Gages and Strain Measurement

Strain gages are basically long pieces of a conductor in the configuration shown in Figure 5. The conductor is on a carrier which allows application to the material of interest via an adhesive.

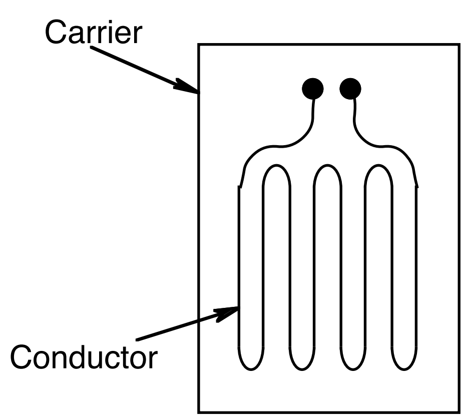

Figure 5. Illustration of strain gage

As the base material, to which the strain gage is bonded, changes length, the length of the strain gage changes. This changes the resistance of the strain gage material (as you learned in Physics). A calibration has been done by the manufacturer to determine the relationship between the changes in the resistance of the strain gage and the measured strain. This is the basic concept of the strain gage.

These changes in resistance are very small. A special circuit, known as the *Wheatstone bridge*, is utilized to measure small changes in voltage, caused by the change in resistance of the strain gage in one of the *arms* of the Wheatstone bridge. This change in voltage is related to the strain and thus a strain measurement results. Because the strain is so small, these readings are given in microstrain (μstrain = 10^{-6}).

More details on circuits and these concepts are provided in the S part of Unified.

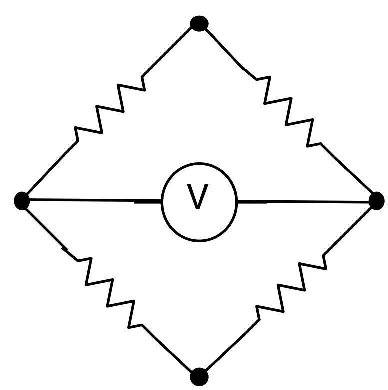

Figure 6. Illustration of Wheatstone bridge.

Deflection Meter

The deflection meter/gage basically consists of a dial readout with a spring-loaded protrusion. This protruding piece is placed normal to a flat surface at the point where deflection is to be measured. The gage is rigidly mounted so that deflection is measured relative to a known surface. The spring-loaded piece is *preloaded* (i.e. placed tightly against the surface so that it already registers a deflection) so that there is no dead space between it and the surface of interest. As the structure deflects, the protruding piece moves, causing the dial gage to move. The change in this reading gives the deflection of the structure at that point.

Experimental Procedure

(Be sure to wear safety glasses in this experiment since a failure of the loading mechanism or the truss could be dangerous)

To facilitate accessibility to the hardware for the laboratory, two different set-ups are used. Each has the exact same devices, geometry, etc. **except** that the components of one truss are made of steel and those of the other truss are made of aluminum. This only makes a difference in the calibration of the bars instrumented with strain gages and in the loads to which the overall three-dimensional truss configurations are subjected. For the case of the truss made of steel components, loading will be from 0 to 1000 pounds in ten even increments of 100 pounds (50 pounds per load cell). For the case of the truss made of aluminum components, loading will be from 0 to 500 pounds in ten even increments of 50 pounds (25 pounds per load cell). In both cases, six readings will be taken at each load level: readings of the strain in the two load cells and the three instrumented members, and a reading of the deflection. Note that the calibration and use of the two load cells does not depend on the material of the truss since these load cells are independent items from the trusses.

Measurements of the calibrated microstrain for each strain gage are obtained using a digital voltage readout box. By setting a dial on the box, you can select which of the five strain gages is being displayed on the box. Each strain gage is labeled so you can tell which gage corresponds to which channel on the digital readout box. The instrumented truss members correspond to channels 5, 6, and 7, as shown in Figure 2. The load cell gages correspond to channels 8 and 9. When reading these calibrated values, be sure to wait until the readout has settled and is showing a constant value. These outputs are basically in millivolts and can take several seconds to settle.

The deflection meter should be set up under the central joint as shown in Figure 3, and should be preloaded as described previously.

The specific steps are as follows:

1. Record the initial *zero* readings of all instruments at zero load. As noted in the discussion of the measurement of strain, we are interested in *changes* in the readings of the gages, not necessarily the absolute values. Thus, readings can be taken at zero load and these readings subtracted from readings at the other loads to

determine the actual reading. Record the calibrated readings for each gage and the reading of the deflection meter in Table 1 of the Lab Worksheet.

2. Prior to beginning any loading, the calibration of the two load cells (#8 and #9) needs to be checked. Hang a known weight (50 lb) off of each load cell, one at a time, using the hook apparatus provided in lab. Record the calibrated values for each load cell in Table 2. Check the reading you obtain against that expected for 50 pounds of applied load (50 pounds). Note that because we are only hanging 50 lb off of the gage, this is not really sufficient to check the entire calibration of the gage, but only one point and the associated region.

