Visualizing Tension and Compression Using a Paperboard Truss

James W. Jones, M.Eng. and John W. Warner, MA and Don Chen, Ph.D.
Ball State University
Muncie, Indiana

One common challenge that classroom teachers face is to help students understand and apply pre-engineering concepts that are not easily visualized. Teachers who are able to help students "see" these important but sometimes elusive concepts as they are actually applied and interact in everyday life help learners grasp these concepts more quickly and concretely. This article presents a paperboard truss activity that motivates and engages students as it provides visual and intuitive understanding of the basic static forces of tension and compression as well as the graphical language used to express them.

Key Words: truss, visualization, tension, compression, problem-solving

Introduction

One common challenge that classroom teachers face is to help students understand and apply pre-engineering concepts that are not easily visualized. Teachers who are able to help students "see" these important but sometimes elusive concepts as they are actually applied and interact in everyday life help learners grasp these concepts more quickly and concretely. This article presents a paperboard truss activity that motivates and engages students as it provides visual and intuitive understanding of the basic static forces of tension and compression as well as the graphical language used to express them.

Definitions

- **Truss**: An assemblage of members (as beams) forming a rigid framework (Encyclopædia Britannica, 2007, as below).
- **Chord**: Either of the two outside members of a truss connected and braced by the web members.
- **Strut**: A structural piece designed to resist pressure in the direction of its length.
- **Tie**: A structural element (as a rod or angle iron) holding two pieces together: a tension member in a construction.
- **Tension**: The act or action of stretching or the condition or degree of being stretched to stiffness.
- **Compression**: The act, process, or result of compressing.
- **Live Load**: The load to which a structure is subjected in addition to its own weight.

Figure 1 illustrates a typical truss and its members.

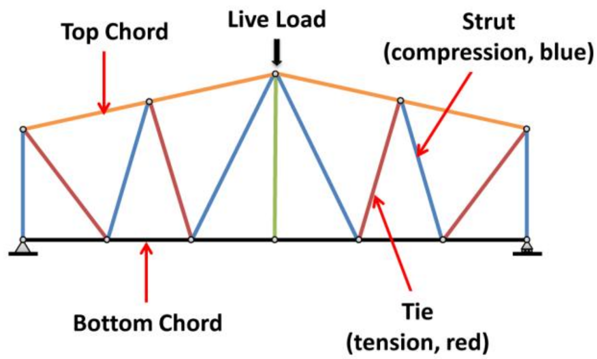

Figure 1. A typical truss

Learning Process

A truss can look very sophisticated comparing with a simple beam. However, solving a truss can be fairly simple once the technique described in this article is understood. In this course project, the visual method and the mathematical method were introduced to students. Students then construct paper trusses and analyzed the member forces under different load conditions.

Visual Method

A truss can be thought of as a solid beam full of holes. The point is to dispose the material as far from the neutral axis as possible in order to resist the deflection under the external forces, since materials near the neutral axis is not contributing to this effort.
Thus a truss and a beam will behave similarly as far as the deflection, tension, and compression are concerned under the same live load.

An imaginary rubber beam is used in this article to demonstrate how to identify tension and compression members in an equivalent truss.

A rubber beam can deform visibly when loaded. Under a typical vertical live load, the top beam fiber tends to shrink (compression), and the bottom fiber tends to stretch (tension). Analogically, the top chord of the equivalent truss is in compression, and the bottom chord of the equivalent truss is in tension.

Top-Loaded Truss

When a live load is acting on the top of the rubber beam, the area beneath the point of application is defined as the Compression Zone – the fibers in this zone tend to shrink. For an equivalent truss, members disposed in the corresponding compression zone are compression members. Non-vertical members next to these compression members must be tension members, because at each joint, the sum of the vertical components of the member forces must be zero, or it would move. Likewise for the horizontal direction. Therefore, for a top-loaded truss, non-vertical members beyond the compression zone must be in tension or compression, alternately distributed. This visual method is shown in Figure 2.

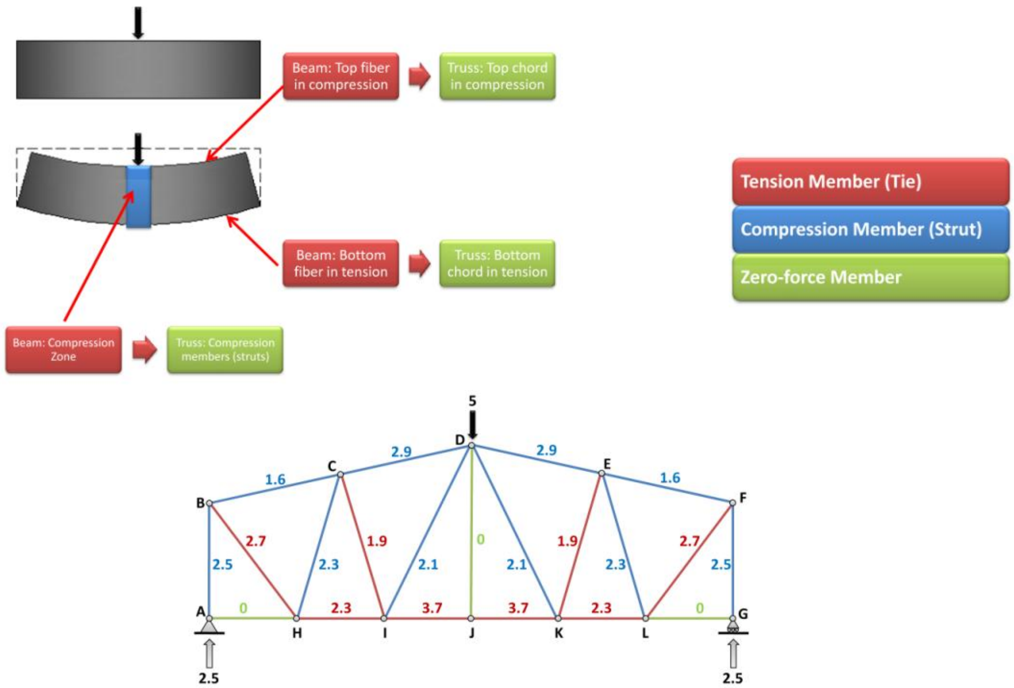

Figure 2. Visual Method: Top-loaded Truss

Note: The figures beside the truss members are the magnitudes of the member forces when the live load is 5 load units. In the first part of the paper truss project, the instructor will analyze the truss and provide the member forces and tension and/or compression information to students.

Truss members DI and DK are in the corresponding compression zone. Thus they are in compression. The non-vertical member next to DI (DK), which is CI (EK), is in tension.

Bottom-Loaded Truss

When a live load is acting on the bottom of the rubber beam, the area above the point of application is defined as the Tension Zone – the fibers in this zone tend to stretch. For an equivalent truss, members disposed in the corresponding tension zone are tension members. For the same reason described in the previous section, non-vertical members next to these tension members must be compression members. Therefore, for a bottom-loaded truss, non-vertical members beyond the compression zone must also be in tension or compression, alternate distributed. This visual method is shown in Figure 3.