3. Once the initial zero readings have been taken and the calibration check is finished, begin loading by jacking the load apparatus until the two load cells give a calibrated reading corresponding to the desired load increment for each load cell (Remembering assumption (b) with regard to the analytical model and using this assumption in terms of load distribution between the two two-dimensional trusses in the experimental model, this value is 50 pounds for each load cell for the truss made of steel components; and 25 pounds for each load cell for the truss made of aluminum components). Record the calibrated readings of the two load cells (#8 and #9), the (partially) calibrated readings for the three instrumented members (#5, #6, #7), and reading for the deflection meter in Table 3. The zero readings you recorded earlier will be used later to correct these values.

4. Repeat this procedure for all ten increments of load by increasing the load on each load cell by the desired load increments up to the desired maximum load. (500 pounds per load cell for the steel truss; 250 pounds per load cell for the aluminum truss.) Do not exceed this maximum value on each load cell - monitor the load cells while loading the truss. When complete, slowly remove the loading.

5. When the load is again zero, **again** take readings and record these in Table 4. This allows you to check to see if the zero values you originally read/set are again achieved. If not, this gives you some idea as to errors within the system.

This ends the experimental work.

Overall Work

There are three parts of work that constitute this overall laboratory exercise: Pre-Lab Preparation, In-Lab Work, and Post-Lab Work. These descriptions follow.

Pre-Lab Preparation

The truss configuration and loading shown in Figure 2 was analyzed to determine the loads in bars #5, #6, and #7 as a function of the load, P, applied to the structure. This will then give the slope of a line, to later be plotted, relating the member loads to the applied load. These results are:

$$\text{Bar 5 Load} = -P$$
$$\text{Bar 6 Load} = +P/2$$
$$\text{Bar 7 Load} = +0.707\,P$$

These are to checked by doing an analysis of the truss. This analysis is to be included as an Appendix with the Laboratory Report handed in upon completion of the work.

To be completed prior to performing laboratory

In-Lab Work

The data described in the "Experimental Procedure" section are to be collected: load cell strains (2 load cells), instrumented member strains (3 instrumented members), and deflection for the ten load increments. In addition, the calibration check readings and zero readings are to be taken and recorded. Tables 1 through 4 of the "Laboratory Worksheets" are to be completed.

To be completed prior to leaving laboratory

Post-Lab Work

The first task in preparation to consider the data taken in the laboratory is to a final conversion of the calibrated readings to load, as needed, using the calibration factors provided herein. Before doing this conversion, the raw data must first be corrected for any zero readings (Table 1) by subtracting the zero readings from the direct data. After correcting for zero readings and converting via the final calibration factors, enter the final results in Table 5.

As determined beforehand, there are no further calibration factors needed for the readings from the load cells -- these were set to directly yield readings in pounds via the initial calibration. For the three instrumented bar members, an additional calibration factor is required to yield the final data in pounds of load. These calibration factors are 2.5 pounds/millivolt, that is to be applied to the readings taken directly in millivolts.

From these final corrected and calibrated data, plots are to be made. For each of the three instrumented members (#5, #6, #7), plots of bar load versus load applied to the two-dimensional truss, P, are to be made first using the results from the analysis. This results in a line. Then the experimental data is to be plotted as points on these same figures for each case. Remember that as per assumption (b):

$$P = \frac{\text{Load Cell 1} + \text{Load Cell 2}}{2}$$

All plots should be made on appropriate graph paper. Plot the load in each member on a separate graph, with the maximum applied load along the vertical axis going to maximum value of P achieved in your experiment for the truss you used. Label your axes, including units and use sensible intervals on the axes (for example, 1, 2, 5, or 10, ***not*** 3 or 8). Also plot the deflection of the truss versus load applied to the two-dimensional truss on a separate graph. Again, label axes appropriately with sensible intervals on the axes.

Write a short report of 2-3 pages (double-spaced) summarizing the work done with emphasis on making comments on the analytical and experimental results, with particular attention to the ability of the model to capture the behavior actually observed. Try to explain any differences by considering possible sources of error in the measurements as well as inadequacies of the analytical model. Include all plots of the results with this write-up along with the Tables of the data taken and that “processed”. Also include the analysis of the two-dimensional truss as an appropriately labeled appendix.

Due in class on Wednesday, November 26, 2008.

LABORATORY WORKSHEETS

The Truss

Initial Zero Readings

Table 1
Direct readings at initial zero load

Load Cell 8	Load Cell 9	Bar 3	Bar 4	Bar 5	Deflection Meter

Be sure to include proper units

Load Cell Calibration Readings

Table 2
Calibration readings

Known Load	Load Cell 8	Load Cell 9

Be sure to include proper units

Direct Test Readings

Table 3
Direct experimental readings

Interval	Load Cell 8	Load Cell 9	Bar 5	Bar 6	Bar 7	Deflection Meter
Units -->						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Put proper units at head of column

Final Zero Check

Table 4
Direct readings at final zero load

Load Cell 8	Load Cell 9	Bar 5	Bar 6	Bar 7	Deflection Meter

Be sure to include proper units

Converted Test Results

Use proper calibration factors as provided (and needed).

Table 5
Converted measurements

Interval	Load Cell 8	Load Cell 9	Bar 5	Bar 6	Bar 7	Deflection Meter
Units -->						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Rezero						

Put proper units at head of column