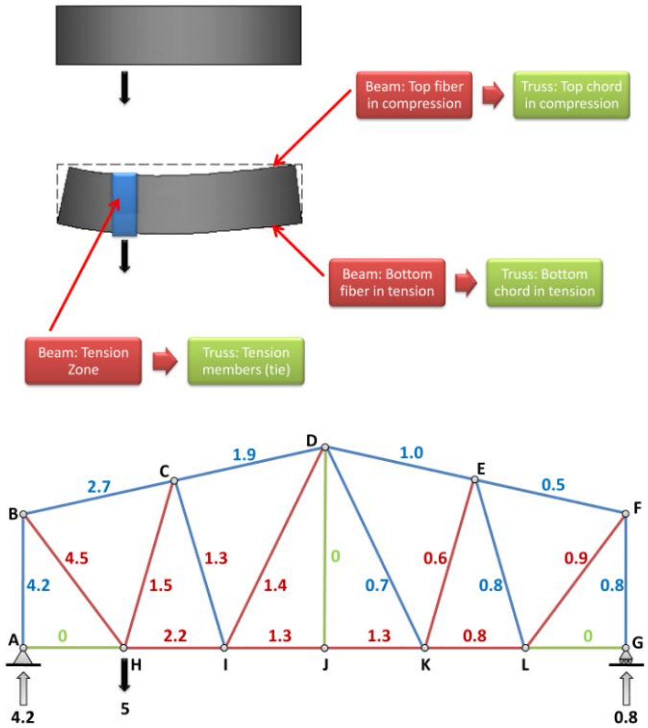

Figure 3. Visual Method: Bottom-loaded Truss

Note: The figures beside the truss members are the magnitudes of the member forces when the live load is 5 load units.

Truss members BH and CH are in the tension zone. Thus they are in tension. The non-vertical member next to CH, which is CI, is in compression.

Mathematical Method

Mathematically, a truss can be analyzed easily using the Method of Joints. "For a truss to be in equilibrium, each joint of the truss must also be equilibrium" (Onouye & Kane, 2007). Therefore, for each joint with no more than two unknown member forces, $\sum Fx=0$ and $\sum Fy=0$. After one joint is solved, select the next joint that has no more than two unknown forces. This method is illustrated in Figure 4.

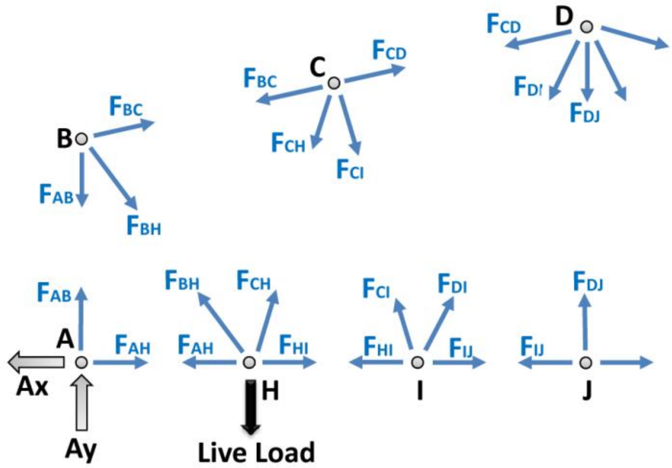

Figure 4. Mathematical Method

Student Assignment

Students work cooperatively in teams during this activity to design and construct a truss for structural analysis to determine which members are in tension and which are in compression. Students use their graphic communication skills to develop and relate their truss design to others and apply scientific and mathematical principles to develop hypotheses as to which members will be in tension and which will be in compression, as well as the relative degrees of each. Students then construct scale models and test their hypotheses to determine if they were correct. Successful teams integrate and apply communication, mathematical, scientific, and engineering design skills and abilities as they work through the assignment.

The Challenge

Working in teams of three to five members, students will design and construct a cardboard truss to test their hypotheses regarding which members are in compression and which are in tension. Students will determine which members are in tension, which are in compression, as well as their relative degree of either force.

Objectives

1. Work safely, efficiently, and effectively to design, build and test a paperboard truss.
2. Visualize concepts of tension and compression.
3. Apply mathematical and scientific principles to formulate hypotheses for testing.
4. Use creativity and critical thinking to systematically design a truss and communicate this design to others through graphical and written means.
5. Interpret and communicate the results of the testing process and analyze and explain any discrepancies.
6. Solve problems throughout the process.
7. Research designs using the library and the Internet.

Materials/Equipment

- Paperboard (preferably double-thickness)
- Slips of paper
- Duct tape
- Utility knives
- Straight edges
- Clamps
- Spacer blocks

Limitations/Requirements

1. Each team must complete all testing and documentation.
2. Truss designs must have eight to twelve members.
3. Trusses will be scaled so that they are between 3-4’ in length and 12-18” in height.
4. Trusses must be constructed only out of the supplied materials.
5. Trusses may only be two-dimensional and must lay flat for testing.
6. Trusses will be tested with two bottom support points at the outer edges and a single load applied to the center of the top chord.

Procedures

1. Follow all safety requirements in the lab.
2. Read all materials thoroughly before proceeding.
3. Select a Team Leader who will manage the design, construction, testing, and reporting processes.
4. Construct the paper truss.
5. Cut one member and load the truss under two different live load conditions.
6. Place a piece of paper in the cut and pull it out under different load conditions.
7. Decide tension or compression and its magnitude. Record the result.
8. Tape the cut and test the next member.
9. Repeat 5-8 until all members are tested.
10. Apply the visual method and the mathematical method to analyze the truss.
11. Compare the results from 7 and 10.

The photos below show how the paper truss was loaded and analyzed.

Figure 5. The supports of the paper truss

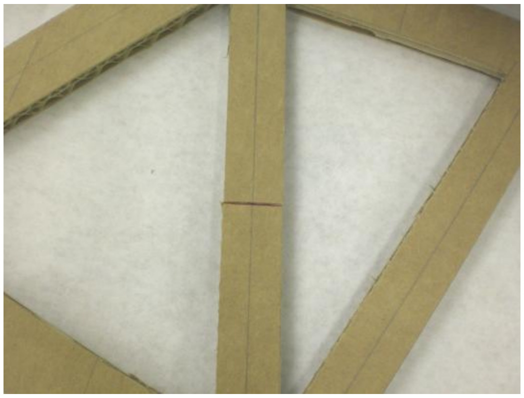

Figure 6. The cut on the major member

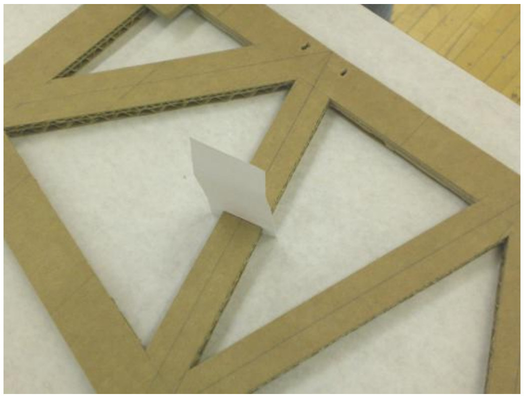

Figure 7. The paper in the cut

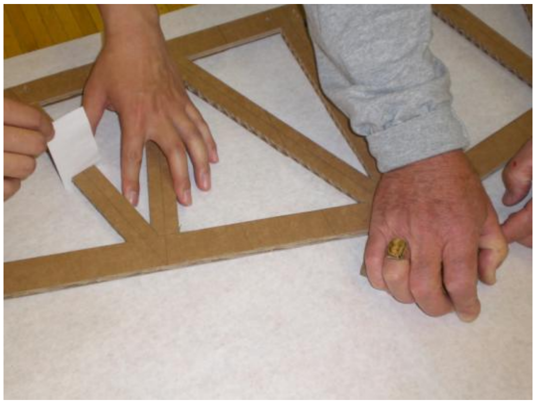

Figure 8. Pulling out the paper under the top load

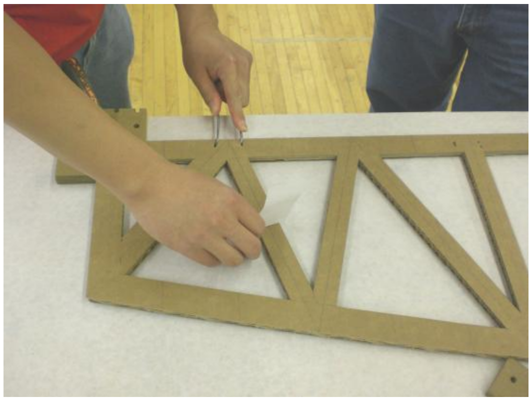

Figure 9. Pulling out the paper under the bottom load

In this class project, students follow the instructor to learn how to solve the three sample questions (Figure 9-11), and apply what learned in the class to solve the two practice questions (Figure 12-13), and compare the results with the instructor's answers (Figure 14-15).

The three sample questions are:

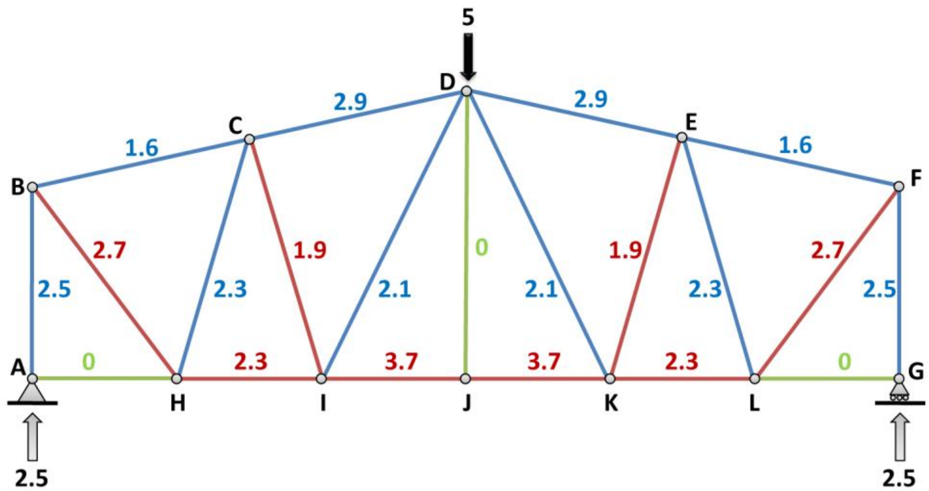

Figure 10. Sample Question #1

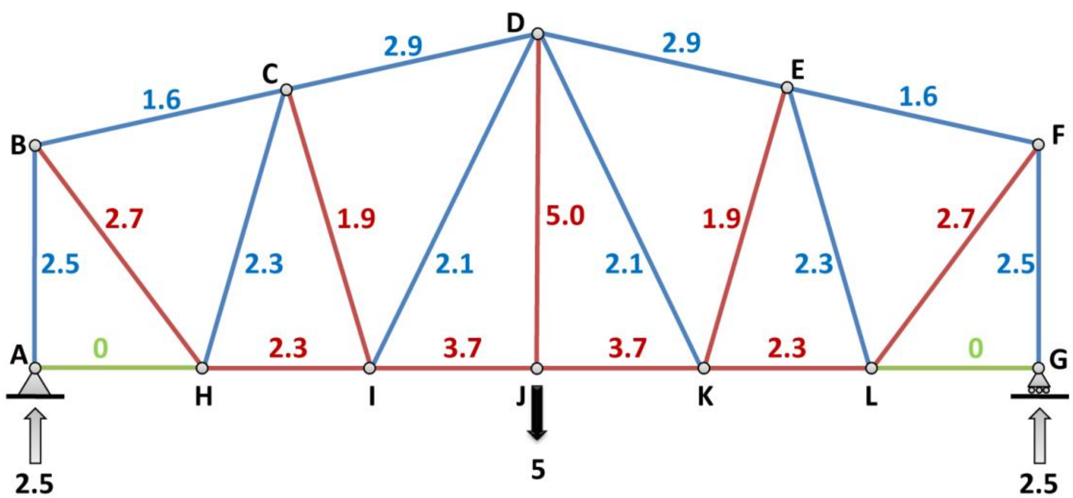

Figure 11. Sample Question #2

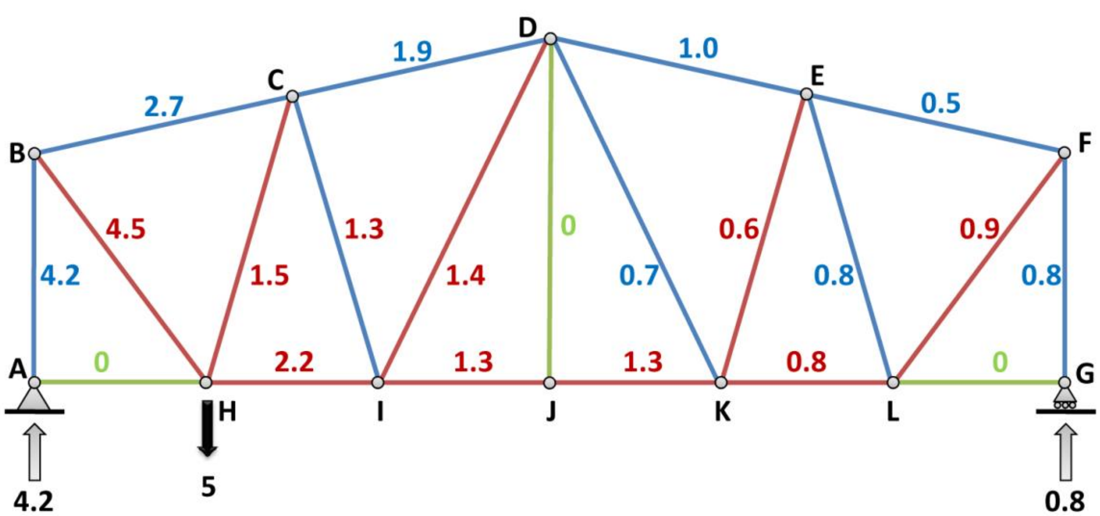

Figure 12. Sample Question #3

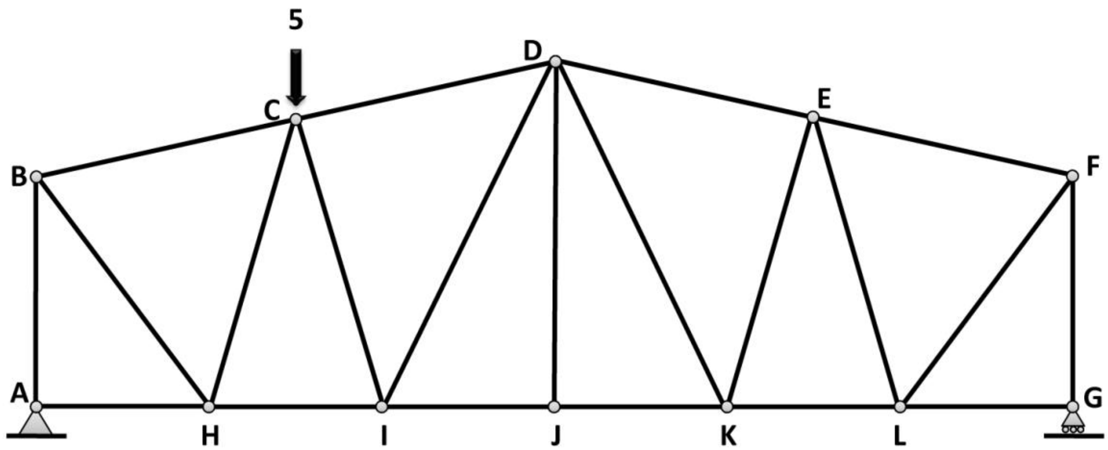

Figure 13. Practice Question #1

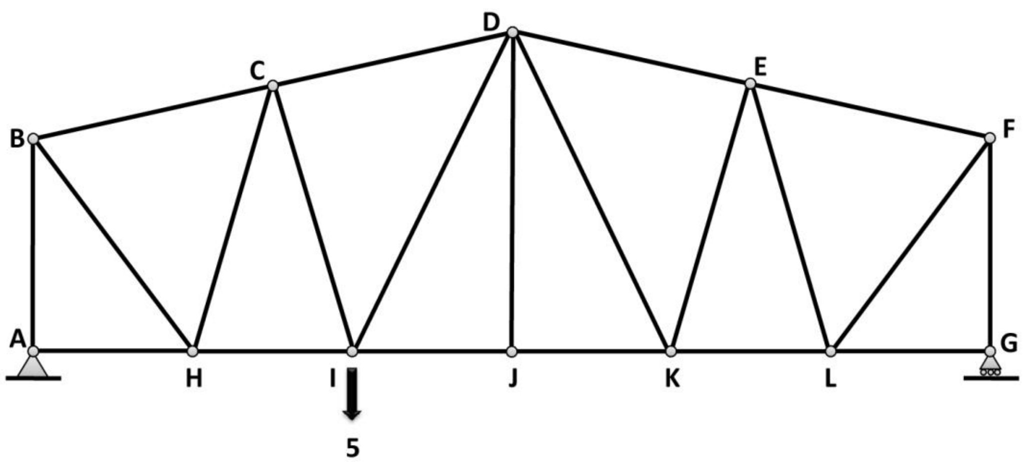

Figure 14. Practice Question #2

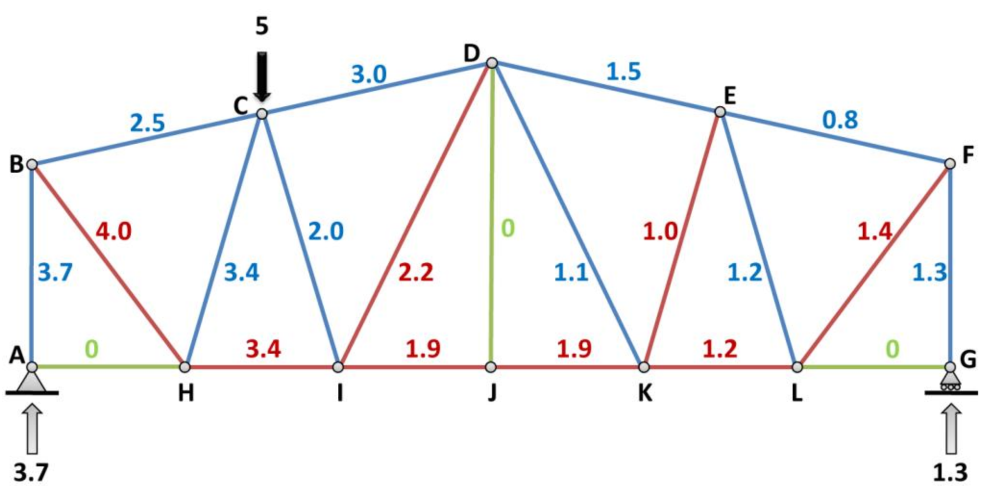

Figure 15. Answers to Practice Question #1

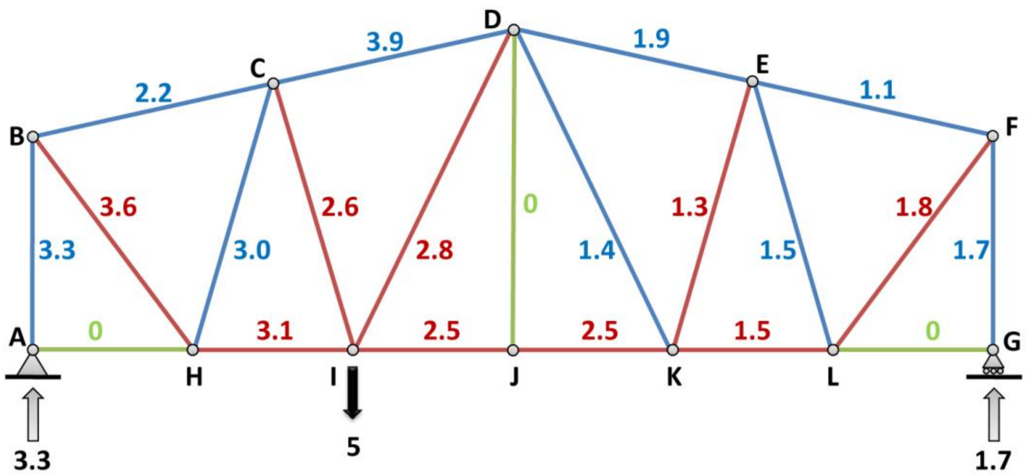

Figure 16. Answers to Practice Question #2

Conclusions

The Visual Method and the Mathematical Method described in this paper helped students to understand the relatively complicated truss-solving process. Paperboard truss tests helped students to determine tension and compression members. Students became more engaged in solving truss problems because they can verify their solutions using several methods they learned in this paper.

References

Onouye, B. S., & Kane, K. (2007). Statics and strength of materials for architecture and building construction (3rd ed.), Upper Saddle River, NJ: Prentice-Hall

Truss. (2007). *Encyclopædia Britannica* (electronic version).